CECW-EE / CECW-OD

DEPARTMENT OF THE ARMY
U.S. Army Corps of Engineers
Washington, DC 20314-1000

EM 1110-2-1003
Change 1

Manual
No. 1110-2-1003

1 April 2004

Engineering and Design
HYDROGRAPHIC SURVEYING

1. This Change 1 to EM 1110-2-1003, 1 January 2002, provides updated guidance in Chapter 11 on the use of acoustic multibeam technology for dredging measurement and payment surveys.

2. Substitute the attached chapters as shown below:

Remove Pages	Insert Pages
i – x	i – x
11-1 thru 11-33	11-1 thru 11-44

3. File this change sheet in front of the publication for reference purposes.

FOR THE COMMANDER:

MICHAEL J. WALSH
Colonel, Corps of Engineers
Chief of Staff

CECW-EE / CECW-OD

DEPARTMENT OF THE ARMY
U.S. Army Corps of Engineers
Washington, DC 20314-1000

EM 1110-2-1003

Manual
No. 1110-2-1003

1 January 2002

Engineering and Design
HYDROGRAPHIC SURVEYING

1. Purpose. This manual provides technical guidance for performing hydrographic surveys that support the planning, engineering design, construction, operation, maintenance, and regulation of navigation, flood control, river engineering, charting, and coastal engineering projects. Accuracy standards and quality control criteria are defined to establish U.S. Army Corps of Engineers (USACE)-wide uniformity in performing surveys involving dredging measurement, payment, and acceptance.

2. Applicability. This manual applies to all USACE commands having responsibility for performing, contracting, or monitoring hydrographic surveys in support of the Corps civil works activities.

3. Discussion. Hydrographic surveying is performed to determine the underwater topography of a project site. These surveys provide critical site plan data that are used in the planning, acquisition, design, construction, operation, and maintenance of various types of planned or previously constructed projects. Insufficient, inaccurate, or misinterpreted hydrographic surveys can contribute to costly errors and omissions in the various phases of project development. This directly impacts incidences of construction claims as well as navigation safety. Therefore, the intent of this manual is to establish definitive Corps-wide accuracy and quality control standards along with survey performance and procedural policy that will ensure uniform and accurate hydrographic surveying products. This will reduce costly errors, enhance the equitability of contracted construction administration, and increase the overall quality and safety of Corps navigation and flood control projects.

FOR THE COMMANDER:

3 Appendices
(See Table of Contents)

ROBERT CREAR
Colonel, Corps of Engineers
Chief of Staff

This manual supersedes EM 1110-2-1003, 31 October 1994.

DEPARTMENT OF THE ARMY
U.S. Army Corps of Engineers
Washington, DC 20314-1000

CECW-EE
CECW-OD

Manual
No. 1110-2-1003

1 April 2004

Engineering and Design
HYDROGRAPHIC SURVEYING

Table of Contents

Chapter 1
Introduction

1-1. Purpose

This manual provides technical guidance for performing hydrographic surveys that support the planning, engineering design, construction, operation, maintenance, and regulation of navigation, flood control, river engineering, charting, and coastal engineering projects. Accuracy standards and quality control criteria are defined to establish US Army Corps of Engineers (USACE)-wide uniformity in performing surveys involving dredging measurement, payment, and acceptance.

1-2. Applicability

This manual applies to all USACE commands having responsibility for performing, contracting, or monitoring hydrographic surveys in support of the Corps civil works activities.

1-3. Distribution

This publication is approved for public release; distribution is unlimited.

1-4. References and Bibliography

Referenced USACE publications are listed at Appendix A. Where applicable, bibliographic information is listed at the end of each chapter.

1-5. Use of Manual

This manual shall be used as a technical guide in performing hydrographic surveys with USACE hired-labor forces or contracted survey forces. It should be directly referenced in contract specifications for dredging or Architect-Engineer survey services. The accuracy standards and quality control criteria in the manual shall be specified for all surveys supporting dredging measurement, payment, and acceptance functions. This manual may be referenced should hydrographic surveying functions be required as part of a USACE military construction or environmental restoration activity. It is also applicable to surveys performed or procured by local interest groups under various cooperative or cost-sharing agreements.

1-6. Background

The original version of this manual was published in 1991 and was revised in 1994. Most of the standards and technical guidance in the 1991 and 1994 versions were designed to support older analog depth recording instruments, mechanical, visual, or microwave positioning, and manual data processing and drafting methods. Since the last update, significant advances in hydrographic surveying technology have occurred. These include replacement of short-range microwave positioning techniques with local and nationwide Differential Global Positioning System (DGPS) systems, enhanced applications of and expanded use of full-bottom coverage acoustic multibeam systems, airborne LIDAR hydrographic survey systems, and functional use of carrier phase DGPS for accurate water surface determination. Field-finish data collection equipment and software has also become more robust, allowing for near-final data editing and processing on board the survey boat. Data accuracies have been enhanced through use of inertial and DGPS vessel motion sensors. Automated data editing, processing, transfer, and Internet display methods have also evolved considerably since 1994. In addition, the International Hydrographic Organization (IHO) and the Federal Geographic Data Committee (FGDC) have promulgated updated hydrographic survey accuracy standards, statistical measures, and reporting standards. The accuracy standards in this manual were revised to more closely conform to these international and Federal standards. Older survey classifications (i.e., Contract Payment, Project Condition, and Reconnaissance) were originally developed to reflect accuracy limitations in manual and microwave positioning equipment. DGPS positioning has largely eliminated these distinctions; thus survey classifications have been modified accordingly. The manual now contains separate chapters that detail current procedures for dredging surveys, river engineering and charting surveys, airborne LIDAR surveys, and coastal engineering surveys. The chapter on contracted surveys has been expanded to reflect the increasing use of Architect-Engineer service contracts for hydrographic surveying.

1-7. Mandatory Requirements

ER 1110-2-1150 (Engineering and Design for Civil Works Projects) prescribes that mandatory requirements be identified in engineer manuals. Mandatory requirements in this manual are summarized at the end of each chapter. Mandatory accuracy standards, quality control, and quality assurance criteria are summarized in tables within each chapter. The mandatory criteria contained in this manual are based on the following considerations: (1) assurance of navigation safety, (2) essential to navigation project function, (3) previous Corps experience and practice has demonstrated criteria are critical, (4) Corps-wide geospatial data standardization requirements, (5) adverse economic impacts if criteria are not followed, and (6) HQUSACE commitments to the dredging industry.

a. Previous versions of this manual contained more rigid prescriptive criteria for performing all aspects of hydrographic surveys, including mandatory plant and survey instrumentation, equipment calibration procedures, accuracy standards, data collection procedures, and data plotting criteria. This updated version of the manual now limits mandatory requirements to those dealing with resultant accuracy standards and selected quality control and quality assurance criteria. This change more closely conforms to USACE policy emphasizing performance-based specifications--and recognizes the fact that technical procedures, equipment, and operating specifications are now evolving at a rapid pace.

b. Equipment calibration, operation, and procedural methods for performing and processing automated field hydrographic surveys are now usually detailed in operation manuals provided by the various equipment and software vendors. References and recommendations in this manual to specific operational methods must be carefully weighed against newly evolving technology and the latest manufacturer's recommendations.

c. Other Corps regulations may dictate mandatory requirements for processing, displaying, transferring, and archiving hydrographic survey data. These mandatory regulations will be referenced in each chapter when applicable. As survey technology and procedures develop, districts are strongly encouraged to recommend modifications to all mandatory criteria or technical guidance contained in this manual--see Proponency and Waivers section at the end of this chapter.

1-8. Scope of Manual

This manual covers all aspects of hydrographic surveying performed to support USACE river and harbor navigation activities, flood control projects, and coastal engineering projects. Special emphasis is placed on surveys that support construction/dredging of coastal and inland waterway projects. An overview of these support functions is covered in Chapter 2. The manual focuses on the preparation of design drawings and other documents associated with these projects, including related contracted construction performance activities. Throughout the manual, mandatory or recommended hydrographic survey criteria are normally summarized in tables. Technical or procedural guidance is in more general terms where methodologies are described in readily available references or survey instrumentation operating manuals. Numerous references are made to those more detailed operation manuals. Where procedural guidance is otherwise unavailable from industry sources, it is provided herein. This primarily applies to older manual survey methods--e.g., mechanical tag line surveys.

a. Accuracy standards for USACE hydrographic surveys are provided in Chapter 3. These standards, together with quality control and quality assurance criteria, are presented for various Corps project applications.

b. General project planning criteria are covered in Chapters 3 through 6. Hydrographic positioning techniques are described in Chapter 7. Portions of Chapters 7 and 8 also cover older manual or visual survey techniques. Although these older methods have been made nearly obsolete by acoustic and GPS technology, occasional applications on Corps projects justify retention of the procedures for performing visual and mechanical surveys. The various procedures and systems for acoustic depth measurement are covered in Chapters 9 through 12 and Chapter 21. Cost estimating is covered under contracted survey topics in Chapter 22. The remainder of the chapters (13 through 20) cover specific civil works project applications.

1-9. Metrics

The use of both metric and English systems of measurement in this manual is predicated on the common use of both systems in engineering practice, and the exclusive use of English units by the navigation industry. Although most, if not all, electronic surveying and satellite measurement systems now acquire data in metric units, these data are readily converted to English units by processing software. In the Corps, water depths are typically expressed in feet and accuracy standards are expressed in feet. Distances are measured in either meters or feet; however, accuracy standards are expressed in meters. Engineering project coordinates are normally in English units (feet). Construction measurement quantities are normally measured in linear feet, square feet, or cubic yards; however some recent construction plans and specifications are using metric units of measure. Due to the variety of mixed measurements, equivalent conversions are not shown in this manual; the most common measurement unit is used for example computations. In all cases, metric conversions are based exclusively on the US Survey Foot, which equals *exactly* 1200/3937 m (or 3.280833333333 ft/m).

1-10. Brand Names

The citation in this report of brand names of commercially available products or software systems does not constitute official endorsement or approval of the use of such products.

1-11. Definitions

An explanation of hydrographic surveying terms and acronyms used in this manual is contained in the Glossary. Acronyms that are defined in the Glossary may not be spelled out in each chapter.

1-12. Proponency and Waivers

The overall HQUSACE proponent for this manual is the Engineering and Construction Division, Directorate of Civil Works. Technical development and compilation of the manual was coordinated by the US Army Topographic Engineering Center (CEERD-TS-G). Comments, recommended changes, or waivers to this manual should be forwarded through MSC to HQUSACE (ATTN: CECW-EE). Technical issues or waivers dealing specifically with dredging operations shall be forwarded through MSC to HQUSACE (ATTN: CECW-OD).

Chapter 2
Civil Works Applications

2-1. General Scope

Hydrographic surveys are performed to support the Corps' dredging, navigation, and flood control missions. A wide range of hydrographic survey techniques, vessels, and equipment are required, depending on the nature and location of the survey, as illustrated in Figure 2-1. Nearly 100 in-house and contract survey crews are deployed surveying over 900 navigation projects and 12,000 miles of waterways. Thousands of drawings depicting these projects are produced annually. This chapter describes the requirements and types of hydrographic surveys, and some of the current processes used by districts to accomplish these tasks.

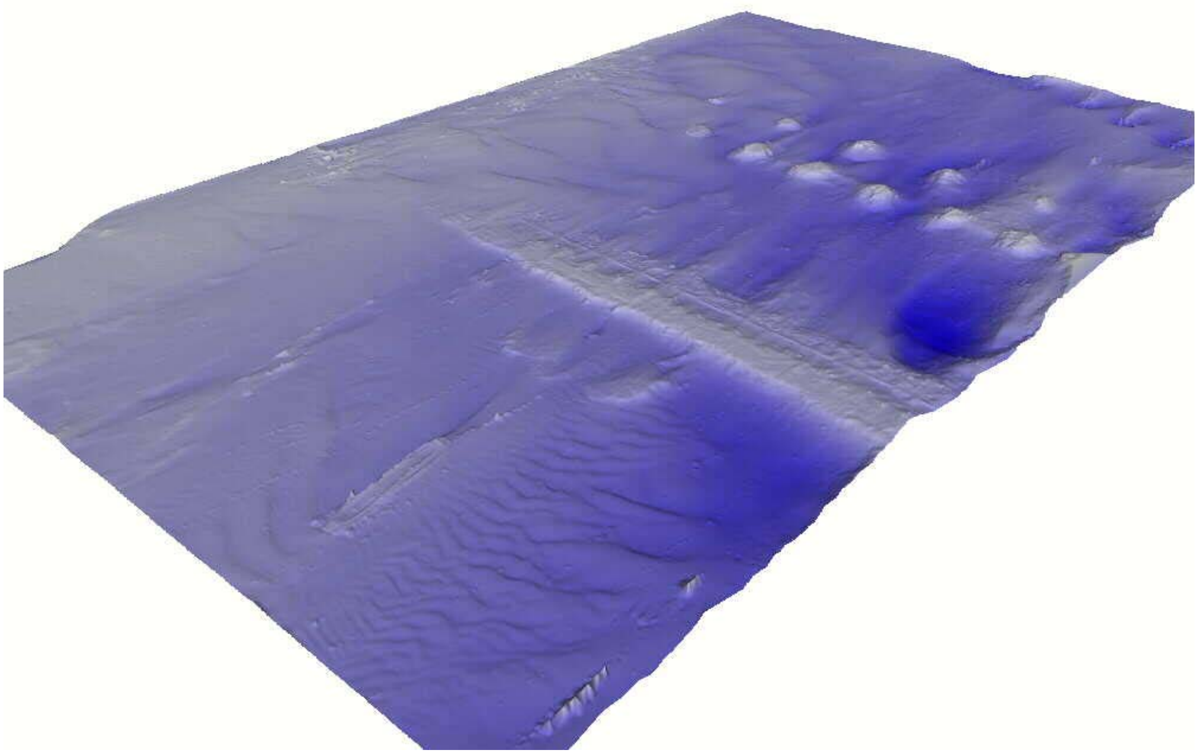


Figure 2-1. Old Lock and Dam 26, Mississippi River. DTM depicts old Lock and Dam 26, the old Alton Bridge piers, and a sunken barge just upstream of the old Lock and Dam 26 foundation. The scour holes below the old bridge piers are from the bridge piers of the new Alton Bridge. This is at River Mile 202.1 on the Upper Mississippi. The data file was collected on the M/V Boyer with a RESON 8125 Multibeam sonar. The 8125 is a 0.5 by 0.5 deg beam, 240 beams, and 120-degree swath. (St. Louis District)

2-2. Civil Works Program Surveying Requirements

Hydrographic surveying support is required throughout most phases of civil works water resource projects. During the early phases of a project, a comprehensive plan should be developed to integrate hydrographic surveying requirements throughout the various stages of a project's life. Procedures for accomplishing this are contained in ER 1110-2-1150, "Engineering and Design for Civil Works Projects." Hydrographic surveying may be required during any of the five project phases outlined in ER 1110-2-1150: Reconnaissance phase, Feasibility phase, Preconstruction Engineering and Design (PED) phase, Construction phase, and Operation and Maintenance phase. Most effort is required during the later three phases.

a. Reconnaissance phase. The reconnaissance phase is general in scope, and at this early stage of project development there is normally no requirement (or funding) for field survey effort. Existing maps or charts are normally adequate for developing the preliminary plans that will ultimately lead to an engineering solution.

b. Feasibility phase. The purpose of the feasibility phase is to formulate a solution to address a specific need. The work includes studying potential solutions, evaluating costs and benefits, preparing initial designs, and recommending a plan to solve the problem. Engineering effort during this phase may include hydrographic surveys of project sites. ER 1110-2-1150 contains the following guidance on surveying requirements:

> *Surveying, Mapping, and other Geospatial Data. Surveying, mapping, and other geospatial data information should be obtained to support all feasibility phase requirements. At this level, existing surveying, mapping, and other geospatial data available through in-house sources or through other federal, county, local, commercial, or private sources may be adequate. Additional information on finding these sources is available in EM 1110-1-2909. The data source, i.e., compilation scale, contour interval, control data and datum, etc., should be verified to assure it meets accuracy requirements to support the level of detail required. Otherwise, new surveying, mapping, and other geospatial data may need to be developed. If sufficiently scaled topography is not available to support the level of detail required, then it shall be developed during the feasibility phase to eliminate the possibility of large quantity errors (e.g., real estate, reservoir volumes, etc.). Detailed guidance on photogrammetric mapping surveys is provided in EM 1110-1-1000. Survey control methods and if possible the actual control points shall be established in the field at this phase of study to avoid rework and errors and to maintain continuity during subsequent phases of the project. Detailed site-specific mapping may be deferred and developed during the PED phase unless it is required to develop an accurate baseline cost estimate. The Geographic Information System (GIS) for the project should be established during this phase in accordance with EM 1110-1-2909 and ER 1110-1-8156.*

During the feasibility phase cost estimates for subsequent modeling requirements are made. These would include any tidal modeling requirements, such as on projects without an established MLLW reference. Also, projects requiring RTK DGPS observations will require geoid modeling during the PED phase.

c. Preconstruction engineering and design phase. The Preconstruction Engineering and Design Phase (PED) is the phase during which the design is finalized, the plans and specifications (P&S) are prepared, and the construction contract is prepared for advertising. A Design Documentation Report (DDR) is developed. This phase may involve physical model studies or development of water level or geoid reference models. Hydrographic surveys are a critical component of the P&S. P&S shall be prepared in accordance with ER 1110-2-1200, the Architect/Engineer/Construction CADD Standards and the CADD/GIS Technology Center (Tri-Service) Spatial Data Standards.

d. Construction phase. Hydrographic survey support is continuous throughout construction--especially for dredging and beach renourishment projects. The various surveys supporting construction are described later in this chapter and in subsequent chapters.

e. Operation and maintenance (O&M) phase. Maintenance of authorized navigation projects requires continuous condition surveys and construction surveys associated with maintenance dredging.

Support to O&M is by far the largest hydrographic surveying activity in the Corps--both in manpower and funding.

2-3. Hydrographic Survey Applications on Civil Works Activities

Hydrographic survey support is required for a wide range of civil works engineering and construction activities, ranging from navigation project dredging to topographic surveys of wetlands. This section describes some of the more common activities or projects requiring survey support.

a. Dredging measurement and payment surveys. Dredge measurement and payment surveys encompass all work associated with contracted construction activities of USACE, most particularly those surveys performed to measure the amount of excavated, deposited, and/or placed material in subsurface areas. These surveys also include investigative studies used for preparing contract bid documents and for directly monitoring and measuring subsequent contract performance, payment, and acceptance. These surveys require a high level of accuracy in both positioning and depth measurement so that payments will be equitable and consistent with the actual work performed. A significant portion of Corps survey resources are engaged in supporting dredging operations. A wide variety of vessels and equipment are used on dredging payment surveys, depending on water depth, inland or coastal location, and material being dredged. During FY 1999, some 328 MCY were excavated under 252 contracts and another 46 MCY by 12 Corps-owned dredges. Corps survey forces were responsible for monitoring most of this excavation in progress.

(1) Plans and specifications surveys. Surveys and investigative studies performed to gather terrain, bathymetric, and geophysical data and related site plan information in advance of a design effort are referred to as plans and specifications (P&S) surveys. These P&S surveys will be used to produce a set of engineering plans and specifications (and related cost estimates) for construction or dredging. These surveys support not only river and harbor dredging construction but also many other forms of marine construction in which detailed site plans are essential to the bid documents. This includes planned construction of offshore structures (jetties, groins, etc.), disposal areas, flood control structures (locks, dams, spillways, dikes, control structures, reservoirs, etc.), and beach/bank erosion protection. In rare instances where no substantive change is expected before the beginning of construction/dredging, these surveys can also serve as the before construction/dredging payment survey. Such a procedure, however, must be clearly allowed in the contract specifications.

(2) Before and after dredging surveys. Most USACE construction contracts structure a payment schedule on a unit price basis, with units, lengths, areas, or volumes determined by in-place surveys. Contracts with daily/hourly rate pay schedules may still require detailed in-place surveys to monitor production. Depending on the provisions of the measurement and payment clause in the construction contract specifications, before/after surveys for construction payment may be performed by government hired-labor forces, dredging contractor forces, or third-party forces contracted by the government, contractor, or local sponsor. These contract payment surveys shall be performed to the accuracy standards contained in this manual. Payment surveys include those surveys performed before, during, and after dredging or other marine construction activity to measure quantities for the determination of the proper (and equitable) payment to be made. Also included in payment surveys are final contract acceptance surveys, including all types of channel sweeping operations to verify project clearance for final contract acceptance and release. Since direct contract payment is involved, this type of survey represents one of the most critical functions performed by a hydrographic survey crew. Final as-built drawings of completed projects are furnished to local sponsors and other public and private entities. In addition, contract personnel evaluating payment, acceptance, and project clearance survey data must clearly and properly correlate these accuracy standards with the field survey data to ensure that data accuracy interpretations are technically sound.

b. Project Condition Surveys. The Corps is responsible for maintaining over 900 shallow- and deep-draft navigation projects plus another 12,000 miles of inland navigation system channels. In FY 1998, some 680,321 vessels moved 2.182 billion tons through inland navigation locks. Project condition surveys are performed over project areas to determine the present condition of these coastal and inland navigation channels, navigation locks, underwater features, river or flood control structures, or beach/bank erosion protection structures. These surveys are variously referred to as project condition surveys, channel condition surveys, condition surveys, or examination surveys, and are used to determine if project conditions have changed enough to warrant future construction or maintenance activities, if additional condition surveys are required at more frequent intervals, or if a greater survey coverage density is necessary. The most prevalent types of project condition surveys are those performed on authorized river and harbor navigation projects. Drawings and/or project condition reports derived from these surveys are usually furnished to local sponsors, commercial navigation interests, and to other federal agencies, such as the U.S. Coast Guard (USCG) and the National Ocean Survey (NOS). For coastal areas charted by NOS, Corps regulations require that condition survey drawings and reports must be furnished within 60 days after completion. These critical submittal requirements are detailed in ER 1130-2-520, EP 1130-2-520 and Section 554 of WRDA 2000. Survey procedures are usually designed to maximize coverage along critical channel navigation points. This is accomplished by surveying a limited number of lines either perpendicular to or parallel with the project alignment. Navigation projects without defined channel limits, e.g., inland waterway projects, may have a broader coverage. This limited density of data provides a good general project condition; however, it is insufficient for accurate quantity take-off computations. In some instances, shoal areas encountered during a condition survey will be immediately surveyed to a density and accuracy suitable for a plans and specifications.

c. Elapsed time between condition surveys. Shipper's reports and USCG Notice to Mariners are indicators of possible shoaling in waterways. Typically each project is assessed and funded on an annual basis. Changes in annual weather patterns may alter scheduled condition surveys. Some projects may require a condition survey every 10 years; other high shoaling areas, such as Southwest Pass, Mississippi River (New Orleans District), require condition surveys on a daily basis. Every project contains unique dredging parameters that require engineering judgment to predict the correct elapsed time between condition surveys. Unless unique circumstances are present, condition schedules should not be more frequent than dredging maintenance work for a given project. For example, if maintenance dredging were required every 18 months, a similar condition survey frequency would be warranted.

d. River stabilization project surveys. Surveys of revetments, dikes, levees, and other river control structures are performed to assess the condition of these control structures--see Figure 2-2. They are often referred to as overbank surveys when hydrographic coverage is extended above the water surface level using conventional topographic survey techniques. These surveys are often performed at regular intervals to determine the condition of the structures, scour, shoaling, revetment voids, etc. They are used to support a variety of engineering requirements--e.g., to develop guidance for minimum sill depth in locks to reduce lock cost, minimum under keel allowance for deep draft vessels in inland channels, and channel width and depth requirements for mixed fleets; to provide improved guidance for the design and layout of lock approach guard and guide walls - resulting in improved safety and efficiency; to develop guidance for evaluating hydraulic and sedimentation characteristics for underwater hydraulic structures and to use results to better design these structures; and to develop design guidance for bendway weirs that considers the effects of the weirs on vessels navigating the waterway. Surveys are also performed during levee grading or during placement of articulated concrete mats.

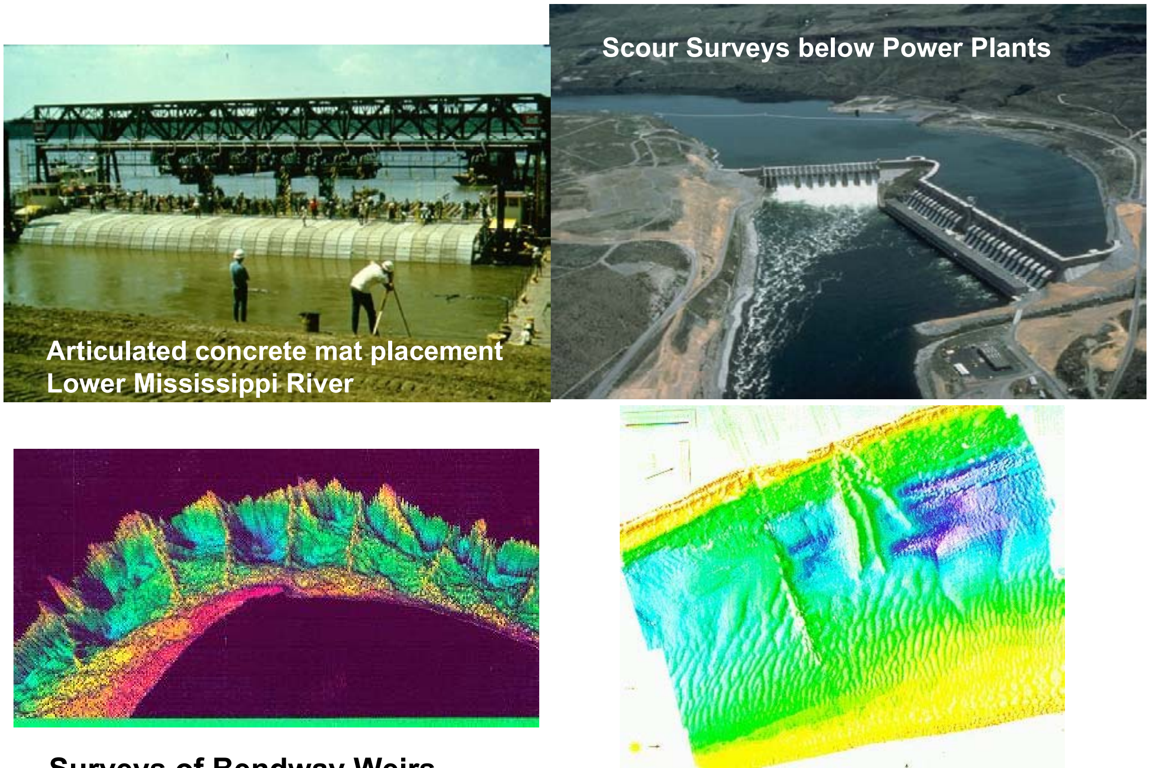


Figure 2-2. River engineering support surveys

e. Underwater obstruction or condition surveys. Surveys performed to detect the existence and extent of obstructions to the safe use of waterways are referred to as underwater obstruction surveys. Side-scan and multibeam sonar are the tools best suited to detect exposed obstructions on the channel bottom made of concrete or steel. Considerable success in locating possible obstructions (targets) has been established using side-scan coupled to a suitable positioning system. Divers may be needed to verify an underwater obstruction in some cases. Magnetometers register magnetic perturbations in the local magnetic field (which usually occur in the vicinity of metallic objects) and are often used to trace buried cables. Unlike side-scan, this equipment can detect unexposed metal. Both systems are used as qualitative tools to find underwater objects. Locations must be verified by survey equipment, and possibly divers, to meet survey standards. Condition surveys are also performed adjacent to bridge piers, locks, and below hydroelectric power plants to assess scour or other conditions. Both acoustic and visual methods may be deployed.

f. Coastal engineering surveys. Coastal engineering surveys are performed for a variety of purposes. In coastal areas, these surveys determine the condition of beach renourishment and hurricane protection projects or to support coastal engineering research studies. Surveys are also performed to study the effects of offshore protection structures (jetties, breakwaters, groins), harbor entrances, estuaries, and coastlines in areas of suspected accretion, erosion, or other material movement or transport. Surveys are also performed to develop, evaluate, and calibrate physical and numerical models used for planning and design of projects.

g. Reservoir sedimentation surveys. The Corps maintains some 390 flood control reservoirs. Many of these are periodically surveyed to assess sedimentation and update area-capacity curves.

h. Inland navigation charting surveys. Surveys are performed to update maps and charts of the Corps inland navigation projects--about 12,000 miles of waterways. Corps-wide, these charts involve hundreds of drawings. Updates are performed every 5 to 10 years. Hydrographic, topographic and facility features are updated.

i. Wetland surveys. Hydrographic surveys are often performed in shallow wetlands or water conservation pools. Different equipment and techniques are required due to the shallow depth and vegetation effects on acoustic signals. Small skiffs or airboats are often used for these surveys.

j. Miscellaneous surveys. Various other marine surveys are performed to support civil works water resources activities. These include: environmental/HTRW surveys/studies of underwater areas, periodic disposal area monitoring surveys during placement of material, offshore drill barge location, subsurface probings (wash or dry), tidal boundary surveys (e.g., MHW demarcation), and underwater archeological surveys. Some of these surveys are illustrated in Figure 2-3.

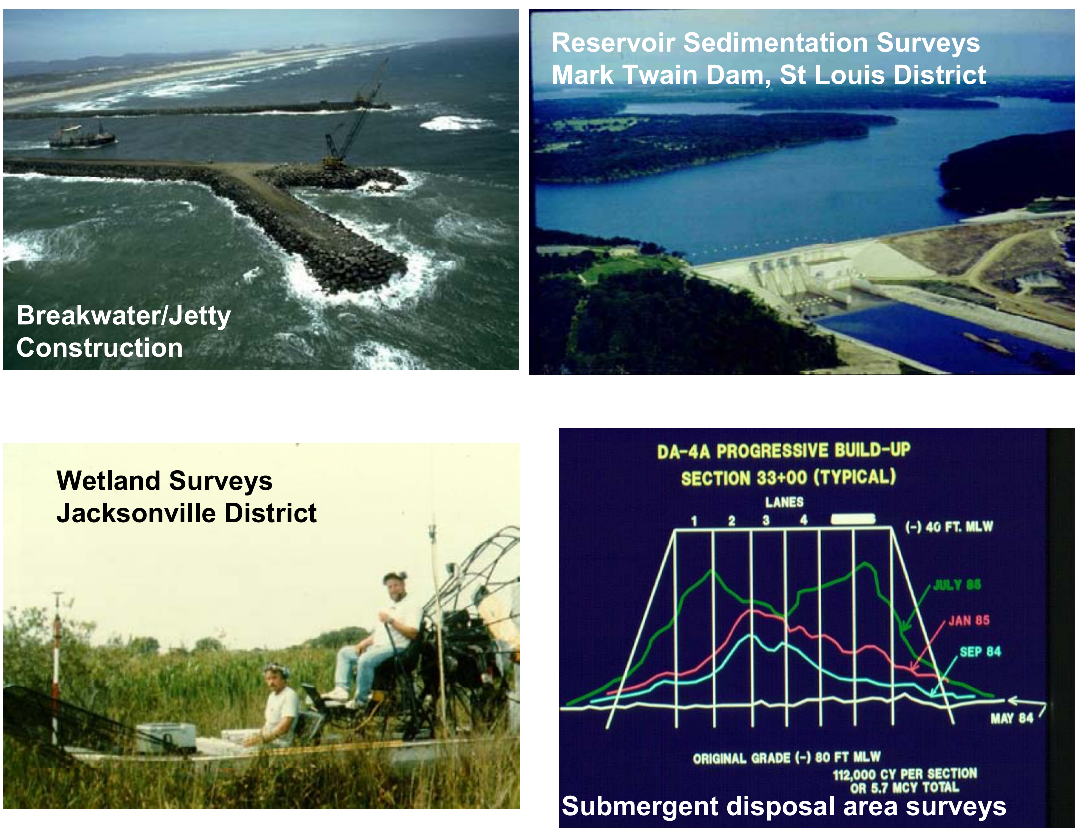


Figure 2-3. Wetland, disposal area, and sedimentation surveys

2-4. Overview of Hydrographic Survey Techniques in Corps--Field to Finish

The following sections are intended to provide an overview of a typical USACE hydrographic survey operation, from the initial planning stages, through the field data acquisition phase to the final processing and finished product stage. It is written to describe the more common navigation dredging and project condition surveys; however, it is applicable to most other types of surveys as well. This overview covers the survey equipment and instrumentation currently used on engineering and construction surveys. It is applicable to both in-house and A-E survey forces. This overview was developed by the Baltimore District.

a. Topographic survey methods. A hydrographic survey is basically a topographic survey of underwater areas. In many cases hydrographic surveys for Corps engineering and construction projects are performed using the same equipment and methods used in topographic site plan surveys. For example, a total station can be set up over a known control point on the shoreline to observe X-Y-Z points on a hand-held rod placed in underwater locations--i.e., an open-end traverse technique. Cross-sections of river or canal projects are run identically with those performed on highway construction. Data points may be recorded in a standard field survey book or electronically logged on a data recorder connected to the total station.

b. Hydrographic variations. When data points are required in areas out of range of a total station, or in water depths deeper than the range of a hand-held rod, hydrographic survey techniques must be employed. This includes use of a floating platform, locating that platform, and measuring the bottom elevation off the platform. Since the platform must be positioned, then the bottom elevation measured relative to that platform, the measurement process is, in effect, a double-leg open-end traverse.

c. Hydrographic positioning. Positioning the platform is performed using a variety of topographic or geodetic survey methods. These include resection (sextant), triangulation (transit/theodolite), trilateration (range-range or GPS), or traverse (total station or differential GPS). The positional accuracy may degrade as a function of distance from the shore-based reference point.

d. Elevation of subsurface points. The major difference between topographic and hydrographic methods involved the methods of determining the elevation of an underwater point, and the reference used to measure the elevation. Perhaps most unique to hydrographic surveys, the water surface is used to measure and reference the elevation of an underwater point, which is then termed a depth or sounding. The water surface is, in effect, the "level bubble" in a level or total station. Since this water surface is not stable (i.e., it is subject to river slope, tides, waves) elevations measured relative to this surface must be corrected. In addition, the required depth is often referenced to a nominal water surface (i.e., a datum) which in itself can vary from point to point. Hydrographic surveys can use mechanical methods to measure the depth of a point relative to the water surface. These include level rods and hand-held lead lines. More commonly, acoustic depth measurement methods are employed to measure depths relative to the floating platform. Single acoustic depths directly under the platform may be recorded as in conventional topographic survey methods. Alternatively, swath array depths may be recorded (i.e., multibeam survey system) which is the hydrographic equivalent of a photogrammetric mapping survey. X-Y-Z point data are recorded and processed similarly to topographic survey methods.

2-5. Survey Scheduling

The primary purpose for most hydrographic surveying done within the USACE is to support a wide variety of navigation-related projects. Most USACE districts routinely conduct periodic project condition surveys (PCS) on all active navigation projects to evaluate their current condition and to determine if any future dredging may be required. If maintenance dredging is necessary, then a plans and specifications (P&S) survey, a before dredge (BD) survey, and an after dredge (AD) survey must also be conducted during the dredging cycle. Because the dredge-related surveys are used to accurately determine the extent of dredge work necessary and also as the basis for final dredge contractor payment, they must meet strict accuracy standards and they need to be fully processed in near real-time. In addition to the navigation-related projects, other sources both inside and outside of the USACE may periodically require some type of hydrographic survey in order to proceed with a project. Some of these other types of projects may include structural assessment surveys, general pre-construction and as-built site surveys, natural resource reconnaissance surveys, or submerged obstruction surveys. Within a district, survey priorities tend to evolve on an almost continual basis. Generally, any contract-related surveying requirements would take priority over other less time-sensitive projects. Most districts will maintain a backlog of PCS work that can be completed during periods when there are no contract-related requirements to address. While survey priorities are an important factor when actually scheduling and conducting the survey data acquisition, many other factors also impact when a particular job may be completed. Whether the work will be conducted by an in-house survey crew or an A-E survey contractor will need to be considered when determining time requirements for completing the work. Generally, the A-E survey work will require more lead time to initiate because a delivery order scope of work will need to be prepared and survey time and cost negotiations will need to be completed. The weather can also be an important consideration when attempting to develop short-term survey schedules. For instance, high priority work in open, unprotected areas may need to be delayed because of rough sea conditions. During this time, lower priority work in more sheltered areas could be scheduled. Similarly, water level or tide conditions may also be an important consideration when scheduling hydrographic survey work. For instance, some shallow-water projects can only be efficiently addressed when water levels are running higher than normal.

2-6. Pre-Survey Planning

Before actual field surveying can begin, it is generally necessary to prepare some type of pre-survey package to assist the field surveyor. For an A-E contract survey, a scope of work must be prepared that outlines all the work required and also provides all relevant background information (e.g., channel or project coordinates, local control information, prior survey information, local contacts and rights of entry requirements, etc.). A similar scope of work may also be developed for in-house survey work, though it is not required. The pre-survey package is generally prepared in the area where most of the required background information is maintained – generally within the main data processing area or within the field office. For repeat surveys to project areas where the surveyor has frequently worked in the past, it is likely that the surveyor will have most of the prior survey information that he may need. For surveys within new project areas or areas that are unfamiliar to the surveyor, there is some pre-survey information that will need to be supplied. For new project areas, the required survey and coverage limits should be clearly indicated on a nautical chart, a quad map, or some other map that accurately depicts the area. Also, a listing of available local horizontal and vertical control information should be provided, as well as a clear indication of the required horizontal and vertical datums for the project. The control listing may represent a combination of historical USACE control, NOAA control, USGS control, or control from some other state or local agency, and should include the reference or relationship that is needed to establish the local water level-based vertical datum (e.g., Mean Lower Low Water).

2-7. Pre-Survey Field Set-up and Calibration

Before hydrographic data acquisition can begin, the field survey crew must complete a number of field set-up tasks. The local control points that will be used to establish the project datum should be recovered and verified. If control points have been destroyed or are not available in the project area, then new control may have to be established. With the strong reliance on differential GPS for survey control, there may no longer be a need to maintain an extensive horizontal control network within the immediate project site. However, If DGPS is being used for survey control, then it is a good idea to have at least one strong control point within the immediate survey that can be used to verify the performance of the positioning system.

a. Horizontal and vertical datums. Most Corps-related projects in coastal waters will use Mean Lower Low Water (MLLW) as the vertical datum. For inland navigation projects or reservoirs, a variety of reference planes may be used for the vertical datum. There are a variety of techniques for establishing a water-level related datum. Whatever vertical datum is selected, there must be a mechanism in place for recording the actual water level relative to this datum during all periods of a survey. A staff or staffs may be installed in the project area by running differential levels from the vertical datum benchmarks; this staff can then be observed and then manually recorded during the survey. Similarly, a recording water-level gauge can also be installed that will automatically record (and possibly transmit) the observed water level at a user-specified time interval. Within some project areas, NOAA or some other agency may maintain a water-level station that can be accessed to obtain the necessary water-level data. If kinematic DGPS is being used to control the hydrographic survey and adequate ellipsoidal height/water-level relationships have been developed, then the required water level information can be extracted from the DGPS data.

b. Data acquisition systems. The most common survey conducted within the USACE is a channel cross-section survey, using a single-beam acoustic echo sounder to measure depth, a differential GPS to provide accurate position, and a PC-based data acquisition system to time-tag and record the depth and position data. Multiple transducer sweep systems or multibeam swath systems may also be used. Prior to beginning this type of survey, the data acquisition system needs to be configured to reflect the particular survey vessel and the types of sensors being used and also the area being surveyed. Accurate sensor offsets must be measured between the echo sounder and the positioning antenna and then applied within the acquisition system. If the GPS antenna is mounted directly over the echo sounder transducer, then no horizontal offsets need to be applied. However, if RTK DGPS is being used to measure vertical movement during the survey, then the vertical offset would need to be measured and applied. Also, any transmit latencies (or delays) in the sensor data output must be accurately measured and also applied within the acquisition system. Finally, the pre-planned survey lines must be laid out within the acquisition system to provide the necessary coverage over the specified survey area. The pre-planned lines should include sufficient cross-check lines so that some comparisons can be made between overlapping soundings from different survey lines.

c. Speed of sound in water calibrations. Before on-line survey data acquisition can begin, the surveyor must properly measure and account for the speed of sound in the water column and the draft of the survey boat, and possibly verify the operation of the positioning system. To account for the speed of sound of the water column, the surveyor could obtain direct readings using a calibrated speed of sound profiler. An assumed speed of sound can be entered into the echo sounder during data acquisition and then the actual speed of sound profile can be applied during post-processing to correct the soundings. The surveyor can also conduct a bar-check calibration of the echo sounder to obtain an average speed of sound that can be entered directly into the echo sounder during data acquisition. Although it does not provide as complete a picture of the water column as an automatic speed of sound profile, a well-calibrated bar-check does provide verifiable proof of the proper operation of the echo sounder. It takes into account both the static draft of the transducer and the speed of sound in the water column, and can be used to provide the optimum echo sounder performance at a desired project depth. In shallow-water project areas, it may also be possible to check the echo sounder using a calibrated rod or sounding pole.

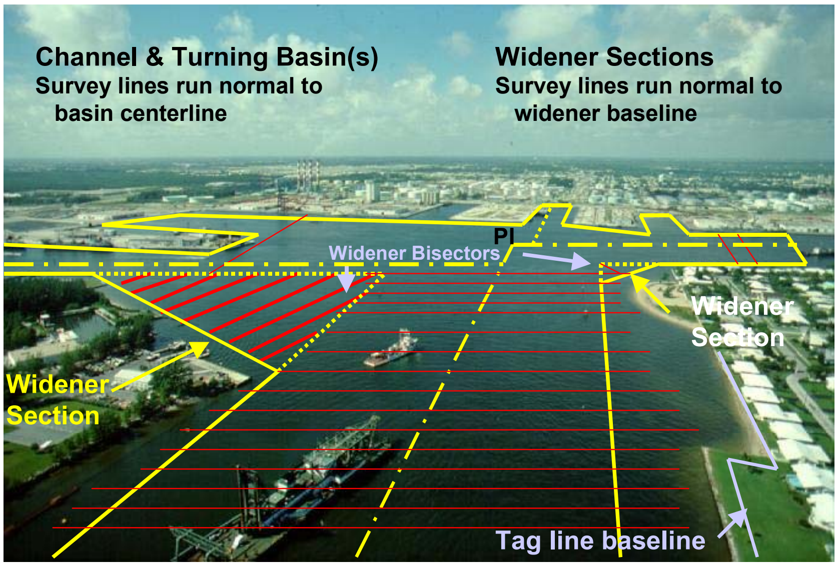
d. Vessel draft corrections. The static draft of the survey boat transducer is physically measured while the boat is out of the water and may be annotated with hash marks on the hull of the boat. The hash marks enable the surveyor to verify the static draft or to note any changes due to vessel loading. Because the draft of the boat may change considerably when underway, it is important to know the dynamic draft of the boat. The dynamic draft is usually measured through periodic settlement and squat tests that track the vertical movement of the transducer as the survey boat moves through various engine speeds. Because the dynamic draft can vary greatly with boat speed, it is usually a good idea to run the boat at a consistent speed throughout the survey. However, because dynamic draft is more a function of boat engine speed (i.e., RPMs) rather than actual speed over water, winds and current may have an effect on how the dynamic draft is applied. Most data acquisition systems measure and record the boat speed over water (based on position), but they do not record engine RPMs. The dynamic draft must either be entered during data acquisition or applied during final post-processing.

e. Positioning system calibration. Although DGPS has proven to be a very reliable system for providing accurate survey positioning data, it may still be reasonable to perform periodic system checks to verify the performance of the system. The performance check can be a straightforward procedure of placing the positioning system antenna alongside a well-known control point (e.g., a PK nail in a piling) and verifying the observed DGPS position. The positioning system performance check would be essential in project areas where a local differential base station had to established, or in wide-open, non-descript areas away from any recognizable cultural or natural features.

2-8. Survey Data Acquisition

After the data acquisition system has been properly configured and all of the necessary calibrations have been completed, on-line data acquisition can begin. For most operations, this generally entails a boat coxswain steering the boat along the pre-planned survey lines, while the surveyor monitors the data acquisition system and the sensor data to ensure that the necessary survey coverage is being obtained. As discussed earlier, tide or water level readings must be recorded during all periods of data acquisition. The water-level data can be applied on the boat during data acquisition or it can be recorded and then applied during data processing.

a. Channel section surveys. During a typical Corps channel cross-section survey, numerous lines (spaced 50, 100, or 200 feet apart) must be run across the channel alignment for the entire length of the defined project--see Figure 2-4. Because these surveys may be conducted in areas with heavy recreational and/or commercial boat traffic, it is important that the boat coxswain is attentive to local channel conditions as he steers the pre-planned survey lines. In addition to the channel cross-sections, survey data should also be acquired along the channel centerline and each of the channel toes. These channel profile lines will provide the overlapping sounding data needed to perform cross-check comparisons, and also may indicate potential shoal areas that exist between the cross-section sounding lines. In addition to the sounding lines, the surveyor should also ensure that all prominent features within the project area have been properly positioned and well described. The list of features should include all fixed and floating aids to navigation, any shoreline features such as docks or bulkheads that extend close or into the project limits, and any visible submerged or partially submerged obstructions.



Port Everglades, Florida   Jacksonville District

Figure 2-4. Cross-section surveys of a typical deep-draft navigation project

b. Annotation of depth data records. During data acquisition, the surveyor should maintain an accurate and detailed written record of the overall survey operation. This written record could be entered within a separate field book and/or entered directly on the echo sounder trace. This written record should include the basic project start-up information (e.g., date, personnel, survey project, weather, sea conditions, etc.), a record or summary of all calibration results, a summary of all survey lines run and any unusual conditions encountered on these lines, and a description of all point features that were positioned during data acquisition. In many congested project areas it is also useful to obtain photographs (regular or digital) to help describe local project conditions. If photographs are obtained, then the written record should also contain a brief description of what these pictures are depicting. A survey position should also be taken to document the point from where the photo was taken.

2-9. Initial Field Data Review and Editing

After field data acquisition is complete, the data must be initially processed and edited in the field. This is typically performed by manual processes described hereafter; however, software is rapidly being developed that will automatically adjust, filter, smooth, edit, and thin hydrographic survey data. The recorded or downloaded tide or water-level information must be properly applied to all sounding data. Each individual sounding line must also be reviewed for both position and depth accuracy. Generally, bad positioning data can either be smoothed over or rejected depending upon the extent of the bad data. If there is only a short positioning gap or "bust" (i.e., less than 15 seconds) then generally the bad positioning data could be smoothed between the adjacent good positioning data. For longer positioning busts, the data must usually be rejected and then re-run if necessary to provide the required survey coverage.

a. Editing depth data. Generally, bad depth data can either be rejected or edited, but should not be smoothed. During depth editing, the digital depth record should be compared to the analog echo sounder trace. In addition to checking for incorrect digital depths (i.e., "spikes"), the surveyor should also ensure that the critical strikes or shoals have been digitized. For instance, if the peak of a shoal or obstruction was not digitized, then the surveyor must scale this depth off of the analog trace and then insert it into the proper location within the digital record. For standard channel cross-section surveys, there is usually not a lot of depth data editing or inserting that must be done. However, for surveys conducted over irregular or varying bottoms, it may take a careful review of the records to ensure that the digital data accurately depicts the true bottom. In these types of areas, the accuracy of the digital data can be improved by increasing the record rate of the echo sounder and/or running the survey boat at slower speeds.

b. Depth interpretation in unconsolidated materials. Other types of bottom conditions can also impact the extent to which the depth data must be reviewed and edited. In naturally soft bottom areas or in dredge areas with unconsolidated materials, it may be difficult to detect or even define the true bottom. A low frequency transducer signal (e.g., 10 – 50 kHz) can usually penetrate a soft bottom layer and can help identify the first hard bottom return. However, even if a dual frequency echo sounder is used, it can still be a somewhat subjective decision as to what constitutes the true bottom. This can become a major point of contention during dredge payment surveys and must be resolved in a consistent and equitable manner. Frequently, the surveyor must prove to the project manager and the dredge contractor that the depths they are using provide the "best" and most consistent representation of the bottom. In shallow water projects, random pole soundings or lead-line soundings can be obtained to verify the accuracy of the echo sounder depths. This is more difficult in deeper projects, though lead-line soundings may still be possible in ideal conditions. The surveyor can also highlight the comparisons of overlapping survey data outside of the dredged or disturbed areas to prove the consistency of the overall survey operations.

c. Surveys in shallow waters or wetlands. Echo sounder depth readings must also be closely reviewed for operations conducted in shallow water areas. Extensive hydrographic surveying over shallow water is often required to support some type of shoreline engineering or wetland creation project and the hydrographic data will frequently be merged with adjacent topographic survey data. Because of the required signal send and receive time delays, most digital echo sounders are unable to effectively sound any shallower than two feet below the transducer. However, most of these echo sounders will still output an incorrect digital depth, even as the transducer is dragging along the bottom. In these cases, the digital depths will be off by up to two feet, but the errors will not be obvious to those who may be reviewing or using the data in the future. For shallow-water surveying, it is important that the surveyor know the limitations of the echo sounder, and either schedule the survey during high-water periods or supplement the echo sounder depths with periodic pole soundings. In order to avoid discrepancies with the overlapping topographic data, it is important that any invalid shallow-water echo sounder depths be rejected during data editing.

d. Insufficient data coverage. While editing the depth data, the surveyor should also be alert for any unusual or questionable features indicated within the echo sounder data. For instance, a slight rise or depression on a normally flat bottom may be the indication of a side echo or scour hole associated with a nearby obstruction. Any echo sounder features that cannot be adequately resolved or defined should be noted; additional data may have to be acquired in the areas immediately around these unresolved features.

e. Final review. After all necessary position and depth edits have been completed, the surveyor should review the overall edited survey package to ensure that adequate coverage has been obtained.

Ideally, this initial editing and review of the data should take place in the field so that any additional field work that may be required can be quickly addressed. This is particularly true for projects that are distant from the area where the survey party is based. During this data review, the surveyor should also check the consistency of the present survey data by comparing any overlapping sounding data. If the survey area is part of a dredging project or has been surveyed in the recent past, then the current survey data can also be compared against any prior survey data to provide another measure of the reliability of this data. Any additional field data that is required to fill in coverage holes caused by rejected data, to better define a potential bottom feature, or to resolve some other discrepancy should be acquired as soon as possible. This additional data should be edited as discussed above and then combined with the prior survey data.

2-10. Field Data Submittal to District Office

After data acquisition and initial field editing are complete, the finished field data package should be submitted for office review and final data processing. Many of the specific procedures used for submitting data and also the office where the final data processing actually occurs will likely vary a great deal between Corps districts. However, in most cases the same basic requirements for data submittal will need to be met. Generally, both raw and edited digital survey data, any applicable digital parameter files, all echo sounder traces, all survey notes or field books, any supplementary tide or GPS data, any digital or regular photographs taken, and any other relevant survey information should be submitted to the final data processing office. In addition to the field survey items outlined above, the field unit may also be responsible for creating and submitting the initial metadata file that will be used to describe and track this data set as it moves through the final data processing phases.

a. District office review of incoming field data package. If the field performed most of the editing and processing of data on board the survey boat, then the amount of district office review will be minimal; and will be primarily a quality assurance check on the adequacy of the field data processing. A cursory scan of cross-sections is usually adequate to pick up any editing deficiencies. A cross line check run in the field may also be rerun to verify data adequacy. Comparisons with any recent surveys should be performed. For contract surveys pre- and post- dredge sections may be compared. Data are then sorted for subsequent volume computations and/or plotting. The type of processing for volumes will depend on the type of collected data and if TIN or average-end-area volumes will be computed. After quantities are computed, they should be quality checked against estimated quantities or progress payment quantities. Data are then sorted at proper increments for eventual plotting. Thinning of data must follow Corps-wide guidelines. Multiple sorts may be required if different plot scales are needed.

b. Convert data to CADD format and distribute to users. Hydrographic data is incorporated with other related information such as digital quad data, aerial mapping data, and digital photos. Data files are merged within a CADD package--e.g., MicroStation/Inroads--and drawings are adjusted to the desired plot scale. Although most surveys are distributed in plan format, other display options are available. Figure 2-5 depicts a condition survey report in which controlling depths are shown by profile lines along the channel. The entire database should be reviewed prior to electronic transmittal to the requesting district function. Project Managers receiving data should be requested to red-line any corrections and provide other comments. Where applicable, controlling depths are determined for project condition reports. Final drawing files are created and raw and edited data and map files are archived. Metadata files are generated and placed on applicable public servers. Project condition survey data is distributed to Federal and local agencies, and posted directly on servers for public access. Digital Project Notebook data are updated if needed to reflect new survey information.

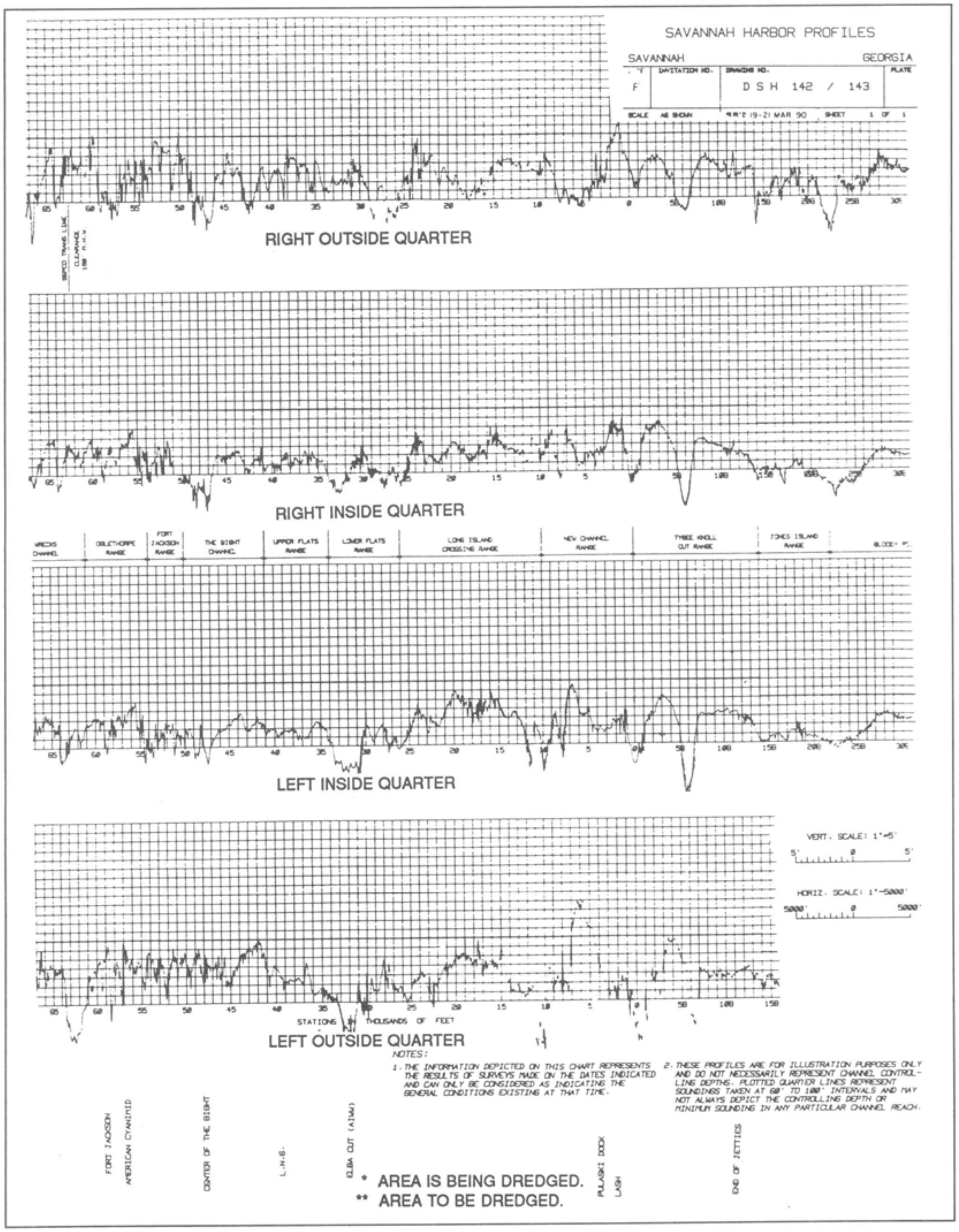


Figure 2-5. Savannah Harbor profile lines (Savannah District)

2-11. Mandatory Requirements

There are no mandatory requirements in this chapter.

Chapter 3
Corps Accuracy Standards, Quality Control, and Quality Assurance Requirements

3-1. Purpose

This chapter contains survey accuracy, quality control, and quality assurance criteria for USACE hydrographic surveys. These criteria are intended to provide Corps-wide consistency and uniformity in performing surveys on civil works projects.

Table 3-1. Minimum Performance Standards for Corps of Engineers Hydrographic Surveys (Mandatory)

PROJECT CLASSIFICATION		Navigation & Dredging Support Surveys Bottom Material Classification		Other General Surveys & Studies (Recommended Standards)
		Hard	Soft	
RESULTANT ELEVATION/DEPTH ACCURACY (95%)				
System	Depth (d)			
Mechanical	(d<15 ft)	± 0.25 ft	± 0.25 ft	± 0.5 ft
Acoustic	(d<15 ft)	± 0.5 ft	± 0.5 ft	± 1.0 ft
Acoustic	(15>d<40 ft)	± 1.0 ft	± 1.0 ft	± 2.0 ft
Acoustic	(d>40 ft)	± 1.0 ft	± 2.0 ft	± 2.0 ft
OBJECT/SHOAL DETECTION CAPABILITY				
Minimum object size (95% confidence)		> 0.5 m cube	> 1 m cube	N/A
Minimum number of acoustic hits		> 3	3	N/A
HORIZONTAL POSITIONING SYSTEM ACCURACY (95%)		< 2 m (6 ft)	2 m (6 ft)	5 m (16 ft)
REPORTED FEATURE HORIZONTAL LOCATION ACCURACY (95%)				
Plotted depth location		2 m (6 ft)	5 m (16 ft)	5 m (16 ft)
Fixed planimetric features		3 m (10 ft)	3 m (10 ft)	3 m (10 ft)
Fixed navigation aids		3 m (10 ft)	3 m (10 ft)	3 m (10 ft)
Floating navigation aids		10 m (30 ft)	10 m (30 ft)	10 m (30 ft)
SUPPLEMENTAL CONTROL ACCURACY				
Horizontal Control		3rd order (I)	3rd order (I)	3rd order (I)
Vertical Control		3rd order	3rd order	3rd order
WATER SURFACE MODEL ACCURACY		[½ depth accuracy standard]		½ depth accuracy
MINIMUM SURVEY COVERAGE DENSITY		100% Sweep	NTE 200 ft or 60 m	NTE 500ft (150m)
QUALITY CONTROL & ASSURANCE CRITERIA				
Sound velocity QC calibration		> 2/day	2/day	1/day
Position calibration QC check		1/day	1/project	1/project
QA performance test		Mandatory	Required (multibeam)	Optional
Maximum allowable bias		± 0.1 ft	± 0.2 ft	± 0.5 ft

3-2. USACE Hydrographic Survey Accuracy Performance Standards (Mandatory)

Table 3-1 contains the most critical technical performance standards for Corps hydrographic surveying activities. These standards are mandatory for "Navigation and Dredging Support Surveys." The standards for "Other Surveys and Studies" are recommended. These standards are designed to reflect current survey instrumentation, practices, and capabilities; however, it is fully recognized that exceptions to these standards will exist for some applications, or as technological advances occur--refer to Chapter 1 for waiver procedures. These standards are considered "minimum technical performance standards" and are independent of the measurement process employed. Explanatory notes and definitions for the classifications and standards are in subsequent sections of this chapter. More detailed standards are found in other chapters covering specific instrumentation, equipment and procedures.

3-3. Accuracy, Quality Control, and Quality Assurance

The standards in Table 3-1 represent the resultant elevation (or depth) accuracies of the data set collected on a survey. Various Quality Control (QC) procedures and Quality Assurance (QA) performance tests are performed to meet and confirm these accuracy requirements. The distinction between QC and QA is important.

a. Quality control. Throughout this manual a variety of QC procedures are prescribed for survey instrumentation and data collection techniques in order to minimize systematic and random errors in individual data points. Table 3-1 only specifies general speed of sound and position QC tests. Related QC tests include: bar checks, velocity casts, patch tests, instrument alignment tests, vessel velocity limitations, multibeam beam-width restrictions, and overlapping coverage. Recommended QC procedures are contained in this manual and in equipment manufacturer's operating manuals. These recommended QC procedures are based on past experience and practices by Corps districts and should not be waived without thorough justification and analysis. Performing all recommended QC procedures does not necessarily ensure that the resultant elevation data will meet the accuracy standards in Table 3-1, as measured by a QA performance test.

b. Quality assurance. QA tests are performed to verify the survey data meets the required accuracy standard. An ideal QA procedure compares observed X-Y-Z coordinate dataset values with coordinate values obtained from an independent source of higher accuracy for the same identical points -- reference FGDC Geospatial Positioning Accuracy Standards: Part 3--National Standard for Spatial Data Accuracy. Obtaining independent, higher-accuracy test points is either impractical or impossible for most hydrographic survey data collection systems. Thus, acceptable hydrographic QA performance tests typically compare two nearly independent sets of elevation data collected over the same area. The resultant statistical comparison between the two data sets is evaluated against the required elevation accuracy in Table 3-1. If a QA test indicates data does not meet the accuracy standard, then additional or more stringent QC procedures and calibrations may be required. QA performance tests are not always feasible or practical for all survey methods -- e.g., lead line surveys -- or the results may not be definitive due to few independent depth comparisons -- e.g., single-transducer cross-section surveys. QA tests are essential for acoustic multibeam surveys and typically compare more accurate vertical beam elevations and positions against those obtained from the outer portions of the array.

3-4. Project Classifications Relative to Accuracy Standards

The accuracy performance criteria in Table 3-1 distinguish between two general classes of USACE support surveys--those performed in support of navigation and dredging projects and those supporting general engineering studies. In general, accuracy requirements are more demanding for navigation projects where ship clearance and contract dredging payment issues are especially critical. Surveys for general hydraulic engineering studies, reconnaissance, planning, etc., usually do not require the same levels of accuracy. This distinction is not entirely rigid -- specific horizontal and vertical accuracy requirements should always be assessed and defined for each project. The accuracy standards in Table 3-1 are considered "minimum" -- they may not be applicable or adequate (i.e., accurate enough) for all projects, or the horizontal and vertical accuracy requirements for a particular project are unique. For example, hydraulic sections on a small drainage project may be require ± 0.1 foot elevation accuracies but only 20 ft horizontal accuracy. In cases where these standards are considered too rigid, then waivers must be requested from HQUSACE.

3-5. Navigation and Dredging Support Surveys

This classification applies to all surveys performed in support of the Corps navigation mission. It includes both deep-draft (> 15 ft) and shallow-draft (< 15 ft) navigation projects. Types of surveys include: project condition surveys of navigation channels, dredging contract plans and specifications surveys, dredging measurement, payment, clearance, and acceptance surveys, and river charting surveys. The two distinct sub-categories are based on the characteristics of bottom conditions and the potential for navigation hazards in the project. These sub-classifications, and related accuracy standards, are intended to correspond closely with recently revised international and Federal hydrographic surveying standards for navigation projects. In effect, the survey instrumentation requirements, accuracy standards, and quality control procedures vary as a function of bottom type in a navigation channel; as does the required accuracy of dredge measurement and payment. The standards in Table 3-1 are mandatory for this class of survey.

a. Hard bottom material and/or new work. This sub-category of surveys includes those involving newly authorized navigation projects containing hard bottom material, such as rock or highly compacted material, or maintenance dredging of existing navigation projects containing hard bottom or otherwise hazardous material. This would also include recurring condition surveys of these projects. This category may also include navigation projects where low under-keel clearances are anticipated over potentially hazardous bottom conditions, hazardous cargo is transported, or where bottom sediment could adversely impact naval vessels transiting a project. Mechanical or acoustic sweep methods must be employed to ensure 100% bottom coverage in order to detect small objects remaining above the required dredging prism. The most precise carrier-phase DGPS positioning and elevation measurement techniques must be employed for this class of project. In actuality, only a small number of Corps projects fall under this category--for example, projects such as Kill Van Kull, NJ, Port of Los Angeles/Long Beach, and St. Marys River, MI. A hard bottom classification does not require *in situ* bottom density sampling but should be based on a professional geotechnical opinion given local project knowledge, historical information, and project requirements.

b. Soft bottom material and/or maintenance dredging. This sub-category of surveys is intended to cover navigation projects containing soft sand/silt bottoms not judged to be hazardous to vessel hulls; or in projects with soft, featureless, and relatively continuous channel bottoms where gaps in coverage between survey lines are unlikely to yield potential hazards/strikes. The vast majority of the Corps 926 deep- and shallow-draft navigation projects and 12,000 miles of maintained waterways fall within this category--e.g., inland and intracoastal navigation systems and most coastal harbor projects. Accuracy, QC, and QA standards are slightly relaxed for this class of projects. Vessel positioning is usually accomplished using nationwide or local DGPS -- e.g., USCG Radiobeacon System. Dredge measurement, payment, and acceptance surveys are typically performed by cross-section methods using single beam acoustic transducer systems. Acoustic multi-transducer or multibeam sweep systems may optionally be used on deep-draft projects.

c. Underwater investigation surveys. These surveys include precise investigation surveys of/around locks, dams, power plants, abutments, piers, jetties, bulkheads, and other structures. Detailed investigation surveys of hazardous objects lying within the authorized navigation prism or project depth should follow the accuracy standards prescribed for navigation and dredging surveys. If full bottom coverage and/or object detection sweeping is required, then the standards for the most precise (Hard Material) sub-category of surveys should be followed. On critical surveys, 200% acoustic coverage is usually recommended.

3-6. Other General Surveys and Studies

This category includes all other hydrographic surveys not directly associated with construction measurement, payment, and acceptance functions, or surveys not associated with a navigation project or data that is incorporated directly or indirectly into a Corps, NIMA, or NOAA navigation chart. Examples of these surveys include: general reconnaissance or planning surveys/studies, flood control project surveys, reservoir sedimentation surveys, flood plain boundary surveys, hydrological and hydraulic surveys, coastal engineering surveys, beach surveys, environmental investigations, geotechnical investigations, and disposal area surveys. The accuracy standards shown in Table 3-1 are not mandatory for this class of surveys.

3-7. Resultant Elevation/Depth Accuracy Standard

In Table 3-1, the root-mean-square (RMS) elevation accuracy performance standards are evaluated at the 95% confidence level (1.96-σ), and are specified for a reduced depth, relative to a local reference datum. An accuracy reported at the 95% confidence level means that 95% of the elevations in the dataset will have an error with respect to true ground elevation that is equal to or smaller than the reported accuracy value. It includes all propagated error components that make up a reduced elevation (i.e., local geodetic datum errors, tide/stage modeling-extrapolation-interpretation errors, dynamic-latency/roll/pitch/heave errors, acoustic measurement errors, including velocity, refraction, and beam forming errors, etc.). It also includes any horizontal errors propagated through the vessel positioning system employed (e.g., DGPS, tag line, total station). Different depth measuring systems have widely varying accuracies. Typically, mechanical and acoustic depth measurement accuracy degrades with increasing depth. Multibeam system accuracies degrade as beam angle increases. Other factors, such as tide or water surface model uncertainty, can further compound the assumed depth-accuracy relationship. The depth-dependent accuracy standards shown in Table 3-1 attempt to accommodate the differing project depths found on USACE navigation projects, and the typical survey equipment and procedures used on these projects. They also recognize that shallow-draft projects (< 15 ft) generally have more accurate tide/stage or water level surface models than deep-draft projects in coastal (tidal) areas. Likewise, deep-draft projects over 40 ft will typically have less accurate tidal modeling.

a. Mechanical depth measurement methods in less than 15 feet of water include lead line, differential leveling, total station, etc. Beyond 15 feet of depth, mechanical depth measurement accuracy significantly degrades, so these devices are now rarely used for dredging and navigation surveys in these greater depths.

b. Acoustic methods include single-transducer, multiple-transducer, or multibeam systems. Accuracy standards for project depths less than 15 feet are intended to include shallow draft or inland navigation projects where tide/stage and sea state corrections are minimal. Depths over 40 feet are intended to include coastal entrance channels or other offshore areas subject to significant tidal phase, tidal range, and sea state variations. The elevation accuracy standards are only applicable for project depths less than 80 feet or 25 m.

c. In areas with uncertain datum reference planes, undefined tidal modeling, or subject to large hydraulic grade or weather induced water surface anomalies, centimeter-level carrier-phase DGPS elevation measurements may be necessary to achieve the more stringent accuracy requirements.

d. The elevation accuracy standard is assessed by computing the standard deviation between two overlapping surveys--multibeam or single-beam cross-line check comparisons. The process is described in Chapter 4.

3-8. Horizontal Positioning System Accuracy Standard

The horizontal positioning system accuracy standards indicated in Table 3-1 are prescribed to ensure that data shown on contract drawings or river charts meet minimal feature location accuracy standards. In reality, this horizontal accuracy standard is a QC procedure in that horizontal errors propagate into the resultant elevation accuracy. The standard is a two-dimensional radial (circular) error measured at 95% confidence region accuracy, and is specified for the transducer location relative to a local project or nationwide geodetic framework. It includes all propagated error components that make up the overall position error budget (i.e., local geodetic network accuracy, electronic positioning system/DGPS accuracy, dynamic-latency/roll/pitch errors, antenna-transducer translation errors, etc.). This positioning system accuracy is not the reported horizontal accuracy of the projected depth feature--see paragraph 3-10 below. Nationwide code phase DGPS networks will generally achieve the 2-meter accuracy standard at reasonable distances from the reference station; however, in some cases, more accurate total station or carrier-phase DGPS positioning may be necessary to ensure less than 2-meter positional accuracy is consistently obtained so that a resultant feature is located within the required tolerance.

3-9. Object and Shoal Detection Standards

The performance standard is based on detection of object of cubic side dimensions indicated, using either mechanical or acoustic sweeping/scanning methods. Demonstration testing of the acoustic detection system's capability should be specified/required on critical projects. This would entail deployment of an artificial object with the required dimensions. A minimum of three acoustic returns must be received from a shoal or object to confirm its existence. These acoustic hits may be obtained on a single pass or, more conclusively, over successive passes. Reconfirmation of a strike above project grade by successive passes on different courses is strongly recommended for dredging clearance surveys.

3-10. Reported Feature Horizontal Location Accuracy

Topographic and planimetric features shown on navigation drawings or charts should be located so as not to exceed ~~to~~ the indicated accuracies in Table 3-1. Feature positional accuracies (and elevation accuracies) are estimated and reported at the 95% RMS level, and are usually averaged for a project--refer to FGDC Geospatial Positioning Accuracy Standards--Part 1: Reporting Methodology. The reported horizontal accuracy of a recorded (geospatially plotted) depth(s) should account for the various propagated error components that are contained in the positioning system and echo-sounding beam forming systems. The positional accuracy of a recorded depth will generally degrade as depth increases, and in the outermost arrays of a multibeam system. Estimating the overall (average) resultant horizontal accuracy of recorded depths is project dependent, and must factor in the overall horizontal error budget--see Chapter 4 for additional guidance. Fixed planimetric features include dredging limits, bulkheads, piers, etc. Fixed navigation aids are lighthouses, ranges, beacons, daymarks, etc. In general, code-phase DGPS accuracy is sufficient for positioning fixed navigational features. These accuracies of fixed features do not apply to design or construction of marine facilities or structures. Contract plans for such facilities require conventional topographic or photogrammetric mapping accuracies--see EM 1110-1-1000 (Photogrammetric Mapping) and EM 1110-1-1005 (Topographic Surveying).

3-11. Supplemental Control Accuracy

These standards refer to supplemental control surveys performed to extend project control for other applications. This would include control for traditional tag line or range-azimuth surveys of areas where DGPS is obscured, beach renourishment surveys, or surveys to transfer elevations to supplemental gages or staffs. Technical guidance for control surveys may be found in Chapter 11 (Accuracy Standards for

Engineering, Construction, and Facility Management Surveying and Mapping) of EM 1110-1-2909 (Geospatial Data and Systems) and EM 1110-1-1005 (Topographic Surveying).

3-12. Tidal or Water Level Surface Modeling Accuracy

These standards refer to the accuracy by which the water surface elevation is determined at the point a depth measurement is observed. Tide or stage uncertainty can often be the major error component in the resultant accuracy of an elevation measurement. It includes the precision which a tide or river stage is interpolated or extrapolated (i.e., modeled) relative to a reference gage. In areas where modeling techniques are inadequate, where the project area is distant from the reference gage, or with large tidal range and phase variations, carrier-phase DGPS techniques may be necessary to meet the required standard.

3-13. Survey Density

a. Hard Material. Full bottom coverage (i.e., 100%) may be obtained using any of the following methods: mechanical bar sweep, multi-transducer acoustic sweep, acoustic multibeam sweep, or side-scan sonar sweep. Sweep alignment may be run in any direction. Double (200%) coverage may be specified on critical navigation projects.

b. Soft Material. In soft material, either multibeam or single-beam survey systems may be used. Multibeam systems are recommended for deep-draft navigation projects. If single-beam systems are deployed, cross-section spacing shall not exceed the 200-foot standard, where cross-sections are run perpendicular to the channel alignment. 100-foot sections are recommended for most dredging measurement and payment projects. If single-beam longitudinal sections are run, additional (denser) sections shall be required along channel side slopes. Some condition surveys may not require side slope coverage. Cross-section spacing may be increased on condition surveys of shallow-draft projects containing soft, uniform bottoms. Other exceptions would include general project condition surveys of narrow intracoastal waterways or undefined river channels where longitudinal or centerline surveys are conducted for shoal investigation or reconnaissance purposes.

c. Other Surveys and Studies. Standard specified for single-beam echo sounder, cross-sections run either perpendicular to or longitudinal with the project alignment. Full coverage LIDAR or acoustic sweep systems may optionally be used if available.

3-14. Quality Control and Quality Assurance Criteria

Table 3-1 contains four of the more critical quality control and quality assurance criteria required for USACE hydrographic surveys. Other supplemental quality control calibrations required for individual system components are described in manufacturer's operation manuals and in later chapters of this manual. The QC and QA criteria listed in Table 3-1 are based on generally accepted procedures currently in practice. More detailed guidance on QC/QA tests can be found in chapters dealing with the specific survey systems.

a. Sound velocity calibrations. Sound velocities for all acoustic systems shall be observed at the minimum intervals shown in Table 3-1. Velocity measurements by bar check, ball check, and/or velocity meters are mandatory. Some equipment (e.g., multibeam) may require more calibrations than that indicated, based on QA performance results.

b. Horizontal position calibration. Criteria are specified for local or regional code or carrier phase DGPS positioning system. Generally, only a position verification (i.e., blunder) check is required, either at known project control point or from redundant USCG beacon positions. Other positioning systems require more demanding calibrations, as indicated in subsequent chapters.

c. Quality assurance performance test. QA performance tests shall be performed in order to verify compliance with the depth accuracy standard. Performance tests are required for multibeam systems and are optional (but recommended) for single-beam systems. Procedures and criteria for QA performance tests are found under the chapters covering single-beam, multiple-transducer, and multibeam systems.

d. Maximum allowable bias. The maximum bias between two surveys is indicated in Table 3-1. This bias is determined by computing the mean difference between two overlapping surveys--multibeam or single-beam cross-line check comparisons.

3-15. Related Standards

Following is a list of international, Federal, and USACE standards that may have application to navigation data collected on Corps projects. Additional standards are listed in Chapter 6.

a. EM 1110-1-2909 (Geospatial Data and Systems), Chapter 11 (Accuracy Standards for Engineering, Construction, and Facility Management Surveying and Mapping). This chapter of EM 1110-1-2909 provides technical guidance on engineering surveying and mapping accuracy standards used in engineering and construction. It is intended for use in developing specifications for geospatial data used in various project documents, such as architectural and engineering drawings, master planning maps, construction plans, navigation project condition charts and reports, and related GIS, CADD, and AM/FM products.

b. FGDC Geospatial Positioning Accuracy Standards, Part 3: National Standard for Spatial Data Accuracy. This FGDC standard is used to evaluate and report the positional accuracy of spatial data produced, revised, or disseminated by or for the Federal Government. According to Executive Order 12906, Coordinating Geographic Data Acquisition and Access: the National Spatial Data Infrastructure, *"Federal agencies collecting or producing geospatial data, either directly or indirectly (e.g. through grants, partnerships, or contracts with other entities), shall ensure, prior to obligating funds for such activities, that data will be collected in a manner that meets all relevant standards adopted through the FGDC process."* Related FGDC standards include:

(1) FGDC Standards for A/E/C Surveys. Federal Geographic Data Committee (FGDC), Facilities Working Group, Geospatial Positioning Accuracy Standards PART 4: Standards for Architecture, Engineering, Construction (A/E/C) and Facility Management. This standard is currently in draft form. The Corps of Engineers (HQUSACE) was the primary developer for this standard; thus it reflects most Corps civil works and military construction activities. It provides recommended accuracy tolerances for site plan mapping supporting engineering and construction. It also contains recommended control survey accuracy standards for these projects. Its application to hydrographic surveying would be depiction of topographic and planimetric detail adjacent to projects.

(2) FGDC Standards for Nautical Charting Surveys. Federal Geographic Data Committee (FGDC), Bathymetric Subcommittee. Geospatial Positioning Accuracy Standards PART 5: Standards for Nautical Charting Hydrographic Surveys, (July 2000 Draft). This document provides minimum standards for the horizontal and vertical accuracy of features associated with hydrographic surveys that support nautical charting. Such features include, but are not limited to, water depths, objects on the seafloor, navigational aids, and shoreline. The scope of these standards includes the coastal waters of the U.S. and its territories. A copy of the latest draft (July 2000) of this standard is at Appendix B.

c. International Hydrographic Organization (IHO) Standards for Hydrographic Surveys. Special Publication No. 44, Fourth Edition, Monaco, (1997 Draft). IHO is an intergovernmental consultative and technical organization working to support the safety of navigation and the protection of the marine environment. The purpose of this standard is to specify minimum criteria for hydrographic surveys in order that hydrographic data collected is sufficiently accurate and that the spatial uncertainty of data is adequately quantified to be safely used by mariners (commercial, military or recreational) as primary users. The FGDC Part 5 standard at Appendix B was taken directly from this IHO standard. Therefore, these two standards are nearly equivalent.

d. FGDC Bathymetric Subcommittee. National Hydrography Data Content Standard for Coastal and Inland Waterways – January 2000 (Draft). This document contains a catalog of hydrographic feature terms and definitions pertaining to navigation of coastal and inland waterways, as they relate to charting and electronic chart display applications. The standard does not address data distribution formats, extraction criteria, or accuracy reporting methods beyond inland and coastal waterways. This standard does not currently address hydrographic symbology. However, in future versions/releases it is planned to add standard symbology information. A copy of the latest draft of this standard is at Appendix C.

e. International Hydrographic Organization's S-57 (IHO S-57) Appendix A, Object Catalog for Digital Hydrographic Data.

f. National Institute of Standards and Technology, Federal Information Processing Standard Publication 173 (Spatial Data Transfer Standards), U. S. Department of Commerce, 1992.

g. North Atlantic Treaty Organization's (NATO) Digital Geographic Information Exchange Standard (DIGEST) Part 4, Feature Attribute Coding Catalog (FACC). This is a comprehensive coding scheme for features, their attributes and attribute. This allows for joint naval operations between sovereign countries and requires naval personnel to have familiarity amongst traditional S-57 and FACC.

h. CADD/GIS Technology Center *(Tri-Service*) *Spatial Data Standard (SDS).* Primarily used for civil and military installation mapping and facility management.

i. U.S. Army Corps of Engineers (USACE) Regional Engineering and Environmental Geographic Information System (REEGIS). A data dictionary for inland waterways developed by the Mississippi Valley Division for engineering, navigation and flood control structures along the Mississippi River.

3-16. Mandatory Requirements

Mandatory Corps accuracy standards, QC criteria, and QA requirements are identified in Tables 3-1 and in subsequent explanatory paragraphs in this chapter.

Chapter 4
Survey Accuracy Estimates for Dredging and Navigation Projects

4-1. General Scope

This chapter defines the hydrographic surveying accuracy standards used in Table 3-1. It also provides guidance on statistically evaluating the accuracy of an observed geospatial point (i.e., a depth measurement) or a set of points in a database. Such evaluations are used in assessing the accuracy of a hydrographic survey relative to channel clearance, dredge measurement and payment, and related coastal engineering or hydraulic engineering computations.

4-2. Hydrographic Survey Accuracy

Hydrographic surveying is, in its most basic form, a two-legged, open-end traverse. The first leg of the traverse is the positioning of the survey platform. The X-Y location of the survey boat is typically determined by visual or electronic methods described in this manual. The elevation of the boat is usually obtained relative to the elevation of the local water surface. Thus the vessel position and elevation are independent measurements—each with their own accuracies. The underwater depth measurement—the second leg of the open-end traverse--is made relative to the water surface using mechanical or acoustic methods. Depth measurement methods have widely varying accuracies. Unlike conventional terrestrial surveying, there is no method to "close out" the traverse on a measured depth. Therefore, the accuracy assessment of an observed depth can only be estimated using statistical assumptions. In addition, hydrographic surveying has few real-time quality control indicators to verify or check its resultant accuracy. Since the subsurface point is not visible, even gross blunders are difficult to detect. Maintaining prescribed accuracy criteria, therefore, requires precision, care, and quality control in the measurement process. There are few opportunities to correct or adjust the data after the fact.

a. Vessel horizontal position accuracy. A survey vessel's horizontal position is determined by an open-ended survey method--trilateration, triangulation, or traverse. Because these positioning methods have no independent check, the accuracy of an offshore position is totally dependent on the precision of the measuring process. The positional accuracy is a function of the measurement method, distance from the reference baseline, atmospheric conditions, sea state, and numerous other factors. Positional accuracies can vary from less than 0.5 meters (carrier phase real-time-kinematic (RTK) DGPS) to over 20 meters when visual location methods are used.

b. Depth measurement accuracy. Depth measurement accuracy likewise has many potential error components. These include measurement method (mechanical or acoustic), sea state, water temperature and salinity, transducer beam width, bottom irregularity, bottom consistency, and vessel heave-pitch-roll motions. In addition, the depth must be referenced to the local water surface which, in turn, must be referenced to a datum plane at some remote point. All these factors make up the error budget of the depth measurement.

c. Combined horizontal and vertical accuracy. The overall accuracy of an observed bottom depth elevation is dependent on many random and systematic errors that are present in the measurement processes used to measure that elevation. This makes any quantitative comparisons of the observed elevations difficult, particularly in areas of irregular terrain. Thus, any efforts to compare different surveys made over the same presumed point must factor in the inaccuracies in all three dimensions and their resultant impact on an existing terrain gradient. An overall assessment of the accuracy of an individual depth or bottom elevation must also fully consider all the error components contained in the observations that were used to determine the point. The resultant accuracy of a single depth point is represented by a 3-D error ellipsoid, as shown in Figure 4-1. The dimensions of this ellipsoid are indicated by the standard errors in all three dimensions—s_X, s_Y, and s_Z. The size and orientation of this 3-D ellipsoid is determined from all the various error components ("uncertainties") that made up the position and depth measurements. In general, the dimensions of the ellipsoid are larger in the X and Y planes, due to positional accuracy being less accurate than the depth measurement (e.g., 2 meter DGPS accuracy and $\pm$1 foot depth accuracy).

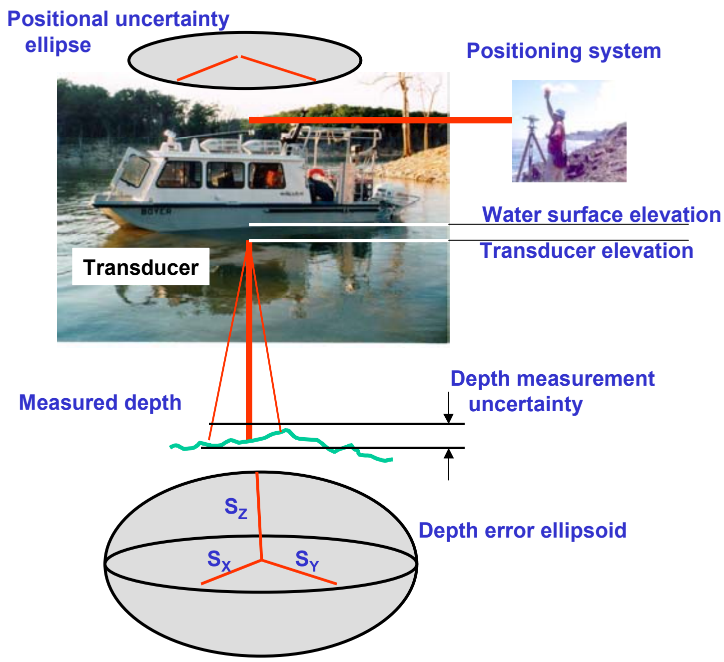


Figure 4-1. Three-dimensional uncertainty of a measured depth

d. The accuracy of hydrographic survey measurements is therefore highly dependent on the accuracy of each measurement component, including calibrations, parametric correlation (time, distance, or velocity) of the measured components, reductions, and corrections made to the data. It is also highly time-dependent, given the inability to make frequent calibrations, short-term physical changes in the measurement mediums (water and air), and the wide area over which these variations may occur. Hydrographic surveys can exhibit different results when measurements are repeated at different times. This variation becomes obvious when comparing cross sections (and resultant end area volumes) measured by different survey crews and/or systems, or even the same crew and system in many cases. It is extremely difficult to independently verify the accuracy of a dynamic hydrographic measurement. In general, the accuracy of a hydrographic survey can only be estimated based on results obtained during repeated equipment calibrations. Since these calibrations are not always performed in a dynamic (on-line) environment, the ultimate accuracy must be estimated (thus the use of the term "estimated accuracy") using statistical estimating measures. Other techniques that may be used to evaluate the accuracy of a hydrographic survey include cross-check lines and performance tests in multibeam surveys. These are described in later chapters of this manual.

4-3. Accuracy, Precision, and Root Mean Square Error

A clear distinction must be made between the terms *accuracy* and *precision* when referring to a hydrographic measurement or series of measurements (i.e., a data set from a particular survey). These concepts are illustrated in the depth observation dispersion curves in Figure 4-2. In this figure, observed depths are dispersed around a "true" value that is unknown. The depth observations contain both random errors and systematic biases. Biases are often referred to as systematic or external errors and may contain observational blunders. A constant error in tide or stage would be an example of a bias. Random errors are those errors present in the measurement system that cannot be easily minimized by further calibration.

Examples include echo sounder resolution, water sound velocity variations, tide/staff gage reading resolution, etc. The *precision* of the observations is a measure of the closeness of a set of measurements--or their internal agreement-- shown as $\sigma_{\text{RANDOM ERROR}}$ in the figure. This is synonymous with "repeatability." Accuracy relates to the closeness of measurements to their true or actual value. Accuracy, therefore, includes both precision ($\sigma_{\text{RANDOM ERROR}}$) and any systematic biases (shown as σ_{BIAS}) that may be present. For example, a depth digitizer may repeatedly display a given depth to precisely $\pm$ 0.1 ft; however, the accuracy of the depth may be only $\pm$ 1.5 ft when other error components are included. Repeated observations during a static calibration will not always remove systematic biases that may be present--e.g., a tidal datum error in a depth observation. High precision, or repeatability, does not necessarily indicate high accuracy. Apparently scattered data may be highly accurate, whereas highly repeatable data could have large undetected biases.

a. The upper curve in Figure 4-2 illustrates such a case. The measurements have a high "precision" of say $\pm$ 0.2 ft but there could be a (-) 1.3 ft bias due to a tidal modeling error at the work site, a bar check calibration blunder, or erroneous squat/settlement correction. A smooth, flat bottom in calm waters would yield a small variance such as the $\pm$ 0.2 ft value.

b. The lower curve is an example of a low "precision" depth measurement. In this case, the depth observations vary by say $\pm$ 0.8 ft ($\sigma_{\text{RANDOM ERROR}}$) but there is only a small (+) 0.1 ft bias in the observations. The random error component could be due to such causes as uneven bottom topography, bottom vegetation, positioning error, or speed of sound variations in the water column--errors that are difficult or impossible to remove by calibration. The small (+) 0.1 ft bias indicates that most systematic errors have been removed.

c. Both curves shown in Figure 4-2 occur in real hydrographic survey data sets. The preferred distribution is the lower curve in that the systematic bias is minimal. A degree of randomness in the observations is far more tolerable than systematic bias errors. Thus the objective is to minimize the biases in a survey. Biases can be estimated using cross-line checks or multibeam performance tests.

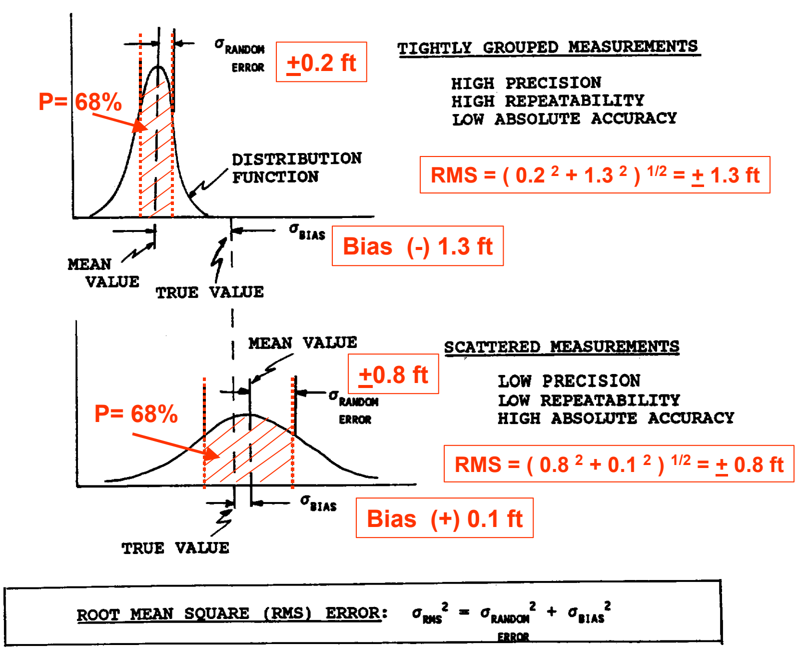


Figure 4-2. Typical dispersion curves for depth observations

d. Root Mean Square error measure. Given geospatial depth observations containing both random errors and systematic biases, a consistent accuracy measurement is required. These *biases* and *random errors* can be combined to obtain the *Mean Square Error (MSE)* or *Root Mean Square (RMS)* error of a depth observation. The equation for computing one-dimensional MSE or RMS error is:

$$RMS\ error = sqrt\,[\ \sigma^2_{RANDOM\ ERROR} + \sigma^2_{BIAS}\ ] \qquad \text{(Eq 4-1)}$$

The RMS error estimator is used for comparing relative accuracies of estimates that differ substantially in bias and precision. The random error and bias components in Equation 4-1 can be estimated from actual depth comparisons--either relative to a fixed "true" surface (e.g., lock chamber) or based on duplicate measurements over the same terrain.

(1) The distribution curve shown in Figure 4-2 could represent repeated depth measurements taken over some "true" point--say observations made in a regulated lock chamber where the depth is accurately known and controlled. In practice, such a "true" (or known) elevation in a lock chamber is rarely ever available, and depth accuracies must be estimated using comparative readings taken over the same point on the bottom (i.e., cross-line checks or performance tests). If the depth observations are randomly distributed, the mean of all the observations will fall at the peak of the distribution curve. The mean of a sample series of n depth measurements x is computed by:

$$\text{Mean depth} \quad z_M = \Sigma[\,z_i\,]\ /\ (\,n\,) \qquad \text{(Eq 4-2)}$$

where

n = number of observed depths in sample
z_i = individual observed depths (i = 1 to i = n)

The difference of the mean z_M from the "true" depth (shown as σ_{BIAS} in Figure 4-2) represents a systematic error in the observations that was not removed by calibration or modeling. The precision to which the mean is computed is a function of the number of observation "*n.*" The more observations in the sample, the more precisely the mean can be determined. Some biases are difficult to identify or remove. Examples of this type of bias are temperature change, salinity changes, and tidal modeling. These biases are systematic in nature but will vary randomly in time and position. They may be considered random from survey to survey, and this allows their error contribution to be estimated with statistics.

(2) The shape, or spread, of the bell-shaped error distribution curve is an indicator of the dispersion in the depth observations--i.e., the random errors. The upper curve in Figure 4-2 indicates tightly packed observations and the lower curve indicates high variability in the observations. If the depth errors are assumed to be random, then the dispersion of the depth observations can be estimated by computing the *Standard Error* (s_Z) of the sample:

$$Standard\ error \quad s_Z = sqrt\,[\ (1/(n-1))\ \Sigma[\,z_i - z_M\,]^2\ ] \qquad \text{(Eq 4-3)}$$

The magnitude of the dispersion is shown as $\sigma_{RANDOM\ ERROR}$ in Figure 4-2. This distance represents the $\pm$ one-sigma (1-σ) points on the normal distribution curve, with the cross-hatched area being a probability of 68% that the computed mean of the observed depths falls within this area of the curve. For example, on the lower curve, 68% of observed depths would fall within $\pm$ 0.8 ft from the mean. This means that a hydrographic survey data set containing hundreds or thousands of geospatial points has a dispersion of $\pm$ 0.8 ft at the 1-σ (68%) level. 32% of the depths can be expected to fall outside the $\pm$ 0.8 ft interval. Which individual depths are inside or outside this interval cannot be determined--only that the estimated 1-σ standard deviation of the survey is $\pm$ 0.8 ft. The overall RMS accuracy may be larger if biases are present in the data.

(3) The RMS error is estimated by substituting the standard (random) error (Equation 4-3) and bias (Equation 4-2) into Equation 4-1. This is illustrated in Figure 4-2.

e. RMS error should not exceed the stated tolerance in Table 3-1 for a USACE survey class. Minimization of the many random and systematic errors (and blunders) present in horizontal and vertical measurements is accomplished by repeated instrument calibration, adherence to prescribed procedural criteria, and recognition of limitations in the measurement equipment. Careful field procedures, coupled with adequate survey planning, equipment selection, and equipment maintenance, are also essential.

f. Subsequent chapters in this manual discuss some of the more common error sources in hydrographic surveys. These factors apply to manual hydrographic survey methods or those using electronic positioning and to echo sounding depth measurement systems. All these factors are capable of producing errors that behave systematically, resulting in biases in a given survey. One objective of the criteria presented in this manual is to reduce the magnitudes of these errors to tolerable levels and then presume that they will offset one another randomly (noise like), with the resultant horizontal and vertical standard errors falling within the prescribed levels for each survey class.

4-4. One-Dimensional Depth Accuracy Estimates--95% Confidence Estimation Level

RMS depth errors are computed and reported at the 95% confidence level in accordance with FGDC Geospatial Positioning Accuracy Standards (Parts 1 and 3)--see Appendix A. USACE depth accuracy tolerances in Table 3-1 are expressed at this 95% confidence level. This simply means that on average 19 of every 20 observed depths will fall within the specified accuracy tolerance. Since the 1-sigma (68%) standard is computed when depth accuracy is assessed, it can be converted to a 95% RMS confidence level statistic by the following:

$$\text{RMS (95\%) depth accuracy} = 1.96 \cdot \text{RMS (68\%)} \qquad \text{(Eq 4-4)}$$

a. The above formula assumes the data are random and contain no large biases. It represents the area under the $\pm 1.96\text{-}\sigma$ points on the distribution curves in Figure 4-2. This area covers 95% probable error of all points in a data set. For example, when a data set for a pre-dredge survey of a 45-ft project is reported accurate to ± 2.0 ft, this means that 95% of the points in the data set will have an error with respect to true ground position that is equal to or smaller than the reported accuracy value. 5% of the depths in the data set will have errors exceeding ± 2.0 ft. Again, it is impossible to determine which particular depth in the data base lies within or outside the stated accuracy tolerance. If the pre-dredge survey was performed using multibeam equipment, and 100,000 points are in a binned grid, some 5, 000 of these points could be outside the 95% tolerance level. For this reason, a single depth observation above a required grade cannot be assumed to be representative of the area—multiple observations above grade are needed to statistically defend any assessment. Unlike land-based topographic and photogrammetric surveys, it is extremely difficult to independently determine the resultant accuracy of any hydrographic survey. Photogrammetric or topographic survey elevation accuracies are assessed by comparing observed elevations with those determined by a "significantly" more accurate method—e.g., a photo-derived elevation point is tested against that obtained by a spirit level or total station. Typically 20 or more points are tested and if 19 of 20 fall within the required tolerance, then the survey is deemed to be within the required accuracy. Hydrographic surveys do not have "significantly" more accurate independent method of testing observed data. Most depth measurement methods contain inherent errors of such magnitude that it is difficult to statistically certify one method as more accurate than the other. One exception might be testing observed depths inside a lock chamber.

b. Confidence of accuracy estimates. Confidence intervals are used to provide an indication of how good an accuracy estimate is and how much it can be relied on (Mikhail, 1976). Confidence intervals are also termed *degree of confidence*. The confidence interval describes a boundary within which there is a probability that the computed mean (or standard error) of depths in a data set fall relative to the true or actual mean value (which is not known). The larger the observed data set, the better is the confidence of a computed mean or standard error. Confidence intervals of means or standard deviations are also expressed at the 95% level. The confidence interval of the mean has also been termed the *standard error of the mean*.

(1) For example, assume 50 depth comparisons are made between cross-line intersections from two overlapping surveys conducted on different days. Average water depth was 45 ft. The bias between the two surveys was (-) 0.02 ft--i.e., negligible. The computed standard deviation for the 50 points was ± 0.85 ft. The 95% confidence interval of the computed mean (± 0.24 feet) is computed by standard t-distribution statistical methods.

$$\pm (t_{0.025})\ (s) / (n)^{1/2} = \pm 2.01 \cdot 0.85 / (50)^{1/2} = \pm 0.24 \text{ ft}$$

where t = t-test critical value from Student-t probability table with (50-1) degrees of freedom and 0.025 probability
s = computed standard deviation of the sample
n = number of data values in sample

The 95% confidence interval of the computed mean is then shown as:

Probability { (-) 0.26 < computed mean (- 0.02 ft) < (+) 0.22 } = 0.95 (95%)

This means that the computed mean (-0.02 ft) is uncertain up to ± 0.24 ft at the 95% confidence level. It also means that a sufficient number of comparisons must be made in order to assess the accuracy of a survey. If it is required to achieve a ± 0.2 ft confidence in the mean to preclude against the existence of systematic biases, then more comparison points than 50 are needed. Had 100 cross-line comparisons been conducted, then the confidence interval of the computed mean would be ± 0.17 ft, and the confidence range shown as:

Probability { (-) 0.19 < computed mean (-0.02) < (+) 0.15 } = 0.95 (95%)

With 100 comparisons, the ± 0.17 estimated confidence of the mean is below the desired ±0.20. To achieve a more reliable (or confident) estimate of the mean requires considerably more data set comparisons. Better accuracies are also achieved with smaller standard deviations in the data.

(2) Minimizing biases by assessing the standard error of the mean is critical for hydrographic surveys involving payment. Any constant bias present in a survey must be evaluated and reduced. Corps QA Performance Tests allow a difference (or tolerance) of up to 0.2 feet when two surveys of the same area are compared--see Performance Test standards in Tables 3-1, 9-1, 10-1, and 11-2. However, a much smaller mean difference is desired in practice. To ensure that the standard error of the mean does not exceed, say a ± 0.05 ft level, then the number of comparisons can be computed given the assumed survey's 1-σ RMS error (function of project depth). If a survey is performed in 50-ft of water (i.e., required RMS accuracy = ± 2.0 ft), and a ±0.05 ft confidence in the mean is desired, then, at minimum, some 1,500 cross-line or multibeam comparison points are needed. This number of comparisons would only be practical for multiple transducer or multibeam surveys.

(3) The 95% confidence of the computed standard deviation can also be estimated using statistical methods--see Mikhail, 1976.

4-5. Depth Measurement Error Components

Major error components of electronic echo sounding depth measurement methods are described in the following paragraphs. From these error sources, relative accuracy estimates for varying project conditions can be derived. The criteria standards for depths in Table 3-1 were established from these estimates.

a. Depth measurement system. The precision of any depth measurement will, in general, degrade as a function of water depth. The accuracy of an echo-sounding measurement degrades with depth due to a number of electronic and physical factors inherent in the sound travel-time measurement process, i.e., changes in water temperature, salinity, etc. Multibeam depth measurement accuracy typically degrades over the outer beams on the array, depending on the type of depth resolution method employed and the bottom characteristics or reflectivity. Beam refraction (ray bending) can also be a problem if not corrected. Older analog recording devices have mechanical movements that contribute to inaccuracies in the recorded depth. These errors are minimized by frequent calibration of the echo sounding equipment.

b. System calibration and alignment. Calibration of electronic echo sounding instruments is, in itself, an imprecise process, particularly in deep-draft projects. Because bar check calibrations are performed while the vessel is stationary, actual dynamic survey conditions are not truly simulated. The bar check procedure is not error-free due to line slope in currents, signal strength variations between the bar plate and the typical bottom condition, loading changes during calibration, and other factors. The accuracy of a bar check calibration ranges from ±0.1 to ±0.2 ft, depending on the depth of the bar and sea conditions. On small boats, personnel movement during bar checks may vary the transducer draft from that under normal running conditions, causing a constant index error to occur. Velocity probes are in themselves dependent on the accuracy and stability of their initial reference calibrations. Calibration of multibeam swath systems is especially critical. Repeatability of some patch tests is difficult to achieve, due to inadequate vessel position and terrain factors.

c. Resolution of measured elevations. An accuracy of less than 0.1 ft is not possible on mechanical recording echo sounders with relatively small-scale vertical divisions. Electronic depth digitizing devices typically record and log depth data to a precision (*not* accuracy) of ±0.1 ft.

d. Echo sounding system draft/index errors. Echo sounding measurements made from a hull- or side-mounted transducer must be corrected for the distance between the transducer and the reference water surface. This distance is normally referred to as the "draft" correction. Due to mechanical and electrical indexing errors present in an echo sounding device, this "draft" correction is *not* always equal to the physical (as-measured) distance between the water surface and transducer plate. Thus, the so-called "draft" setting on an echo sounder should not be arbitrarily adjusted based only on short-term physical measurements of the vessel's draft. Only a bar check calibration will effectively confirm this distance or confirm that it is stable over the long term. Subsequent loading changes during the survey (added personnel, fuel, etc.) may be adjusted for based on differential changes to a vessel's draft. The adequacy of such adjustments should have been confirmed by a bar check calibration. Errors due to inadequate compensation for the varied index, loading, and draft variations are systematic and can be significant, especially on small boats with side-mounted transducers. These errors can exceed 0.5 ft in some instances.

e. Vertical reference datum. Hydrographic depth measurements are reduced and referenced to the local water surface at the time the measurement is made. This water surface is normally referenced to an on-shore reference benchmark or gage. The accuracy of the entire process is highly variable, and systematic errors in the survey can result if adequate precautions are not taken. The most significant error component involves the assumed stability of the water surface between the on-shore gage and the survey vessel. This stability is usually valid in most non-tidal lakes, impoundment reservoirs, and rivers where extensive stage surface modeling has been performed, and staff gages can be set at every 0.2- to 0.4-ft change in river slope. In these areas, interpolated vertical reference accuracies within ±0.1 ft are attainable. However, on coastal navigation projects subject to tidal influences, any surface gradients between the gage and underway vessel must be corrected--usually by imprecise extrapolations from an on-shore gage to a distant point offshore. Performing this correction is complex and costly, and is more fully explained later in this manual. Uncorrected tidal surface gradient errors can exceed more than 2 ft, depending on the tidal range, ebb/flood characteristics, gage location relative to work site, and other physical factors associated with tidal variations. Since tidal gradient variations involve time- and location-dependent parameters, on-line or after-the-fact correction is difficult and time-consuming. These types of errors are often manifested by apparent vertical disagreement in surveys conducted at different times over relatively stable and flat areas.

f. Platform stability. Sea conditions obviously impact the ability to reference a depth measurement to the uniform water surface alongside the survey vessel with precision. This applies to difficulties in interpreting the superimposed effects of sea roll, pitch, and heave on a depth measured with an echo sounder. Errors due to this source are assumed to be random over the long term, and are usually compensated for by meaning or averaging a series of short-term observations. This is done visually when fluctuations on an echo sounding record are averaged. The accuracy of this correction is only as good as the interpretative skill and experience of the individual performing the reduction. The apparent mean of the fluctuations may not be accurate given varying roll and pitch periods. Because this interpretative process is not an exact science, constant biases may result in some cases. Electronic depth digitizing and automated depth recording software may not be any better. Depths collected and averaged over, say, one second may also fail to compensate for the actual roll, pitch, and heave periods experienced by the vessel. Thus, depending on the severity of sea conditions, an individual elevation (or sounding) contains an error component resulting from this source. Heave-pitch-roll-yaw motion compensators have been developed to minimize this error.

g. Vessel velocity. Since echo sounding instrument calibrations are performed while the vessel is stationary, the “draft” index derived during that calibration may vary from the index occurring while the vessel is under way. This is due to changes in the vessel's trim while under way. This variance is often referred to as squat, or as a squat correction. It is systematic and varies as a function of velocity. A squat calibration is performed to measure the change of trim. However, the calibration process itself is not totally precise, especially on smaller boats where personnel and loading characteristics can vary significantly between the time of the squat test and the time of the actual survey.

h. Subsurface material density and echo sounding sensitivity. The relative density of the subsurface material affects all depth measurement methods, especially echo sounding instruments, which are highly dependent on finite density changes to distinguish between and record acoustical returns. On sounding poles, sounding disks, and lead lines, the surface area, weight, and drop velocity determine their stopping or refusal points. In many instances, these points are difficult to establish, especially when these devices continue to free-fall under their own weight in low-density sediments. Echo sounding returns are dependent on the frequency of the acoustic pulse, receiver sensitivity settings, and distinct density changes in the subsurface material. Difficulties arise in areas with suspended sediments (fluff) present, such as naturally occurring fluff or disturbed sediments from dredging operations. Small variations in sensitivity (or signal gain) settings can cause large variations in the return point. These errors are systematic, and no definitive methods exist to fully compensate for them. Dual-frequency sounders and other devices have been developed to handle this problem. In many instances, echo sounding measurements need to be augmented with lead line measurements.

4-6. Quantitative Assessment of Depth Measurement Accuracy

Given the error sources described above, a quantitative estimate can be made of the resultant accuracy of a depth measurement--see Table 4-1. The magnitude of each error component is estimated based on the type of equipment used, the project depth, tide gradient, and typical sea states for four representative project conditions. The resultant RMS error is computed by taking the square root of the sum of the squares of the error components. The RMS is multiplied by 1.96 to convert it to a 95% confidence accuracy level which is consistent with FGDC accuracy reporting requirements--see Appendix A.

Table 4-1. Quantitative estimate of acoustic depth measurement accuracy in different project conditions

Single-beam 200 kHz echo sounder in soft, flat bottom
USCG DGPS vessel positioning accurate to ± 2 m RMS
All values in ± feet

Error Budget Source	Inland Navigation Min river slope Staff gage < 0.5 mile 12-ft project <26-ft boat No H-P-R	Turning basin 2 ft tide range Gage < 1 mile 26-ft project <26-ft boat No H-P-R	Coastal entrance 4-ft tide range Gage < 2 mile 43-ft project <26-ft boat No H-P-R	Coastal offshore 8-ft tide range Gage > 5 mile 43-ft project 65-ft boat H-P-R corrn
Measurement system accuracy	0.05	0.05	0.1	0.2
Velocity calibration accuracy	0.05	0.1	0.1	0.15
Sounder resolution	0.1	0.1	0.1	0.1
Draft/index accuracy	0.05	0.1	0.1	0.1
Tide/stage correction accuracy	0.1	0.15	0.25	0.5
Platform stability error	0.05	0.2	0.3	0.25
Vessel velocity error	0.05	0.1	0.1	0.15
Bottom reflectivity/sensitivity	0.05	0.1	0.1	0.2
RMS (95%)	**± 0.37 ft**	**± 0.66 ft**	**± 0.90 ft**	**± 1.32 ft**
Allowed per Table 3-1	**± 0.5 ft**	**±1.0 ft**	**± 1.0 ft**	**± 2.0 ft**

From the above table, the following conclusions may be made:

a. The major error components in the depth error budget are tide/stage corrections and sea state corrections. Tide correction accuracy can be improved by use of RTK DGPS techniques. This would be required had the offshore coastal project involved a rock-cut channel--the ± 1.33-ft RMS would have exceeded the ± 1.0-ft RMS allowed for such a project. Sea state inaccuracies can be minimized by use of heave-pitch-roll sensors.

b. Obtaining acoustic depths to an accuracy much better than ±0.3 ft will require conventional differential leveling techniques. In shallow waters, lead lines or sounding poles may be used. Such methods are feasible on some nearshore construction projects (revetments, groins, jetties, etc.). Total stations may also be employed. Foresight distances must be limited based on the accuracy of the level employed, equality with backsight distance, and rod/target visibility, with 500 ft being about the maximum practical limit to maintain ±0.1 ft accuracy.

c. Under *average* river and harbor project conditions, the estimated accuracy of an individual (i.e., shot point) echo sounding depth falls approximately between ±0.4 and ±1.0 ft, with larger errors between ±1.0 and ± 2.0 ft occurring as physical and acoustic conditions degrade--i.e., deep-draft projects located in open waters off shore. Depth measurement equipment and accuracy criteria contained in this manual account for these estimated resultant accuracies. It is possible to reduce some of the error component magnitudes shown in Table 4-1. This could result in significantly better accuracy estimates for a specific project area. This may be accomplished by obtaining higher-resolution (higher frequency) echo sounders, RTK DGPS centimeter-level horizontal and vertical positioning, accurate heave-pitch-roll sensors, intensive velocity calibration programs, etc. In effect, taking steps to minimize as many error components in Table 4-1 as possible.

d. On offshore entrances and in distant submergent disposal areas subject to uncertain or unverified tidal influences, or in any survey area subject to less than ideal survey conditions due to higher sea states and/or uncertain tidal/stage levels, elevation inaccuracies of $\pm$1 ft or greater may be expected. Data depiction and evaluation should properly account for this uncertainty by an appropriate note.

e. The error estimates in Table 4-1 assume a flat, smooth bottom; thus no error component is included for bottom undulations, acoustic beam width footprint, fluff, or vegetation. Such conditions would further degrade the depth accuracy assessment.

f. Corps engineering standards require that depth elevations on navigation projects be displayed/plotted to the nearest 0.1 foot. Such a resolution is not statistically consistent with the accuracy of typical acoustic depth observations. It could be argued that depths should be rounded to a level that is representative of their accuracy--e.g., nearest quarter, half, or even foot.

g. The resultant depth accuracy of a survey can be highly variable, regardless of the particular accuracy tolerance specified for the project. Thus, the estimated resultant accuracy must be evaluated on a project-by-project basis, and adequate control procedures should be taken to meet the criteria for each survey. If this is not feasible, a realistic assessment of the survey accuracy should be clearly identified on all drawings and contract specifications, including equitable consideration and adjustment to contract acceptance and/or payment.

4-7. Approximate Field Assessments of Depth Measurement Accuracy

The depth accuracy estimates in Table 4-1 are based on an assumed error budget for the measurement process given the typical project conditions indicated. It is far more desirable to determine the resultant accuracy of measurements based on actual observations. This can be approximately achieved by comparing different data sets taken over the same area--e.g., Cross-Line checks in single-beam surveys and Performance Tests in multiple transducer or multibeam surveys. These methods are described in the chapters covering these systems. These assessment methods can only be considered an *approximate estimate* of depth accuracy since the two data sets are usually obtained from the same instrument platform. In addition, both data sets may have similar inaccuracies. These tests are, however, good quality assurance indicators and should be performed on all critical projects. They also tend to indicate the existence of systematic biases in the data. Results of Cross-line and Performance Tests conducted to date correlate fairly closely to the assumed accuracies derived in Table 4-1. The following example is taken from actual field data collected on a coastal entrance project . The project is subject to a tidal range of nearly 7 feet with significant tidal phase and range differences between the entrance and offshore points. The cross-lines were run as cross-sections over 50-ft spaced longitudinal lines, at different tide phases, and in depths ranging between 48 and 53 feet of water. Tides in this channel reach some 5 to 10 miles offshore were obtained using RTK DGPS techniques with the reference station based at the entrance. Differences shown in the table below were determined using Coastal Oceanographics HYPACK software.

Table 4-2. Kings Bay Navy Base Entrance Channel (Cut 1N) Cross-Line Comparisons
Surveyboat Florida, Jacksonville District
1-2 August 2000
RTK DGPS positioning and elevation. Heave compensation active.
Search radius set at 10-ft
Single beam cross line check differences in feet

+1.16	-0.72	-0.19	-1.47	-0.41	-0.07	-0.71	+0.43
-0.14	+0.86	-1.52	-0.50	-0.41	-0.61	+0.98	+1.71
-0.89	-0.29	+0.60	-1.95	+1.26	+0.02	-0.05	-0.26
+2.04	-0.24	-1.17	-0.79	+0.19	+0.88	+0.99	+0.38
+0.55	-0.16	-0.28	-0.89	-4.05	-0.46	-0.45	+0.56
+0.82	-0.69	+0.36	-0.43	-0.67	-0.35	-1.6	+0.17
-0.53	-0.24	+0.45	-0.12	-0.86	+1.77	+0.45	-1.65
+1.95	-0.04	+0.57	+0.00	+0.61	+0.91	+0.88	-0.80
+0.33	+0.09	+1.15	-0.08	+0.03	+0.38	-0.14	
+1.08	-0.06	+0.17	-1.18	+0.10	-0.07	-0.05	

Total number of cross-check observations = 78

Mean of Differences	**= (-) 0.043 ft**	**<< than 0.2 ft maximum allowable bias (Table 3-1)**
Confidence of computed mean (95%)	**= ± 0.21 ft**	
Standard Deviation (67%)	**= ± 0.944 ft**	
95% Estimated Accuracy	**= ± 1.85 ft**	**< than ± 2.0 ft allowed**

a. Mean difference. The mean of the differences (-0.04 feet) indicates there is no large systematic (constant) bias present in the data. Had tidal values been extrapolated from an onshore tide gage, obtaining such a small difference would have been impossible--carrier phase RTK DGPS is the only effective procedure to provide accurate tidal models in distant offshore channels. The 0.2-foot allowable mean difference is a prescribed Corps tolerance--see the QA standards shown for single-beam and multibeam systems in Chapters 9, 10 and 11. Check surveys exceeding this value are suspect in that constant systematic biases are present, and such a bias will adversely impact dredge payment computations. It is difficult/impossible to determine which one of the two check surveys is in error since both were performed using similar equipment and techniques. It was also demonstrated in a previous section that the confidence level of this mean difference is not good due to an insufficient number of cross-line points. In fact, the confidence or standard error of the mean (95%) is only ±0.21 ft. If a far more confident mean is required, then additional cross-line points would be needed.

b. Number of cross-line checks required. The mean difference computed between the comparative surveys is an indicator of possible constant or systematic depth biases. The ± 0.2 ft tolerance specified in Chapter 9 for single-beam cross-line check comparison surveys may be too large to be acceptable for some surveys. A ± 0.1 ft or ± 0.05 ft tolerance may be demanded to ensure no constant bias in dredged quantity computations. Regardless of the actual mean difference computed, an estimate of the confidence of that mean difference value may be significant. This can be estimated using confidence interval estimation and the "standard error of the mean" statistics discussed earlier. From these statistics, an approximate number of cross-line checks can be estimated.

(1) The number of cross-line checks is a function of the desired 95% confidence level of the computed mean and the estimated variance of the data set. For example, if the mean difference of 40 cross-line checks is computed as (-) 0.11 ft, the 95% confidence interval estimation of this (-) 0.11 ft value might only be ± 0.25 ft. Thus, the confidence interval of the computed mean is somewhere between (-) 0.36 ft and

(+) 0.14 ft. This may or may not be an acceptable range, nor is there much confidence in the accuracy of the (-) 0.11 mean difference. What this indicates is that in insufficient number of cross-lines were obtained. The ± 0.25 ft "standard error of the mean" is large--more data comparisons are required to reduce this range down to an "acceptable" level. The estimated variance of the data also affects the confidence of the computed mean. Fewer checks would be required for tightly grouped data--e.g., < 15-ft shallow draft work with an estimated 95% accuracy of ± 0.25 ft (Table 3-1).

(2) The following is a tabulation of the theoretical number of cross-lines required for a given survey accuracy (Table 3-1). Numbers of comparisons are computed for different confidence levels of the computed mean. These are computed by solving for n in the standard formula:

$$\text{Standard error of the mean (95\%)} = \pm 1.96 \, (\sigma / n^{1/2}) \quad \text{(Eq 4-5)}$$

where σ = population standard error (i.e., estimated 1-σ accuracy at various project depths)

n = number of observations

Table 4-3. Cross-line Comparisons Required for Different Confidence Intervals

Estimated Depth Accuracy 95% *	Confidence Interval of Computed Mean (95%) ± 0.2 ft	±0.1 ft	± 0.05 ft
± 0.25 ft	2	6	24
± 0.5 ft	6	24	96
± 1.0 ft	24	96	384
± 2.0 ft	96	384	1536

* These 95% values relate to estimated depth accuracies in Table 3-1. The 1-σ deviation is used in the computation

From the above tabulation, it is clear that the computed mean for lead line surveys in shallow water can be determined with relatively few cross-line checks. This is because the expected depth accuracy is good in shallow depths. The number of cross-line checks increases as the desired confidence level in the mean difference increases. For less accurate acoustic surveys in deeper water depths, more comparison points are required. In a deep-draft 50-ft project, at least 100 check points should be obtained to ensure a ± 0.2 ft confidence in the mean. Higher confidence levels would require an impractical number of comparisons for most single-beam cross-section surveys--only overlapping multibeam or multiple transducer surveys could (economically) obtain these higher numbers.

(3) Although cross-check line checks are required as a QA process in single-beam survey (Chapter 9), the resultant value of the mean difference must account for the statistical uncertainty in the computation--plus the fact that the surveys may not be independent. With few cross-line check points, the *apparent* mean difference between the surveys is, at best, only a rough indicator of the true difference. It is, however, better than having no QA comparison, and will indicate any large blunders that may exist.

c. Standard deviation. The standard deviation computed at the one-sigma level is adjusted to the 95% confidence level. This 95% deviation (± 1.85 ft) in Table 4-2 is typical of results in deep-draft navigation channels of uneven topography. It is, however, less than the ± 2.0 ft allowable accuracy defined in Table 3-1 for project depths greater than 40 feet. Without RTK vertical elevations and heave compensation, the deviation would have been much larger--probably exceeding the allowable tolerance.

Some of the variation could be attributable to the uneven bottom topography coupled with the 10-ft HYPACK search radius. The footprint size of the acoustic beam covers a larger area in these 50-foot depths, causing a generalization in the recorded depths. In general, however, standard deviations at this level would be expected based on the estimated results back in Table 4-1 and the fact that this distant project area represents a "worst case" condition than that assumed in Table 4-1. (Note that the computed standard deviation is not the same as the RMS in that the (-) 0.04 ft is not included. The difference is negligible given the small mean bias--the RMS (95%) could be computed from Equation 4-1, e.g., RMS (95%) = 1.96 $(0.944^2 + 0.043^2)^{1/2} = \pm 1.85$ ft). Like the computed mean above, the confidence level of the computed deviation could also have been computed--Mikhail, 1976. Such a computation would have shown that the ± 0.94 standard deviation actually lies somewhere between ± 0.8 and ± 1.2 (95% confidence level). Additional cross-line comparisons would have reduced this spread.

d. Multiple transducer or multibeam comparison. Had the above project been surveyed using swath survey systems, then two digital elevation models could have been generated with which to perform a comparison. Thousands of comparison points would have resulted rather than the 78 in the single beam example. Regardless of the number of comparative points, the computed mean and deviation should not be significantly different--at least within the range of the confidence interval estimations described above. The standard deviation of multibeam data might be slightly higher since the accuracy of the outer rays is not as good as near-vertical depths. However, the confidence level of the mean would have a very small value since a larger number of points are included.

e. Unaccounted biases. It is again emphasized that such comparisons are only indicators of data quality. There could be biases in the data that would not be detected. Examples might include: (1) a constant error in the tidal datum reference plane or MLLW elevation reference, (2) an error in the DGPS vertical geoid model, or (3) a constant vessel draft error. Data outliers can also be present in the data, such as the 4.05 foot difference in Table 4-2. These outliers represent values well outside the 95% confidence level. They may or may not be correct. Typically, outliers falling more than 3 times the estimated standard error (i.e., $3 \cdot 0.944$ ft) are rejected.

f. Final analysis of results. The nearly ± 2 foot depth deviation in this example clearly exhibits the case that individual depth observations contain significant random errors. It also illustrates that a single depth observation cannot be evaluated based on the "apparent accuracy" of its plotted value (i.e., nearest 0.1 foot). Moreover, this case shows that the accuracy of a survey must be evaluated based on the statistical agreement of the entire data set--or portions of that data set. Minimizing constant bias errors is far more important than reducing deviations. More refined acoustic measurement techniques will have to be developed if more accurate depth observations are required.

4-8. Evaluation of Depth Accuracy on Dredging Projects

Evaluating channel clearance on dredging projects involves a review of the soundings obtained on the final after dredge survey and/or final channel clearance sweep survey. Numerous shoals or strikes above the required grade may be present on these surveys. The project manager or contracting officer's representative (COR) must determine whether these shoals/strikes above grade warrant additional work effort to assure project clearance, or they are isolated, stray soundings within the "noise" (i.e., accuracy) level of depth measurement. Therefore, this assessment of above-grade soundings must consider (1) the error budget of individual depth measurements, (2) their relative magnitude, (3) survey accuracy standards specified for the project--Table 3-1, and (4) the detection repeatability of the acoustic system.

a. The object detection standard in Table 3-1 specifies that a *minimum* of three acoustic "hits" be obtained on a potential shoal or strike. These hits should ideally be obtained on repeated passes over an object. A single pass is adequate if numerous hits above grade are obtained, and the depths are consistently above the required grade.

b. A single hit 0.1-ft to 0.5-ft above grade presents problems. This hit could be the edge of a shoal or rock of larger size and shoaler elevation. If the estimated accuracy of the depth measurement process used is ± 1.0 ft, then this could be an observation lying within that 95% accuracy tolerance--e.g., taken when a vessel without heave compensation was surging down in the trough of a wave. Such a potential variation between depths and surveys is clearly exhibited in Table 4-2. Thus, additional observations are needed to confirm the existence (or non-existence) of material lying above the project grade. Additional passes should be run over the area. If acoustic hits above grade are repeatedly obtained on these additional passes, then a high probability exists that a shoal or rock strike is present in the channel. The confidence levels of shoal detection can be estimated given (1) height of hits above grade (dZ), (2) standard error of depth measurements (s), and (3) number of hits (n). Using approximate t-density functions, it can be shown that all three of the above factors (variables) will determine the overall confidence of detection, which can be roughly computed by the following:

$$t_{\alpha/2,\, n-1} \approx \mathrm{sqrt}\,(n)\ (dZ)\ /\ s$$

For example, given 3 hits averaging 1-ft above grade and a ± 1.0 ft standard error, the detection confidence is roughly 75%. If only 2 hits were recorded, the confidence of a shoal drops to 60%. If 10 hits are recorded, the confidence of detection is 98%. Thus, obtaining a 95% detection confidence may require more than 3 hits, depending on the magnitude of the three variables described above.

c. Obtaining multiple hits with a single, narrow beam echo sounder is difficult. Stealth-like objects may not always be detected with vertical beams. Close line spacing must be run over a suspected strike--e.g., 10 ft to 20 ft intervals. A multiple transducer or multibeam system is far more efficient in detecting strikes and confirming them with multiple passes. Multibeam sweeps should be conducted such that the beam aspect is varied from near-vertical to an outside beam. Multibeam side scan imagery on the outer beams will also be of value in detecting strikes above grade. On critical projects, towed side scan may be necessary to locate strikes.

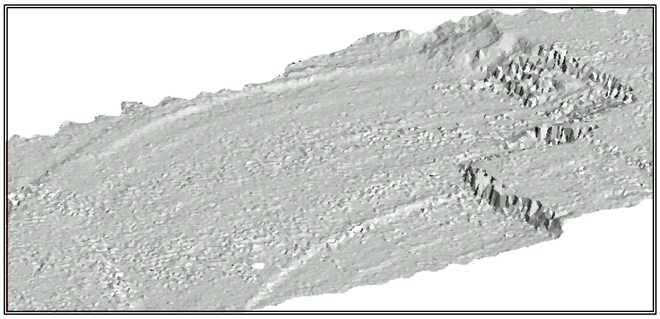
d. The relative height of an object or shoal above grade will determine the need for clearance. This may depend on the location of the shoal within the channel, type of bottom material, size of shoal, potential navigation hazard, etc. The project COR makes the final determination on whether to mobilize or remobilize a dredge to remove the object/shoal.

4-9. Evaluation of Dredge Quantity Estimates Based on Depth Accuracy and Density

Three primary factors impact the accuracy of dredge volume computations, in this order:

- Terrain irregularity and data density
- Bias errors in depth measurements
- Deviation of depth observations

It has been shown that data density has the most important effect on the overall accuracy of a quantity computation. Required data density is a function of the irregularities in the terrain, as is clearly illustrated in Figure 4-3. Systematic biases in the depth database will obviously cause constant dredge volume errors. The deviation or estimated accuracy of the depths can cause volume errors if the standard error is large and an insufficient number of points are observed. A volume derived from a densely gridded/binned multibeam survey will yield a more accurate quantity than that obtained from 100-ft spaced cross-sections, even if the depth accuracy (i.e., standard deviation) of the multibeam survey is not a good as the cross-section depths. These concepts are discussed below.



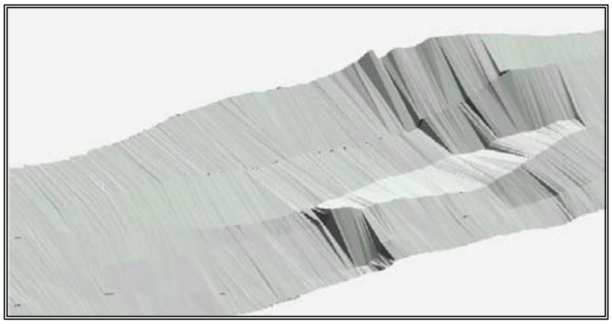


Figure 4-3. Single beam versus multibeam coverage--Port of Los Angeles. Drawings compare low density single beam coverage (bottom view) with detailed multibeam coverage (top view). Dredged sections are generalized in the single beam coverage. (Coastal Oceanographics, Inc. and Los Angeles District)

a. Terrain irregularity impacts on volume accuracy. The effects of terrain irregularities on dredge volume computations depend on the density of data coverage. When end areas are computed for single-beam cross-sections, large variations in the end areas would indicate terrain irregularity exists between the sections. Even if the cross-section data points were absolutely error-free (no bias or standard deviation) large volume errors due to terrain irregularity would still exist due to lack of measurements between the 100-ft sections. These effects can be illustrated by the following single-beam survey example.

Given: Typical 400-ft wide box-cut channel (no side slope quantities computed)
Predredge shoaling fairly uniform at around 10 feet above pay grade
100-ft cross-sections run over 3,000 ft Acceptance Section
Standard average-end-area volume computation

Station	Cross-sectional End Area
60+00	3850 sq ft
61+00	4125
62+00	3975
63+00	4225
64+00	4150
.	
.	
.	
89+00	4125
90+00	3950

(1) In looking at the variations in end areas for the 31 cross-sections, it is determined that their average deviation is approximately $\pm$ 100 sq ft. If depth measurement biases and deviations are assumed to be zero, then this end-area variance between cross-sections in a uniform shoal area is due to irregularities in

the terrain. Had cross-sections been observed at 1-ft intervals (e.g., multibeam) then the end-area variations would be expected to be significantly less. The volume error over due to this ±100 sq ft can be computed by comparing the quantities over the section for a 4,000 sq ft and 4,100 sq ft end area. The percentage quantity error is simply:

% error in volume = (100 sq ft / 4000 sq ft) · 100% = 2.5 %

This 2.5 % error equates to 370 cy per 100-ft section or about 11,000 cy over the entire acceptance section (which has a total yardage of nearly 450,000 cy).

(2) Had the bottom terrain been more uniform, then the computed end-area variations would be smaller. A variation of ± 20 sq ft would have represented only a 0.5 % error on this project. If the end-areas were linearly increasing or decreasing (sloping shoal), then this slope would be considered in looking at variations in end areas. On the other hand, had there only been an average of 4 feet of shoaling above grade, then the relative volume error would be larger--i.e., (100 sq ft/1,600 sq ft) · 100% = 6.25%.

(3) Minimizing end-area volume errors due to terrain irregularities between single-beam cross sections is often impractical. Since the only way to minimize the error is to decrease line spacing, practical limitations prevent this. Decreasing line spacing to, say 20 ft, adds field survey time and cost. In addition, a 20-ft line spacing is near the tolerance of the ability to control the survey vessel on line. Since most average-end-area computations assume cross-sections are equally spaced--i.e., no off line steering deviations--projecting these lines over 20-ft distances is no longer valid. However, given the sparse cross-sections data sets, a TIN model may be generated for all the observed data points and volumes computed using the vertical TIN prismoidal elements rather than average-end-area projections. This would represent a more accurate volume computation than average-end-area methods. See additional discussion in Chapter 15 (Dredge Measurement and Payment Volume Computations).

b. Impact of depth measurement bias errors on volume computations. The causes of depth bias in a data set were discussed in the preceding paragraphs. A constant depth bias in the data set is estimated from cross-line checks or multibeam performance test data. The effect of a constant depth bias on a dredged quantity computation is fairly obvious--the error projects over the entire dredging section (e.g., Acceptance Section). Thus, minimizing any depth biases is critical. Using the 3,000 ft acceptance section in the above example, the quantity error due to a 0.1 ft depth bias can be approximately computed by projecting the bias over the entire section:

volume error = 0.1 ft · 400 ft · 3,000 ft / (27 cy/ft) = 4,450 cy

percent error = 4,450 cy / 450,000 cy = 1 %

In the above example, it is seen that the bias error (1%) is smaller than the error due to terrain variations (2.5%). This corresponds to theory and is roughly what occurs in practice. Bias error can become more significant in offshore tidal areas where modeling becomes difficult.

c. Impact of deviations in depth observations on volume computations. From the sample computation from the Kings bay project cross-line data in Table 4-2, the standard deviation of the depth measurements was estimated to be ± 0.9 ft, or ± 1.8 ft at the 95% level. If there are no biases in the data, volumes computed over a given area from an infinite number of observed data points would have no error due to inaccuracies in individual depths. However, an infinite number of points are never observed. When single-beam cross-sections are taken, "full-coverage" is observed along the section if depths are recorded at intervals of 10-15 per sec. Normally, however, for both single-beam and multibeam surveys, data sets are generalized or "thinned"--i.e., binned or gridded. For example, single-beam cross-section data collected at 1-ft intervals may be generalized to points every 5- or 25-ft along the line, or dense multibeam data may be generalized into one data point in a 5 x 5 ft (25 sq ft) cell. This generalization is usually performed to reduce the size of the database. Either an average of all the points in a range or area is used or a single point nearest the cell center is used. The following over-simplified example illustrates how the data point accuracy and number of points can affect the dredge quantity computation.

Given: 100-ft single beam cross-section run over 26.0 ft lock chamber

OFFSET	DEPTH	Depth Used
0	26.1	26.1
5	26	
10	26	
15	26	
20	26.2	
25	26	26
30	25.9	
35	25.9	
40	26	
45	26.2	
50	25.9	25.9
55	26	
60	26	
65	25.8	
70	25.9	
75	26.3	26.3
80	26	
85	25.7	
90	26.1	
95	26	
100	26.2	26.2

(1) The mean of the 21 depths observed at 5-ft intervals is 26.0 ft and their 1-σ standard deviation is ± 0.14 ft. This indicates no bias in the data was observed in this dataset. The 95% confidence of the mean is ± 0.06 ft. Thus, if all the points were used to compute an end-area of this cross-section, the accuracy of the end area would be good.

(2) If depths were thinned to the even 25-ft intervals as shown in the above table, and only these depths used to compute the end-area of the cross-section, the end area accuracy would degrade significantly due to the few data points used. In this example, the mean of the five points is 26.1 ft, which, in effect adds a false 0.1 ft bias to the data. This 0.1 ft bias would be projected over the project area. The 95% confidence of this mean is also only (roughly) ± 0.14 ft., indicating little confidence in the measurements and ultimately the volume.

(3) The above illustrates that higher data density improves volume accuracy, either for average-end-area cross-sections or full DEM/DTM binned models. Larger numbers of data points negates out random errors in the individual data points. Improperly thinning datasets will cause errors in the volumes. The values from Table 4-3 may be used to roughly estimate the number of points needed along a cross-section to ensure some level of confidence in the end-area. For example, to maintain a confidence level of ± 0.05 ft on a 30-ft project (estimated 95% depth accuracy is ± 1.0 ft), at least 400 points should be collected. For a shallow-draft project, then only 100 data points would be needed to ensure ± 0.05 ft confidence.

d. Conclusions.

(1) Terrain irregularity has the major impact on the accuracy of volume computations. These effects are minimized by increasing data density and using spatial volume computation methods. Average-

end-area volume computation methods should only be used on projects with relatively uniform bottom terrain and where linearized end-area variations between successive sections are less than 0.5%. If end-area variations are large due to irregular bottom topography, then closer spaced cross-sections should be run or full-coverage multibeam surveys obtained.

(2) When sparse data sets (i.e., cross-sections) are observed, TIN or dense grid volume computation methods using prismoidal projection elements are more accurate than average-end-area methods. If full multibeam datasets are observed, volumes should not be computed by passing sparse cross-sections through the dataset and using average-end-area methods.

(3) Collected survey data used for volume computations should not be thinned in order to minimize volume errors due to data density and data point variance. If thinning is needed due to data processing limitations, it should be kept to a minimum. The degree of bottom irregularity will determine the amount of allowable thinning--i.e., maximum cell size. All observed depths on single beam surveys should be used in computing end-areas. For multibeam surveys, cell sizes should generally not exceed 5x5 ft bins. The smallest bin size that can be efficiently computed should always be used.

(4) Other factors may impact dredge volumes. These may include errors due to fluff, vegetation, short-term draft or velocity variations, or sensitivity drift. These errors are difficult or impossible to quantify.

4-10. Horizontal Positioning Accuracy Estimates

The horizontal position accuracy standard specified in Table 3-1 is a two-dimensional circular (radial) accuracy measure. A circular accuracy is an approximate estimate in that it approximates a 2-D error ellipse, as shown in Figure 4-4. The Federal (FGDC) and Corps positional accuracy standard is specified relative to this 95% confidence level. This means that on average 19 of 20 observed positions will fall within the required standard. The standard could be evaluated by comparing the observed position with a higher accuracy position. In a static mode, this can be done by recording DGPS positions with the receiving antenna set up over a known geodetic control point. Differences in X and Y coordinates between the known position and observed position are recorded, RMS errors are computed for each coordinate, and the two-dimensional positional error is estimated at the 95% level. It is far more difficult to evaluate the positional accuracy on a moving vessel since a more accurate position is not easily obtained with which to compare the observed position.

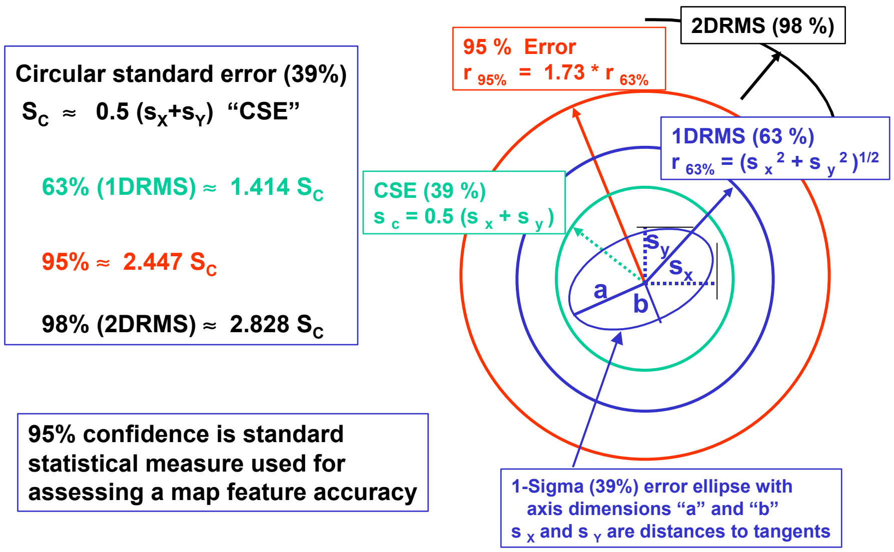


Figure 4-4. Two-dimensional radial positional accuracy estimates

a. Two-dimensional elliptical positional accuracy. Computed horizontal positions from surveying measurements produce coordinate pairs on a flat map of two dimensions. The ellipse in Figure 4-4 represents a joint probability distribution of the errors in the X and Y directions. This elliptical distribution assumes no biases are present in the data. It represents a 39% probability. The dimensions of the ellipse are defined by its two axes—*a* and *b*—and its orientation relative to the X-Y grid. The standard error in each X-Y dimension is defined by the lengths of the tangents to the ellipse--s_x and s_y --as shown in Figure 4-4. This ellipse will have standard deviations s_x, s_y, and correlation (s_{xy}) unless the axes of the ellipse are oriented parallel with the coordinate system axes. These standard deviations are computed directly from the ellipse's dimensions and orientation. The probability of locating a randomly selected computed position within a standard error ellipse is 39.4%. Any error in the *x* or *y* direction will distort the ellipse in a perpendicular sense to show the magnitude of the error. The two-dimensional ellipse in Figure 4-4 indicates the *x* coordinate component has the greatest error. Often, however, constant positional biases may be present. These biases may exceed the apparent dispersion levels of the data. The biases must be included in any estimate of the 95% positional confidence.

b. Two dimensional error measures. The error ellipse refers to probability as a measure of survey precision quality. If the circle (special case of an ellipse) could represent the error, then one number could define the precision of survey measurements. A radial error measure is used to approximate the ellipse. The radius *r* of the Circular Standard Error (CSE) circle is computed from the standard deviations--s_x and s_y –in the error ellipse, as shown in the figure. This CSE circle represents a 39% probability. A more common circular approximation is the 63% circle, or 1DRMS. It is computed by taking the square root of the sum of the variances in x and y. It may also be approximated by multiplying 1.1414 times the average of the standard deviations—a valid assumption if the ellipse is nearly circular. The 63% 1DRMS circle is also known as a *1-deviation RMS--i.e., 1DRMS*. A *2DRMS* is defined as two deviations of circular error with probabilities of approximately 98%. The 95% error circle shown in Figure 4-4 is 1.73 times the radius of the 1DRMS circle. GPS manufacturers typically use a 2DRMS (i.e., approximately 98%) measure of positional accuracy, not the 95% radial accuracy measure used by FGDC and this manual. Another circular error approximation is the Circular Probable Error (CPE)—a 50% probability. Errors computed by the statistical methods are linked to the probabilities that the actual error at a given point will not exceed the computed error value. The actual error at the given point may be far less. Probabilities predict computed errors based on the theory of repeated trials. In mapping, repeated measurements are rare and the actual error is unknown except for upper and lower limits. See Bowditch, 1984 for additional information.

c. Horizontal positioning error components. The estimated accuracy **A** of a vessel's offshore position can be generalized by the following expression (in matrix form):

$$\text{Two-dimensional Accuracy} \quad \mathbf{A} = \sigma_0^{\,2} \cdot \mathbf{Q} \qquad \text{(Eq 4-6)}$$

where σ_0 is the estimated standard error of each component of the particular positioning system used (tag line, microwave range, GPS satellite range, etc.). Each measurement component may have different estimated standard errors. Variable **Q** (cofactor matrix) is a two-dimensional geometric factor associated with intersection angles of ranges or angles used to coordinate the offshore point (circular range-range intersection, circular range-transit azimuth intersection, or multiple range intersections).

(1) The resultant estimated accuracy **A** is a two-dimensional term containing the variances and covariances of the particular observation. A reduced form is usually best represented by an ellipse (see Figure 4-4) since the geometrical component **Q** influences the accuracy in varying magnitude and direction.

(2) Standard error of individual observations. The standard error (σ_0) term is a function of the estimated accuracy of the measurement system, including survey methods and techniques used to calibrate the system. Each EDM or GPS satellite range will have a standard error associated with it. This standard error is not the internal precision of the range measurement. It must additionally include an estimate of the systematic (or constant) biases present. As explained earlier, determining the standard error (or standard deviation) of a dynamic hydrographic distance measurement is extremely difficult and can only be roughly estimated from a limited number of static calibration checks. For example, estimates of a total station EDM range measurement will normally be based on the unbiased standard deviation of the calibration comparisons over a fixed baseline, namely:

$$\sigma = sqrt\ [\ \Sigma(X_i\ -\ X_m)^2\ ]\ /\ [n-1] \qquad \text{(Eq 4-7)}$$

where

X_i = Observed distance observation

n = number of observations (i = 1 through n)

X_m = mean of all observations

(3) Average deviation. For many practical survey purposes, it is often simpler to compute the "average deviation" rather than the standard deviation:

$$\text{Average deviation} = [\ \Sigma|X_m\ -\ X_i\,|\ ]\ /\ n \qquad \text{(Eq 4-8)}$$

where $\Sigma|X_m - X_i|$ is the sum of the absolute values of the deviations (signs disregarded).

(4) Geometrical factors. This can be the major error component in the resultant accuracy of an offshore position. All offshore positioning methods commonly used on engineering surveys reduce to determining the coordinate intersection of two or more lines that have been generated by constant distances

or angles from the reference points ashore or from satellites. These lines are often termed "lines of position." The relative strength of a position is a direct function of the angle of intersection between these lines. The strongest position "fix" is usually obtained when two position lines intersect at 90 deg. As the angle of intersection deviates from 90 deg, the relative strength of position weakens. In positioning systems in which the standard error increases with distance offshore (e.g., total station range azimuth), the strength of position will also vary with the distance from the observing unit. Systems that observe more than two lines of position are termed "redundant" or "multi-ranging." GPS satellite position involves four or more lines of position. The angle by which these three or more lines intersect is also factored into this geometrical component, although in a more complex manner. When the standard error components are plotted (at a large scale) for each line of position, the intersections can be generalized to a trapezoidal figure (in the case of two observations only) which roughly depicts the 2-D positional error. From this plot and/or data, a standard error ellipse of constant probability can be derived. The size and shape of this error ellipse vary directly with the angle of intersection between the lines of position and the range error. The one-sigma standard error ellipse is a figure that represents a 0.39 probability; or there is a 39-percent chance that the position falls somewhere within this ellipse. Conversely, there is a 61-percent probability that the position falls outside the ellipse—see Figure 4-3. Due to changing geometry, the size and direction of the error ellipse will vary as a survey vessel traverses from point to point in a project area. Particular note should be made that the uncertainty of a position can be several magnitudes larger along one (semi-major) axis. This may be significant on some projects where detail is critical in one dimension. The error ellipse is only a graphical representation (or approximation) of a position's estimated accuracy. For a number of reasons, because of the non-random (or non-normal) distribution of errors in surveys, this representation must be considered approximate. Since error ellipses are difficult to conceptualize, an elliptical positional accuracy estimate is usually approximated by a circle whose radius represents some function of the ellipse's axes--e.g., CSE, 2DRMS.

d. Geometrical Dilution of Precision (GDOP). Another statistic commonly used in static and kinematic GPS surveying is the Geometric Dilution of Precision (GDOP). This term is directly related to the $\boldsymbol{Q}$ term in Equation 4-6, and is used as an indicator of a position's degradation due to changing intersection geometry. For the simple case of a 2-D horizontal position, the term Horizontal Dilution of Precision (HDOP) is used. HDOP is computed as follows:

$$HDOP = Tr\,|\boldsymbol{Q}\,| \;/\; \sigma_0 \quad = [\, \sigma_X^2 + \sigma_Y^2 \,] / \sigma_0$$

(Eq 4-9)

where $Tr\,|\boldsymbol{Q}\,|$ is the trace of the $\boldsymbol{Q}$ matrix and σ_0 is the assumed accuracy of a satellite or EDM range measurement. For a positioning system of given accuracy and a desired horizontal accuracy limit, a maximum HDOP limit may be established. Data points outside this HDOP would be rejected. Since HDOP varies with location on non-GPS surveys, it is applicable only to a static point. In the case of a hydrographic survey being positioned using differential GPS, the moving reference satellites will vary the GDOP/HDOP with time rather than position in a given project area. This is opposite to the case of a vessel moving relative to the fixed EDM (or angular) reference stations.

4-11. FGDC Accuracy Reporting Criteria

The *FGDC Geospatial Positioning Accuracy Standards, Part 3: National Standard for Spatial Data Accuracy* uses root-mean-square error (RMSE) to estimate positional accuracy. The FGDC defines RMSE as the square root of the average of the set of squared differences between dataset coordinate values, and coordinate values from an independent source of higher accuracy for identical points. RMS errors are computed for both the X and Y coordinates, then are combined to obtain a 95% positional accuracy estimate--see FGDC reference at end of chapter. Accuracy is reported in ground distances at the 95% confidence level. Accuracy reported at the 95% confidence level means that 95% of the positions in the dataset will have an error with respect to true ground position that is equal to or smaller than the reported accuracy value. The reported accuracy value reflects all uncertainties, including those introduced by geodetic control coordinates, compilation, and final computation of ground coordinate values in the product.

a. Horizontal. The reporting standard in the horizontal component is the radius of a circle of uncertainty, such that the true or theoretical location of the point falls within that circle 95% of the time.

b. Vertical. The reporting standard in the vertical component is a linear uncertainty value, such that the true or theoretical location of the point falls within $\pm$ of that linear uncertainty value 95-percent of the time. The reporting accuracy standard should be defined in metric (International System of Units, SI) units. However, accuracy will be reported in English (inch-pound) units where the point coordinates or elevations are reported in English units.

Corps position and elevation (depth) accuracy statistics, accuracy assessment techniques, and reporting methods, as defined in this manual, are designed to conform to the above FGDC standards.

4-12. References

Bowditch 1984
Bowditch, Nathaniel, *The American Practical Navigator: An Epitome of Navigation*, Appendix Q: Navigational Accuracy, Defense Mapping Agency Hydrographic/Topographic Center, 1984

Mikhail 1976
Mikhail, Edward M., *Observations and Least Squares*, 1976

4-13. Mandatory Requirements

There are no mandatory requirements in this chapter.

Chapter 5
Project Control, Coordinate Systems, and Datums

5-1. General Scope

This chapter provides guidance on the required geodetic reference datums and coordinate systems for USACE navigation and flood control projects. General guidance is also provided on setting survey control for dredging projects and positioning aids to navigation in these projects. The major emphasis in this chapter is on vertical reference datums for navigation projects--tidal, river, lake, pool, and flood control reservoirs. This chapter has minimal coverage of horizontal coordinate systems, horizontal datums, and control survey methods since this material is fully covered in other engineer manuals listed in Appendix A. In addition, nearly all hydrographic surveys and dredge positioning are now controlled by established, nationwide DGPS networks; thus reducing the need to establish supplemental horizontal control on dredging and navigation projects.

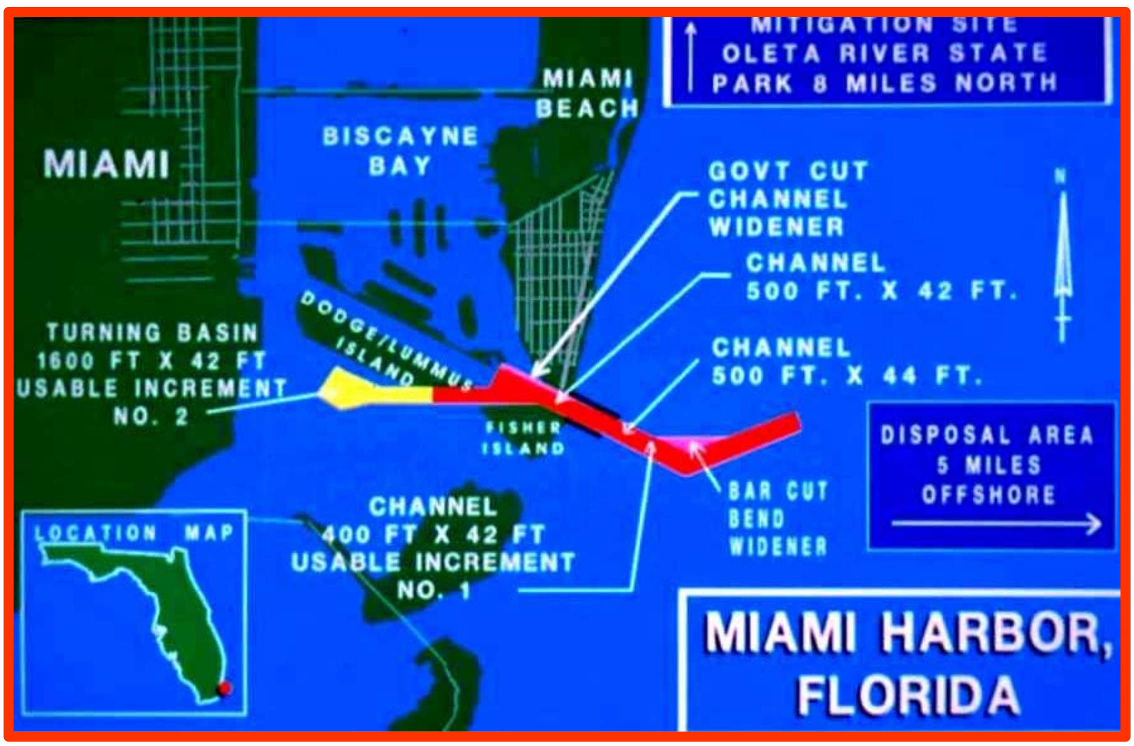


Figure 5-1. Channel and basin layouts for a typical deep-draft navigation project

5-2. Horizontal Control for Navigation and Flood Control Projects

Throughout the Corps, authorized engineering and construction projects are referenced to a variety of horizontal systems. Hydrographic surveys performed on dredging, navigation, and flood control projects must utilize the existing design dimensions for the project--Figure 5-1. In general, a horizontal reference system for a project is defined by the grid system covering the project and the origin (or reference datum) of that grid system. Grid systems used in the Corps include: Geographical (latitude-longitude), State Plane

Coordinate Systems (SPCS), Universal Transverse Mercator (UTM) grid system, and Chainage-Offset grid systems. These varied grid systems are usually (but not always) referenced to a local, regional, national, or international datum, such as the North American Datum (NAD) or the World Geodetic System (WGS).

a. Project control. All engineering projects should have permanent control monuments established along the project's perimeter. These marks are used to control offshore surveying and construction, and to define limits and scopes of work in contract plans and specifications. They may also serve as boundary monuments defining the project's limits. This control ideally has been connected to nearby National Geodetic Survey (NGS) control of higher-order accuracy, or connected to state or regional control surveys. Boundary monuments should have been connected to local property corners, rights-of-way, section corners, etc. The density of horizontal control was once determined by the need for visual dredging ranges and baseline requirements along each reach of a project. Typically, permanently monumented control points were required at 500 to 2,000 feet intervals along each side of a navigation project, and at denser intervals along jetties, beaches, and near structures. These points were generally accurately controlled within themselves. Ties to regional or national network systems were not always necessary. The recent use of GPS has largely eliminated the need for dense survey control around a project.

b. State plane coordinate systems. Navigation and flood control projects should be referenced to the local State Plane Coordinate System (SPCS) for that area. These X-Y grid systems are used to define project boundaries, construction limits, dredging limits, and channel dimensions. Hydrographic surveys are performed relative to these grid systems and data are collected in these coordinates. A limited number of Corps projects are referenced to the Universal Transverse Coordinate (UTM) grid system, a worldwide military grid system. Usually, UTM coordinates are determined by direct transform of local SPCS coordinates.

c. Reference systems for dredging control. Most engineering and construction work, including dredging, is aligned to a local project coordinate system. The datum for such local systems is typically a reference monument/baseline or, in the case of river and harbor construction, an artificial point such as the point of intersection (PI) between two channel alignment centerlines—see Figures 5-2 or 5-3. This PI may, in turn, be referenced by azimuth and distance to one or more monuments ashore. From such reference datum points, a local project grid is aligned to the project azimuth using standard station-offset coordinate convention. Most projects are additionally connected to the National Geodetic Reference System (NGRS) network using the local SPCS. The NGRS in itself may be defined by different datum references – the NAD 1927 or NAD 1983.

d. Global Positioning System (GPS). Differential GPS techniques are now used for setting most horizontal control on USACE projects--see EM 1110-1-1003 (NAVSTAR GPS Surveying) for procedures and standards. As detailed in EM 1110-1-1003, GPS satellite coordinates are referenced to the WGS 84 system, which has a direct relationship to the North American Datum of 1983 (NAD 83). GPS geocentric coordinates referenced to the WGS 84 ellipsoid must be converted to either the NAD 27 or NAD 83 datums, depending on which of these is used for a particular project. The NAD 27 or NAD 83 system is then converted to the local State Plane Coordinate System or Universal Transverse Mercator grid system. Most data acquisition software will perform these conversions automatically, using CORPSCON type conversion software. If not, it will be necessary to manually enter the WGS 84-NAD 27/83 conversions (in geocentric coordinate differences) for the local area. These conversions may be scaled to the nearest meter from contour maps depicting the differences in geocentric coordinates. The small difference between WGS 84 and NAD 83 (which uses the GRS 80 reference ellipsoid) is not significant for most Corps applications.

e. North American Datum. Most local project datums in USACE have been referenced to the NAD 27 coordinate system by direct survey connections with higher order monuments in the NGRS network. SPCS or UTM coordinates on common reference monuments or artificial alignment points define this relationship. Angular (or geodetic/geographic) latitude and longitude coordinates are sometimes used. Many USACE projects will eventually be converted to the redefined NAD 83. CORPSCON, a coordinate conversion program, should be used to convert to and from North American Datum of 1927 (NAD 27).

f. Supplemental project control. Supplemental project control may be needed in areas where GPS is inoperable (near bridges, power plants, etc.), or when fixed monuments are needed for beach renourishment projects or boundary control. Survey control for most hydrographic work should be established to 3rd Order, Class I accuracy standards (1 part in 10,000)—see Table 5-1. Control should be established from the National Spatial Reference System (NGRS) monuments where possible. Supplemental points within a project may be established by 3rd Order, Class II (1:5,000) procedures. Topographic mapping and surveying methods are described in EM 1110-1-1005 (Topographic Surveying). Standard engineering and construction surveying methods are acceptable for laying out baselines of limited range. Monumentation should conform to the requirements indicated in EM 1110-1-1002 (Survey Markers and Monumentation). Horizontal positions should normally be referred to (connected with) either NAD 27 or NAD 83. NAD 83 is the preferred datum. However, the continued use of NAD 27 will be acceptable until the surveys and project control systems can be converted to NAD 83. In either case, the horizontal datum actually used will be clearly noted on all plots, charts, maps, and coordinate files. All positions reported to other agencies should be in state plane coordinates, expressed in feet or meters within the proper zone. Exceptions to this will be allowed when UTM coordinates are used to eliminate the use of several state plane coordinate zones on a single project.

Table 5-1. USACE Point Closure Standards

Horizontal Control Surveys

USACE Classification	Point Closure Standard (Ratio)
Second Order Class I	1:50,000
Second Order Class II	1:20,000
Third Order Class I	1:10,000
Third Order Class II	1: 5,000
4th Order - Construction Layout	1: 2,500 - 1:20:000

Vertical Control Surveys

USACE Classification	Point Closure Standard (Feet)
Second Order Class I	0.025 sqrt (M)
Second Order Class II	0.035 sqrt (M)
Third Order	0.050 sqrt (M)
4th Order - Construction Layout	0.100 sqrt (M)

(M--distance in miles of level line)

g. Chainage-Offset coordinate systems. Navigation and flood control projects are locally referenced using an engineering chainage-offset system--Figure 5-2. Hydrographic surveys are performed relative to this system. Hydrographic data acquisition systems are also designed to operate on a chainage-offset system. Some systems allow use of geodetic latitude and longitude. Usually, SPCS coordinates are input to the system for reference, and the coordinates of the local chainage-offset grid are internally transformed to survey-specific cross sections or longitudinal range offsets.

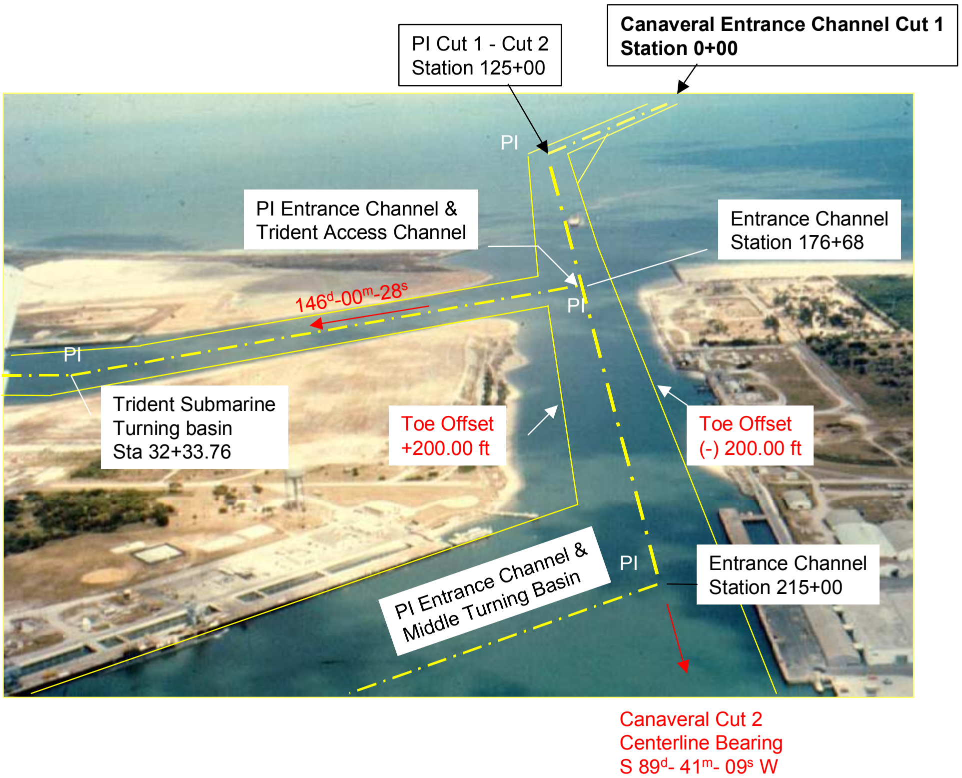


Figure 5-2. Chainage-offset project control scheme for a typical deep-draft navigation project--Cape Canaveral, FL (Jacksonville District)

(1) Station. Alignment stationing (or chainage) zero references are arbitrarily established for a given project or sectional area. Stationing on a navigation project usually commences offshore on coastal projects and runs inland or upstream. Stationing follows the channel centerline alignment. Stationing may be accumulated through each PI or zero out at each PI or new channel reach. Separate stationing is established for widener sections, turning basins, levees, floodwalls, etc. Each district may have its own convention. Stationing coordinates use "+" signs to separate the second- and third-place units (XXX + XX.XX). Metric chainage often separates the third and fourth places (XXX + XXX.XX) to distinguish the units from English feet; however, some districts use this convention for English stationing units.

(2) Offsets. Offset coordinates are distances from the centerline alignment of the channel or structure. Offsets carry plus/minus coordinate values. Normally, offsets are positive to the right (looking toward increasing stationing). Some districts designate cardinal compass points (east-west or north-south) in lieu of a coordinate sign. On some navigation projects, the offset coordinate is termed a "range," and is defined relative to the project centerline or, in some instances, the channel-slope intersection line (toe). Channel or canal offsets may be defined relative to a fixed baseline on the bank or levee.

(3) Azimuth. Channel azimuths are computed relative to the two defining PIs. Either 360-deg azimuth or bearing designations may be used. Azimuths of navigation projects should be shown to the nearest second.

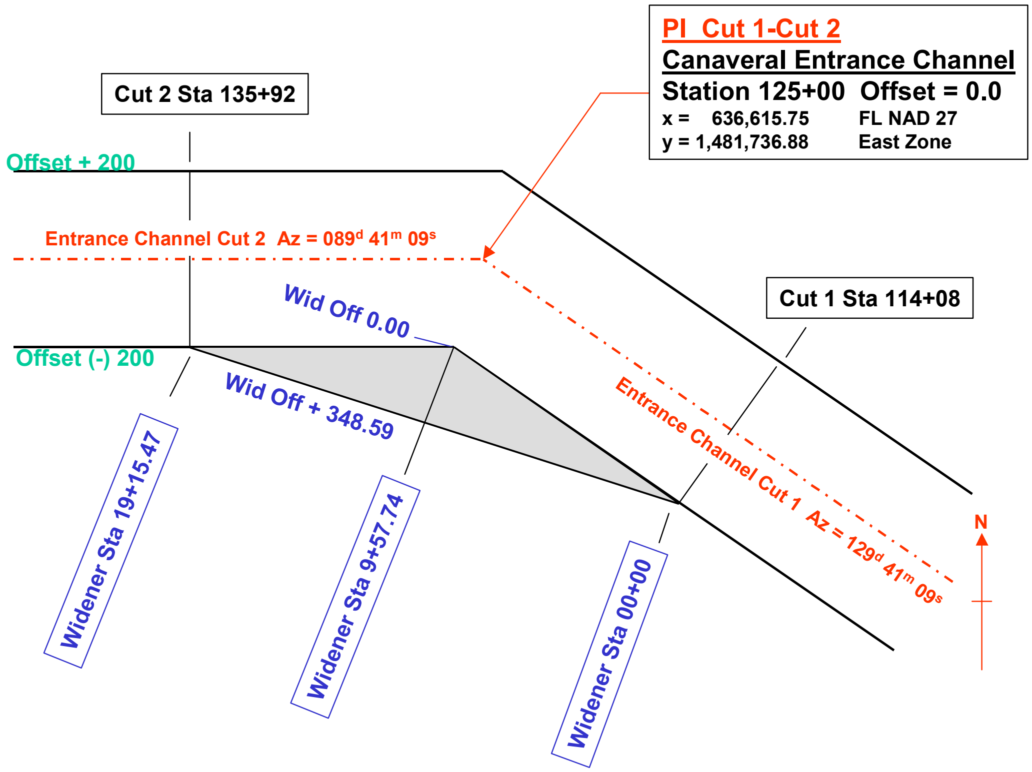


Figure 5-3. Chainage-offset control for a 400-ft coastal navigation project. Widener section has separate chainage-offset system from main channel. Note project stationing accumulates between channel reaches

h. Other local alignments. Different project reference grids may be established for widener sections (Figure 5-3), turning basins, and disposal areas. River sections and coastal beach sections are often aligned perpendicular to the project/coast. Each of these sections is basically a separate local datum with a different reference point and azimuth alignment. Beach sections may also be referenced to an established coastal construction setback line. Circular and transition (spiral) curve alignments are also found in some rivers, canals, and flood control projects such as spillways and levees. Hydrographic surveys will generally be aligned to the chainage and offsets along such curves.

i. River systems. Surveys along inland waterways, such as the Mississippi River, are often referenced to either arbitrary or monumented baselines along the bank. In many instances, a reference baseline for a levee is used, and surveys for revetment construction are performed from offsets to this line. Separate baselines may exist over the same section of river, often from levees on opposite banks or as the result of revised river flow alignments. Baseline stationing may increase either upstream or downstream. Most often, the mouth of a river is considered the starting point (Station 0 + 00), or the river reaches are summed to assign a station number at the channel confluence. Stationing may increase consecutively through PIs or reinitialize at channel turns. In addition, supplemental horizontal reference is made to a river mile designation system, in particular when interpolating stage gradients between two points (sections). River mile systems established years ago may no longer be exact if the river course has subsequently realigned itself. River mile designations are used to specify geographical features and provide navigation reference for users.

j. Automated survey coordinate systems. To perform a translation from SPCS to the project chainage-offset coordinate system (or vice versa), only two points common to both grid systems are required--or, one common point and an azimuth relationship. When a series of cross-sections is run on a given project, the common coordinates of the end points of one of these sections is input in the automated positioning system. These points are commonly termed the “start point” and “stop point,” and basically define an artificial reference baseline--refer to Figure 5-4. Actually, a new reference grid/datum is established for the automated positioning system. These end points are selected such that the full project is covered. In dredging work, the end points are placed a sufficient distance outside the channel toes to ensure adequate side slope coverage. The length of this artificial baseline is used to measure the distance along the offset track, and is displayed to the helmsman for reference. The “left-right” indicator displays the lateral deviation from the track. On a uniform channel, section “offsets” are run parallel to this reference baseline. Most automated systems allow input of a constant offset increment--e.g., 100-ft-spaced cross sections. Hydrographic systems vary in the way lines are computed by the system. For some nonuniform sections (river sections, beach profiles, etc.), a separate reference line may have to be input for each desired line. Some systems allow a series of these reference lines to be saved in a database. Due to the possibility of accumulated round-off errors in the internal software, care should be taken not to project this reference line beyond 10 to 20 times its length. Vessel guidance and “distance along track” measurements are performed relative to this reference baseline and its offsets. Automated system input reference computations are performed in the field. A record of these computations should be made in a field book or on a worksheet.

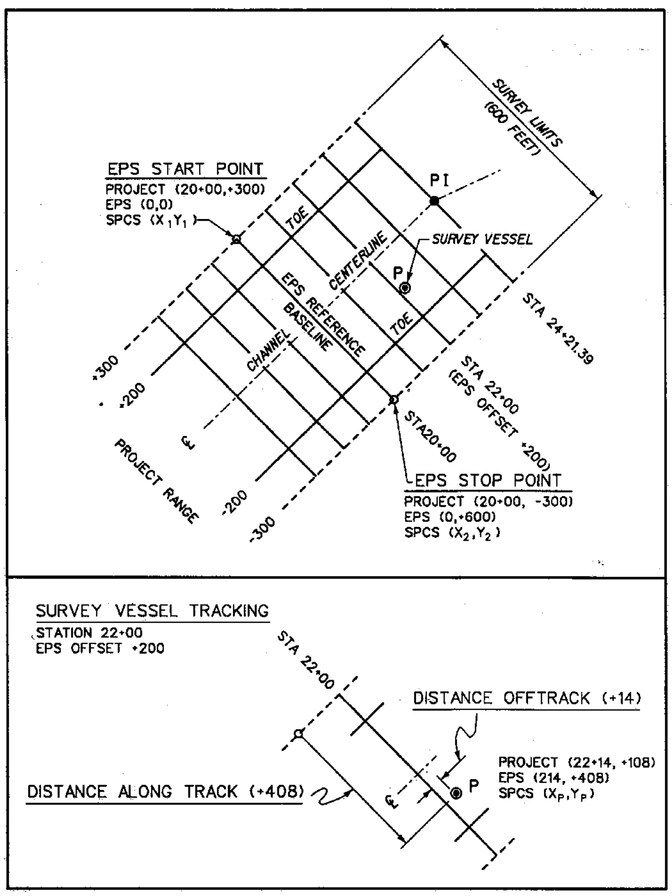


Figure 5-4. Reference baselines and coordinate systems used in automated data acquisition systems

k. Direct surveying on project coordinates. Many construction surveys are performed directly on the project coordinate system, and are not referenced to any SPCS or NGRS grid systems. Tag line baselines are normally laid out on the local project datum, and all subsequent coordinates are referenced to that station-offset system. Any type of automated positioning system can be operated using project coordinates. One advantage is that displayed coordinates are in the station-offset system. A disadvantage is that resultant positions may not be referenced to the local SPCS datum.

5-3. Positioning of Aids to Navigation in Authorized Projects

Surveys to determine the positions of navigation aids (NAVAIDs) in estuaries, inland rivers, harbors, or lakes may be required as part of some hydrographic surveys. Specific NAVAID positioning requirements will be contained in project instructions or scopes of work. Navigation aid positions will be transmitted to other mapping agencies for inclusion on charts, notices to mariners, etc. Failure to identify/locate critical NAVAIDs on surveys for contract plans and specifications could lead to subsequent contract disputes, especially if temporary NAVAID relocation is required during the contract period. Since these aids are critical in controlling navigation, special care shall be used to obtain accurate positions consistent with the standards specified in Table 3-1. Since it is not always practical (or necessary for design/construction purposes) to locate every NAVAID on a project, only major, permanent NAVAID structures require topographic survey methods and precision. Such structures include lighthouses and fixed sailing ranges on major navigation channels. These types of NAVAIDs are distinguished from the more numerous smaller fixed beacons, daymarks, piles, dolphins, and the like, which hereafter will be termed semi-permanent fixed NAVAIDs. Buoys, lighted or otherwise, are called floating NAVAIDs. Permanent fixed NAVAID structures should be positioned to USACE 3rd Order, Class II standards per Table 5-1. Semi-permanent fixed NAVAIDs and floating NAVAIDs may be positioned within the accuracy levels of the hydrographic survey system being used--e.g., 2-meter code-phase DGPS. Positions of navigational aids should be reported in the form of State plane coordinates on NAD 27 or NAD 83, and expressed in feet along with the accuracy to which they were positioned. Values reported to USCG and other maritime interests should be provided with their geographic latitude and longitude coordinates and the accuracy to which they were positioned. USCG criteria for NAVAID positioning may call for USACE Third Order, Class I accuracy. When NAVAID locationing is performed in support of, and funded by the USCG, that agency's accuracy requirements should be adhered to. Otherwise, Third Order, Class II, or DGPS-level accuracies described above will suffice.

5-4. Vertical Control for Navigation and Flood Control Projects

Providing an accurate vertical reference is perhaps the most important aspect in hydrographic surveying. This is especially critical on river and harbor navigation projects that are subject to varying tidal phase and range, sloping river stage, and uncertain vertical network benchmark accuracies. Figure 5-5 depicts the various vertical reference planes used on Corps projects—ranging from coastal ocean navigation to headwater flood control reservoirs. The various hydraulic reference planes are shown relative to the NGVD 29 national reference. The newer NAVD 88 vertical reference system is different from and not parallel with the NGVD 29, as will be explained in later sections. The NGVD 29 approximates a mean sea level datum. NAVD 88 does not; in fact it is 3 feet below mean sea level on the US West Coast--refer to Figure 5-8.

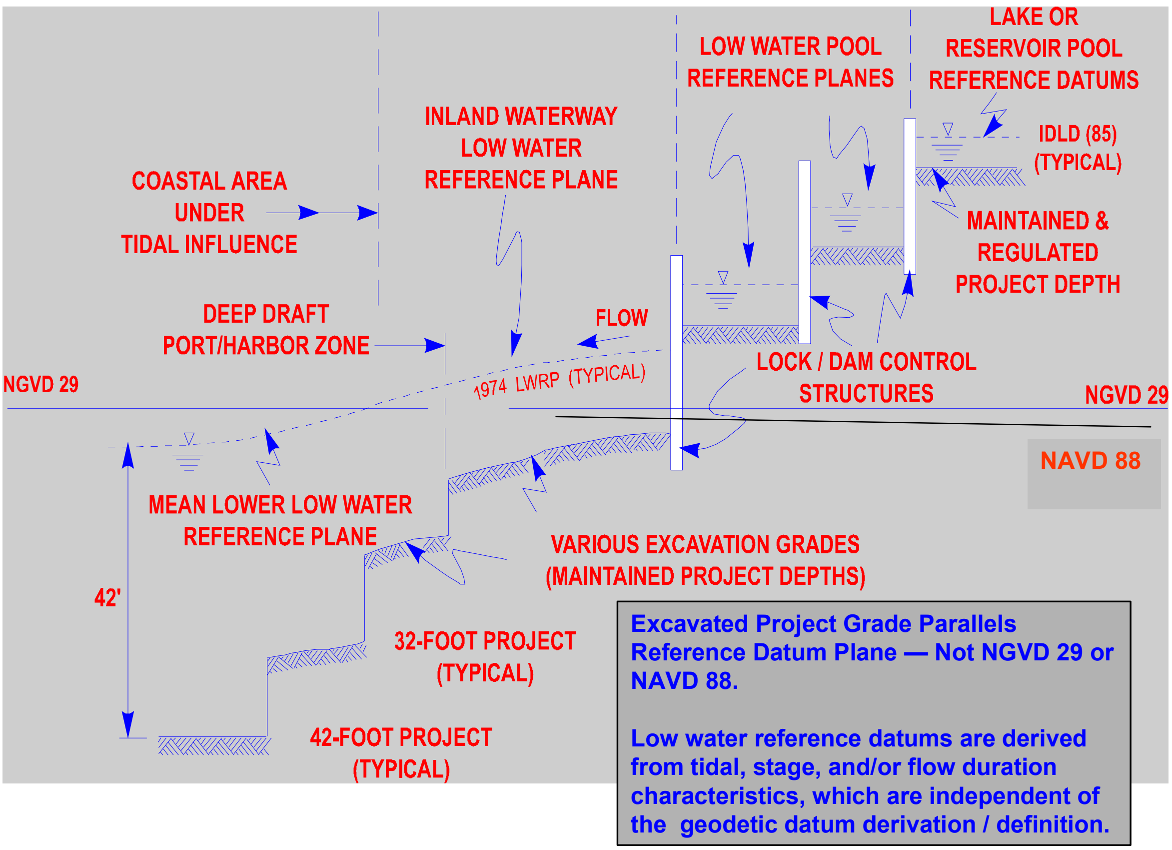


Figure 5-5. Vertical reference planes for navigation and flood control projects

a. Tidal areas. In offshore coastal areas, navigation projects are referenced to a tidal datum—Mean Lower Low Water (MLLW) throughout CONUS. This MLLW reference plane is not a flat surface but slopes as a function of the tidal range in the area. Tidal range can increase or decrease near coastal entrances; thus the MLLW must be accurately modeled throughout the navigation project. The required project depth also slopes as a function of the tidal range in an offshore area. The project depth is parallel to the MLLW curve as shown in Figure 5-5, an indication of decreasing tidal range towards shore. If the tidal range were increasing in Figure 5-5, then the slope of the grade and MLLW curve would be downward. At some point near or upstream of an entrance, the MLLW curve crosses the NGVD 29 plane, being influenced by river slope but still subject to tidal range superimposed on this slope. The required grade at all points on the navigation project is dependent on tidal modeling--i.e., determining the elevation of the MLLW datum plane from a series of gage observations at each point. A number of tide gages may need to be established along a navigation project to adequately model the MLLW curve. Depending on the magnitude of the tidal range and linearity of the slope, recording gages may need to be placed at 0.5- to 5-mile increments along the project. Gages should be spaced such that the accuracy of the MLLW elevation at any point in the project is +/- 0.1 ft. This may be achieved by 3 to 30 days of observations. The MLLW reference elevation between the gages is estimated by linear interpolation.

b. River areas. Proceeding up river in Figure 5-5, a constant maintained navigation depth will slope with the average river surface. River datums are referenced to a low water reference plane (LWRP), such as the LWRP 1974 reference used in the unregulated portion of the Mississippi River. Like tidal MLLW, the low water river datum must be determined from gage/staff observations at sufficient points along the river to adequately define the surface. The spacing of these observations must be sufficient to allow linear interpolation between staff gage points. For a river that drops 0.5 ft/mile (e.g., Mississippi) gages or benchmarks may be required at least every quarter- to half-mile in order to reference hydrographic surveys.

c. Controlled river pools. Between river control structures, low water pools are used to reference maintained navigation depths, as shown in Figure 5-5. Since these pools themselves may exhibit some slope, sufficient gages/benchmarks within the pools should be established to account for any minor slope.

d. Reservoir pools. Depths in controlled reservoirs are usually referenced to a national vertical datum (e.g., NGVD 29 or NAVD 88).

e. Great Lakes. Depths in the Great Lakes and connecting channels are referenced to the International Great Lakes Datum (IGLD) of 1985. IGLD 85 represents a low water datum from which navigation is maintained. The datum must be adjusted for slope in the connecting channels between the Great Lakes.

5-5. Tides and Tidal Datums

A datum is defined as the base elevation used as a reference from which to reckon heights or depths. Example datums which most surveyors are familiar with are mean sea level, mean lower low water (MLLW) and mean high water. Tidal datums are defined in terms of the rise and fall or phase of the tide. High Water is the maximum height reached by a rising tide while Low Water is the minimum height reached by a falling tide. Vertical datums are used as a reference on NOS nautical charts. Depths are referred to MLLW--also called chart datum. Heights, such as towers and bridge clearances, are referred to Mean High Water (MHW). A tidal benchmark is a fixed vertical monument used to reference a local tidal datum. A minimum of three benchmarks is required unless the station datum is connected to NAVD 88.

a. Hydrographic surveys in tidal areas should be referenced to a base elevation on NAVD 88. In areas where this is not possible, hydrographic surveys in tidal areas should be referenced to a base elevation on NGVD 29, which has been determined by meaning the tide heights over the National Tidal Datum Epoch. The National Tidal Datum Epoch is the specific 19-year period (Metonic cycle) adopted by the NOS as the official time segment over which tide observations are taken and reduced to obtain mean values (e.g., MLLW) for tidal datums. The present National Tidal Datum Epoch is 1960 through 1978. Due to the long-term rise in global sea level and land subsidence, tidal datums are constantly changing and require continuous monitoring and updating. It is the mission of the NOS to collect tidal data and to reduce it to a mean value relative to the National Tidal Datum Epoch; therefore, NOS tidal datums should be used as a basis for hydrographic surveying in tidal areas. The National Tidal Datum Epoch is reviewed annually by NOS for possible revision and must be actively considered for revision every 25 years.

b. NOAA's *User's Guide for the Installation of Bench Marks and Leveling Requirements for Water Level Stations* prescribes the requirements for connecting USACE tidal bench marks to the national vertical network maintained by U.S. Coast & Geodetic Survey (USC&GS). The relationship between MLLW to both NAVD 88 *and* NGVD 29 will be made clear where NAVD 88 data is available. Hydrographic surveys in tidal areas should be referenced to NAVD 88 instead of the older NGVD 29. There are several reasons that NGVD 29 is not supported for these surveys. The old data was adjusted by different manual methods--the new data is collected and adjusted by least squares using digital computers. Many of the 107,000 kilometers measured for the NGVD 29 adjustment have been destroyed by:

- the Interstate Highway System construction,
- subsidence in Texas and Louisiana,
- earthquakes in California,
- flooding in the Midwest
- mass wasting on hillsides
- vegetation

In addition, 730,000 kilometers of levels were measured for the North American Vertical Datum of 1988 (NAVD 88) of which 625,000 kilometers were measured with better equipment.

c. Listed below are some definitions of types of vertical datums and their sources used in USACE.

National Geodetic Vertical Datum of 1929 (NGVD 1929)
- Geodetic datum derived from an adjustment of the first order level network of the United States and Canada.
- In the adjustment, local mean sea level (MSL) was held fixed at 26 tide stations, 21 in the U.S. and 5 in Canada.

North American Vertical Datum of 1988 (NAVD 1988)
- Geodetic datum derived from an adjustment of the first order level network of the U.S., Canada, and Mexico.
- In the adjustment, local MSL was held fixed at Rimouski, Quebec, Canada.
- Releveling First-Order Network
- Least Squares Adjustment
- Decided on Minimum Constrained System
- Primary BM at Father Point, Rimouski, Quebec
- Satisfied IGLD Requirements
- NAVD 88 not tied to MSL for U.S. coastline

International Great Lakes Datum of 1955 (IGLD 1955)
- Geodetic datum derived from first order level network along connecting channels of the lakes and water level transfers across the various lakes.
- In the adjustment, local MSL at Fathers Point, Quebec was held fixed.

International Great Lakes Datum of 1985 (IGLD 1985)
- Geodetic datum derived from first order level network throughout the Great Lakes in the U.S. and Canada.
- In the adjustment, local MSL at Rimouski, Quebec was held fixed.

5-6. Tide Stations

To facilitate the process of establishing tidal datums, tide stations are operated at various locations for long- (primary), medium- (secondary), and short-term (tertiary) durations--refer to Figure 5-6.

a. Primary control tide station. Long-term tide stations are referred to as primary control tide stations. These are tide stations at which continuous observations have been made over a minimum 19-year Metonic cycle. Their purpose is to provide data for computing accepted values of the harmonic constants essential to tide predictions and to the determination of tidal datums. The data series from these stations serves as a primary control for the reduction of relatively short series of observations from subordinate tide stations through comparison of simultaneous observations, and for monitoring long-period sea level trends and variations.

b. Secondary control tide station. Medium-term tide stations are referred to as secondary tide stations. These are stations at which continuous observations have been made over a minimum period of one year but for less than a 19-year Metonic cycle. The series is reduced by comparison with simultaneous observations from a primary control tide station. These stations provide for a 365-day harmonic analysis, which includes the seasonal fluctuation of sea level.

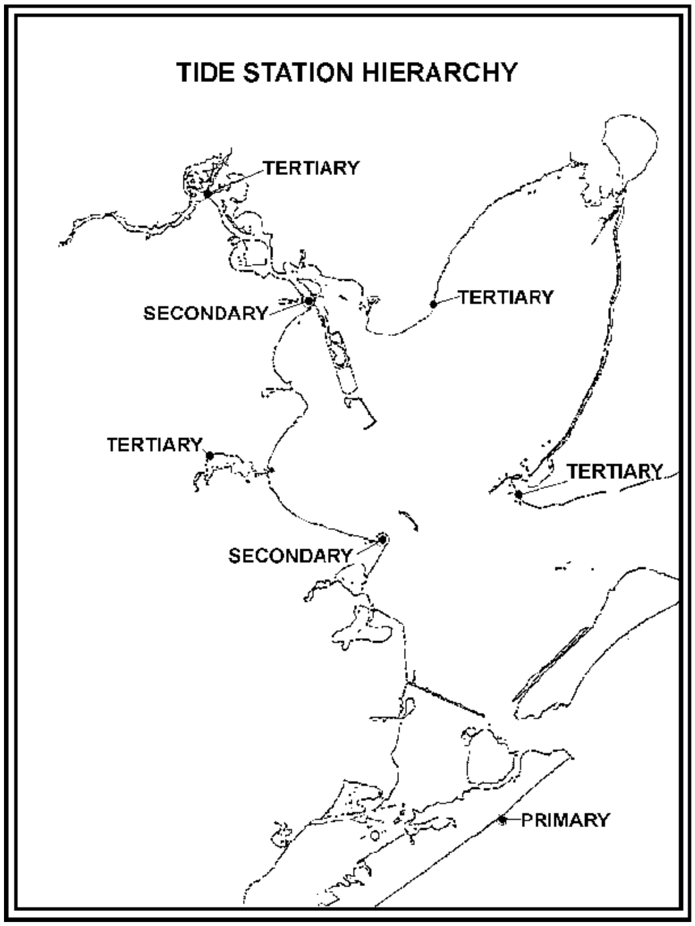


Figure 5-6. Schematic map showing relationship of tide stations

c. Tertiary tide station. Short-term tide stations are referred to as tertiary tide stations. These are tide stations at which continuous observations have been made over a minimum period of 30 days but for less than one year. The series is reduced by comparison with simultaneous observations from a secondary control tide station. These stations provide for a 29-day harmonic analysis.

d. Comparison of simultaneous observations. This is a reduction process in which a short series of tidal observations at any place is compared with simultaneous observations at a control station where tidal constants have previously been determined from a long series of observations. It is usually used to adjust constants from a subordinate station to the equivalent of those that would be obtained from a 19-year series. The National Tidal Benchmark System (NTBMS) provides datum information for previously occupied tidal measurement locations. Listed below are the general statistics for this system.

- Number of stations: approx. 6000
- East Coast: 3000
- Gulf Coast: 500
- West Coast: 1000
- Alaska: 1200
- Pacific Islands: 150
- Great Lakes: 177

5-7. Need for Updated Tidal Datums

Since tidal datums used for hydrographic surveying are referenced to benchmarks that are subsiding with the land relative to sea level, they should be monitored and updated constantly to remain valid. For example, in the Hampton Roads area of Virginia, failure to update tidal datums could result in errors of as much as 1.41 ft per century. Even larger errors can result if tidal datums are based on less than a 19-year mean, or, as in some Pacific coast projects, if earthquake activity has occurred.

a. An old and inaccurate rule of thumb often used in dredging is that datum planes be kept level in reference to sea level datums for any given reach of river or throughout any given stretch of dredging, even in areas where the local MLLW was not level. This creates a special problem near inlets and can result in a benchmark having two different dredging datum elevations, one for upstream, another for downstream, and neither corresponding to local MLLW. Level dredging datums will be discussed later in more detail.

b. It should also be noted that if dredging datums do not agree with true local MLLW, one of two problems will result. If dredging datums are below MLLW, charts will show depths shallower than reality, creating more dredging and giving local mariners and pilots a false impression of shoaling. If dredging datums are above MLLW, charts will show depths greater than reality, decreasing the amount of dredging and causing local mariners and pilots to run aground. In the first situation (normally found in areas where tidal datums are not kept current because of rising sea level and land subsidence), the error gives shipping an unrecognized safety factor at the expense of extra dredging. In the second situation, the error could cause a ship grounding.

5-8. Accurate Tidal Datums

Considering the ongoing rise in sea level relative to the landmass (Figure 5-7), accurate and up-to-date tidal datums are required to ensure that channels are dredged to the proper depths. Inaccurate datums result in unknown over- or under-dredging. Over-dredging provides an unknown and expensive safety factor that is not required. Under dredging can cause disastrous groundings. The optimum design depth cannot be obtained unless the proper tidal datum is correctly utilized. In areas charted by NOS, hydrographic surveying datums for dredging should be the same as NOS chart datums (MLLW).

5-9. NOS Tidal Datums

NOS has modified and updated its methods of determining and labeling the various tidal and chart datums for all coasts of the United States. The National Tidal Datum Convention of 1980 became effective November 28, 1980. This convention:

- Established one uniform, continuous tidal datum system for all marine waters of the U.S., its territories, the Commonwealth of Puerto Rico, and the Trust Territory of the Pacific Islands, for the first time in history.

- Provided a tidal datum system independent of computations based on type of tide.

- Lowered chart datum from MLW to MLLW along the Atlantic coast of the U.S.
- Updated the National Tidal Datum Epoch from 1941 through 1959, to 1960 through 1978.
- Changed the name Gulf Coast Lower Water Datum to MLLW.
- Introduced the tidal datum of Mean Higher High Water (MHHW) in areas of predominantly diurnal tides.
- Lowered Mean High Water (MHW) in areas of predominantly diurnal tides.

a. USACE navigation projects that are referenced to older datums (e.g., MLW along the Atlantic coast or various Gulf coast low water reference planes) must be converted to and correlated with the local MLLW tidal reference established by the NOS. Changes in project grades due to redefining the datum from MLW to NOS MLLW will normally be small, and in many cases will be compensated for by offsetting secular sea level or epochal increases occurring over the years. Thus, impacts on dredging due to the redefinition of the datum reference are expected to be small and offsetting in most cases.

b. All USACE project reference datums, including those currently believed to be on MLLW, must be checked to ensure that they are properly referred to the latest tidal epoch, and that variations in secular sea level, local reference gage or benchmark subsidence/uplift, and other long-term physical phenomena are properly accounted for. In addition, projects should be reviewed to ensure that tidal phase and range characteristics are properly modeled and corrected during dredging, surveying, and other marine construction activity, and that specified project clearances above grade properly compensate for any tidal range variances. Depending on the age and technical adequacy of the existing MLLW reference (relative to NOS MLLW), significant differences could be encountered. Such differences may dictate changes in channels currently maintained. Future NOS tidal epoch revisions will also change the project reference planes.

c. Conversion of project datum reference to NOS MLLW may or may not involve field tidal observations. In many projects, existing NOS tidal records can be used to perform the conversion, and short-term simultaneous tidal comparisons will not be required. Tidal observations and/or comparisons will be necessary for projects in areas not monitored by NOS or in cases where no recent or reliable observations are available.

(1) Since the shoreline, as depicted on NOS nautical charts and bathymetric maps, is the MHW line, the computational method adopted by this convention provides one uniform and continuous shoreline along all coasts of the coterminous U.S., Hawaii and Alaska, U.S. possessions, Puerto Rico, the Virgin Islands, the Trust Territories of the Pacific Islands, and UN Trust Territories under U.S. jurisdiction.

(2) Use of this computational method also allows states that have designated the MHW line as the boundary between private and state land and have one, two, three, four and/or six tides per tidal day along part (or all) of their coast, and two tides along the rest, to implement the tidal datum of MHW so that they will possess one uniform and continuous boundary between private and state lands.

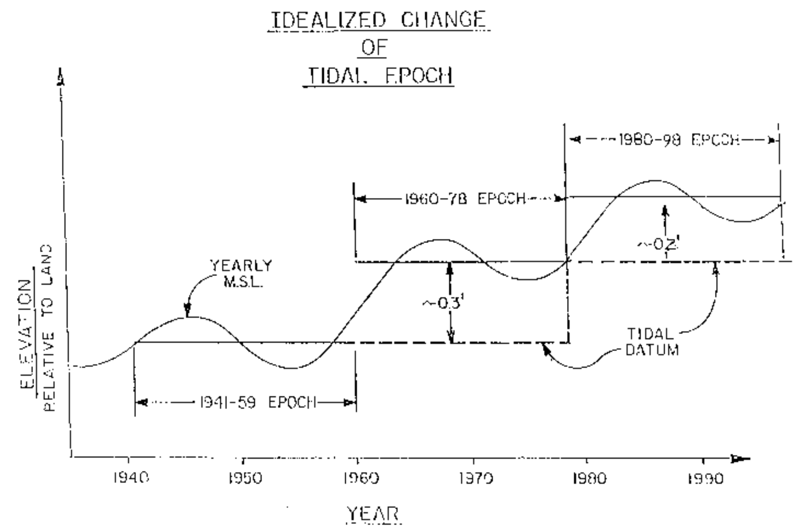


Figure 5-7. Schematic diagram of tidal epochs

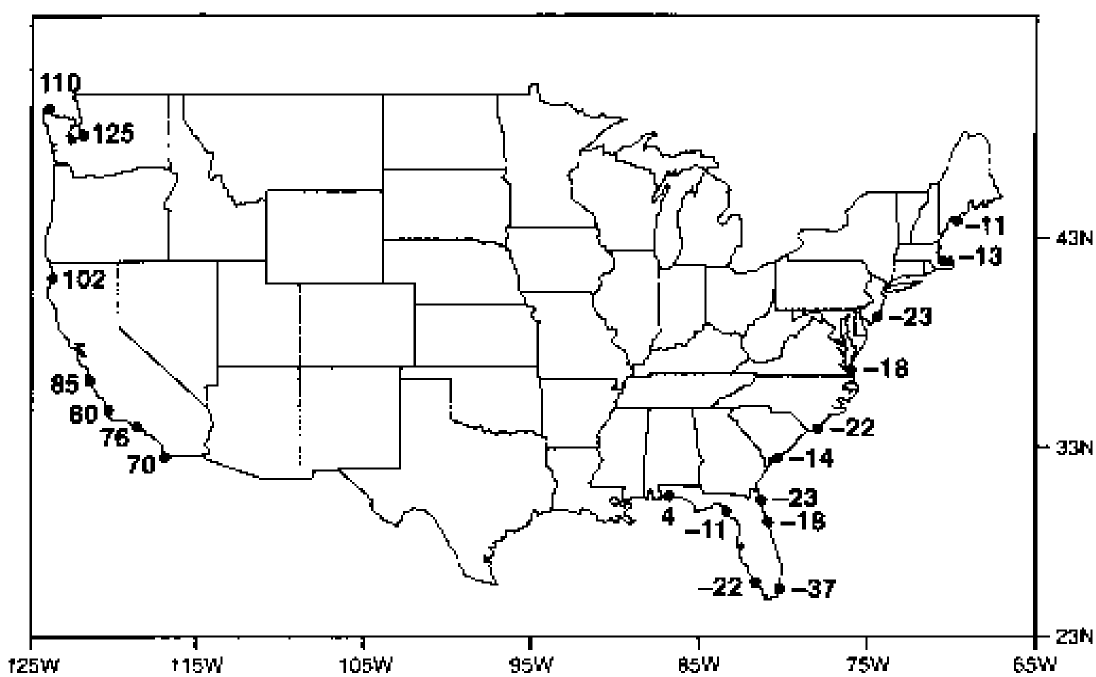


Figure 5-8. MSL datum relative to NAVD 88-- units in centimeters

Of particular importance for USACE--refer also to Figures 5-9 and 5-10:

Atlantic coast. Along the east coast of the U.S., the tide is semidiurnal with two high waters (on average) each tidal day. The chart datum has been changed from MLW to MLLW. This will be given lowest priority when publishing new values. However, MLW on the 1941-1959 epoch will closely approximate MLLW on the 1960-1978 epoch. Thus, MLW on the 1941-1959 epoch will continue to be acceptable until the MLLW data on the 1960-1978 epoch are available.

Gulf coast. Along the Gulf coast of the U.S., the tide is mixed in some areas and diurnal in others. There are other tides associated with islands, distances up bays and estuaries, and within lagoons. The presence of diurnal tides in the Gulf, and the fact that they do not stay purely diurnal at any one place, caused the tidal datum of MHW, as previously defined, to be non-uniform and discontinuous. In order to provide a uniform and continuous MHW Line, this convention intended that all (except in very special cases) high waters appearing with adjacent ranges equal to or greater than 0.1 foot be used in the mean for the datum of MHW regardless of the type of tide. For the MHHW line, the one high water of a diurnal tidal day and the highest high water of a multiple high water tidal day will be used in the mean for the datum. The MLW and MLLW lines are determined by similar computations of their respective datums. The name of the chart datum has been changed from Gulf Coast Low Water Datum (GCLWD) to MLLW, only to be consistent with those of other coasts of the United States. The GCLWD is a tidal datum that was used as an NOS chart datum from November 14, 1977, to November 27, 1980, for the coastal waters of the U.S. Gulf Coast. GCLWD is defined as MLLW when the type of tide is mixed and was MLW (now MLLW) when the type of tide was diurnal.

Pacific coast. Along the west coast, the tide is almost always mixed, with two high waters (often unequal in height) each day. The chart datum will continue to be MLLW.

d. These modifications have provided one uniform and continuous chart datum, MLLW, for all coasts of the U.S. With few exceptions in these coastal tidal areas, MLLW should be the dredging datum. This datum should be based on local tidal observations and computations referred to the National Tidal Datum Epoch. To ensure this, hydrographic surveys should be based on MLLW and should also be related to the NGVD 29 *and* NAVD 88, as specified previously. This allows continuity and identification of the slopes of local MLLW datums for long channels or when various reaches are dredged.

e. Depths of USACE navigation projects in coastal areas subject to tidal influences are currently referred to a variety of vertical reference planes, or datums. Most project depths are referenced to a local or regional datum based on tidal phase criteria, such as MLW, MLLW, Mean Low Gulf, or GCLWD. Some of these tidal reference planes were originally derived from U.S. Department of Commerce, NOS observations and definitions used for the various coasts. Others were specifically developed for a local project and may be without reference to an established vertical network (e.g., NAVD 88 or NGVD 29) or a tidal reference. Depending on the year of project authorization, tidal epoch, procedures, and the agency responsible for or connected to the reference datum, the current adequacy of the vertical reference may be uncertain or, in some cases, unknown. In some instances, project tidal reference grades may not have been updated since original construction. In addition, long-term physical effects may have significantly impacted presumed relationships to the NOS MLLW datum.

f. Since 1989, nautical charts published by USC&GS, U.S. Department of Commerce, reference depths (or soundings) to the local MLLW reference datum, also termed a "chart datum." USCG Notices to Mariners also refer depths or clearances over obstructions to MLLW. Depths and clearances reported on USACE project/channel condition surveys provided to USC&GS, for incorporation into its published charts in plan or tabular format, must be on the same NOS MLLW reference as the local chart of the project site.

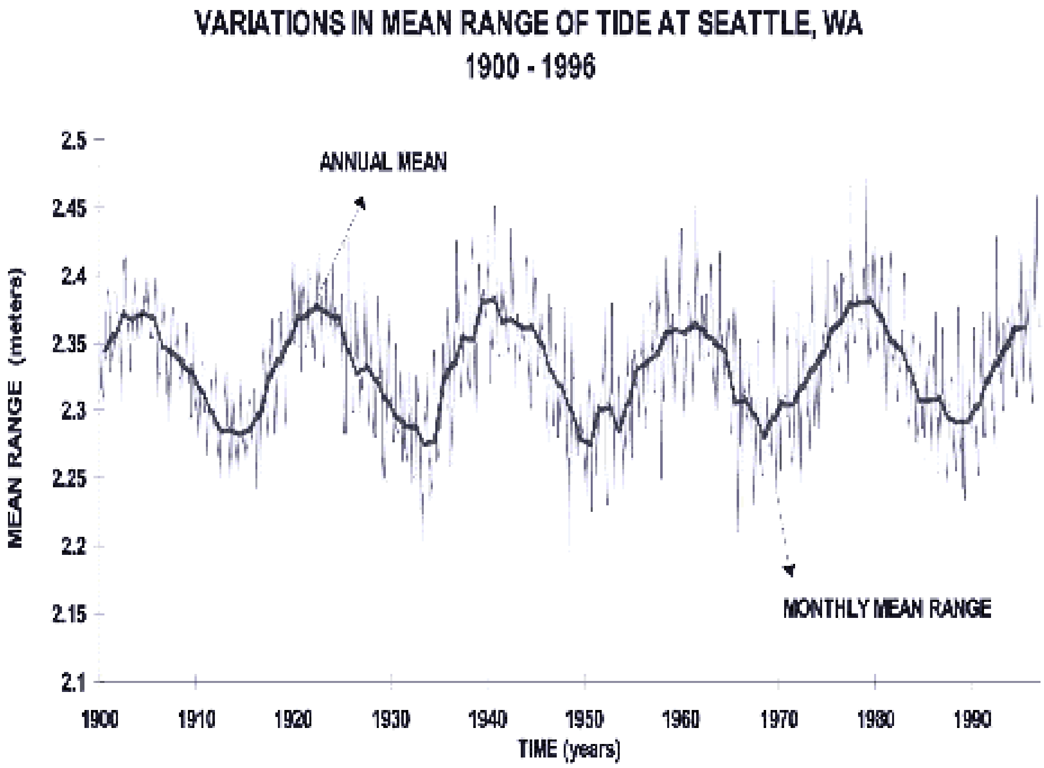


Figure 5-9. Example of mean range of tide on Pacific coast

g. The Water Resources Development Act of 1992 (WRDA 92), Section 224, requires consistency between USACE project datums and USC&GS marine charting datums. This act amended Section 5 of the Rivers and Harbors Appropriation Act of 1915 to define project depths of operational projects as being measured relative to a MLLW reference datum for all coastal regions; only the Pacific coast was previously referenced to MLLW. The amendment states that this reference datum shall be as defined by the Department of Commerce for nautical charts and tidal prediction tables (NOS) for a given area. This provision requires USACE project reference grades to be consistent with NOS MLLW.

h. Implementation actions. A number of options are available to USACE commands in assessing individual projects for consistency and accuracy of reference datums, and performing the necessary tidal observations and/or computations required to adequately define NOS MLLW project reference grade. Datum establishment or verification may be done using USACE technical personnel, through an outside Architect-Engineer (A-E) contract, by another USACE district or laboratory having special expertise in tidal work, or through reimbursable agreement with NOS. Regardless of who performs the tidal study, all work should be closely coordinated with both the USC&GS and NOS in the Department of Commerce.

i. Technical specifications. The general techniques for evaluating, establishing, and/or transferring a tidal reference plane are fully described in the USACE and Department of Commerce publications.

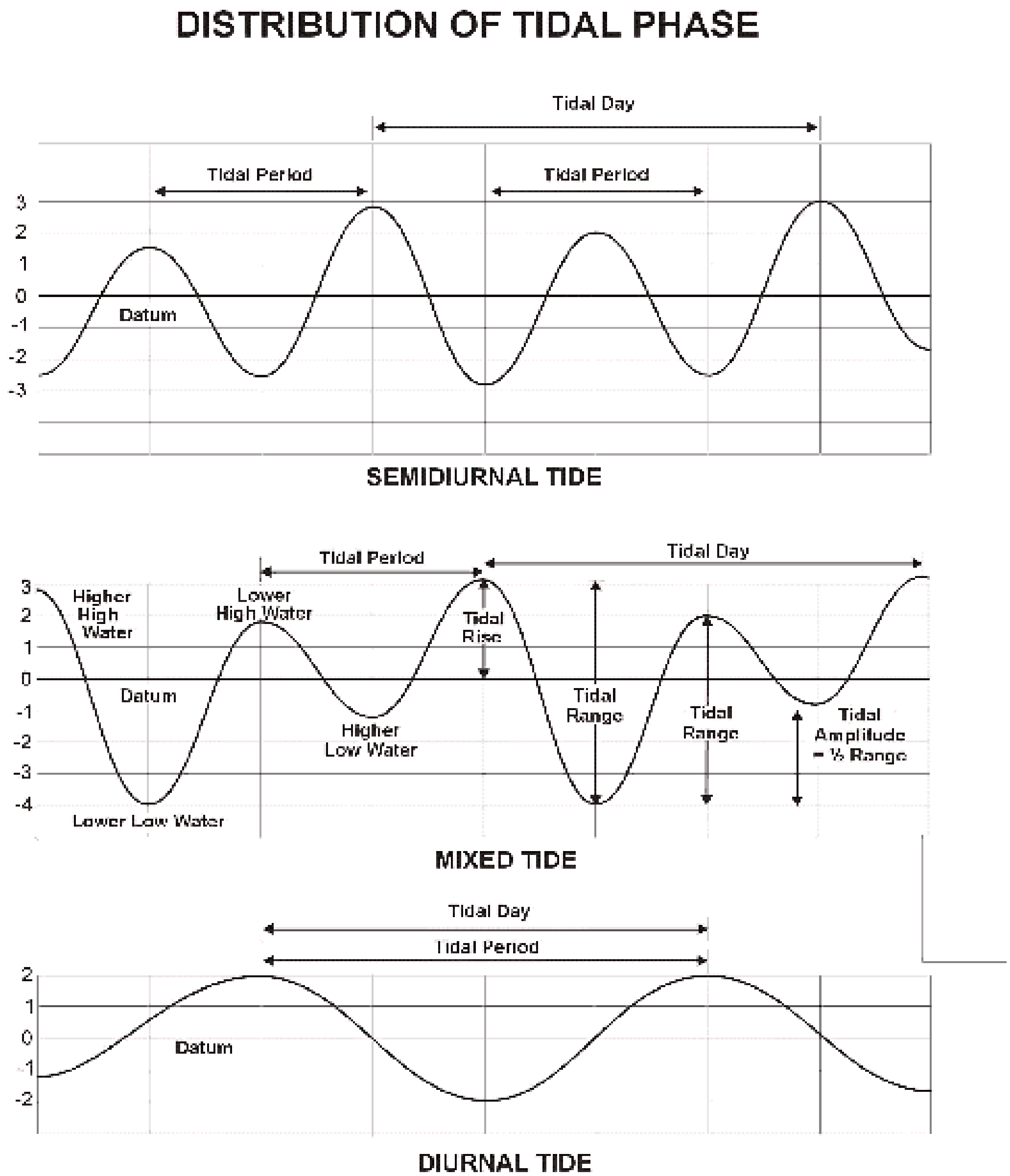


Figure 5-10. Types of tidal phases

5-10. Establishing Tidal Datums

Establishing tidal datums for the United States and its territories is the primary responsibility of NOS. Depending on the location, NOS may already have all the necessary information to ensure that proper tidal datums are utilized for hydrographic surveys. This would include NOS tidal benchmarks in the immediate vicinity of the project site (the tidal characteristics at the project site should be the same as those at the site of the tidal benchmarks) and 1960-1978 epoch and NGVD values (NAVD 88) and descriptions for these marks.

a. Department of Commerce contacts. Before and during the course of any tidal study, close coordination is required with NOS.

b. Sources. If in-house forces are not used, the following outside sources may be utilized to perform a tidal study of a project, including any field tidal observations.

(1) *Architect-Engineer (A-E) contract.* A number of private firms possess capabilities to perform this work. Either a fixed-scope contract or indefinite delivery type (IDT) contract form may be utilized. In some instances, this type of work may be within the scope of existing IDT contracts. Contact NOS to obtain a typical technical specification which may be used in developing a scope of work.

(2) *Reimbursable support agreement.* Tidal studies and datum determinations may be obtained directly from the NOS, Department of Commerce, via a reimbursable support agreement. A cooperative agreement can be configured to include any number of projects within a district. Funds are provided to NOS by standard inter-agency transfer methods and may be broken down to individual projects. Contact the Chief of the Ocean and Lake Levels Division to coordinate and schedule a study agreement.

c. Scheduling of conversions. Section 224 of WRDA 92 did not specify an implementation schedule for converting existing projects to NOS MLLW (or verifying the adequacy of an existing MLLW datum). It is recommended that a tidal datum study be initiated during a project's next major maintenance cycle.

d. If all necessary tidal datum information is not available, one of the following methods may be utilized.

(1) *NGVD/MLLW differential method.* This involves NOS tidal benchmarks in the immediate vicinity (tidal characteristics the same as those at the project site) with 1960-1978 and NGVD elevations and project benchmarks with NGVD elevations. Direct comparison of the existing project datum to the actual NOS tidal datum can be made by computing the NGVD/MLLW differential for the tidal benchmarks and comparing it with the NGVD-project datum differential at the project site. In effect, this is the same as leveling between them. The error in the existing project datum can then be computed and corrected by applying the NGVD/MLLW differential to the project benchmarks.

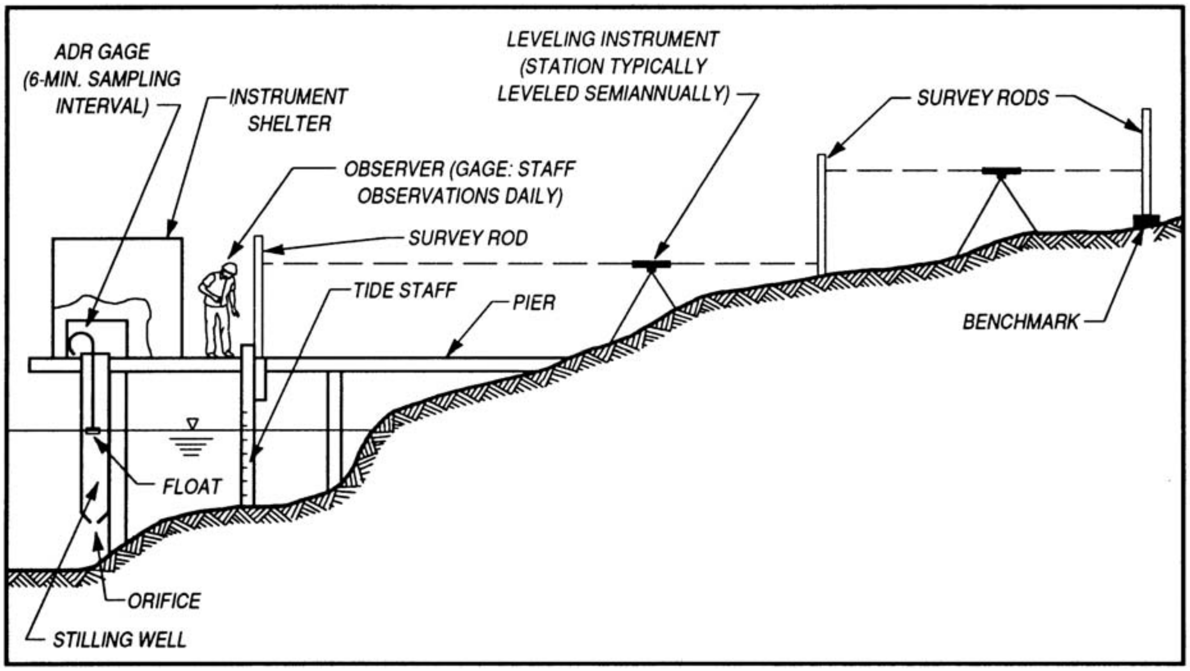


Figure 5-11. Schematic of method of differential leveling

(2) *Leveling and NGVD/MLLW differential method.* This involves the same situation outlined in the first method, except that neither the project datum nor the NOS tidal datum has been related to NGVD. Field leveling (Figure 5-11) is needed to develop the required relationships, after which the differentials, errors, and necessary corrections are computed as discussed above.

(3) *Leveling to a known tidal datum method.* This involves leveling from the project site to a known tidal datum due to the nonavailability of NGVD at either site. Tidal characteristics are assumed to be the same at both sites. If the leveling is too costly, operating tide stations at both sites and performing simultaneous comparison computations to determine the datum at the project site may be more efficient.

(4) *Interpolation method.* This involves interpolation between two existing sites where tidal datums were previously determined. The estuary's tidal characteristics are assumed to be changing at a fairly constant and linear rate, with one previously established tidal datum upstream and another one downstream of the project site. The upstream project site and downstream sites will have to be related to each other by one of the above methods or by transfer through simultaneous staff reading at all three sites. The differentials can then be computed as outlined in the NGVD/MLLW differential method. A linear interpolation can then be performed. Finally, errors in the existing project datum and necessary corrections are computed as outlined in the NGVD/MLLW differential method.

(5) *Operating tide stations method.* This involves situations in which existing tidal datums are not reliable, are too far from the project site, or do not exist. Operation of a tide station is required to establish the datum. Since 19 years of records are required to establish an accurate tidal datum, the principles of comparison of simultaneous observations should be employed to adjust short-term readings to the 19-year equivalent, with several tide stations operated simultaneously. One station should be at the project site (tertiary) and another one at a primary station site. Depending on the geographical relationships and tidal characteristics, a secondary station may also be required. Primary stations operated

throughout the United States by NOS provide the 19 years of continuous readings required. NOS also operates some secondary stations possibly providing the seasonal comparisons required. The operation of tertiary stations on project sites and possible reinstallation and operation of gages at previous secondary sites for simultaneous comparisons will be required. Due to the potential use of the tidal data for marine boundaries and other non-dredging purposes, collection of adequate data for court verification should be considered. This generally requires three months of data at the tertiary station along with data for the same three months at the associated secondary and primary stations. Arrangements should be made for NOS to process the data and determine the tidal datum. A cooperative agreement with NOS may be initiated by contacting the Chief, Ocean and Lake Levels Division.

e. Tidal reference boundaries. Figure 5-12 depicts various jurisdiction zones on the Atlantic Coast. Determination and demarcation of the MHW line is often required for some Corps regulatory permitting activities. Procedures and accuracy standards may vary widely between jurisdictions and/or projects. The processes for performing MHW demarcation surveys are beyond the scope of this manual.

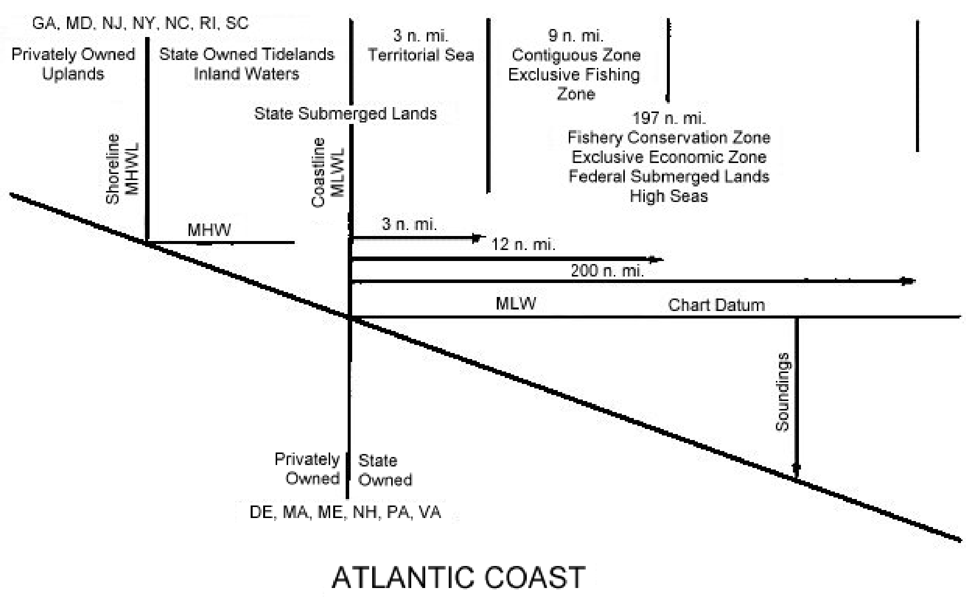


Figure 5-12. Diagram of terminology of tidal datums on Atlantic Coast

5-11. Equipment and Field Work Associated with Operating Tide Stations

To determine a tidal datum at a given site, a true and accurate record of the tide levels and times should be obtained. The length of this record depends upon the local characteristics and other factors previously discussed. The three types of tide stations (primary, secondary, and tertiary) usually require different amounts and types of facilities and services.

a. Structures. The purpose of the structure is to protect the installation. A variety of structures may be used, including buildings, piers, wharves, and pilings in open water. Primary stations usually require buildings; secondary stations may require a small house depending on the location and environment; and tertiary stations can usually be installed on any supporting structure.

Figure 5-13. Primary automatic gage to record tides

b. Gages. The purpose of the gage is to record continuous times and water level heights at the site--Figure 5-13. This is usually an automatic electromechanical type recorder. The only variation in gages from primary to tertiary stations would be that primary stations may have more than one gage and may have additional equipment for telemetering the data to other locations.

c. Float wells. A float well is a stilling well in which the float of a float-actuated gage operates. A stilling well is a vertical pipe with a relatively small opening (intake) in the bottom. It is used in a gage installation to dampen short-period surface waves while freely admitting the tide, other long-period waves, and sea level variations, which can then be measured by a tide gage sensor inside. The well provides a protected place for a float, which is connected to the gage by a wire or cable, to maintain itself at the water's surface for accurate recordings. In general, larger wells of 12 inch diameter with small intakes are used with primary and secondary stations to provide more damping effect for accurate readings. Smaller wells of 4 in. diameter with small intakes are generally used with tertiary stations for ease of installation for shorter periods.

d. Staffs. A tide staff is a tide gage consisting of a vertical graduated staff from which the height of the tide can be read directly. It is called a fixed staff when secured in place so that it cannot be easily removed. A portable staff is one designed for removal from the water when not in use. For such a staff a fixed support is provided. The support has a metal stop secured to it so that the staff will always have the same elevation when installed for use. The staff provides a means for manual observations to verify recordings and serves as a fixed reference for recording water levels and a direct connection to tidal benchmarks. Staff types can vary from an electric tape device to a vitrified or fiberglass staff.

e. Observers. A local tide observer is required to provide a daily manual check to verify recorded data. NOS requires five observations per week in most situations.

f. Reports. Weekly reports are submitted to the district by observers for monitoring purposes. Records can be obtained that document any changes or modifications to the gage or staff for proper data processing and reduction.

g. Leveling. Leveling from the staff or the electric tape to tidal benchmarks is the means of transferring the tidal datums to permanent marks for future use and ensuring staff stability. 3^{rd} order leveling is usually required.

h. Benchmarks. Benchmarks are used as a fixed reference and permanent record of the tidal datums. Benchmarks are established in accordance with the standards set forth in EM 1110-1-1002. In low-lying marshes and beach areas, deep-driven rod-type marks driven to refusal are required.

5-12. Off-Site Tide Observations

These observations usually occur in inlets, offshore entrance channels, and open waters of bays where on-site tide observations are not easily obtained.

a. Errors associated with off-site tide observations are as follows:

(1) Figure 5-14 shows two tide curves of equal range with a 1-hr time offset. The solid line represents the tide at the project site, and the dashed line represents the tide at the observer's site. The tide height at the two sites will coincide only once every 6.2 hr. At all other times, errors will occur at a maximum of 0.6 ft (for the case shown) at the middle of each ebb and flood tide. If the first survey were done on an ebbing tide and the second survey were done on a flooding tide, or vice versa, the error would be doubled, resulting in a total maximum error between surveys of 1.2 ft.

(2) Figure 5-15 shows two tide curves with a 0.5-ft range difference and a 1-hr time offset. The solid line again represents the tide at the project site, and the dashed line represents the tide at the observer's site. It is again shown that the tide heights at the two sites will coincide only once about every 6 hr. At all other times, errors will occur at a maximum of 1.0 ft near the end of a flood tide and at 0.5 ft near the end of an ebb tide. If two surveys were made with the first near the end of an ebb tide and the second near the end of the flood tide, the error would be compounded to a total of 1.5 ft. Note that larger tide ranges or increased time offsets will create even larger errors than those shown here.

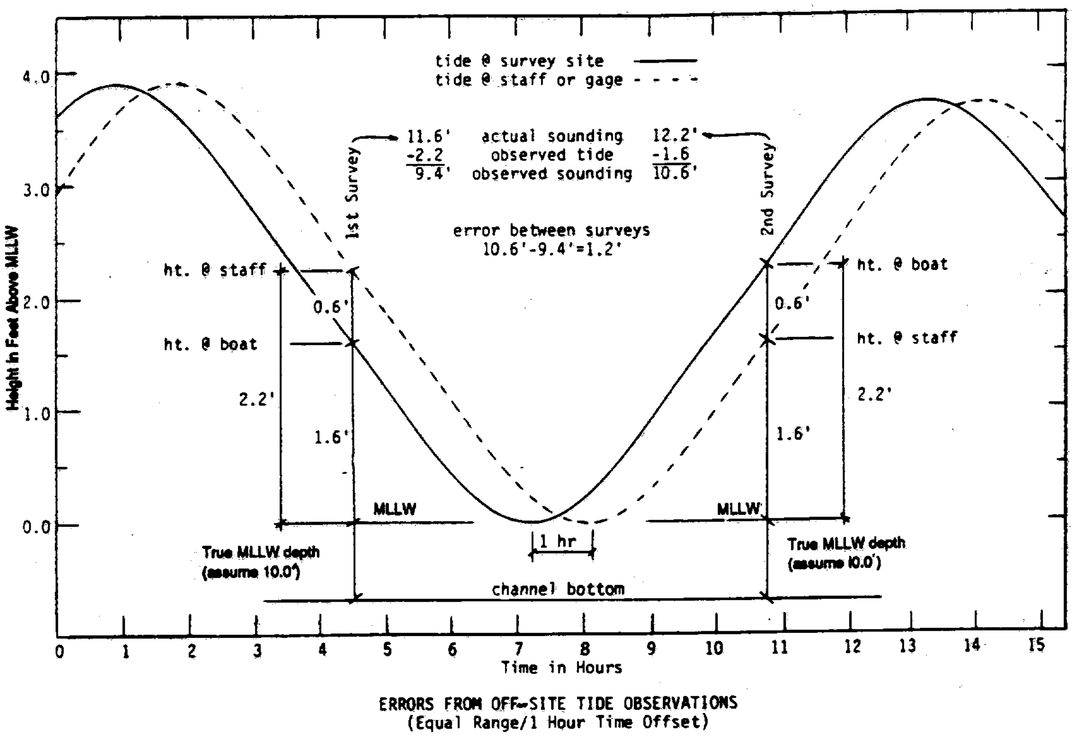


Figure 5-14. Errors from off-site tide observations. (Equal range of tide with 1 hour time offset)

b. Depending on the geographical location and local tidal characteristics, several alternative solutions should be considered to eliminate these errors:

(1) The first would occur where it is possible to surround the site with several tide stations operating simultaneously. Appropriate interpolations could provide accurate on-site tidal data. If all tide stations and the survey and dredge vessels were equipped with telemetering devices, this could be done in real time onboard. Note that the tidal datums should have been determined in advance of the surveying or dredging. Without telemetering devices, the recorded tides could be analyzed and the appropriate interpolations performed with tide correctors computed for use in postprocessing and plotting the hydrographic surveys. The dredge would require real-time information to ensure proper operation.

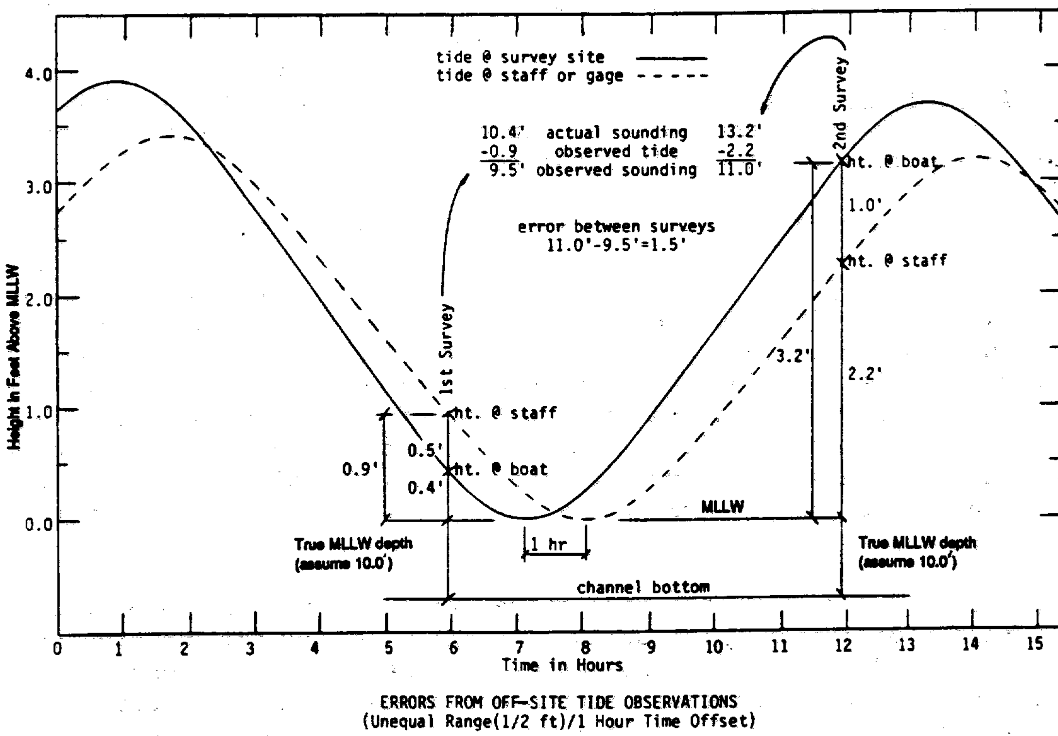


Figure 5-15. Errors from off-site tide observations.
(Unequal range of tide with 0.5 range and 1 hour time offset)

(2) Another approach would be required if the site could not be surrounded by tide stations. In this case, an on-site tide station could be installed on an offshore platform and actual tides recorded. This would require collecting enough reliable data to determine a tidal datum as previously discussed through short-term simultaneous readings and comparisons with secondary and primary control tide stations. Once the datum was established, real-time tides could be telemetered to the survey and dredge vessels or the recorded tides could be used later to postprocess and plot the surveys.

(3) In areas where it is not feasible to maintain an offshore tide station indefinitely, a zoning approach may prove adequate. This would involve operating onshore tide stations simultaneously with the offshore station as outlined above. However, by mathematical modeling or zoning of the tidal regime in the offshore area, the offshore station could be removed and the tides at the offshore site accurately projected from the onshore tide stations, which would continue to operate. Some districts have had limited success with offshore tide gages using either acoustic or pressure sensing devices to determine offshore water elevations. Historical information for zoning models and predicted information from tide tables may be provided by NOS.

c. The key to utilizing offshore tide stations effectively is to collect enough data for a datum determination through the method of comparison of simultaneous observations with secondary and primary control tide stations before the channel design is complete.

5-13. Water Level Reference Planes

The following sections describe some of the low water reference planes used in the Great Lakes and on inland waterway systems.

5-14. International Great Lakes Datums

a. The Great Lakes-St. Lawrence River system area (Figure 5-16). The official datum is now IGLD 85. IGLD 85 was officially established in January 1992, replacing IGLD 55. Districts working with the previous official datum, IGLD 55, were to have moved over from IGLD 55 to IGLD 85 by January 1993. This changeover cannot be accomplished in a practical sense until NOAA publishes the IGLD 85 benchmark data for the area. IGLD 85 data is available for the gages, but the spacing of the gages is not dense enough to support project control. As soon as NOAA data is available for a project area, IGLD 85 should be used for any hydrographic surveys on the Great Lakes.

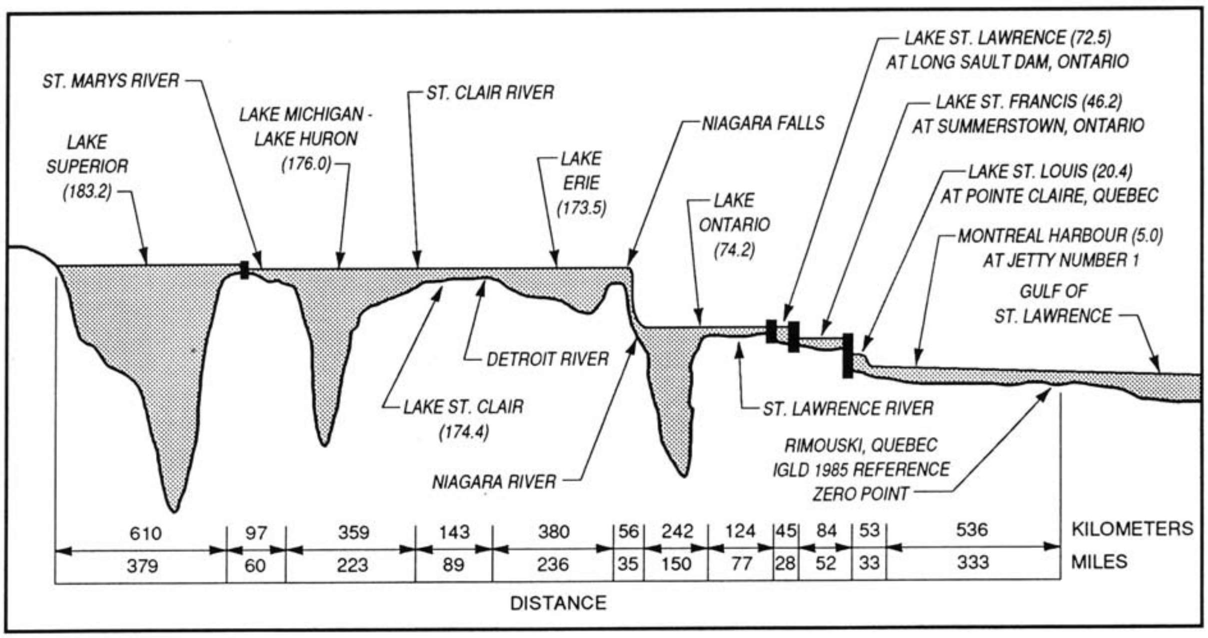


Figure 5-16. IGLD 85 datums for the Great Lakes-St. Lawrence River systems

(1) The earth's crust experiences movements around the entire Great Lakes-St. Lawrence River system area and therefore must be vertically readjusted every 25 to 30 years. This crustal movement is called isostatic rebound, which is the gradual rising of the earth rebounding from the weight of the glaciers during the last glacial age. The reference point for IGLD 55 was Pointe-au-Pere (Father's Point), Québec. When IGLD 55 was created, it was known that readjustment would be necessary due to the effects of isostatic rebound. Crustal movement is not uniform across the Great Lakes basin and causes bench marks to shift not only with respect to each other, but also with respect to the initial reference point. Subsidence and other local effects can cause bench marks to shift as well. In addition to these reasons, new surveying technology and adjustment techniques made the time ripe to revise the datum.

(2) The Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data revised the IGLD 55 datum and established IGLD 85. This committee has input to the international management of the Great Lakes-St. Lawrence River system. Representatives from the U.S. and Canada are members on this committee. The efforts of the Coordinating Committee to revise IGLD 55 and establish IGLD 85 were coordinated with the efforts to establish the new common international vertical datum for the U.S., Canada, and Mexico, NAVD 88. 1985 is the central year of the period during which water level information was collected for the datum revision (1982-1988). The reference zero point for IGLD 85 is located at benchmark #1250G, at Rimouski, Québec--see Figure 5-16. This benchmark has an IGLD 85 elevation of 6.723 m and IGLD 55 elevation of 6.263 m. IGLD 85 increases the number and accuracy of

benchmarks in the Great Lakes area. Agencies within both the U.S. and Canada will use IGLD 85. NOS and the Canadian Hydrographic Service (CHS) began reporting water levels referenced to IGLD 85 upon its implementation in January 1992. For a period of time, conversion factors for both IGLD 55 and IGLD 85 water level data will be provided by NOAA/NOS Great Lakes Section and CHS. The monthly water level bulletins published by USACE and CHS will reflect this information.

(3) IGLD 85 will not change water levels established for federal flood insurance programs in the U.S. These levels are referred to NAVD 88. Elevations common to both NAVD 88 and IGLD 85 are available from NOAA/NOS Great Lakes Section and NGS Vertical Network Branch. Lake-level outflows will not be affected by the datum change to IGLD 85. As benchmark information becomes available, navigation, construction, and other improvement work on the Great Lakes should be referred to IGLD 85. Either datum is acceptable until the benchmark data is available for the respective USACE district. Drawings should include a note for the vertical IGLD datum in use to avoid blunders.

(4) USACE permit applications will still be referenced to the Ordinary High Water Mark (OHWM) as defined under Section 10 of the Rivers and Harbors Act. As benchmark information becomes available, new applications should reference IGLD 85.

b. Each of the Great Lakes has an independent low water reference plane, or chart datum. The elevations of these planes of reference on IGLD 85 are shown in Figures 5-16 and 5-17.

c. Low water datums are also established at points along the connecting channels where surface gradients occur. Improvements to navigation projects (including surveys) within these areas are performed relative to the low water datum for a particular reach of a river. Surveys performed within any section of a connecting waterway must be appropriately corrected for these datum gradients (Figure 5-17).

GREAT LAKES, CONNECTING CHANNELS AND ST. LAWRENCE RIVER WATER LEVELS AND DEPTHS

Department of the Army, Detroit District Corps of Engineers

The present and expected water levels on the Great Lakes, Connecting Channels and the St. Lawrence River, as well as the period-of-record average levels for the Great Lakes, are given in **Inches** above (+) or below (−) Low Water Datum (LWD). Low Water Datum is a plane of reference used on a navigation chart. It is also known as Chart Datum. The Low Water Datums for each location below, are given in feet on International Great Lakes Datum, 1955.

Indicator Points		Period-of-record* Average Levels 20 JAN	Present Levels 20 JAN 90	Period-of-record* Average Levels 5 FEB	Expected Levels 5 FEB 90	Low Water Datum
	GREAT LAKES					
	Lake Ontario	+ 15"	+ 14"	+ 16"	+ 13"	242.80
	Lake Erie	+ 16	+ 18	+ 16	+ 18	568.60
	Lake St. Clair	+ 13	+ 12	+ 10	+ 10	571.70
	Lakes Michigan-Huron	+ 13	+ 4	+ 13	+ 3	576.80
	Lake Superior	+ 4	− 3	+ 3	− 4	600.00
	ST. LAWRENCE RIVER					
0	Above Long Sault Dam		+ 1		− 4	237.50
1	Above Iroquois Dam		+ 19		+ 16	239.90
2	Ogdensburg		+ 11		+ 10	242.20
2½	Alexandria Bay		+ 12		+ 12	242.60
3	Head of River at Cape Vincent		+ 14		+ 13	242.80
	DETROIT RIVER					
4	Lake Erie at Pelee Passage		+ 18		+ 18	568.60
5	Mouth of River at Gibraltar		+ 16		+ 16	568.77
6	Head of River above Belle Isle		+ 12		+ 11	571.47
	ST. CLAIR RIVER					
7	Mouth of River at St. Clair Flats		+ 12		+ 10	571.70
8	Algonac		+ 9		+ 8	572.50
9	St. Clair		+ 7		+ 6	574.04
10	Blue Water Bridge		+ 5		+ 4	576.25
11	Head of River at Fort Gratiot		+ 4		+ 3	576.50
12	Lake Huron Approach Channel		+ 4		+ 3	576.50
	ST. MARYS RIVER					
13	Mouth of River at Detour		+ 4		+ 3	576.80
14	West and Middle Neebish		+ 7		+ 7	577.00
15	Head of Little Rapids		+ 12		+ 11	577.60
16	Below Locks		+ 14		+ 14	577.80
17	Above Locks		0		0	599.50
18	Head of River at Point Iroquois		− 3		− 4	600.00

Available water depth is determined for a location by adding (if+) or subtracting (if−) the amount from the above table to the appropriate channel depth shown in the profile on the backside of this table or to the water depths shown on National Oceanic and Atmospheric Administration (NOAA) navigational charts.

CAUTION: Depths so determined are representative of a still water surface elevation, disturbed by neither wind nor other causes. Depths, however, may be reduced or increased as much as several feet for short periods of time due to these disturbances, or when sections of channels develop shoals. Vessel masters should refer to "Local Notice to Mariners" for extent of shoaling and scattered bedrock projections in all channels.

Figure 5-17. Reference datums for connecting channel in the Great Lakes

d. Geopotential numbers for individual benchmarks are the same in both the NAVD 88 and the IGLD 85. A difference between IGLD 85 and NAVD 88 is that the IGLD 85 benchmark values are given as dynamic heights and the NAVD 88 values are given in Helmert orthometric heights. Dynamic heights show potential energy of a system, whereas orthometric heights are the result of geopotential number (energy surface) divided by local gravity. The dynamic height for the same point on IGLD 85 and IGLD 55 can vary between 1 cm and 40 cm. Orthometric elevations from differential leveling will not yield dynamic elevations. The differences between the two datums (e.g., IGLD 55 and NGVD 29) have been determined from differential leveling and long-term stage observations. These differences are published where stage observations have been made. For example, on Lake Erie (IGLD 55 = 563.6 ft), differences between NGVD 29 and IGLD 55 are (-) 1.57 ft at Cleveland, OH, (-) 1.45 ft at Toledo, OH, and (-) 1.29 ft at Buffalo, NY. To establish a reference datum at any point from a NGVD 29 benchmark elevation requires application of the NGVD 29-IGLD 55 conversion for that area, including any required interpolations between reference points.

e. Other local reference planes have been established by local jurisdictions (Table 5-2). These local reference planes can be related to either IGLD 85 or NAVD 88. If the data is not available to refer to IGLD 85, then IGLD 55 may be referred to; if the data is not available to refer to NAVD 88 then NGVD 29 may be referred to. The relationship between the various datums should be clearly indicated on all drawings or plots of surveys performed in such areas.

Table 5-2.
Local Datum Reference Elevations

Area	IGLD (1955) Elevation (feet)
Chicago city datum plane	578.18
Cleveland city datum plane	573.27
Buffalo city datum plane	574.28
Milwaukee city datum plane	579.30

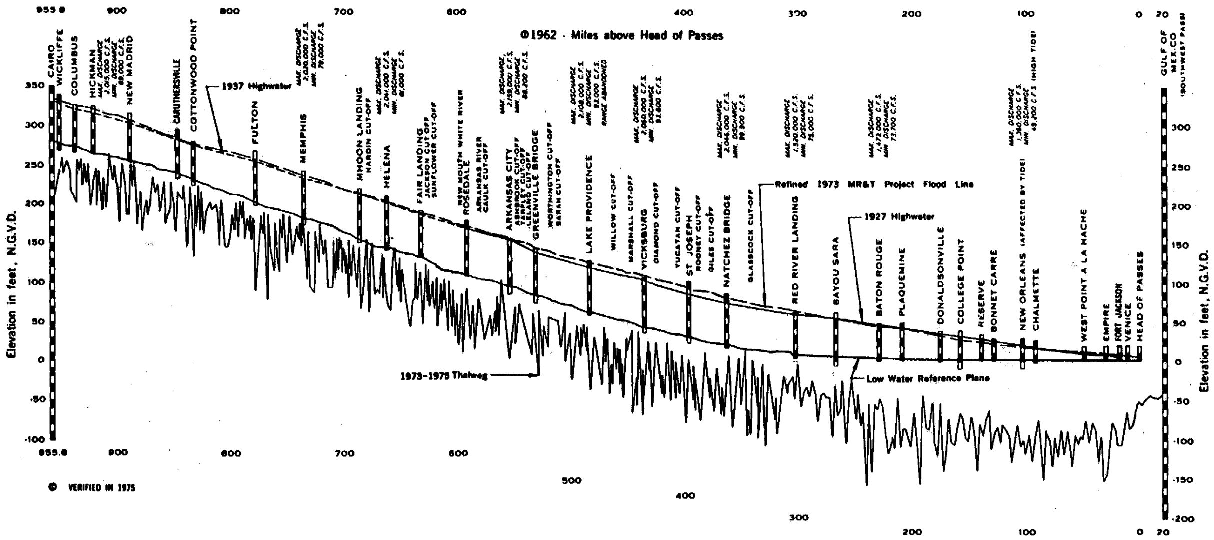
For example, at Chicago, the difference between IGLD 55 on Lake Michigan and the Chicago City Datum Plane is:

IGLD 55 Lake Michigan:		576.80 feet
Chicago city datum	-	<u>578.18</u> feet
Difference	(-)	1.38 feet

In other words, an IGLD 55 Lake Michigan elevation adjusted relative to the Chicago city datum would decrease 1.38 ft. Differences between all points in an area may not be constant. Velocity head, pressure head, and vertical adjustment residuals are factors.

5-15. Low Water Reference Planes (LWRP) -- Middle and Lower Mississippi River

On the Mississippi River, between the mouths of the Missouri and the Ohio Rivers (the Middle Mississippi River), depths and improvements are referenced to a LWRP. No specific LWRP year is used for the Middle Mississippi north of Cairo, IL. Below Cairo, IL, depths and improvements along the Mississippi River are referenced to the 1974 LWRP--see Figure 5-18--and most recently, the 1993 LWRP. These hydraulic-based reference planes were established from long-term observations of the river's stage, discharge rates, and flow duration periods developed about the 97-percent flow duration line. The elevation of the LWRP drops gradually throughout the course of the Mississippi; however, some anomalies in the profile are present in places (particularly in areas containing a rock bottom). The gradient is approximately 0.5 ft per river mile. The ever-changing river bottom will influence the LWRP. Changes in the stage-discharge relationship will influence the theoretical flow line for the LWRP.



PROFILE CAIRO, ILL., TO GULF OF MEXICO
VIA
SOUTHWEST PASS, MISSISSIPPI RIVER

PREPARED UNDER THE DIRECTION OF
PRESIDENT, MISSISSIPPI RIVER COMMISSION
VICKSBURG, MISS.

GAGE	⊕1962 MILES A.H.P.	GAGE ZERO	GAGE READING - FT.			
		FT. NGVD	HIGHEST	LOWEST	BANKFULL	* LWRP
CAIRO, ILL. (OHIO RIVER)	953.8	270.47	59.51	−1.0	44	9.6
WICKLIFFE, KY. (A)	951.5	269.12	58.18	4.95	42	10.2
COLUMBUS, KY.	937.2	266.38	54.54	0.05	43	7.8
HICKMAN, KY. (B)	922.0	264.73	51.5	−0.4	37	3.4
NEW MADRID, MO.	889.0	255.40	47.97	−0.60	40	2.7
CARUTHERSVILLE, MO.	846.4	235.49	46.0	−0.72	35	4.0
COTTONWOOD POINT, MO.	832.7	230.18	44.4	−3.9	36	3.1
FULTON, TENN.	770.2	208.61	47.25	−7.7	34	−3.1
MEMPHIS, TENN.	734.7	183.91	48.7	−5.35	34	−2.6
MHOON LANDING, MISS.	687.5	161.22	53.2	−0.85	35	−3.9
HELENA, ARK.	663.0	141.70	60.21	−3.0	41	4.1
FAIR LANDING, ARK. (C)	632.5	132.20	55.6	−4.8	40	−0.9
ROSEDALE, MISS.	592.2	100.73	50.4	−2.05	44	3.0
ARKANSAS CITY, ARK.	554.1	96.66	59.2	−5.3	44	0.2
GREENVILLE (BRIDGE), MISS. (D)	531.5	74.92	58.2	6.7	48	11.3
LAKE PROVIDENCE, LA.	487.2	69.71	50.7	−7.7	37	
VICKSBURG (CANAL), MISS.	437.6	46.25	58.4	−6.8	42	—
VICKSBURG, MISS.	435.7	46.23	53.24	−7.0	43	0.1
ST. JOSEPH, LA.	396.4	33.12	55.3	−10.7	40	0.0
NATCHEZ, MISS.	363.3	17.28	58.04	−2.7	48	6.1
RED RIVER LANDING, LA.	302.4	0.00	60.94	2.89	46	10.6
BAYOU SARA, LA.	265.4	0.00	55.46	0.96	36	5.25
BATON ROUGE, LA.	228.4	0.00	47.28	−0.07	29	2.57
PLAQUEMINE, LA.	208.8	0.00	43.04	−0.9	25	1.7
DONALDSONVILLE, LA.	175.4	0.00	36.01	−0.39	23	1.33
COLLEGE POINT, LA.	157.4	0.00	32.32	−0.6	17	1.06
RESERVE, LA. (B)	138.7	0.00	26.0	−0.1	15	0.70
BONNET CARRE, LA. (C)	128.0	0.00	23.79	−0.62	14	0.68
NEW ORLEANS, LA.	102.8	0.00	21.27	−1.6	11	0.48
CHALMETTE, LA.	91.0	0.00	17.58	−0.52	8	0.08
WEST POINTE A LA HACHE, LA.	48.7	0.00	15.25	−1.06	3	0.06
EMPIRE, LA. (G)	29.5	0.00	10.92	−0.74	1	−0.21
FORT JACKSON, LA.	18.6	0.00	14.3	−2.67	2	−0.40
VENICE, LA. (F)	10.7	0.00	9.11	−0.73	1	−0.36
HEAD OF PASSES LA. (E)	−0.6	0.00	12.03	−0.85	1	−0.36

Figure 5-18. Profile of Lower Mississippi River 1974 low water reference plane

a. Construction and improvements along the river are performed relative to the LWRP at a particular point. Differences in LWRP elevations between successive points along the river are determined from simultaneous staff readings and are referenced to benchmarks along the bank. The LWRP slope gradients between any two points must be corrected by linear interpolation of the profile. Thus, over a typical 1-mile-long section of river with a 0.5-ft gradient, each 1,000-ft O/C river cross section will have a different LWRP correction, each dropping successively at 0.1-ft increments.

b. From 1993 on, NAVD 88 should be used as the common reference plane from which LWRP elevations are measured, if possible. The relationship of all project datums to both NGVD 29 and NAVD 88 will be clearly noted on all drawings, charts, maps, and elevation data files. All initial surveys should be referenced to both NAVD 88 and NGVD 29. If this is not possible then NGVD 29 should be used as the common reference plane from which LWRP elevations are measured until the move to NAVD 88 can be made. Differences between the LWRP and NGVD 29 are published for the reference benchmarks used to control surveys and construction activities. In some FOAs, surveys are performed directly on NGVD 29 without regard to the LWRP profile (elevations above NGVD 29 are plotted rather than depths). The LWRP depths are then contoured from the plotted NGVD 29 elevations, with the LWRP profile gradients applied during the contouring process.

c. If a survey is conducted over a given reach of the river, the LWRP-NAVD 88 and/or the LWRP-NGVD 29 conversion must be interpolated based on the slope profile over that reach. For example:

@ River Mile 736.0: LWRP = 181.5 NGVD 29

@ River Mile 736.4: LWRP = 182.2 NGVD 29

The 0.7-ft drop in 0.4 mile is linearly interpolated for any river cross section run within this 0.4-mile stretch, i.e., a river cross section at mile 736.2 would use a 181.85-ft conversion from NGVD 29 to LWRP.

5-16. Other Inland Water Reference Systems

Controlled portions of the Mississippi are referred to pool levels between the controlling structures. Although a variety of reference datums are used on other controlled river systems or impoundment reservoirs, most are hydraulically based and relate to some statistical pool level (e.g., "normal pool level," "flat pool level," "minimum regulated pool level," etc.).

a. On the Mississippi River above Melvin Price Locks and Dam at Alton, IL, to Lock and Dam No. 22 at Saverton, MO, (Figure 5-19) the reference used is related to the minimum regulated pool elevation. These pools are regulated referenced to a "hinge point." The pools are drawn down when the river's flow will provide adequate navigation depths naturally. When the flows are reduced to low volumes, the pools are reestablished and are essentially level. The depths and improvements along this reach of the Mississippi River are referenced to the "minimum regulated pool" elevations.

b. On the Mississippi River above Lock and Dam No. 22 at Saverton, MO, to St. Paul, MN, a "flat pool level" reference is used, and soundings are shown as "depth below flat pool." The flat pool is the authorized elevation of the navigation project and can be referenced to any number of local datums. Most commonly, this level is referenced to the mean sea level (MSL) datum of 1912, the general adjustment which preceded 1929. Conversions between MSL 1912 and NGVD 29 are available. The Illinois Waterway pool elevations (Figure 5-20) are referred to NGVD 29; however, relationships to numerous other datums are also made.

c. Vertical clearances (bridges, transmission lines, etc.) are usually measured relative to high and low waters of record, or relative to full pool elevations. Shore lines shown on river drawings and navigation maps may be referenced to a low water datum (i.e., LWRP). On the Mississippi River above Lock and Dam No. 22 at Saverton, MO, the plotted shore line is referenced to full pool stage at dams with discharges equaled or exceeded 90 percent of the time. Given the variety of reference levels, special care must be taken to properly identify the nature and source of all vertical reference datums used on a project.

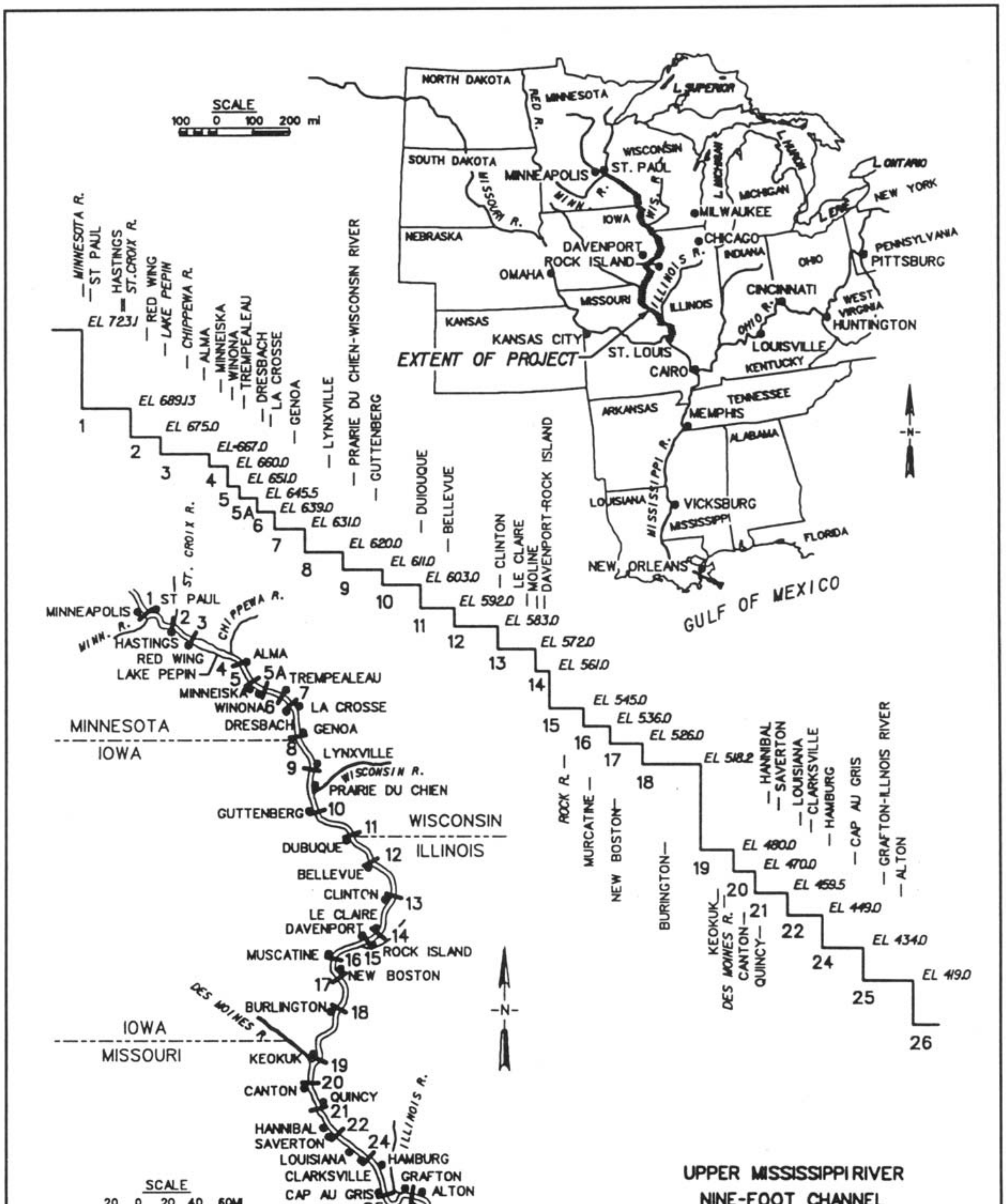


Figure 5-19. Upper Mississippi River reference systems

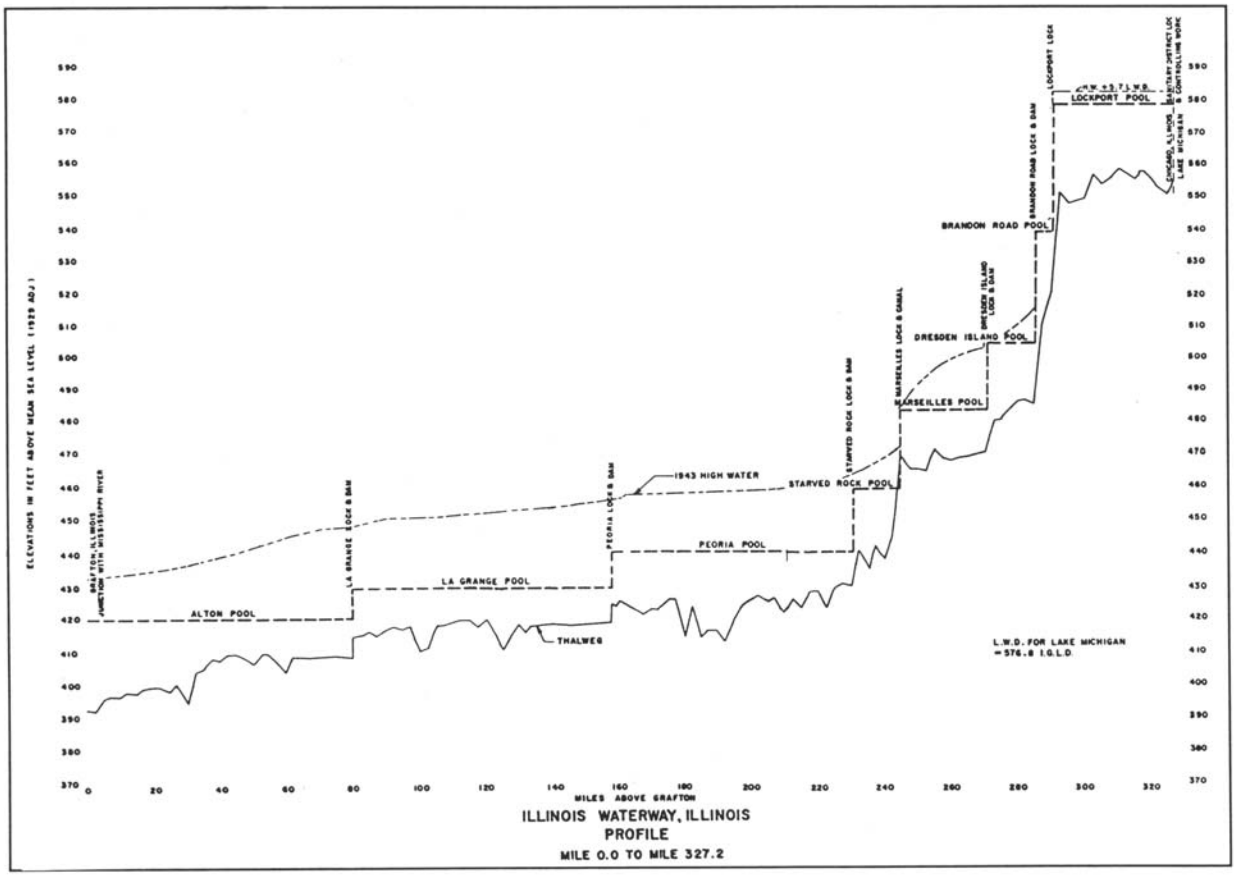


Figure 5-20. Illinois Waterway Profiles -- Mile 0.0 to Mile 327.2

5-17. Tides and Water Level Stage Measurement Systems--Reference Gage Location

Criteria for each survey class are given in Table 5-4. The vertical reference benchmark and/or staff should be located as close to the work area as possible to minimize the effects of tidal phase lags and range differences (or river slopes) which may exist between the staff site and the project area. The possibility of a wind setup may be minimized by working during low wind velocity conditions (less than 15 knots). The staff should be located on the same body of water as the project area (e.g., do not observe tides on intracoastal waterways for work offshore). The same benchmark/staff should be used for all surveys associated with a project. Vicinity sketches should be maintained in project records indicating the precise gage location in relation to surrounding features. To assist in reestablishment of the datums used, a minimum of three tidal benchmarks should be set or chosen within 500 ft of the gage and, by leveling, their elevation above the tide datum determined. Descriptions of each benchmark are to be written in accordance with EM 1110-1-1002.

5-18. Tidal Zoning

Tidal zoning is the practice of dividing a hydrographic survey area into discrete zones or sections, each one possessing similar tidal characteristics. One set of tide reducers is assigned to each zone. Tide reducers are used to adjust the soundings in that zone to chart datum (MLLW). Tidal zoning is necessary to correct for differing water level heights occurring throughout the survey area at any given time. Each zone of the survey is geographically delineated such that the differences in time and range do not exceed certain limits, generally 0.2 hr and 0.2 ft respectively; however, these limits could change depending upon the type of survey, location, and tidal characteristics. The tide reducers are derived from the water levels recorded at an appropriate tide station, usually nearby. Tide reducers are used to correct the soundings throughout the hydrographic survey area to a common, uniform, uninterrupted chart datum. On large bays, tide gage zoning should be used to find the correct water elevation at the vessel. Tidal zonings, as developed by the NOS, are used where there is a difference in water level slope and/or time of tidal phase between the tide gage and survey sites. For many surveying requirements in these areas, it is impractical and cost-prohibitive to actively maintain tide gages close to the survey site, making the use of tidal zonings advantageous. Figure 5-21 shows a tidal zoning model for Chesapeake Bay. Table 5-3 lists corrections for the model at the Cape Henry Channel location relative to the southern-most tide gage on the southerly end of the Chesapeake Bay Bridge Tunnel. Note that all the time corrections are negative. This is because the entire Cape Henry Channel is east of the gage toward the Atlantic Ocean.

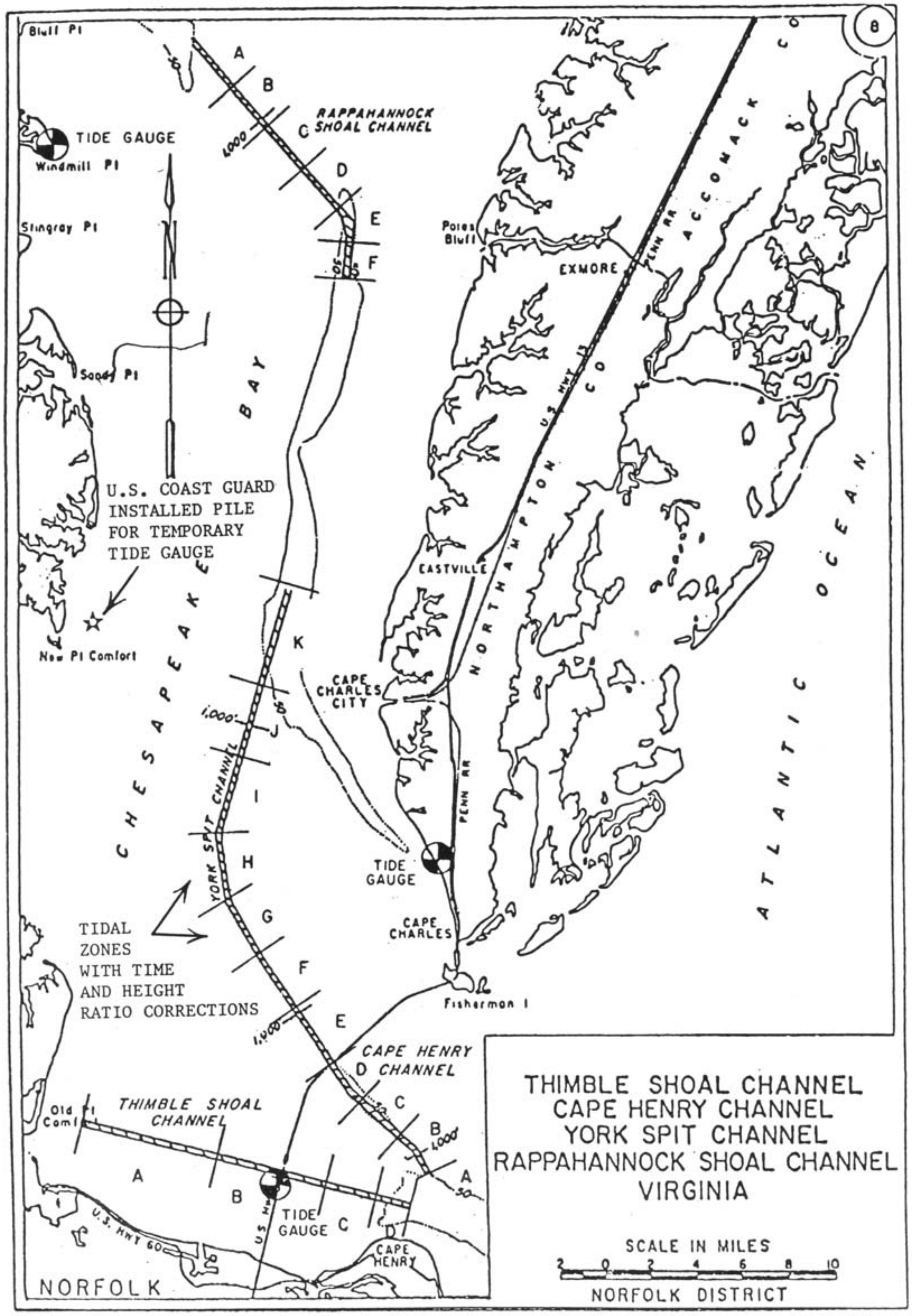


Figure 5-21. Chesapeake Bay tidal zones

Table 5-3. Cape Henry Channel Tidal Zoning
Tide Correction Factors Based on Chesapeake Bay Bridge Tunnel Gage
10 July 1991

Zones	Station to Station	Time of Occurrence	Height Ratio
A	-20+00 to +20+00	-23 min high water -17 min mean -11 min low water	x 1.21
B	+21+01 to +133+00	-17 min high water -13 min mean -09 min low water	x 1.15
C	+133+01 to +239+73	-11 min high water -9.5 min mean -08 min low water	x 1.08
D	+239+74 to +332+86	Direct on CBBT gage " "	N/A

Example of tidal zoning correction for tidal zone B:

Channel Station 100+00 **Time 1000 EST**

Tide stage occurs 13 minutes (on average) later at CBBT tide gage … i.e., 1013 EST

Gage reading at 1013 EST:	**+2.00 ft above MLLW**
height ratio:	**x1.15**
Gage reading corrected for time and height to be applies to the 1000 EST sounding	**+ 2.30 ft above MLLW**

Table 5-4.
Tides and Water Levels Measurement Criteria

Criteria	Minimum Standard per Survey Class		
	Hard Material	Soft Material	Other Surveys
Gage/Staff Location (1)	On-Site	On-Site	Near-Site
Tidal Zoning Requirements	Determine on Case-by-Case Basis		Not Required
Gage Reading Frequency	As needed for 0.1-ft surface change		
Leveling Frequency -- Gage to Benchmarks (3rd Order Levels -- 2 BM's Required) per Project	Start & Finish of Project		Project Start Only
Start/Finish Difference in Gage Reference Elevation	0.05 ft	0.1 ft	n/a
Staff Marking Intervals	0.1 ft		
Least Count of Readings	0.1 ft		
Stilling Wells Required if Sea States Exceed	0.5 ft	1.0 ft	2.0 ft

(1) An on-site gage for "Hard Material" is defined as a location relative to the project area such that not more than a 0.1-ft surface gradient exists between the two sites. Slopes of 0.3 and 0.8 ft are allowable for "Soft Material" and "Other Survey" gages, respectively. Tidal or surface gradient zoning is required if these criteria cannot be met.

5-19. Gage Reading Intervals

During the course of a survey, gage readings shall be recorded in either standard field books, forms, or automated printouts--see Figure 5-22.

a. Tidal. For each survey class, gage readings will be taken at intervals equal to or shorter than those indicated. Readings at proper intervals will ensure a correct determination of the actual tidal curve. Because certain reduction computations use only high and low readings, care should be taken near the time of high or low water to take accurate readings.

b. Inland. The slope or gradient of the water surface along inland streams and rivers is constantly varying. Water surface determinations should be made daily at 1-mile intervals or less. For more critical navigation and dredging surveys, determinations shall be made a minimum of twice daily at intervals not exceeding 0.5 mile, except near major stabilization or improvement structures where water surface determination should be made immediately upstream and downstream of the structure. The water surface should be computed for each section by a method similar to that previously described.

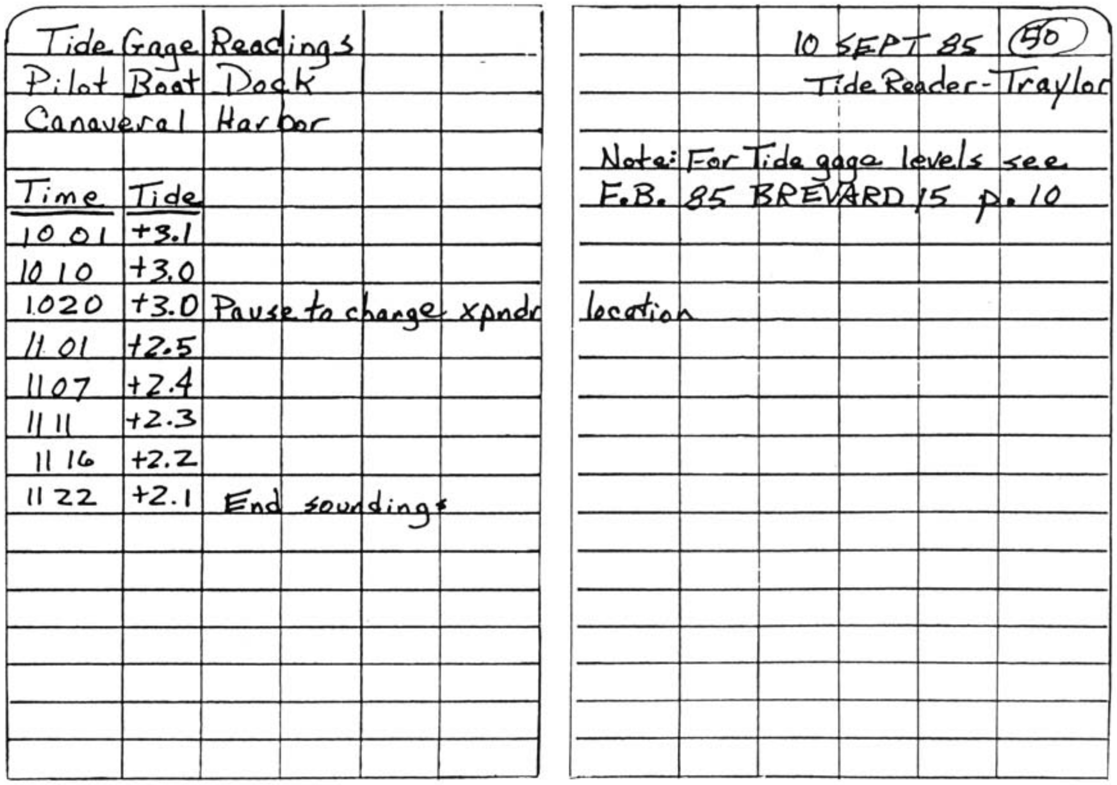


Figure 5-22. Tide gage/staff readings recorded in a surveyor's field book

5-20. Leveling Frequency

On major coastal projects, leveling from at least two tidal benchmarks to the gage (or staff) should be performed at the beginning and end of a project. USACE 3rd order standards should be followed for all differential leveling work. The tidal benchmarks which reference the tide staff should be connected with at least two firmly established benchmarks, preferably USC&GS/NOS marks, on NAVD 88 where possible and NGVD 29 where the appropriate data for NAVD 88 is not available. This is critical since the entire project will be referenced to the established datum at that point. Any oddities or anomalies in the vertical datum should be investigated. All subsequent surveys should utilize the same benchmark. When temporary staffs are set for short duration surveys, they should be periodically checked for movement, especially if the staff is situated in an unstable location. A temporary benchmark (TBM) should be set adjacent to the gage/staff to facilitate this checking process. On stable river surfaces, lakes, or reservoirs, the surface elevation may be obtained from a level rod shot to the surface each day. In such stable mediums, a staff or gage would not be necessary. Staffs or water level/tide gages may be set to directly read on the local low water reference datum, project datum, or at any arbitrary level (Figure 5-23). Setting staffs/gages to read directly on the local datum helps to preclude conversion blunders.

5-21. Start/Finish Difference in Gage Elevation

Gage leveling should be performed before and after a payment survey project, and the measured gage elevation should be within prescribed limits to ensure that the gage has not been disturbed or settled.

5-22. Staff Markings/Least Count of Readings

All gages/staffs are to be marked to 0.1 ft, and readings are to be expressed to the nearest 0.1 ft. This precision will ensure the required accuracy in reduction computations. However, if prevailing conditions permit reading to 0.01 ft, this should be done to improve accuracy. Unit markings will be dependent on whether the gage is set to an absolute or reference datum.

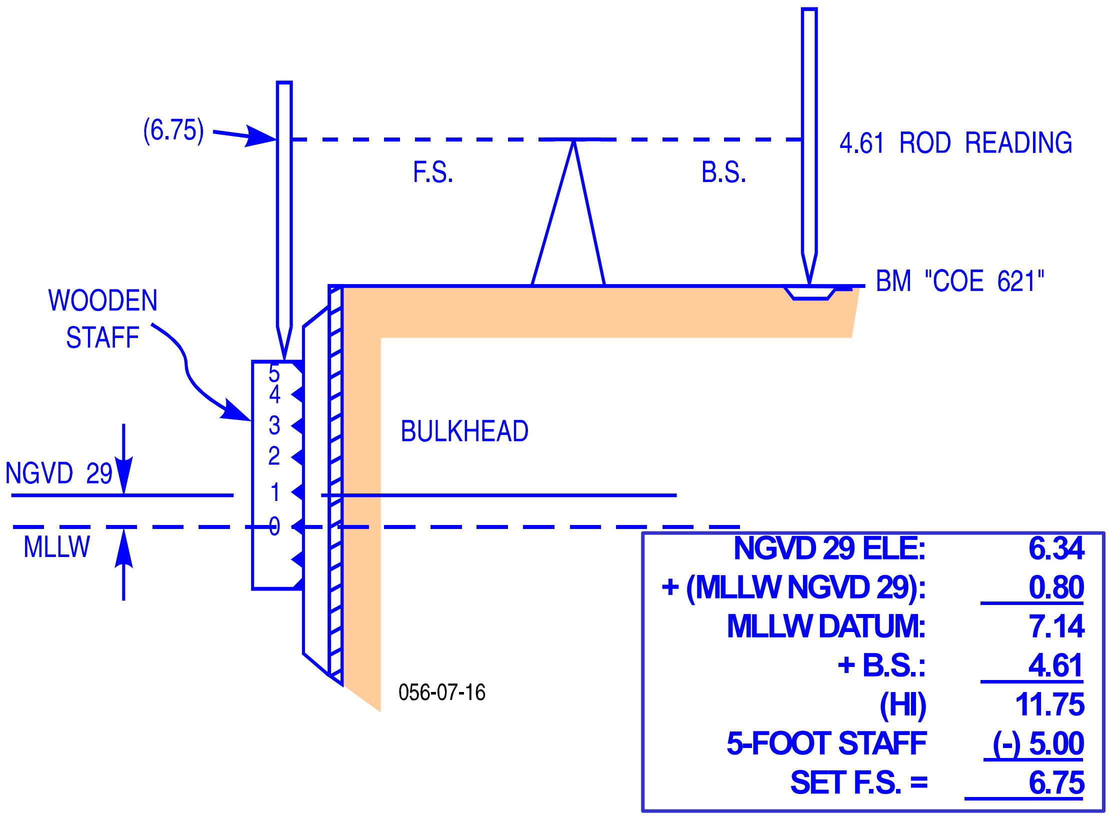


Figure 5-23. Procedure for setting a staff gage relative to a construction datum plane

5-23. Stilling Procedures

Water surface fluctuations at a gage should be stilled so that the maximum range of water rise and fall with one wave passage is negligible. Stilling well construction ranges from the very simple Plexiglas tube to a more complex float system in a PVC tube. Electronic filters are also used to still the surface fluctuations. The orifice for water entry should be located near the well's bottom and at least three multiples of wave height below the surface . The opening's size should be regulated to permit adequate movement of water into or out of the well for long-term tide changes but to prohibit a significant water exchange during passage of a wave crest or trough. On some offshore gages, the stilling well itself is used to support the gage platform.

5-24. Mandatory Requirements

The criteria in Table 5-1 and Table 5-4, including supplemental explanatory paragraphs, are considered mandatory.

Chapter 6
Planning and Processing Surveys for Civil Works Projects

6-1. General Scope

Providing quality hydrographic data on dredging, navigation, and flood control projects requires careful planning and evaluation of all phases of the process. Those process considerations include: basic identification of areas to be surveyed and the conditions under which they will be surveyed, use of in-house hired labor or Architect-Engineer (A-E) service contract forces, dredging performance and time constraints, the most appropriate equipment to collect the data, data density requirements, development of a general survey plan and subsequent site specific survey plans, data processing, data presentation, and data archival and retrieval. Other general factors to be considered might include geodetic survey methods, hydrographic survey methods, computer systems design, acceptable vessel modifications, safe vessel operation, and regional knowledge of survey conditions. This chapter will discuss these items. The chapter is divided into four sections:

Section I: General Guidance in Performing Hydrographic Surveys for Engineering and Construction

Section II: Planning Survey Coverage

Section III: Data Processing, Editing, and Plotting Options

Section IV: USACE Standards for Survey Coverage, Processing, and Plotting

6-2. General Planning Considerations

A variety of resource options are available for ordering or procuring hydrographic surveys of USACE projects. These surveys may be obtained from either in-house (hired labor) forces or contracted forces. Contracted forces include A-E contractors or construction contractors--usually dredging firms. A-E contractors may be either specialized surveying firms or design firms with in-house or subcontracted surveying capabilities. The project engineer/manager must weigh the costs and benefits of these different source options. Although data quality is the most important consideration, cost often becomes a primary planning criteria. Some of the more critical factors are discussed below.

a. Project funding. Often only limited project or study funds are available for site plan mapping or surveying. Funding limits will often dictate the scope of work, often restricting the data density that can be collected and resultant data quality. Limited funds often necessitate a search for the most economical survey force. Survey costs can vary widely between in-house crews and between A-E contractors. Often geography, or mobilization distance to the project site, is a major factor. However, there are many other factors that can cause large cost differences between crews. Over-capability is one factor; e.g., using multibeam-equipped vessel with a 5-man crew to run single-line beach profiles that could be performed more efficiently by a 2-man topographic survey team. Obtaining optimum cost services may require comparisons between in-house and contracted survey forces, or even comparisons of capabilities and costs between survey crews.

b. Response time. Project or study milestones may put receipt of survey data on a critical path. In-house or A-E contractors may have varying response capabilities that should be evaluated if rapid delivery of survey information is critical. Most field hydrographic survey crews have (or should have at this time) a "field-finish" capability. This means that a fully edited and processed survey can be delivered from the field--in MicroStation or AutoCad format--usually on the same day the survey is performed. When critical project milestones are dependent on site plan data, project engineers should expect a rapid response to a data request--including expedited "field-finish" deliverables. Ordering or procuring such service may often take longer than performing the work. In-house forces may not be immediately available. A-E contracting task orders can take from 2 to 6 weeks to process, depending on the command. Not all districts maintain A-E labor-hour contracts that allow immediate response. Alternative rapid response options include verbal notices to proceed by the Contracting Officer or credit card purchase of services. Dredging projects have strictly mandated deliverable milestones--see chapter on dredging support surveys for details. These time standards will often dictate whether in-house or contracted forces will be used to perform dredge measurement and payment surveys, based on response capabilities.

c. Project scope and location. Many dredging payment surveys are relatively small projects, typically less than one-day effort with current surveying technology. Thus, it is not uncommon for mobilization and demobilization time to far exceed the actual survey time. This is especially true if the survey crew has a long travel distance to the work site. Small-scope survey projects always cost more per unit than large efforts, due to mobilization and general overhead costs, among other factors. To reduce costs, it is always desirable to bundle geographically close projects under one order. When this is not feasible, then the most capable survey crew nearest the work site should be located.

d. Survey performance and productivity capabilities. The survey crew selected for a project must be capable of performing the work in accordance with the required accuracy and quality specifications, such as those in this manual. All in-house or contract survey forces have varying hydrographic surveying capabilities. These variations could involve equipment and/or personnel. Experience and capability must be demonstrated based on past performance. Assessing such capabilities is difficult and time consuming for a study/project manager--he must rely on the advise of someone familiar with the individual survey crews (in-house or A-E). Survey crews with updated technology and equipment is another indicator of performance capability. It is also a good productivity indicator. An example of productivity increases for a typical project is shown in Table 6-1. The table indicates that survey productivity has increased by a factor of about 75 times since the 1960s and about 10 times since 1993. This later increase is primarily due to implementation of DGPS positioning. However, the data density, accuracy, and quality have also significantly increased since 1993 (and especially since 1973) given that a full-bottom coverage (multibeam) survey was obtained on the latest survey. This table also illustrates that a 3-man survey crew today equals the output productivity of three to five crews in 1993.

Table 6-1. Annual Project Condition Survey--Tampa Harbor 43-Foot Project
Gulf of Mexico to Port of Tampa
Field Survey Time Required to Perform Survey

Year	Positioning	Coverage	Crew-Days	Man-Days
to 1973	Visual (tag line)	200 ft O/C	360	1800
to 1993	Microwave	100 ft O/C	40	280
to Date	DGPS	100 % (Multibeam)	8	24 [1]

[1] EMC, Inc (Greenville, MS) … 1997 (using 3-man crew)

IMPACT: Decreased fieldwork…Increased data density, accuracy & data processing

Section I
General Guidance in Performing Hydrographic Surveys for Engineering and Construction

The guidance provided in this section was developed by the Los Angles District whose coastal engineering construction projects, shallow- and deep-draft navigation projects, and inland reservoir projects are as varied as any other district in the Corps. The guidance focuses on some of the more critical aspects involved in planning, equipping, performing, and processing hydrographic surveys for engineering projects. Although developed from the perspective of the Los Angles District, many of the recommended planning considerations are applicable Corps-wide.

6-3. Survey Equipment and Instrumentation Requirements Relative to Project Scope

It is important to have a good understanding of the areas that will be surveyed to make the necessary decisions on how to survey them. For example, if 90% of the hydrographic surveying is going to be in water less than 15 feet deep, it would be a waste of resources to use a multibeam system to perform the work (unless the survey is to locate small items). A better choice would be a multiple transducer swath system or a single-beam system. If the water depth exceeds 15 feet, then the multiple transducer swath system starts to become inappropriate and the single-head multibeam system becomes a better choice. Also, shallow water often precludes the use of deep draft vessels. The general classifications for survey conditions are: water depth, channel width, fresh or salt water, water current strength, tubidity, wave conditions, and weather. Each one of these can effect the type of vessel to use and the equipment that would be used aboard the vessel.

a. The most appropriate equipment for data collection is subject to many considerations. A single-head, multibeam-equipped survey boat will probably cost more than $400,000. This commitment of resources must be considered carefully. It is also required that commands obtain approval from HQUSACE prior to acquisition of multibeam equipment. Considerations are workload, type of work, skill level of personnel, safety, and data requirements. These items are tightly interrelated, but must be addressed. If just one of these items fails the whole survey system fails.

b. Workload must be sufficient to support the cost of the equipment and personnel. This is true of in-house work crews or contractors. A multibeam survey vessel should be programmed for most of the year. If the workload drops below 50% utilization then there may be a problem. In some circumstances the survey boat has other duties, or the limited requirement is sufficient to support the vessel.

c. The type of work relates to the different survey situations. Some situations warrant the use of a multibeam system and others may not. An example would be to acquire an in-house or contract multibeam vessel and use it to check the condition of non-critical depths in a channel, knowing that it would cost significantly less to utilize a different survey system. If all the work were in shallow water (less than 15 feet deep) it would not be a good use of a single-head, multibeam system to perform the survey. If the work were in rough open sea conditions, a multiple transducer swath system would be a poor choice of equipment.

d. However, key personnel will still need to be fully knowledgeable of the entire system and have a special knowledge of certain aspects of the data collection and processing systems. Without a complete knowledge of the entire process it will become difficult to efficiently survey or contract a survey in that particular district. It therefore follows that before acquiring a complex system such as multibeam, management must decide if sufficient personnel skills are available.

e. Data requirements are always increasing in complexity. Several years ago there were no digital files, only the paper plot. Now the paper plot is not significant, only the digital file has a real use to the navigation community. With the advent of computer-aided drafting and design (CADD), and modern surfacing programs, providing digital data has become a necessity. This requirement has driven hydrographic surveying to the use of more complex survey systems. The current state-of-the-art system has a solid dedicated work boat (20-ft to 30-ft in length), a multibeam echo sounder, a single-beam digital echo sounder, digital compass, Global Positioning System (GPS) navigation, and a motion reference unit. It must also have onboard editing, data processing, and plotting capabilities--i.e., "field-finish" capabilities. It is clear that the future dictates that surveys cover the full bottom accurately and quickly.

f. Turbidity and other water conditions have an effect on the type and make of the echo sounder to be used. Different echo sounders operate differently in turbid conditions. It is essential that the echo sounder used be initially tested in the working conditions that it will be expected to perform in. This test will provide an evaluation as to which type of equipment will generally meet the survey requirements. When contracting hydrographic surveying it is important to verify the type of echo sounder that will be used, and if unsure of its performance, request a test. If there are others in the area using the same equipment, they may be referenced and that may suffice for the evaluation.

6-4. Selection of Appropriate Survey Vessel for Project Area

A wide variety and number of survey vessels are used throughout the Corps. This would be expected given the Corps is by far the largest agency or organization in the world performing hydrographic surveys, and the types of water resource projects surveyed are highly varied. Corps surveys are performed using conventional V-hull boats, catamarans, tugs, open skiffs, LARCs, pontoon boats, underwater sleds, air boats, surface-effect vessels, swamp tractors, converted barges, jack-up barges, aircraft, and jet skis. Sizes of these platforms range from 14 ft up to 120 ft. Some of these vessels are depicted on Figure 6-1. Each district has unique project features and working conditions that dictate the type of vessel used. These may include project depth, inland or coastal navigation channels, geographical range of projects, personnel, dredging program size, and typical sea states encountered, to name a few. Selection of the most appropriate type vessel for the project conditions is critical to both production and cost. Larger vessels (greater than 26-ft) are generally more effective (and safer) on open ocean entrance projects; however, their daily operating cost is high. Smaller, trailerable boats (less than 26-ft) are more efficient on inland navigation projects and coastal harbors and entrances. They also provide more flexibility to rapidly mobilize between projects. Their daily operating costs are significantly lower than larger platforms. Smaller vessels are more subject to sea state motion, which can adversely impact data quality. Smaller vessels may not be able to effectively or safely operate in outer entrance channels of deep-draft coastal projects. Thus, a number of factors must be considered in selecting a survey vessel for a particular application. Some of the more important factors are discussed below.

Figure 6-1. Sample of Corps survey vessels used in different project applications

a. Channel width will limit the size of the vessel due to maneuverability issues and inability to fully cover shallow side slope depth out to the required prism. Also, long narrow channels are much easier to survey using longitudinal survey lines than cross-section survey lines. Longitudinal lines lend themselves to the use of multibeam systems.

b. Fresh or salt water will also dictate the type of equipment that will be usable. Some fresh water vessels are not designed to be used in salt water and will lead to equipment or engine failure. Generally salt water craft are designed to handle larger wave conditions. Most hydrographic survey equipment is designed to be used in both environments; however, computer equipment is another issue. In salt water conditions, more care must be provided to the protection of the computer due to salty air getting to the electronics. Thus, a sealed cabin environment is essential.

c. Water current strength will affect different vessels and equipment differently. It is suggested that the vessel be tested in the water current conditions that it will be required to work in, before purchasing or contracting is completed, to verify that the vessel and crew can perform the required work. Generally a 23-ft to 30-ft vessel with 150-250 HP work best in most conditions. Hull design is best decided by local knowledge of the water current and wave conditions.

d. Wave and general sea state conditions will require different types of vessels. In the past large survey vessels were required to reduce the affect of the heave, pitch, and roll created by heavy sea states.

Now with state-of-the-art motion reference units being able to eliminate most of these sea state effects, smaller survey vessels can be used. However, the vessel must be able to have a cabin sufficient to house the survey equipment, the vessel operator, and the equipment operator. The design should be as low to the water line as possible to make the vessel less subject to pitch and roll as possible. Generally if the roll exceeds or is maintained at seven degrees the vessel becomes too uncomfortable for continued survey operations.

e. Safety is a consideration for both in-house and contracted surveys. The survey vessel must be sea worthy at all times it is in use. The vessel should be designed with the concept of it being a survey boat and have all of the needed brackets and electrical fixtures permanently placed on the boat. If the boat has an over the side transducer mount, it should be fixed so that the mount can pivot and swing back if an object is struck. This can be done with a shear-pin or other similar device. Items should not be mounted on the vessel that will cause it to be open to the water if an accident should happen. Through-the-hull designs for mounting equipment should have the top of the well open to the deck so that any water forced into the well will simply flow onto the deck and then back into the water. Assignments as to who is responsible for safety need to be made clear and documented. The vessel must be designed to operate in the waters were the survey are routinely performed. Survey equipment must be placed in the vessel so as not to interfere with emergency exits or the pilot's view of traffic over 360 degrees. In open ocean areas, life saving provisions must be made for the crew should the vessel sink. These include raft, survival suits, emergency beacon, lights, water, food, flares, and emergency radio. In areas near shore or in inland navigation systems, other provisions can be made, but they should be clearly spelled out. A contractor should provide a report on how they will handle safety situations on the survey job.

f. Weather plays a major role in the vessel design. Most survey vessels are provided with an enclosed cabin; however, in severe weather it becomes a requirement. When contracting surveys weather conditions are a factor in vessel selection. For example, it would be prudent to carefully inspect a vessel coming from Florida to do hydrographic surveying in Alaska. Likewise, a Gulf Coast surveyor may not have the right equipment for the Pacific Northwest due to different wave conditions encountered in the Pacific. Another factor is work areas with high heat and humidity conditions--these areas require air-conditioning to keep the equipment running.

g. Logistics is one of the day-to-day problems that the surveyor must deal with. Contractors realize that they must be able to mobilize their boat to the survey site. Some districts have specific areas that a boat works and thus mobilization is not such a large issue. However, for the most part, districts, dredging firms, and A-E contractors must move their survey boat and personnel to a location easily and quickly. This usually means that the boat must be trailerable. There are varying degrees of trailerable boats. Some are legal only with special permits, escorts, signage, and limited routes and times. It is clear that a boat that does not require any special handling is preferred--and will best ensure that it can get to the project site when needed. This means the use of a trailerable boat 20 ft to 30 ft in length. Such length vessels are by far the most common used in the Corps--see Figure 6-2.

Figure 6-2. Corps standard trailerable survey boat with twin outboard engines and enclosed work cabin (Surveyboat Boyer, St. Louis District)

h. Weather is an issue that is regional in nature and thus the survey plan must address this issue with specific attention to adequate vessel design, equipment mounting, equipment selection, personnel training, and formal weather procedures. The survey vessel must be able to handle any of the expected weather condition it is to work in. If not, then special planning needs to be taken to insure that personnel are not exposed to weather the vessel cannot handle. Equipment mounts that work well in calm conditions may come lose, or worse, cause hull damage in storm conditions. If a vessel gets caught in a storm condition, then the mountings must be strong enough to hold. Some equipment will work well in calm conditions, but in storm or rough water conditions they may be operating outside of their performance range. Personnel should be trained in simple first aid and CPR. Also, they should be trained in the use of all the onboard safety equipment. Management should set out a formal guideline on evaluation of weather hazards, and make sure that the crew is aware of them.

i. Daily operating costs for a survey boat, crew, and survey party is another major factor. The daily operating cost is a function of vessel length, crew licensing requirements, and size of survey crew attached to the vessel. These cost factors are described in the chapter on A-E contracting. Typical costs for operating various survey vessels in the southeast US are shown in Table 6-2 below:

Table 6-2. Average Daily Crew Rates Relative to Vessel Size (1998)

Single Transducer -- USCG DGPS Beacon positioning … SE CONUS

Vessel & Crew Size	USACE In-House	Arch-Engr Contract Rate
26-Ft --4-man crew	$1,590	$1,175
26-Ft --3-Man crew	$1,340	$1,000
26-Ft --2-Man crew	$1,090	$ 825
24-Ft --1-Man crew	$ 687	$ 650 (est)
30-40 Ft -- 3-Man	$2,200	n/a
50-65 Ft -- 4-6 man crew	$3,350 to $4,100	n/a

The higher rates for the larger vessels are readily apparent in the above table. This is primarily due to the increased operation and maintenance costs and requirement for USCG licensed operators. Vessel utilization is another factor: there must be a sufficient deep-draft coastal workload to ensure a 65-foot vessel can be utilized year-round. Utilization is the main factor behind the lower rates for A-E contract forces.

j. Data processing and editing should be done on the boat if it has an enclosed cabin. Plotting can be difficult in limited space or if humidity affects the paper and pens. If it is required to plot at the site, a better choice may be a trailer or van, with data being delivered periodically from the data collection boat. The person who collected the data should perform all editing and processing.

6-5. General and Specific Survey Planning

Development of a general survey plan and subsequent site specific survey plans will create a more efficient survey. The general survey plan addresses the general way that surveys are planned, performed, and processed. This plan must be well thought out and robust to account for as many contingencies as possible. This plan includes training, software, equipment maintenance and upgrades, logistics, all data requirements, schedule, safety, and weather. It may seem that some of these items defy planning; however, the effort must be made. The site specific survey plan will address local notifications, survey lines, datum, data density, and specific equipment and personnel that will meet the general survey plan requirements.

a. Training is probably an ongoing consideration by any surveyor due to constant changes in technology. A complete training program should be laid out for each employee for the equipment and software that that employee is expected to use. As these items are updated, continuing education should be a standard issue in evaluating training needs. Contractors should provide their training background on their equipment and software when being evaluated. This is usually contained in the Standard Form (SF) 154/155 A-E evaluation submittals.

b. Software is critical to the overall survey system. It would take an entire manual to adequately detail software guidelines and requirements, and that is not the intent of this section. However, the software must be robust and free from errors in data collection and processing. The software must perform all required functions with a minimum of training and confusion. It is critical that the software provide data quality control in a fashion that allows real-time or near real-time quality control on the survey boat. And, as a minimum, it must provide X-Y-Z digital files that can be used in a surfacing program to create contours. It may be easier to construct survey lines in one piece of software, export those to the data collection software, then edit the collected data on a third piece of software, and produce final versions on a forth piece of software. This may be the quickest, but keep in mind that this requires acquiring, learning, upgrading, and maintaining four different software programs. Thus, a software package that encompasses most of these features is desired.

c. Equipment will have the largest initial cost, and locks the surveyor into a particular way of doing business. Some equipment will lend itself to particular types of surveys and others will be more general in use. It is paramount that a thorough general plan be in place and have USACE approval prior to purchase of equipment. The same holds for contractors: they will use the equipment they have or can obtain (lease or purchase) to do the work. It is important that their equipment meets the overall survey plan.

d. Data requirements are being set by different end users of the data. Some of the Corps of Engineer's customers are the harbor pilots, port authorities, levee boards, commercial tug and tow operators, harbor maintenance groups, National Oceanic and Atmospheric Administration (NOAA), coastal engineers, general recreational boaters, and environmentalists. Each user has a different use for the data and in some cases a different data requirement. The purpose for the survey will usually dictate the data requirement (data density, data coverage, and data precision). However, if there is no impact to cost and schedule, then as many requirements should be addressed as possible in the survey plan.

e. Schedule is often a critical element in a hydrographic survey plan. The data requirement usually has as a specific deliverable date assigned, such that the survey data collection and processing occur within a very specific time frame. This requires that the personnel and equipment resources be adequate to meet this need. In some cases, if the schedule cannot be met, then the survey simply will not be requested and other sources will be used. Considering this, it is important to plan and analyze all aspects of a general survey plan with the ability to meet schedule as a prime element of the plan. In evaluating contractors, it is also import to evaluate their ability to meet schedule and the district's ability to contract in a timely manner.

f. Safety is a key element in any plan. This is true for surveying in general and, in particular, hydrographic surveying. It can not be emphasized enough to survey crews that safety is first and production is second. If the general survey plan or the site-specific plan omits or is lacking in safety then it is a bad plan. It is incumbent on the person in charge in the field to evaluate every situation for possible hazards. If there is an identified hazard, then it needs to be addressed before continuing with the activity. Contractors are held to the same degree of safety that Corps employees are held to. The Corps safety manual covers general safety, but does not address all of the safety issues that can happen aboard a survey vessel. These items need direct management input and resolution.

g. Notifications to the Coast Guard, and the local harbormaster office should be made with enough time to allow them to notify the local boaters of the survey. This notice should include a simple map showing the survey area.

h. Survey lines for multibeam surveys (showing the course the survey boat should travel while collecting data) should follow the contours of the harbor bottom. This will reduce the changes in bottom coverage created by different water depths. However, when using a single beam survey system, the lines should run perpendicular to contours. This will help in determining changes in the bottom relief. Survey lines for multibeam surveys should not be too long. Long lines will generate large data files that are difficult to edit. Thus a long entrance channel might be broken up into 10,000 ft segments. Multibeam survey lines also need to be spaced so as to achieve the proper amount of overlap or data density to meet the survey standard, as described in the following section in this chapter.

i. Vertical project datum refers to the particular reference point or plan that the survey is measured from. These datums are commonly referenced to an elevation or a sea level. Rivers have slopes that must be correctly modeled in order to obtain a constant reference plane. Lake and reservoir datums differ based on their location. The Great Lakes has a datum that is unique to each major lake. The ocean has more than one datum. The most common to navigation is Mean Lower Low Water (MLLW). This datum is established by NOAA. NOAA's tidal monuments are the reference that must be used to establish MLLW or transfer it to other points in the project. When a survey is performed, an integral part of the data for that survey is the reference datum. It is required, by good survey practice, to clearly indicate by note on the published survey the actual vertical reference monument used, and the procedures used to establish the datum for the survey.

j. Data density will vary based on method of survey, water depth, and need. The method of survey will be determined by equipment available for the survey, the personnel, and survey site conditions. If only a single beam survey system is available, then data density will be less; unless the survey lines are about a half-meter apart and the boat operator can stay exactly on line. With a single head, multibeam system, the greater the water depth the less dense the data will be, unless multiple passes are made. It should be noted that data redundancy and data density are not the same thing. Data density is the number of soundings per unit of area, while data redundancy refers to data overlap or data collected at a different time at the same location. The type of survey defines data redundancy or data overlap requirements--refer to Chapter 3. Full coverage surveys deal more with data density insuring that the whole bottom is measured. These items need to be clearly understood by those requesting the survey and those doing the survey to insure compliance with the standards in this manual.

k. Specific equipment requirements fall into two groups. The first is operational equipment such as vehicles, safety gear, and radios. The second is survey equipment such as echo sounders, GPS, and lead lines. It is important in either case to standardize the equipment as much as possible to limit training, maintenance, and mistakes. Contractors that have mixed equipment must have their personnel trained in all the equipment to insure that mistakes will be limited. Management must have in place some sort of equipment plan for each type of project, and insure that the personnel are aware of that plan. Again, safety equipment is of no value if some personnel do not know of the equipment and/or how to use it.

l. Personnel for the survey must be qualified to perform the survey. Qualification can be determined by past experience if that experience is with equipment and methods being used for the particular survey mission. Another qualification is documented training in the equipment and methods. Training or experience, or both, must address all operational and survey equipment and procedures. The number of personnel required to perform a survey mission can vary due to survey method and operational concerns, but the minimum number required is the number to operate safely.

6-6. Data Management

Data management relates to transporting, processing, presentation, and archival/retrieval of survey data. In modern hydrographic surveying vast amounts of quality data can be generated very quickly. With the advances in digital terrain modeling (DTM) programs and CADD, the need for this type of geospatial data is growing. A solid plan must be in place for moving data from place to place physically, processing the data, preparing the required deliverable product(s), and achieving this in such a way as to promote data retrieval and use.

a. Moving data physically or by some digital communications system is critical for the hydrographic surveyor. With modern data collection systems, collecting gigabytes of data per day is increasingly common--see Table 6-3 below. The general survey plan must have as a major component the movement of the data from the survey vessel to the office. This will vary from location to location, and the type of equipment in the survey vessel and the survey office. The system needs to be simple and yet robust due to the environment it is exposed to. It is important to always ensure the data is backed up in two places.

Table 6-3. Increase in Data Collection Density since 1960 [1]

Method	Soundings/Hr	Ratio
Tag/Lead Line (<1960)	20	1
Topo/Total Station	40	2
S/B Echo Sounder >1960	21,600	1,080
Multibeam (EM-100) >1992	292,400	14,620
Multibeam (EM-1000)	324,400	16,200
Multibeam (EM-3000)	1,500,000 (450 MB/Hr)	75,000
LIDAR/SHOALS > 1990	1,400,000 (3,000 MB/Hr)	70,000

[1] per Survey Crew ... Drop from 5-7 persons (tag/lead line) to 2-3 persons (multibeam)

b. Processing data in the district office must be carefully planned. It is easy to get confused and inadvertently delete important data files or apply incorrect tides or velocity files. It is also important to train personnel not only in the use of the software, but also in the proper interpretation of the data. If at all possible, the data collector is the preferred data editor. It is important to not over-automate the editing processes and inadvertently remove objects that do exist. This will require prudent and limited use of automated editing features of the software, and ensure that each anomaly is identified by a qualified person. This is time consuming; however, the mistake of removing something like a large rock that actually exists from the survey is not acceptable.

c. Deliverable products can range from the raw data files to completed hydrographic maps with digital surfaces. The Corps is required to submit its survey data to NOAA for inclusion in their navigation charts. The format of that data changes from waterway to waterway and through time as NOAA updates their methods and products. It is important to stay current with NOAA and adjust the general survey plan to accommodate their needs. Once NOAA converts its charts to the metric system (they have not converted as of 2001) standards for data presentation will change to meet metric requirements. Some of those changes are that text height will be three millimeters, grid ticks will be every 0.1 meters on charts, plots will be on metric sized sheets, and that scales will be replaced by ratios. A rule of thumb is that data density for engineering purposes (volumes and contours) is an average of all edited soundings in a three meter square given the coordinate of the center of that square. Another rule is that plotting at ratios of 1:2,000 or 1:3,000, the density should be about one sounding every 15 meters, and this sounding should be the sounding closest to the center of the 15-meter square. The use of a non-averaged sounding near the cell center (or centroid) means that the plotted data represents real measurements and not calculated measurements. It is becoming more common in industry to supply digital data as the main product. This has the advantage of being more easily used in DTM and CADD programs; however, if there is a requirement to sign the deliverable or place a stamp or seal on it, then the digital file will have to be supplemented with a hard copy of the survey. This will change as electronic certification procedures are put in place.

d. Data archival and retrieval are required, and good business. The Corps has a FGDC mandate to make their hydrographic data available through the Internet. Equipment and systems must be in place or developed to move this data to the Internet to make it available to the public. Currently the best methods are to place the data in a district or USACE Internet server or on media such CD-ROM. The data must also be placed or referenced on the Geospatial Data Clearinghouse--refer to EM 1110-1-2909 (Geospatial Data and Systems) for details on USACE data archiving and retrieval requirements.

Section II
Planning Survey Coverage

This section provides guidance for determining the amount of coverage needed for surveys of Corps navigation, coastal engineering, and flood control projects. It provides additional guidance to supplement the survey coverage requirements in Table 3-1.

6-7. Density of Data and Line Spacing

Minimum requirements for survey coverage are prescribed in Table 3-1. These are minimum standards and may need to be adjusted based on project-specific requirements. The density of bathymetric data collected is determined by a number of project-dependent factors. Some of the considerations used to determine the required data density and the survey coverage needed to obtain that data density include:

- Type of construction project (dredging, rock placement, revetment construction, etc.) and related site investigation requirements.

- Survey data collection equipment (lead line, analog echo sounder, multiple-array acoustic sweep system, automated data collection, etc.) capabilities and limitations.

- Subsurface relief (rock, sand, silt, probability of intermediate pinnacles or shoals requiring development, etc.).

- Project economics (costs of surveys relative to engineering and design costs and estimated construction costs).

- Method of construction payment and/or computation thereof (in place, daily unit rate, average end area, triangulated irregular network, etc.).

a. Single-beam line spacing and alignment. From the above evaluation, a line spacing is selected which will provide the necessary density of coverage--or overlapping coverage in the case of swath survey systems. On dredging projects, the survey line spacing will govern the amount of coverage over a given project area, regardless of whether lines are run as cross-sections or run parallel to the project alignment (profiles or longitudinal lines). For single-beam cross-section surveys, data density usually covers less than five percent of the project by area. From this relatively low density, quantity computations are estimated, the major assumption being uniformity of terrain between successive survey lines or sections. This is normally a valid assumption. It becomes invalid if abrupt changes occur between lines, in turn causing inaccuracies in quantity take-offs made using average end area methods. The line spacing densities indicated in Table 3-1 are considered to be representative for USACE construction and dredging activities. Maintaining these criteria will ensure USACE-wide uniformity on contracted construction projects. In areas undergoing construction, or where shoals or other irregularities occur, the line spacing shall be made closer in order to detect and depict the full extent of irregularities. Far wider spacings are specified by project engineers for non-navigation surveys, such as river sections for hydraulic models, reservoir sedimentation studies, and coastal engineering transport studies. Cross-sections are nearly always run normal to the project's centerline alignment, as shown in Figure 6-3, or relative to a fixed baseline located ashore. These could include levee baselines or beach construction baselines or setback lines. Project alignments may be straight, circular curves, or transition curves--cross-sections are run normal to the line or curve tangent. Exceptions may occur in turning basins, wideners, or other irregular shaped areas.

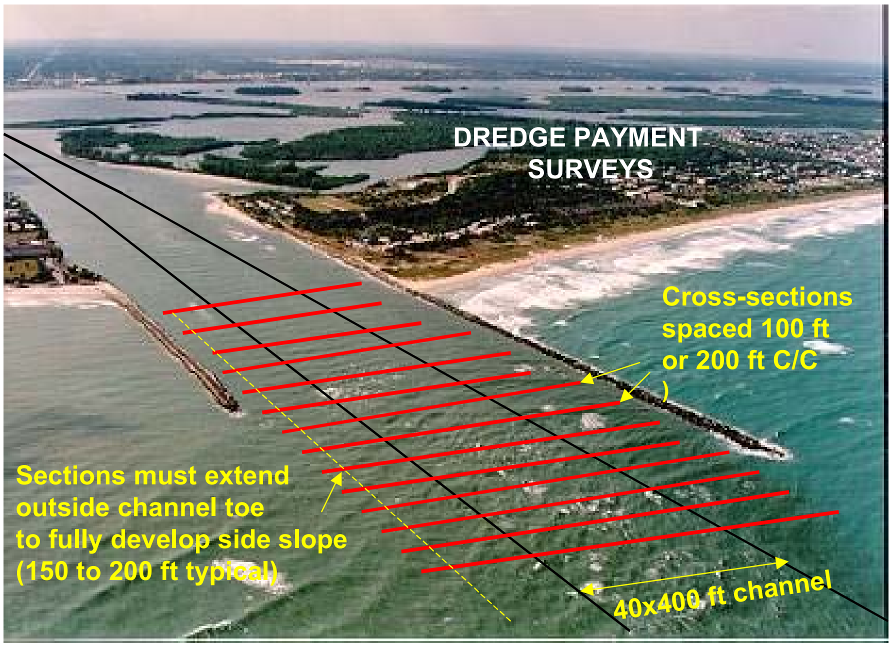


Figure 6-3. Cross-section coverage of a typical navigation project

(1) Data acquisition packages (such as HYPACK MAX) have a variety of features to set up survey lines relative to a project or channel alignment. These are found in its LINE EDITOR and CHANNEL DESIGN programs. Both straight or curved survey lines can be generated. Survey lines can be set up to cover turning basins--see example at Figure 6-4. Included with the cross-section alignments are the channel turning point coordinates along with side slope grades. This data is used for subsequent end-area volume computations.

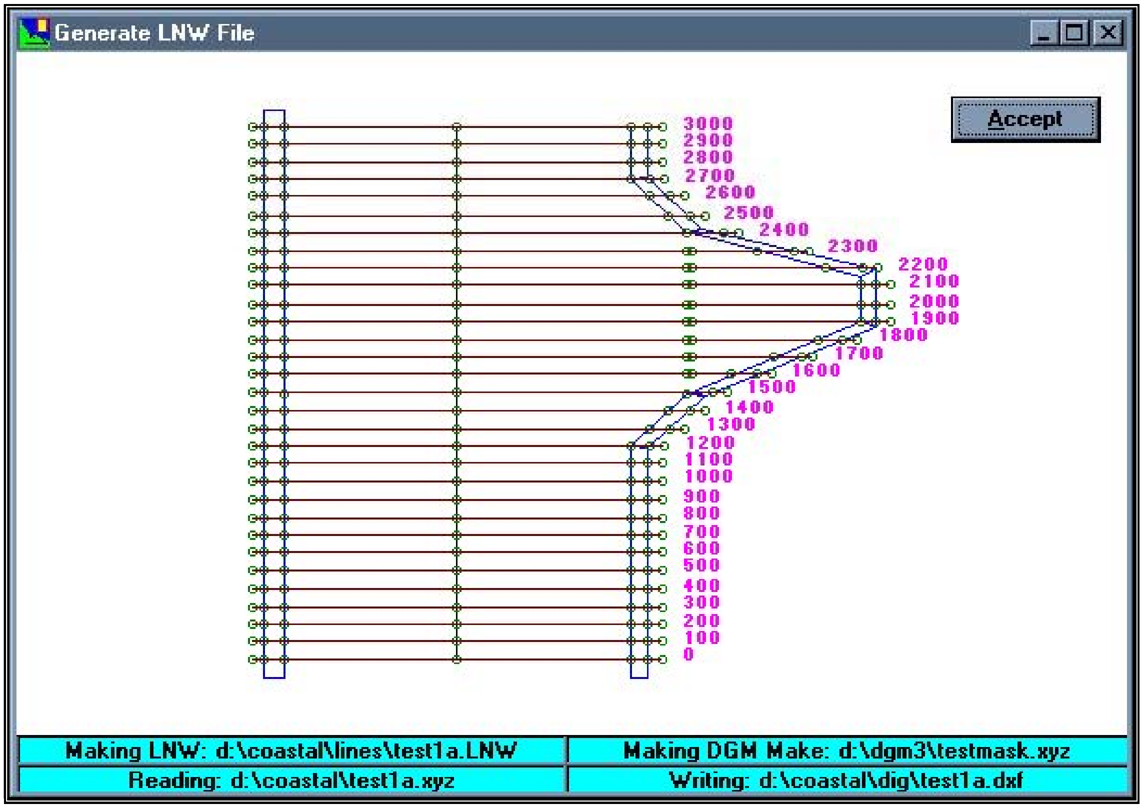


Figure 6-4 HYPACK MAX planned survey lines covering channel and adjacent turning basin including channel limits and side slope parameters

(2) HYPACK MAX can also be configured to optimize spacing of cross-sections through varying channel baseline alignments, as shown in Figure 6-5. This so-called SMART CORNERS option can be used to simplify average-end-area volume computations in these irregular areas; however, in this example, a TIN model might be an easier method of computing dredge quantities.

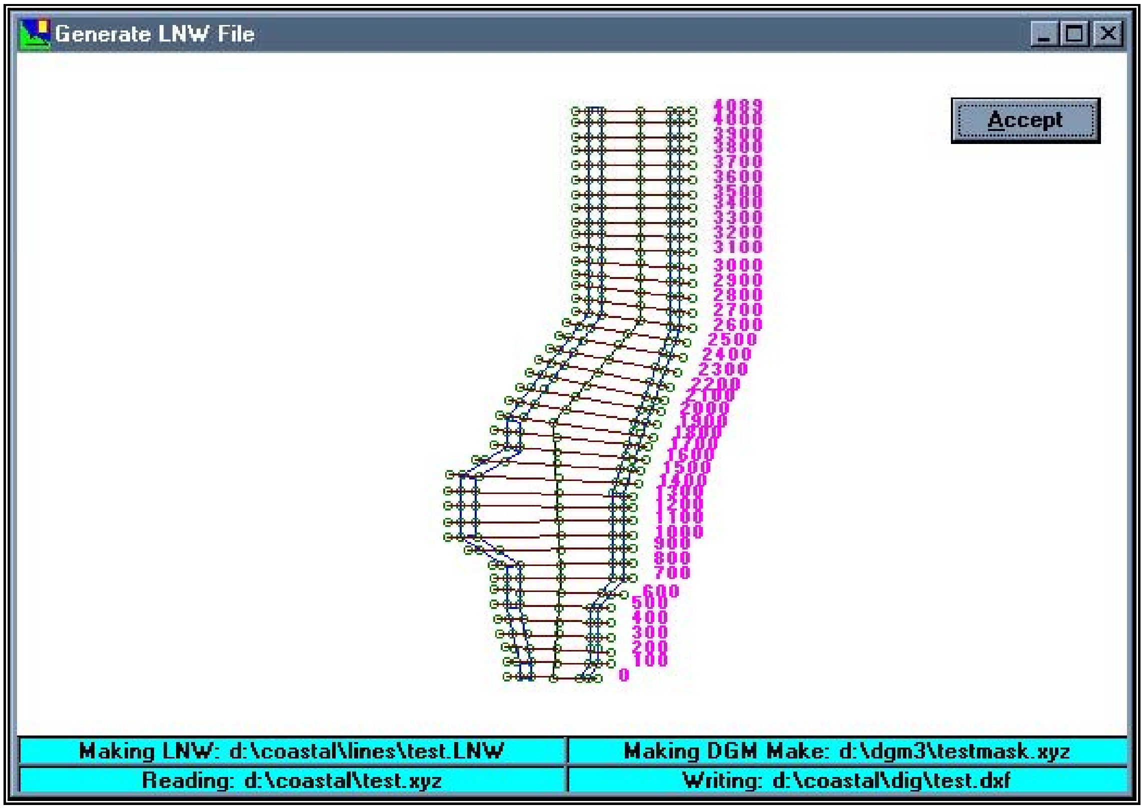


Figure 6-5. HYPACK MAX "Smart Corners" generated planned survey lines covering irregular channel alignments--cross-section alignment varies over channel intersections

b. Multibeam coverage and line spacing. Acoustic multibeam sonar systems provide full-bottom coverage from a single acoustic transducer. Entire cross-sections of a channel can be generated many times a second. Multibeam systems are now capable of providing full-channel coverage surveys in near real-time, including on-board data processing, editing, color plots, and CADD files for direct import into MicroStation or AutoCad platform. Quantity computations using full digital terrain models acquired from multibeam data are significantly more accurate than average-end-area quantity take-offs from single beam cross-section surveys. These computations can also be performed directly in the field. The primary application for multibeam systems is for surveys of deep-draft navigation projects--typically those projects over 20 ft in depth. Multiple transducer systems are more effective in shallow draft projects when full-bottom coverage is required for channel or clearance requirements. Multibeam swath widths typically range from twice to seven times the water depth. Thus, for a 45-ft project, a 200- to 300-ft swath can be obtained with a single pass. Figure 6-6 depicts full swath survey coverage of a 400-ft-wide deep draft channel with two vessel passes.

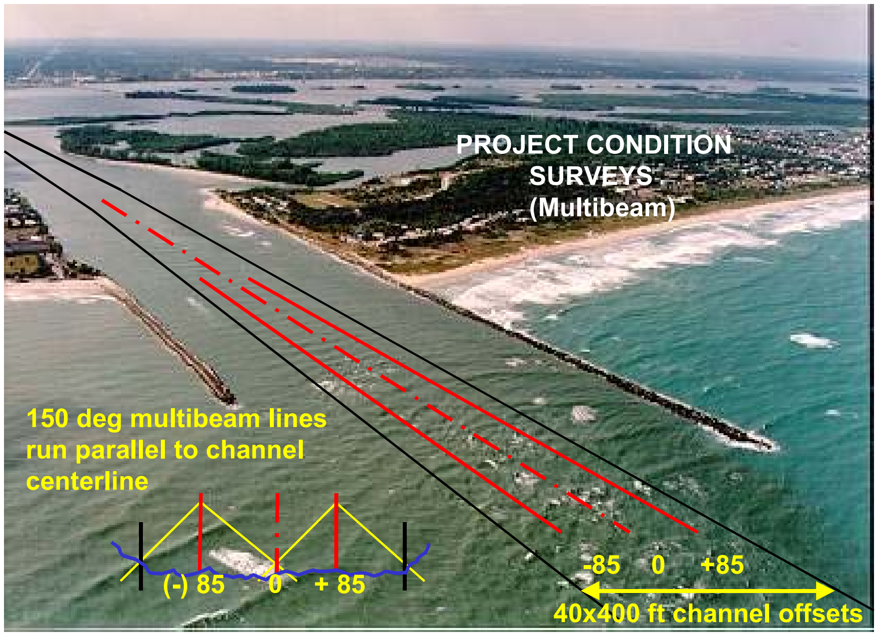
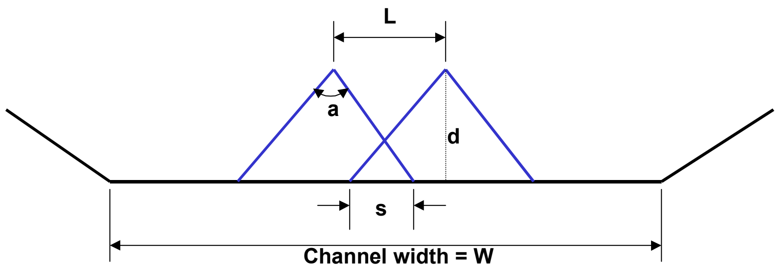


Figure 6-6. Project condition survey coverage of a deep-draft navigation project with two 150-deg multibeam passes

(1) Multibeam line spacing *("L")* and the number of longitudinal lines *("N")* for a typical navigation project can be computed using the methods shown in Figure 6-7. The depth *(d)* is the average project depth. The sidelap *(s)* should be set such that overlap exists between the parallel multibeam swath lines and the toes or side slope limits. Sidelap is intended to compensate for survey line steering limitations and/or duplicate coverage requirements. A 50% sidelap would provide duplicate bottom coverage if there were no steering misalignment. For a project condition survey where coverage is only required between the channel toes, an allowance should be made for vessel steering misalignment. If the steering accuracy is $\pm$20 ft, then the channel width should be increased by at least that amount to ensure full coverage between the toes. When duplicate bottom coverage is required throughout the channel (i.e., 50% sidelap), additional lines should be run on each channel toe.



Given:
a = Multibeam swath angle (deg)
d = depth beneath transducer (ft)
s = swath sidelap (%)

Treat side slope coverage separately based on varying depth up slope (more compressed line spacing may be required)

Find: Number of Multibeam lines required in channel

Nominal line spacing "L":
L = 2 d tan (a/2)*(1 - s)

Required number of lines:
N = | W / L | + 1

Figure 6-7. Computing multibeam line spacing on a navigation project given array width, project depth, and overlap requirements

(2) The following examples illustrate line spacing computations for multibeam surveys:

Given: Project Condition Survey of 40x400 ft channel
(no coverage of side slopes required)
10% overlap between multibeam lines

a = 150 deg multibeam swath angle
d = 40 ft project depth
s = 10%
at 10% overlap, s = [2d tan (a/2)] · 10%) = 30 ft

Line Spacing: L = 2d tan (a/2) · (1-s) = 2 · 40 · tan (75 deg) · (1 - 0.1) = 269 ft … 270 ft

Number of lines: N = | 400 / 270 | + 1 = 2

Since the two lines easily cover the channel area, they would be spaced to provide overlap along the toes and with each other. If a 20-ft steering accuracy is assumed, then the two lines would be run along channel offsets (+) 85 ft and (-) 85 ft from the centerline. The line spacing in this case would only be 170 ft, resulting in considerable overlapping coverage in the channel center plus a 20-ft tolerance outside the toes. Running offsets ± 100 ft would be adequate for this coverage as well. This line spacing is depicted back on Figure 6-6.

If, in the above example, a more realistic 120 deg multibeam array is used, then the line spacing would be reduced as follows:

Line Spacing: $L = 2d \tan(a/2) \cdot (1-s) = 2 \cdot 40 \cdot \tan(60 \text{ deg}) \cdot (1 - 0.1) =$ 125 ft

The number of lines required to cover the channel between the toes is:

Number of lines: $N = |\, 400 / 125 \,| + 1 = 3 + 1 = \underline{4}$

If the multibeam array is restricted to 90 deg, as might be the case in a pre/post dredging survey, then the following line spacing would result for the same project:

Line Spacing: $L = 2d \tan(a/2) \cdot (1-s) = 2 \cdot 40 \cdot \tan(45 \text{ deg}) \cdot (1 - 0.1) =$ 72 ft … use 75 ft

The number of lines required to cover the channel between the toes is:

Number of lines: $N = |\, 400 / 75 \,| + 1 = 5 + 1 = \underline{6}$

If duplicate coverage were required for this project, the sidelap would be increased to 50%, resulting in the following line spacing:

Line Spacing: $L = 2d \tan(a/2) \cdot (1-s) = 2 \cdot 40 \cdot \tan(45 \text{ deg}) \cdot (1 - 0.5) =$ 40 ft

Number of lines: $N = |\, 400 / 40 \,| + 1 = 10 + 1 = 11$

The above computation is based on coverage between the channel toes. Additional lines may be required for side slope coverage. For a dredging pay survey where multibeam side slope coverage is required, the line spacing computed above will have to be decreased to account for the shallower depths along the slope.

(3) From the computed number of lines, an estimate of total lineal multibeam survey miles can be computed. Given known survey speed and daily rates, the time and cost to conduct the overall survey can be determined.

c. Multibeam transducer arrays can be configured to obtain coverage in a variety of methods. These methods are highly project dependent. Swath systems for dredging work (i.e., developing pay quantities) generally are set vertically to cover twice water depth. The sensor can be tilted to map vertical bulkheads, flood walls, levees, bridge piers, and the area beneath moored vessels. Towed sensors can be used to detail deep excavations, pipelines, and other objects. Use of multiple sensors is also common.

d. Multibeam survey methods do have an advantage over the multiple transducer sweep systems in that the spacing of the boom-sweep transducers is required to be matched to the depth of the project being surveyed. If the transducers of a boom-sweep system are spaced for deep-water project surveys, the transducer spacing must be reconfigured for shallow water projects. If this is not done, large gaps in coverage could result. If the vessel normally is configured for shallow water surveys, then transducer interference may occur while surveying deeper areas of a project. On the other hand, multibeam coverage in shallow-draft navigation projects is limited, generally rendering these systems impractical to use. Multiple transducer boom systems are capable of providing more efficient full-bottom coverage in shallow-draft projects.

6-8. Survey Alignment (Cross-Sections and Longitudinal Sections)

Longitudinal section surveys are often more practical to conduct than cross-section surveys. Full sweep systems are normally always run longitudinal with the channel alignment. When single-beam echo sounders are used, cross-section surveys provide a more definitive depiction of the channel or bank's toes and slopes, which may be critical to engineering design and/or construction acceptance. In USACE, many districts run cross-section surveys for construction payment work and longitudinal surveys for general project condition reports. Although cross-section alignments are preferred, safety considerations in some areas may dictate that longitudinal alignments be run. River and coastal beach sections are normally run as sections perpendicular to the bank or flow. If construction is involved, survey alignment and payment methods must also be adequately described in the construction contract specifications.

a. When single-beam longitudinal surveys are performed for contracted construction measurement and payment, a smaller line spacing should be specified than that shown in Table 3-1. Given the usually large excavations taken from the side slopes, 25-ft C/C spacing up each slope is usually required to obtain sufficient detail. Average end area volumes should be computed by mathematically cutting cross-sections from the longitudinal database. Sections should be derived at 100-ft C/C intervals; however, smaller intervals (25- or 50-ft spacing) may be used if end area variations are excessive.

b. Swath survey systems are more effective if run in a longitudinal alignment. This includes multiple-transducer boom array systems and multibeam swath systems. These full sweep systems will provide 100% coverage, and all recorded data may be used to derive pay quantities.

6-9. Positioning Intervals

The interval at which position fix updates are taken depends on whether manual or automated electronic positioning methods are employed. Tag line positions are typically taken at 25-ft intervals; automated EDM or DGPS positioning systems provide (and record) positions at intervals based on time or preset distances (e.g., every 1 sec or 10 ft). DGPS position outputs are typically 1-sec intervals. Systems updating positions at denser intervals should use (and record) the smallest interval available.

6-10. Depth Recording Density

Sounding equipment shall be configured to record depths at the maximum possible rate. Depth collection density is usually input into a data acquisition system in microseconds. The entire database shall be used in computing pay quantities.

Section III
Data Processing, Editing, and Plotting Options

Most USACE hydrographic survey data are either collected by automated systems or converted into an automated format. Final data processing and plotting are accomplished using onboard or office-based computer systems. Currently, there is no USACE standard for hydrographic data collection format, editing, graphic transfer, or plotting format. Efforts toward standardizing graphic data files to a standard format will require eventual standardization of most hydrographic survey software, graphic file formats, and topographic/planimetric symbology for both in-house and contracted surveys. This section discusses some of the general data collecting, processing, and formatting methods used throughout USACE. Following is a description of a field survey acquisition system and office data processing procedures employed by the Norfolk District. Although the systems and methods used are specific to Norfolk District, and are slightly dated, they are still generally representative of current hydrographic software acquisition and CADD processing systems used throughout the Corps, such as Coastal Oceanographic's HYPACK MAX (Figure 6-8), Trimble's HYDROpro, AutoCAD, and MicroStation.

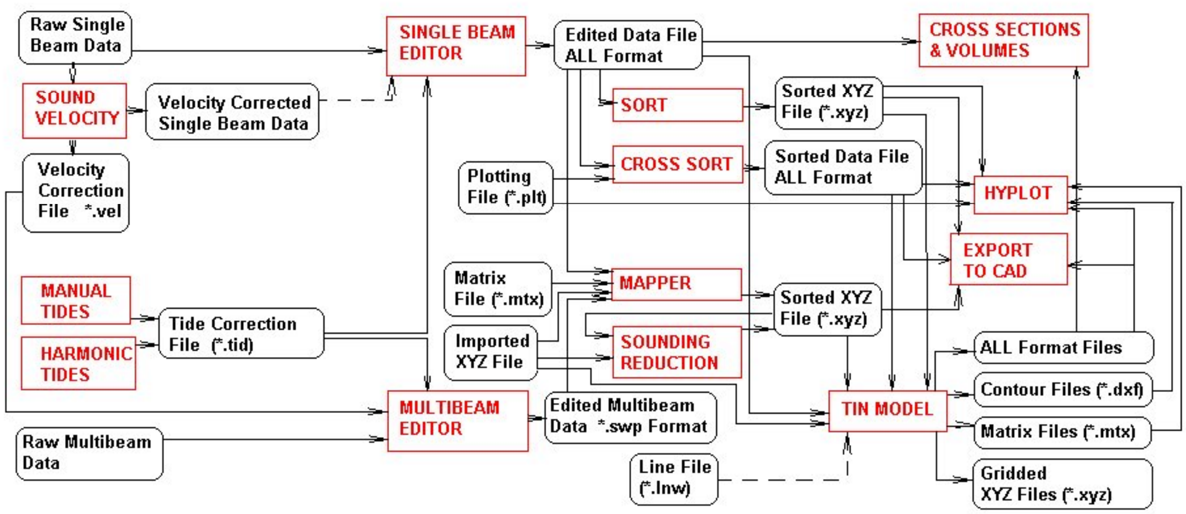


Figure 6-8. Coastal Oceanographics HYPACK MAX post processing flow diagram

6-11. HP/UNIX Field Data Collection System--Norfolk District

a. General description. Most hydrographic survey systems are now capable of performing "field-finish" operations wherein survey data is collected, processed, plotted, and analyzed in the field. Personal computer (PC) and UNIX-based systems in the field have the capability to process, edit, plot, and perform quantity computations on single-beam, multiple transducer, or multibeam survey systems. This allows for immediate data review during critical construction phases--eliminating delays normally associated with the transfer of data to a remote district office for processing. Most field data acquisition systems are capable of processing, editing, and plotting multicolor E-size drawings aboard 26-ft survey vessels during hydrographic surveys or immediately following the surveys.

(1) The automated hydrographic survey system is based on the UNIX operating system, which allows it to be both multitasking and multi-user. This means that, along with the many on-line real-time abilities, when more than one operator is monitoring the real-time data collection, another may view and compare previous data. The on-line screen is capable of displaying a variety of information to both the surveyor and the boat operator. Distances to line, toes, and end point are displayed in feet and are color-coordinated to help in determining position. Speed (in knots) and depth (in feet) are shown in the lower left corner of the video screen. The lower right window is used to display various messages and outputs (discussed later). The middle right window is used to display a cross-sectional plot of the project; toes and other significant features can be input and displayed. The upper right window is used to display a real-time vertical plot of the cross-section. Toes are displayed in red. A depth (usually project depth) is displayed on this screen at a 75% position of the vertical screen. The toes and depth bar help to form a template to allow a fast assessment of data. A previous vertical display of the same cross-section can be loaded into memory and displayed in real-time to allow the system operator the opportunity to compare the historical and current cross-sections. All depths on this screen are corrected for tide, if the tide information was collected in real-time.

(2) Data are collected in two types of formats: dense and plan. The dense depth information is collected at a rate of 5 soundings/sec. The dense positional information has an update cycle of once per second. During the post-plot, a position can be determined on any sounding by interpolation. Under normal survey speeds, depths are recorded approximately every 2 ft. Coordinates are provided approximately every 10 to 12 ft. The plan format of information is recorded at an operator-set distance relative to the navigation channel toes. For example, if the operator enters 25 ft for this distance parameter, a family of lines spaced 25 ft apart will be displayed to the video screen. As the vessel passes over the lines during a cross-section pass, the sounding closest to the line will be stored. Because the depth recorder outputs 10 soundings/sec (and the survey vessel speed is approximately 10 ft/sec), the soundings assigned to these positions are usually within 1 ft horizontally.

(3) The system has several modes of operation and allows the operator to turn on or off these various functions:

(a) AUTOMARK: The system will start logging data when the vessel reaches a pre-set distance from the navigation channel toes.

(b) AUTOBREAK: The system will stop logging data when the vessel reaches a pre-set distance from the navigation channel toes.

(c) TRIANGLES: The operator can remove any pair of distances used for the solution of the vessel's position.

(d) BOTTOM SAMPLE: Another display is added to the upper left part of the screen, and this corresponds to the distance to the end of the line entered. This display changes colors when the survey vessel passes the point.

(e) RECON: Surveying may be performed in a "recon" style. No toes are necessary, and sounding will start from keyboard initialization and end with a keyboard command.

(f) SIDE-SCAN: Used when a fix mark is to be annotated on any other device than the depth recorder roll.

(4) The operator also has a wide range of options to use to meet the specific requirements of the survey. The operator can determine the baseline relationships of the microwave positioning shore stations,

edit parameters real-time, view and edit logged data, and display historical or pertinent data. The system operator, at any time, may ascertain the quality of his navigation system. When requested, the system will display a residual for each pair of ranges in use. This residual is the distance (in feet) by which the observed pair of ranges missed the final computed solution. The final computed solution is obtained by an angle-weighted least squares solution of the triangles in use (condition equations). Also displayed is the angle formed by each pair of the ranges used in the position solution. The operator may remove any range-pair considered too pointed (< 35 deg) or flat (> 145 deg) from the final coordinate position solution. Newer applications with DGPS positioning can provide GDOP, HDOP, or VDOP quality data to allow real-time assessment of positional accuracy.

(5) All of the recorded data are logged onto the hard drive of the computer and then transferred to a floppy disk at a later time. Through the use of other programs aboard the boat, and by keeping the raw data on the computer hard drive, the operator is able to compare various surveys of the same site prior to submittal. This also provides insurance against lost data (lost floppies, office computer crashes, etc.).

b. Processing and plotting operations--Norfolk District office. After the initial field work is done, a survey must undergo several procedures and checks before it can be converted to a usable form. There are a wide variety of uses for a processed survey; this procedure outlines the necessary steps used at Norfolk District to convert raw field data into a finished survey with map and volume computations. Following are the major steps involved in processing a hydrographic survey.

(1) Converting soundings to depths (coastal projects). On some jobs (usually when the vessel is surveying relatively close to the gage without the need for tidal zoning), the gage reading is entered directly into the computer following a reception of this information by radio. The gage reading is recorded to disk with the soundings. In this case, depths are computed directly from the sounding and tide information. Conversely, for project surveys at a distance from the gage, tidal zoning adjustments are necessary to align the tide staff readings with the tide state at the survey vessel location. In these cases the tide gage information must be entered by the processor in the office. The tide readings are adjusted first in time units and then in ratios of the tidal ranges at the staff and vessel locations.

(2) Interpolating positions. Soundings are typically collected by the survey vessel at a rate of approximately 5/sec. Large amounts of data are being collected in a real-time mode, so the computer does not have time, nor is it necessary, to apply a coordinate value to every sounding. It therefore attaches a coordinate to every fifth sounding (one every second). Soundings are plotted on maps by coordinates, and all soundings are used when doing volume computations, so it is necessary that all soundings have coordinate values attached. A computer program is used to interpolate between soundings that have field-generated coordinates and then to apply coordinates to the intermediate soundings as necessary.

(3) Sorting survey lines. A hydrographic survey consists of rows of soundings usually taken perpendicular to the centerline of the channel. Each row or line has a section number and a station number. In order to do volume computations and profiles, and overlap and check section comparisons, the surveys must start at the lowest station number and increase in ascending order. Due to field conditions and time restrictions the survey vessels usually cannot fulfill this requirement. Another processing program allows the processor to put lines in any order necessary to fulfill the requirements of the survey.

(4) Scanning/editing bad soundings. While collecting soundings the depth recorder will, from time to time, generate some incorrect soundings. The most common causes for this are air bubbles or debris in the water column, temperature inversions, and even nearby sonar. A computer program is used to scan every sounding in the survey and display any soundings that fall outside the specified range. This allows the operator to either change the sounding or let it stand as is. This decision is based on the general trend of the surrounding soundings, where the suspect sounding is located within the section, the type of survey being

scanned (condition, plans and specifications, before dredging or after dredging) and the operator's general knowledge of existing bottom conditions in that area.

(5) Volume computations. Volume computations are necessary for a number of reasons, including payment to dredging contractors, beach and dike design, placement area capacities, channel design, and accretion rates, just to name a few. Depending on the purpose and the general shape of the surveyed area, one of three programs is used to determine volumes. On areas that are more or less rectangular in shape, volumes are computed with a program written in HP-UX BASIC using the average-end-area method. This program was written in-house and tailored to Norfolk District's specific needs. This program uses the processed survey (hydro) files to compute the number of cubic yards that occupy the user-defined templates. Although this program will compute up to four separate templates in the same run, they must be the same width and have the same side slopes. The only item that can vary is the depth. During program execution, a profile is drawn on the screen of each cross-section with the dredging template. A hard copy is generated showing the end areas of each cross-section at the design depth, the cumulative yardage at each cross-section at the depth, and the average distance between each section. On areas that are irregular in shape or have an unconventional dredging prism, a program by Accugraph Corp., MTX 900 (Mountain Top) is used. This is an interactive CADD/engineering package. There are currently two methods of computing volumes available within this program. Instead of using text files for their computations, both of these programs use DTM (digital terrain modeling) files. DTM files are nothing more than ASCII renditions (X-Y-Z point translation to CADD Files) of the hydrographic survey (X-Y-Z) text files.

(a) The first method is included in the site design portion of the program and best lends itself to irregularly shaped areas. With this method the volumes are computed by geometric means and, therefore, no end areas or cumulative volumes per section are available, just the final volume. The CADD operator must first create a design surface to be compared to the surveyed bathymetry in order to generate a volume.

(b) The second method comes under the "Roads" design portion of the program. Although only one template can be run at a time, the shape (number of bottom faces and/or side slopes) of the template does not matter. This program is best used when the dredging prism or design templates consist of more than one bottom at different elevations with numerous side slopes. The design template can actually include one or more arcs. With this method the computations are done by the average-end-area method and, consequently, the operator can specify a printout which will include the end area of the stations and cumulative volumes per station. In addition, the operator has the option to specify profiles of the sections plotted to any scale he wishes. The after-dredge survey must be compared to the proposed channel (design surface) in order to compute the volume. Although the figures were referenced from the road design method DTM using an average-end-area computation, the site design method using the irregular TIN computation could be used as well.

(6) Creating a plot file. In order to plot the soundings on a map it is necessary to create a plot file. This is an ASCII text file that is created from the soundings in the hydro-file using HP-UX BASIC. The CADD system is then loaded, and the ASCII file is converted into an "easydata" file, which is a special Mountain Top drawing file. The entire file can now be handled like any other drawing file. The soundings now appear on the screen depicting the actual track lines that the boat took in the field. The size, interval, and rotation of the individual soundings are specified when the plot file is created and are determined by the scale and rotation of the map. Each sounding is located by Virginia State Plane Grid coordinates. This file can now be used in any mapping application desired.

(7) Creating a DTM file. When creating a plot file the operator has the option to also create a DTM (digital terrain modeling) file. This is also a type of ASCII file; however, this file consists of nothing more than X-Y-Z points. These points, when read by the CADD system, are shown in only one size, and a point can have no rotation, so only the interval is controlled. Usually, the two files are created together and set up

so that each sounding created for the plot file has a corresponding DTM point. As discussed earlier, a DTM file can be used for computing volumes, but it also has other uses, such as generating contours and 3-D models.

(8) Contouring. When mapping hydrographic surveys, it is usually required that the survey be contoured at some given interval. The interval is based on the intended purpose of the survey. Using a DTM file, the CADD system has the ability to generate and label the contours at any interval specified by the operator. This feature is especially helpful on large jobs covering several linear miles. There are some limitations in this portion of the program, and it is important that the operator be aware of and know how to deal with them. Because most of the data is in the form of relatively straight lines anywhere from 100 to 400 ft apart, the computer is forced to draw contours across relatively large areas which are not supported by elevations. This problem usually manifests itself in the form of contours with large loops, contours crossing, contours passing through the same point, and contours with gaps. As all of these conditions are unacceptable, it is necessary for the operator to closely examine all computer-generated contours and correct them where necessary. Incorporating cross-check lines into the survey will eliminate most of these problems.

(9) 3-D models. In many applications it is useful to create something other than a plan or elevation view of a project. The CADD system can be used to generate 3-D images of any DTM file. Several types of views can be created, ranging from perspective and isometric to triametric and orthographic. Having this type of versatility enables the object to be viewed at any angle, rotation, or elevation. After a wire drawing has been created, it can then be shaded to further enhance the 3-D effect. Although no valid horizontal positions or vertical elevations can be tied to these images, they are useful in giving the viewer an overall picture of terrain that may not be readily visible to the eye. Three-dimensional images are particularly helpful when implementing dike design for placement areas as well as beach replenishment designs. The operator is able to merge the dike or beach design with a DTM file of an existing survey of the area and then create a 3-D image showing the existing ground with the proposed structure in place. This is an extremely useful tool in conveying new concepts and/or ideas to persons not familiar with the project in question, or when trying to illustrate the impact (or lack of it) of a particular project on the surrounding area.

(10) Use of layers. In recent years the drawing of maps has evolved from drafting tables to CADD workstations. Most state-of-the-art CADD systems have a feature called layering. The operator may put together any combination of elements in a drawing and set them to any of 256 different layers. This allows the operator to handle large amounts of information quickly and efficiently. Perhaps the biggest advantage for mapping purposes is that more than one survey can reside on a single base map. Due to limited storage space it is necessary to make the most efficient use of what space is available. Up to four surveys are put on a single base map by setting each survey and anything associated with that survey to their own series of layers. For example, along with the soundings that make up a plans and specification survey, the contours, navigation aids, typical sections, easements, dredging areas, notes and any other items associated with this survey would be set to a specific set of layers. Usually a spread of about ten layers is used for a survey and its related information. On a map containing multiple surveys, the operator need only turn off the layers he does not wish to view and he is left with a map tailored to the information and survey in question. After a map has been completed it is archived to an optical disk reserved for that purpose. The base sheet is then cleared of all surveys and related information and restored to the main mass storage to await the next series of surveys.

(11) Plotting maps. A plot is usually begun by placing the channel lines on a blank sheet or computer screen in an orientation for maximum sheet coverage. Other easement boundaries that may impact construction are also shown. After a survey has been processed, the depths are placed on the sheet relative to the sheet rotation and the navigation channel alignment. Changes to navigation aids, adjacent shoreline, utilities, construction notes, and title blocks are made and placed on the drawing. The drawing is

then plotted as a first draft with felt-tipped pens. The plotted drawing is circulated to engineers for final inspection or signature in the title block. Following this process the drawing is replotted with the final changes, signed, and distributed to the appropriate organizations.

6-12. Depiction on Drawings of Observed Positions and Depths

Depths (or elevations) shall be plotted at the recorded position where they were taken. When fully automated hydrographic systems are used, positions/depths shall not be moved (i.e., smoothed) to the nominal track (cross-section) which was run. The depth shall be plotted at the observed coordinate obtained from the positioning system, and the decimal point shall represent the position. On manual positioning surveys in which no off-track deviation is recorded (e.g., tag line surveys), positions may be moved/smoothed to the nominal track run. Where sweep/swath systems are deployed, some data thinning may be required to plot individual elevations. Alternatively, color coding may be used in order to show all recorded depths. Cross-section plots (profile views) give the appearance of moved soundings, but the plots represent the projection of soundings along the best-fit cross-section (not the nominal section) through a measured survey section. Plot scales and formats should be selected to ensure clear delineation of desired details. Larger scale ratios should be used when needed to show survey information clearly. Depending on the nature or class of survey, any of three plotting formats may be used to depict hydrographic survey data.

a. Plan. A vast majority of surveys are plotted in site plan mapping format. Dredge payment surveys are usually plotted at scales of 100 or 200 ft to the inch, depending on the structural detail required. For more detailed construction work, larger scales (e.g., 1 in. = 40 ft and 1 in. = 50 ft) are commonly used. The recommended plan scale is 100 ft to the inch; however, 200 ft/inch or 400 ft/inch may be used where routine maintenance work is involved. A disadvantage of plan format is the inability to portray all the collected data at a reasonable character size. To increase data density requires a scale reduction, which increases the number of sheets covering a project and subsequent reproduction costs. Plan data are usually contoured relative to an absolute reference datum or an intermediate face above grade. Planimetric data may be added to the drawings depending on the nature and purpose of the survey.

b. Section. Section or profile views are used to depict dredging cross-sections. They are extremely useful in comparing and evaluating various surveys performed over the same cross-section, a common requirement in dredging work. Such comparisons are difficult to perform using plan views. Section views of channels and other construction work are typically drawn at scales of sufficient size to adequately detail construction placement/excavation. Horizontal scales of 20 ft/inch, 40 ft/inch, and 50 ft/inch are common for navigation projects. Vertical scales are usually exaggerated to either 5 ft/inch or 10 ft/inch in order to depict low-gradient side slopes (and provide a larger planimeter end area face). Usually, all recorded elevation data points can be plotted in section; however, the numerical value must be scaled from the drawing. Two-dimensional section plots cannot portray any along-section vessel misalignment. Section views are rarely used for project condition surveys.

c. Profile. Profile sections from surveys run parallel (i.e., longitudinally) along the project alignment are typically constructed for project condition reports or centerline reconnaissance surveys/studies. Profiles of channel centerlines or quarter-points can depict an extensive amount of information in relatively compressed scales, and will readily portray critical above project grade spikes or shoals. The use of profile format can significantly reduce the number of sheets required to cover a given project. For example, a project condition survey requiring a total of 10 to 15 plan sheets at 1 inch = 200 ft can be effectively shown in one or two profile drawings at 1 inch = 5,000 ft.

d. Computer-generated drawings. The digital or hard-copy map or chart is the primary result of a project survey. However, each survey may generate other residual information sources, such as project field notes and geographic information system (GIS) or DTM databases of results. In the past, the graphical plot (in plan, section, and/or profile view) has been the finished product. However, with digital terrain mapping capabilities, the original survey data will reside in computer storage with an unlimited number of display and computational options available. When hard-copy drawings are generated from CADD files, the following general guidelines are prescribed.

(1) Conventional drawing size, content, and layout. Surveys should be plotted on a standard American National Standards Institute (ANSI) sheet size that is compatible with standard report and/or bid document sizes. The first sheet of a series shall contain the following data: project title and limits; construction contract number; reference grid system; vicinity and location maps; and the contractor's logo and certification/seal. In addition, horizontal and vertical control used for the survey should be shown by plan and/or tabulation. The classification, accuracy, quality control results (i.e., cross-line check results), and date of the surveys shall also be indicated.

(2) Grids. Coordinate grids should be plotted on each sheet so as not to exceed 5-in. spacing at final chart scale.

(3) Legend and notes. The first sheet of a series shall contain a legend indicating the physical interpretation of any symbols. Standard notes shall be added to describe all facets of the survey. General notes may be placed on the first sheet, and specific notes shall be placed on the applicable sheets. When two or more surveys are combined onto one sheet, the source and areas of the composite survey shall be shown by a note (or revision thereto). Information which is listed by note may include the following: horizontal control data (tabulate coordinates used); control survey techniques and equipment; source of control data; tabulation of benchmark elevations; vertical datum used with references and conversions; horizontal datum used (e.g., NAD 27 or NAD 83); state plane coordinate system and zone; depth measurement procedures and sectors where methods were employed; size and weight of sounding leads and plates used; navigational aid data (tabulated); positions in latitude and longitude; state plane coordinates, date located, location technique, and accuracy; referenced data sources (field book numbers and dates, database file for DTM data); field party information; survey vessel; firm; contracting agency and contract number; and drafting reviewers. The same data may also be inserted into the assigned Intergraph design file level when such a system is used.

e. Data thinning routines. High density data sets cannot be plotted in plan view due to overlapping depths. High density sets may also be too large to efficiently process in volume routines. A number of methods are used in commercial data processing software to reduce the size of large data sets. These thinning routines typically use the TIN surface model to evaluate the terrain gradient in deciding which depths to eliminate. In flat areas, more depths can be eliminated without loss in overall model accuracy. In many cases, data reductions of 80% to 90% can be made in smooth terrain. Some software thinning routines use TIN contour density to eliminate data points in the TIN, as illustrated in Figure 6-9. Thinning of data sets for dredge volume computations is not recommended. These data sets may be thinned for plotting/display purposes.

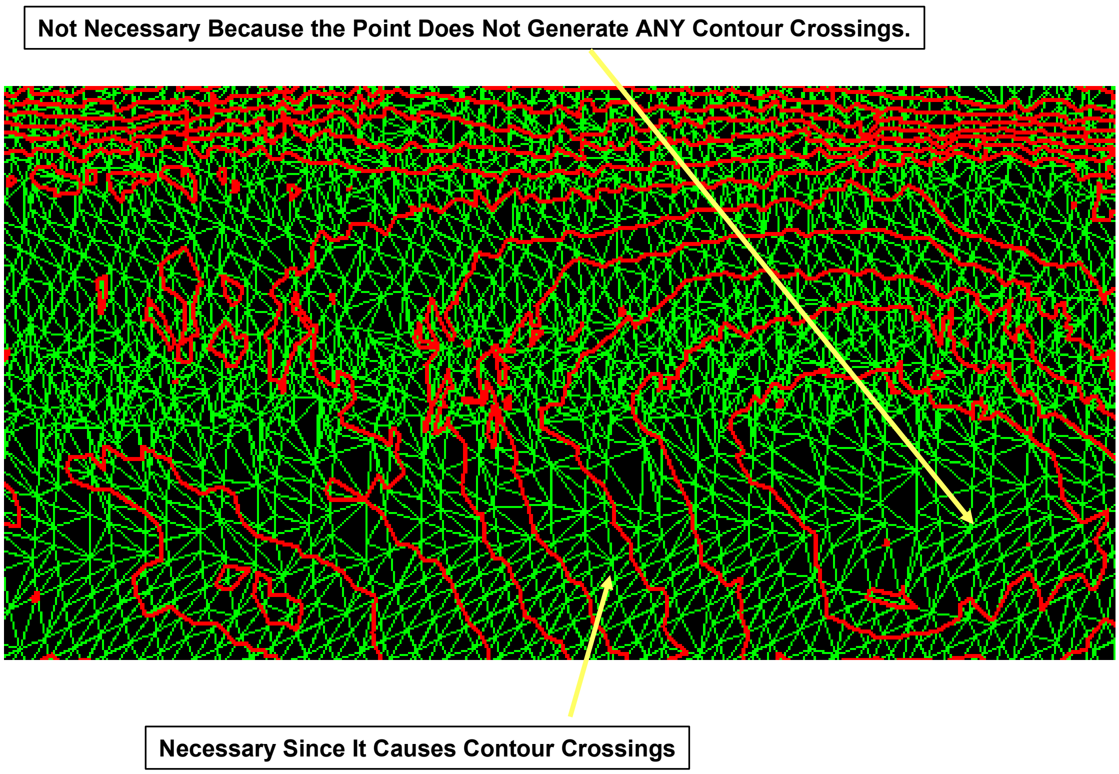


Figure 6-9. Contour thinning algorithm. The algorithm identifies those vertices not responsible for contributing to a single contour crossing in any of the triangles containing them. In addition, spikes can be automatically detected/removed by counting the number of contours enclosing an individual vertex within one edge of that vertex. (Beacon Resources, Inc)

6-13. Data Transfer Standards and Formats

Given the variety of automated hydrographic surveying systems in use throughout USACE (by both in-house and third-party contractor forces), it is not presently feasible or practical to specify a particular data format for recording field data. Recorded data elements should include, as a minimum, event date/time, adjusted position, and raw/ uncorrected depth (soundings). Related observations such as tide/stage/draft corrections, DGPS observables, calibration corrections, project orientation constants, and control station coordinates may also be optionally recorded in the database. Differential GPS systems can record geometry quality values (GDOP, PDOP, HDOP) which may vary during a survey. Automated systems should record uncorrected observations used to derive an adjusted depth. Corrections to these depth observations should be saved in a separate block or file or adequately recorded in a manual survey operation log.

a. Spatial Data Transfer Standard (SDTS). This standard, which was developed and is supported by the U.S. Geological Survey (USGS) under the auspices of the Federal Geographic Data Committee (FGDC), is a feature-based standard that is intended to apply to any geographically referenced data. SDTS has been approved by the National Institute of Standards and Technology (NIST) and the American National Standards Institute (ANSI), and has a staff of personnel at USGS dedicated to maintenance of the standard. It has also been approved by the FGDC as a Federal Information Processing Standard (FIPS).

SDTS is intended to enable complete and unambiguous digital data transfer between a sender and receiver. The standard is not required or intended for internal use, i.e., for transfer from field to office or contractor to office, although this use should be considered after the standard is further developed and becomes better suited to hydrographic data.

(1) Because of its broad and abstract nature, SDTS requires application profiles, or specific sets of implementation rules and guidelines, for actual data transfer use. Currently, the only profile is the Topological Vector Profile, which is not well-suited to hydrographic survey data. However, an application profile for hydrographic data is being developed.

(2) The designation of SDTS as a FIPS obligates all federal agencies to make their digital geographic data available to outside users in this format. Therefore, once a suitable application profile has been developed, districts that provide finished digital hydrographic survey data to non-USACE users need to embrace this standard, if the user requests data in this format. As stated above, this standard should also be considered for internal use.

b. DX-90. The DX-90 Data Exchange Standard was developed primarily by the National Oceanic and Atmospheric Administration (NOAA) and has been adopted by the International Hydrographic Organization for hydrographic data. DX-90 is a feature-based standard and is similar to SDTS in many ways. However, DX-90 is intended solely for geographically referenced hydrographic data. An application profile within the standard is specifically for vector data from hydrographic surveys. DX-90 is well suited to coordinate data, such as hydrographic survey coordinates and point features. However, the standard has partial topology, meaning it may have difficulty transferring large, related geometric shapes, such as revetment outlines, complex shorelines, roads, etc. Note that DX-90 is not a FIPS, meaning that federal agencies are not obligated to use the standard for any application. However, use of this standard, when completed, for field-to-office transfer should also be considered for flexibility, efficiency, and independence of data processing systems. Note that when the standard is completed, software translators and detailed implementation guidance from USGS, NOAA, and/or USACE will be available.

c. Proprietary and open standards. USACE districts currently use various CADD packages that each have their own proprietary graphics format, such as DGN (Intergraph) and DXF (AutoCad). Some of the more recent hydrographic survey systems may have the capability to output data in these or other formats. Software that creates Intergraph DGN files from ASCII X-Y-Z-Descriptor files is available through the U.S. Army Topographic Engineering Center to all USACE districts. This program, CVTPC (convert PC), enables the plotting of soundings and the placement of symbols in MicroStation. If a graphics file is not required for data transfer, then data in ASCII format is commonly recognized by survey system and CADD programs. Using such data, basic information, such as X-Y-Z coordinates, can usually be transferred in digital form.

d. Terrain modeling. Most hydrographic data acquisition and processing software, and office CADD packages, now provide terrain modeling modules to allow input, modeling, editing, and analysis of 3-D models. A user has direct interface necessary to build a non-uniform space point files (XYZ file) that can be used to create triangulated models and/or gridded models. Triangulated models can be created by two methods, Triangulated Irregular Network (TIN) and Topological Triangle Network (TTN). A TIN file is a surface model created from an XYZ file. It is defined by a set of 3-D triangular facets, which are defined by lines drawn between the points that define the surface. The TTN file is a surface model created from an XYZ file and surface specific features, such as breaklines, obscure areas, faults and edges. These elements form an intelligent network that contains information about neighboring triangles. A grid file contains uniformly spaced data that can be derived from a number of sources including XYZ files, TIN and TTN files, digitized or scanned contours, or translated outside sources. After creating the appropriate files, the user can create and display the 3-D model. To interpret the terrain models, the operator has a variety of procedures available, including:

- 2-D and 3-D contour displays
- 3-D cross-sections
- 3-D profile models
- 2-D and 3-D triangulated models
- Color-coded elevation displays
- Color-scaled contours
- Shaded relief (both color and monographic)
- Stereo displays (3-D raised models)

The user also has the necessary procedures to edit the terrain model by adding, deleting, and moving points and inserting new profiles, area edits, noise removal, and arithmetic operations. Options are also available to perform analysis options, such as line-of-sight displays, intervisibility studies, volume calculations, and creation of slope or aspect models.

Section IV
USACE Standards for Survey Coverage, Processing, Plotting, and Archiving

6-14. Geospatial Data Standards and Requirements

ER 11l0-l-8156, supplemented by EM 1110-1-2909 (Geospatial Data and Systems), establishes general criteria and presents policy and guidance for the acquisition, processing, storage, distribution, and utilization of non-tactical geospatial data throughout USACE. The policies contained in these documents apply to hydrographic survey data collected on navigation and flood control projects. These policies are in compliance with Executive Order 12906, *Coordinating Geographic Data Acquisition and Access: The National Spatial Data Infrastructure (NSDI)* and other appropriate standards, including the Spatial Data Transfer Standard/Federal Information Processing Standard 173, Federal Geographic Data Committee standards, and the CADD/GIS Technology Center (Tri-Service) Spatial Data Standards (SDS). EM 1110-1-2909 should be referred to for Corps policy on database development, data documentation, data quality assurance, data access, data archiving, data maintenance, data liability, data policies and coordination, and the appropriate use of Federal and Corps Geospatial data standards. Some of the highlights from ER 1110-1-8156 and EM 1110-1-2909 that specifically relate to hydrographic survey data are summarized below.

. *a. National Geospatial Data Clearinghouse (Clearinghouse).* The Clearinghouse is a distributed, electronic network of geospatial data producers, managers, and users operating on the Internet. The Clearinghouse is a key element of EO 12906 and will allow its users to determine what geospatial data exist, find the data they need, evaluate the usefulness of the data for their applications, and obtain or order the data as economically as possible. USACE hydrographic surveys (especially project condition surveys and river charts) must be listed on this Clearinghouse.

b. USACE Clearinghouse Node. HQUSACE established and maintains a computer network server on the National Geospatial Data Clearinghouse. This node functions as the primary point of public entry to the USACE geospatial data discovery path in the Clearinghouse. A separate electronic data page for each USACE Command has been established on the server. The Internet Universal Resource Locator (URL) address for the USACE Clearinghouse node is http://corps_geol .usace.army.mil

c. Database standards. EM 1110-1-2909 prescribes the following database standards, all of which have applicability to Corps hydrographic surveys.

(1) Data Format Standard -- FIPS PUB 173 Spatial Data Transfer Standard

(2) Metadata Standard-- FGDC Content Standard for Digital Geospatial Metadata

(3) Data Collection Standards-- EM 1110-1-2909, Chapter 11 *(Accuracy Standards for Engineering, Construction, and Facility Management Surveying and Mapping)* and this manual (EM 1110-2-1003 (Hydrographic Surveying)

(4) Data Accuracy Standards -- EM 1110-1-2909, Chapter 11 *(Accuracy Standards for Engineering, Construction, and Facility Management Surveying and Mapping)* and this manual (EM 1110-2-1003 (Hydrographic Surveying)

(5) Data Content Standards -- CADD/GIS Technology Center (Tri-Service) Spatial Data Standards and FGDC Bathymetric Subcommittee. National Hydrography Data Content Standard for Coastal and Inland Waterways – January 2000 (Draft)--see Appendix C.

(6) Data Symbology Standard -- CADD/GIS Technology Center (Tri-Service) Spatial Data Standards.

d. Database specifications. According to EM 1110-2-2909, a database specification serves two purposes: (1) it provides a firm set of rules for data collection and database construction, and (2) it describes the database in sufficient detail to permit application development. The database specification document will permit use of the database inside and outside of the producing organization and result in a substantial cost savings to users. The database specification may take several forms, but at a minimum should include the following sections:

(1) Scope -- a concise abstract of the coverage of the specification.

(2) Applicable Documents -- a bibliographic listing of the standards and references used in developing the specification.

(3) Database Description -- a summary of the information contained in and the structure/format of the database and the intended use of the data.

(4) Metadata -- a listing of the static metadata elements, including accuracy, datum, scale/resolution, source, and projection (if applicable).

(5) Data Format -- a detailed description of the data for-mat.

(6) Data Dictionary - a dictionary of the feature and attribute codes used in the database.

e. Metadata. Metadata is defined as descriptive information about the data in a database. Metadata describes the content, quality, fitness for use, access instructions, and other characteristics about the geospatial data. USACE requirements and policies for Metadata are in Chapter 8 *(USACE and Executive Order 12906)* of EM 1110-1-2909. A sample Metadata file for a hydrographic survey product is illustrated in that chapter. Metadata requirements are also outlined in paragraph 5.10 of Appendix B.

f. Computer-Aided Design and Drafting (CADD) standards. A/E/C CADD Standard has been developed by the CADD/GIS (Tri-Service) Technology Center to reduce redundant CADD standardization efforts within the Army, Navy, Air Force and Corps of Engineers. This standard is part of an initiative to consolidate existing CADD drafting standards into a format generic enough to operate under various CADD software packages (such as MicroStation and AutoCAD) and to incorporate existing industry/national standards. The A/E/C CADD Standard includes presentation graphics, level/layer assignments, electronic file naming, and standard symbology. In the final phase of the standards development, platform-specific software will be provided to aid the user in implementing the standards. In addition, non-graphic attribute data will be developed as part of the standard. In 1995, the combined resources of the CADD/GIS Technology Center, the American Institute of Architects (AIA), the Construction Specifications Institute (CSI), the United States Coast Guard, the Sheet Metal and Air Conditioning Contractors National Association (SMACNA), the General Services Administration (GSA), and the National Institute of Building Sciences' (NIBS) Facilities Information Council began an effort to develop a single CADD standard for the United States--the "US National CAD Standard" Working together, these organizations agreed to develop an integrated set of documents that collectively would represent the United States The US National CAD Standard is now available from NIBS.

6-15. General Hydrographic Survey Acquisition and Processing Criteria

Table 6-4. Recommended Standards for Hydrographic Data Acquisition and Plotting

	PROJECT CLASSIFICATION		
	Dredging Support Surveys	Project Condition Surveys	Other General Surveys
DRAWING PLOTTING SCALES AND DATA DENSITY			
Site Plan: Scale generally not larger than:	200 ft/in	500 ft/in	1,000 ft/in
Recommended scale	100 ft/in	200 ft/in	1,000 ft/in
New work or rock cuts	50 to 100 ft/in	50-100 ft/in	n/a
Section View:			
Horizontal scale generally not greater than:	100 ft/in	200 ft/in	n/a
Recommended horizontal scale	20 to 100 ft/in	as reqd	n/a
Recommended vertical scale	5 to 10 ft/in	as reqd	n/a
Profile View: Typical project condition report horizontal scale	n/a	500 to 5,000 ft/in	500 to 5,000 ft/in
Vertical scale	n/a	5 to 10 ft/in	5 to 10 ft/in
DEPTH DATA PLOTTING INTERVALS			
Site Plans: Plot	4 to 8 depths/in	4 to 8 depths/in	4 to 8 depths/in
Section View: Plot	all depths	n/a	n/a
Profile View: Plot	n/a	all depths	all depths
VESSEL POSITIONING CRITERIA			
Position Update Interval Not to Exceed:			
Tag line surveys	25 ft	50 ft	100 ft
Manual range-azimuth/total station	100 ft	200 ft	200 ft
Automated electronic tracking systems	25 ft or 1 sec	200 ft or 10 sec	200 ft
GPS/DGPS (Code or RTK carrier phase)	1 sec	1 sec	2 sec
Annotate fix mark on back up echo sounder	100 ft	200 ft	optional
Maximum off-track steering deviation distance	± 20 ft	± 20 ft	± 20 ft
or as percent of line spacing	20 %	20 %	20%
DEPTH DATA COLLECTION DENSITY			
Mechanical lead line, total station, sounding pole	10 to 25 ft	25 to 50 ft	as reqd
Analog recording echo sounders: collect depths at	5 to 10/sec	5 to 10/sec	5 to 10/sec
Manually scale depths at least every	25 ft	50 ft	200 ft
Horizontal recorder scale setting	150 ft/in	300 ft/in	as reqd
Nominal paper speed setting	4 in/min	2 in/min	as reqd
Vertical scale setting	10 ft/in	10 ft/in	10 ft/in
Resultant graphical scaling resolution	±0.2(V) ±10 (H)	±0.2(V) ±10 (H)	±0.2(V) ±10 (H)
Scale depths and apply corrections to nearest:	± 0.1 ft	± 0.1 ft	± 0.1 ft
Digital depth recording systems: collect depths at	Max rate	5 to 10/sec	5 to 10/sec
Depth resolution/precision	± 0.1 ft	± 0.1 ft	± 0.1 ft
Record and plot depths to nearest:	± 0.1 ft	± 0.1 ft	± 0.1 ft

Additional guidance for specific positioning and depth recording systems is found in chapters covering those systems.

6-16. Mandatory Requirements

There are no mandatory technical requirements in this general planning chapter. The guidance in Table 6-4 is recommended. Conformance with the Federal and Corps geospatial data standards and requirements listed in this Chapter is mandatory.

Chapter 7
Positioning Techniques for Offshore Engineering Surveys

7-1. General Scope and Applications

This chapter covers general procedural guidance and quality control criteria for visual, mechanical, electronic, and satellite positioning methods used to control surveys of river and harbor projects. Both terrestrial and satellite positioning systems are covered in this chapter. Terrestrial positioning methods include traditional land-based techniques such as sextant resection, triangulation, tag lines, microwave electronic distance measurement (EDM) systems, and electronic total stations. Since the early 1990's most of these terrestrial positioning methods have been largely replaced by satellite-based positioning methods, namely GPS and more accurate code phase Differential GPS (DGPS) and Real Time Kinematic (RTK) carrier phase DGPS. Since there are still isolated project areas where satellite GPS methods may be inaccessible or impractical, one of the traditional terrestrial survey methods covered in this chapter may be needed to provide survey control. Examples of such cases may include: (1) small dredging or marine construction projects where only a limited amount of depth coverage is required, (2) areas under bridges, in deep-draft harbor berths, or near dams where GPS satellite view is blocked, (3) intermittent, low-budget projects where traditional positioning methods may prove more economical than equipping a fully automated DGPS-based hydrographic survey system, or (4) rough reconnaissance surveys where meeting a specific positional accuracy standard is not required. Procedural methods and quality control (QC) criteria for some of these older survey techniques are retained in this manual primarily for reference purposes. The following topics are covered under this chapter:

Section I:	Sextant Resection Positioning
Section II:	Triangulation/Intersection Positioning
Section III:	Visual Positioning Methods
Section IV:	Tag Line Positioning Methods
Section V:	Range-Azimuth Positioning Methods
Section VI:	Land-Based Electronic Positioning Systems
Section VII:	Global Positioning System Techniques
Section VIII:	Summary of Positioning System Quality Control Standards

7-2. Positional Accuracy

All the positioning methods described in this chapter will meet USACE positional accuracy standards in Table 3-1 provided that distances from the shore-based reference point and the vessel are kept within tolerable limits. The "tolerable limit" will vary with the type of positioning method, procedures employed, and accuracy of the instrumentation used. In general, the positional accuracy of all systems will degrade as a function of distance from the baseline reference points--some faster than others. For example, a poorly conducted tag line survey may exceed Corps accuracy standards 300 feet from the baseline whereas an electronic total station could be extended 1000 ft or 2000 ft from the reference point. Sextant, triangulation, and range-range EDM are extremely geometry dependent; thus the accuracy of such methods will vary widely over a project area. DGPS-based positioning is not as significantly effected by such distance and geometrical accuracy degradations. Therefore, terrestrial-based positioning methods should only be employed where DGPS positioning is not available. Users must also fully assess and evaluate the resultant accuracy of any positioning method, including DGPS. Some visual or mechanical positioning methods can, under some conditions, exceed DGPS accuracies.

Section I
Sextant Resection Positioning

7-3. General Applications

Sextant positioning involves the simultaneous observation of two horizontal angles between three known objects from which the position of an offshore platform is resected--see Figure 7-1. Although sextant resection positioning was once one of the most widely used methods of positioning hydrographic survey vessels, channel sweep rafts, and dredges, it is now rarely, if ever, used. Sextant positioning was also widely used to calibrate medium frequency hyperbolic, range-range, and microwave positioning systems. Until the mid 1990s, sextant positioning was the primary method used by the US Coast Guard to locate and place buoys. Sextant positioning is totally performed aboard the survey vessel. It is not dependent on electronics, communications, or shore-based support. Under restricted conditions (i.e., close in on targets and near static position fixes), it can be relatively accurate when properly executed. In general, however, sextant positioning under dynamic vessel conditions is no longer considered accurate for most navigation or dredging applications. Currently, inexpensive hand-held GPS (Standard Positioning Service--SPS) receivers will typically provide accuracies that equal or exceed sextant positioning accuracies.

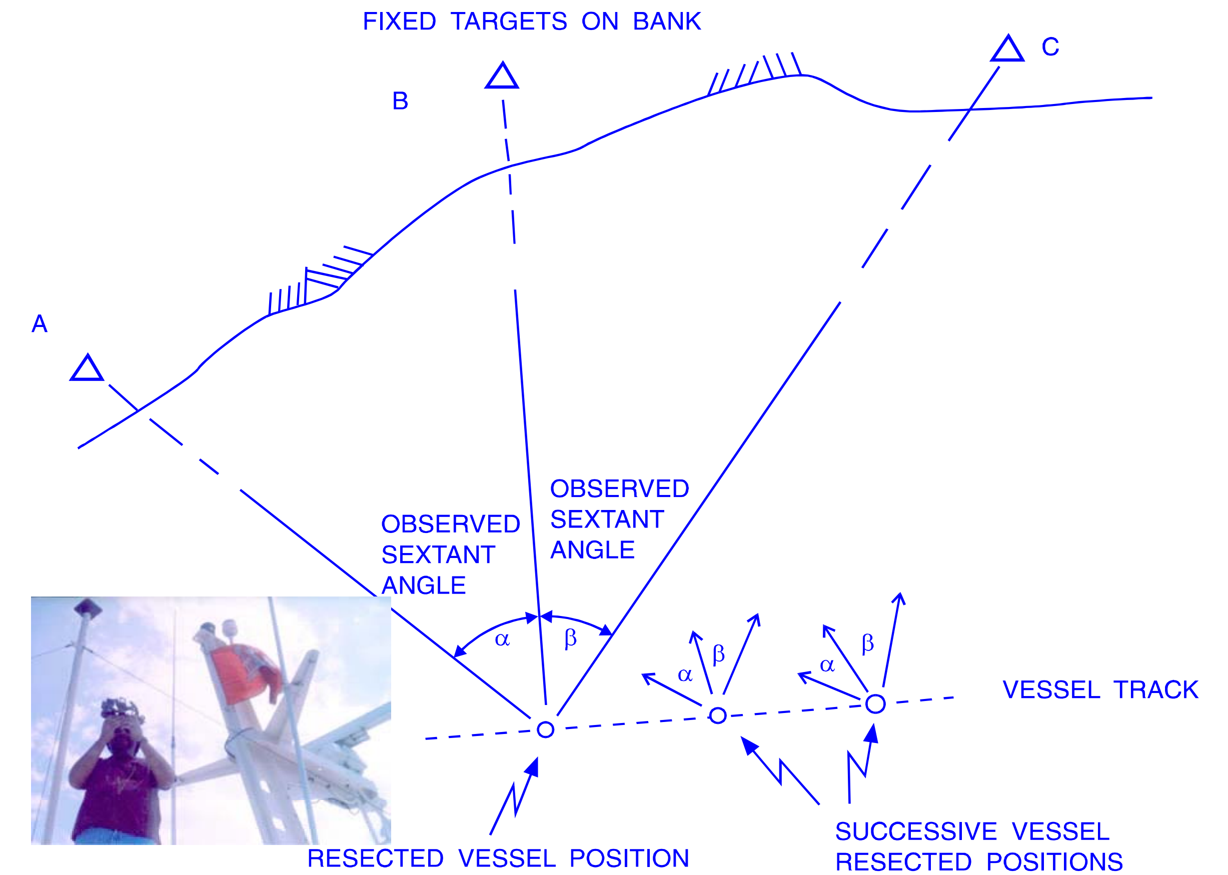


Figure 7-1. Sextant resectioning

7-4. Sextant Resectioning Procedures

Two sextant observers aboard the vessel are required. Sextant "fix" angles are usually taken at some even time interval or as called for by the depth observer (lead line or echo sounder). These angles are called or radioed to the recorder/plotter, along with depth information from that observer. Observed sextant angles are recorded with their times and, if applicable, depth data. These data can be recorded on a worksheet form or in a standard field survey book, or they can be directly input into a data logging device. The vessel's position is determined at the time of the fix by manual plotting with a three-arm protractor. Preconstructed constant sextant angle curves can also be drawn on a plotting sheet for on-line manual plotting. Alternatively, the two observed angles can be input into a computer containing standard survey resection software. Formulas for performing such computations are found in any standard surveying or geodesy textbook. The density of position fix updates varies with the timing and speed of the sextant observers and plotter/computer input. Overall, the process is extremely labor-intensive, requiring a boat operator, two sextant observers, a depth recorder operator, and a data logger/plotter. In extreme cases, these functions can be doubled or even tripled up (i.e., one of the sextant observers could also perform the recording and plotting function).

a. Hopper dredge positioning. A single sextant angle may be used in conjunction with a fixed range line of position, as shown in Figure 7-2. In years past this was a common technique for locating hopper dredges. Preplotted sheets showing the intersecting sextant angles and ranges were drawn up for each channel. A single sextant angle would quickly locate the dredge running along a constant channel range.

b. Redundant sextant resectioning. On stable offshore vessels and other platforms, multiple sextant angles can be observed to several targets. The resultant fix can be adjusted by onboard software using least squares adjustment techniques. This adjustment will provide an assessment of the positional accuracy. The results of a multiple resection can be quite accurate, and can be less than ± 1 m in some isolated cases. The US Coast Guard used this technique on buoy tenders.

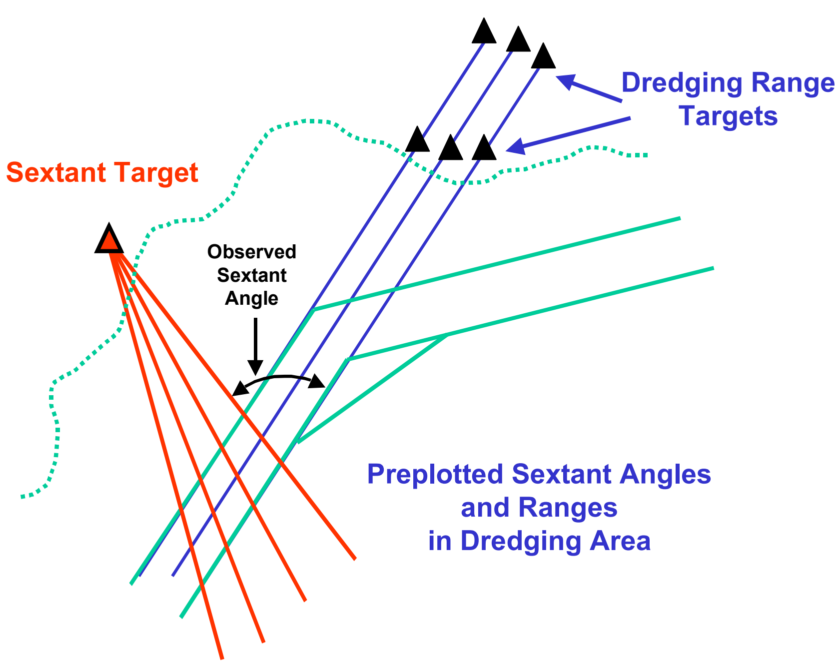


Figure 7-2. Hopper dredge control using combined visual ranges and sextant angles

7-5. Accuracy and Quality Control of Sextant Resection Positioning

The two observed sextant angles form the loci of circles, the intersection of which is the vessel's position. Each angle forms a circle defined by three points: the two shore control points/targets and the vessel. The geometry of these two intersecting circles is a primary factor in determining the strength of a sextant resection. As the two intersecting circles converge on each other, the resultant position weakens drastically. This is often termed the "swinger" since a three-arm protractor will swing along this arc to any position. As a result, the accuracy of a sextant position varies significantly with the geometrical location relative to the targets. In the best conditions, dynamic positional accuracies rarely exceeded 5 meters (95% RMS). Average accuracies were generally in the 10 to 20 meter range.

a. Determining the accuracy of a resected position. Historically, various numerical formulas were developed to depict the relative accuracy of a resected position. Constant error contours could also be drawn for any given target configuration. The simplest method for estimating resection accuracy at any point is to move each angle by its estimated accuracy and assess the resultant change in position. This is readily done when automated resection computing software is available, or by noting the position shift in a three-arm protractor. Positional accuracy needs to be accessed at various points in the work area.

b. Quality control factors. In performing sextant resection positioning the following QC factors must be considered. All impact the overall accuracy of a resected position.

(1) Precision of sextant angles. This is a function of the instrument's resolution, sharpness of the shore-based targets, relative rate of angular change, and, most importantly, the skills of the observers. Estimating the standard error of a sextant angle observed on a moving vessel is difficult--a range of ±1 to ±5 minutes of arc is typical. Sextant angles are usually recorded to the nearest minute of arc and, in some cases, to the nearest 0.1 minute of arc.

(2) Observer synchronization. Both angles must be observed simultaneously and from the same point. This is usually not feasible in practice, and observer eccentricities are accepted errors.

(3) Plotting errors. Plotting sextant fixes with a three-arm protractor aboard a moving vessel is not an exact process, and significant inaccuracies can result.

(4) Velocity and motion of the vessel. Vessel motion affects the ability of the observers to maintain angles on both targets. Slow vessel velocities are essential in performing accurate sextant surveys.

(5) Observer fatigue. Continuous sextant surveying is extremely fatiguing for the observers and plotter. Data quality usually degrades during the course of a survey due to fatigue.

(6) Targets. Sextant angle targets may include water tanks, lights, daymarks, beacons, etc. When natural targets with coordinated points are not available, temporary targets must be constructed and surveyed. The type of target (and its distance away when fog or haze is present) affects the sextant pointing accuracy.

c. Sextant calibration. Due to design and handling, internal sextant instrument calibration is not particularly stable. Observers must continuously check the calibration of their sextants. This is usually done periodically during the survey--typically at the end of each survey line.

d. Quality assurance. Few opportunities existed to perform QA checks on sextant positioning. When more than three targets were visible, different resection positions could be compared at an anchored position.

Section II
Triangulation/Intersection Positioning

7-6. General Applications

An offshore vessel or platform can be positioned (triangulated) by transit or theodolite angles observed from base line points on shore. This method was also commonly used to calibrate microwave positioning systems when fixed points were inaccessible to the vessel (e.g., dredges, drill barges). Intersection techniques are no longer employed in dynamic hydrographic surveying practice; however, the technique may have application in areas where electronic positioning systems cannot be deployed or where increased positional accuracy is required. As with sextant surveying methods, angular intersection positioning techniques are labor-intensive. As indicated in Figure 7-3, two (or more) shore-based transit or theodolite observers are required, along with either visual or radio communication equipment with which to transmit the observed angles (or direction azimuths) to the offshore vessel for on-line recording, plotting, and/or calibration analysis. Due to the higher precision and stability of the instruments, the resultant positional accuracy can be quite good, provided observing procedures are properly executed. Theodolite angular observations to align static platforms are extremely accurate, and triangulation techniques are often used to supplement electronic distance measurement (EDM) or DGPS positioning of fixed offshore structures (piers, bridges, rigs, etc.)--both during construction and subsequent deformation monitoring.

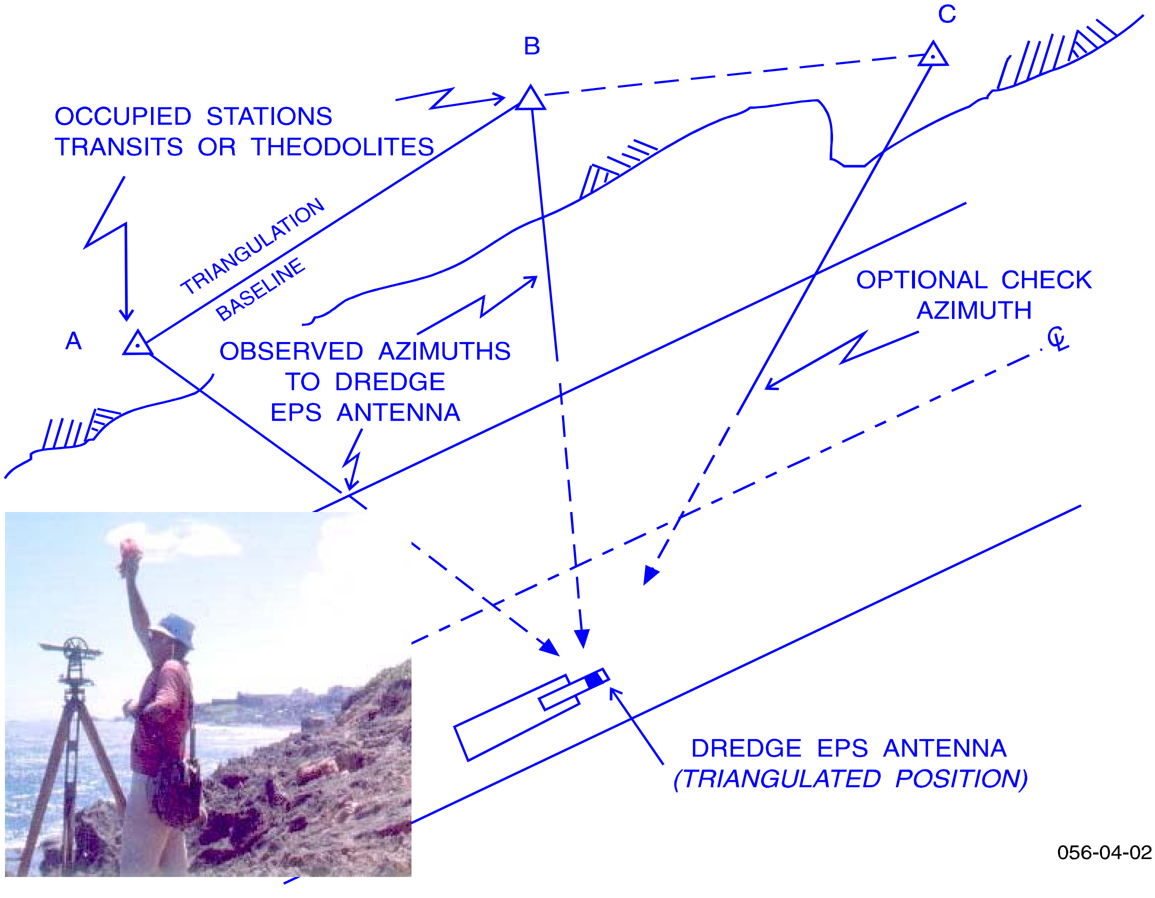


Figure 7-3. Vessel location using triangulation/intersection positioning methods

7-7. Intersection Positioning Procedures

A wide variety of angle or azimuth direction measuring instruments may be used. These include standard surveying transits, geodetic theodolites, and total stations. Instruments have been designed with hand cranks to facilitate continuous tracking of a moving vessel. The shore-based direction measuring instruments are set over known control monuments and aligned/referenced to one another or other positioned targets or landmarks. Two backsight check points are recommended, and frequent rechecks of the backsight orientations should be made during the course of the survey (normally every half-hour). Backsight orientations may be set to zero (resultant direction observations to the boat are then angles) or aligned to the grid azimuth between the occupied point and reference backsight (resultant directions to the boat are direct grid azimuths). The selected orientation depends on the onboard position computation/plotting method employed. Simultaneously observed positional "fixes" are usually called for from the boat by radio (or by visual flags where radio communication is unavailable). Fixes may be at equal time intervals or as called for on a random or as-needed basis. Advance warning is made of upcoming fix events so that observers can initiate precise tracking of the boat. A defined point aboard the vessel is tracked. This well-marked point should be centered over the echo sounder transducer or may be the positioning system antenna in the case of calibration work. In some instances, a preset alignment of an offshore platform is required. In this case, the precomputed alignment is set into each of the instruments and the platform is "walked" into position by the observers.

7-8. Data Recording and Plotting

Angles/direction azimuths are observed to units commensurate with the instruments and relative distance and velocity of the offshore vessel. Normally the nearest minute (or 0.01 deg) is adequate for dynamic hydrographic applications. Static observations will use repeated directions to increase accuracy to the ±1 second of arc level if needed. Angular data are relayed to and recorded aboard the boat and, in cases in which communications are erratic, at the instrument point also. Data may be recorded on worksheet forms or standard field survey books or input into a data logging device. Intersection data may be plotted aboard a dredge or survey vessel using standard drafting machines or preplotted azimuth array sheets. Neither of these methods is considered highly accurate, but each is adequate for visual navigation purposes

7-9. Accuracy of Triangulation/Intersection Positioning

As in conventional land surveying triangulation work, the accuracy of a point intersected by two azimuth directions depends on the precision of the instruments (their tracking accuracy) and the geometrical strength of the intersection. The positional accuracy, therefore, varies throughout the project area. An overall error analysis is complex since the angular standard errors for each instrument vary as a function of distance between the instrument and the vessel. Thus, determining the dimensions of the resultant error ellipse is more difficult.

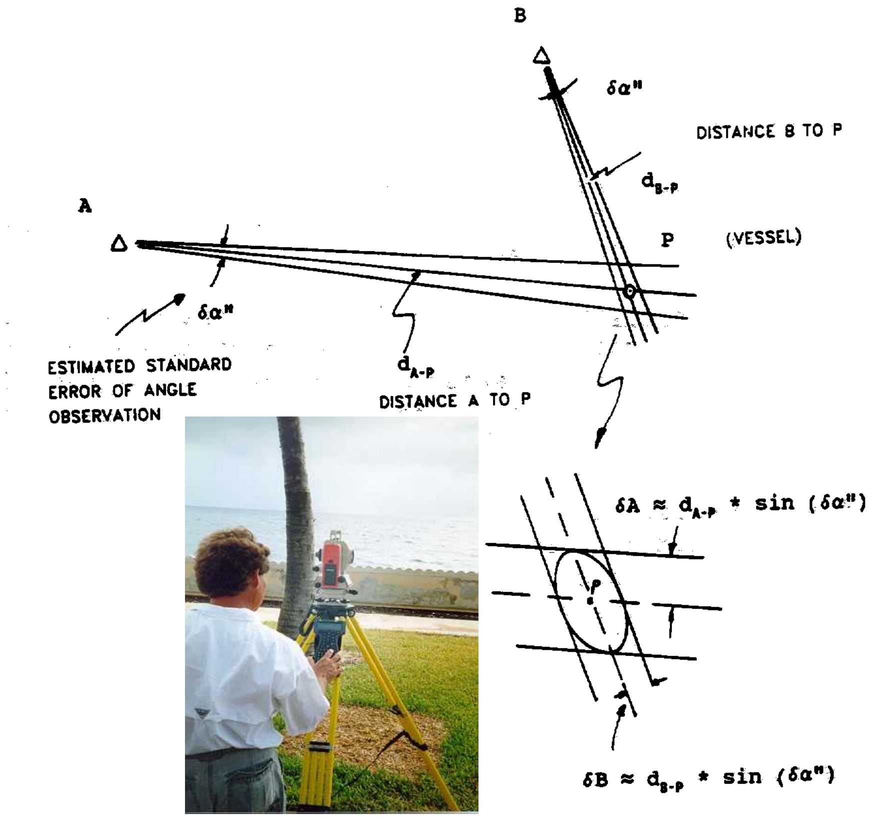


Figure 7-4. Estimating accuracy of intersected angles

a. A practical (but only *approximate*) estimate of the accuracy of an intersected position may be made by averaging the standard errors of each azimuth displacement at the offshore location, using the computed distances from each observing point. Given the theodolite/transit observing points *A* and *B*, and distances d_{A-P} and d_{B-P} to the offshore platform (Figure 7-4):

$$\delta_A = d_{A-P} \cdot \sin(\delta\alpha'')$$

$$\delta_B = d_{B-P} \cdot \sin(\delta\alpha'')$$

$$\text{then,} \quad \sigma_{Avg} = (\delta_A + \delta_B)/2 \qquad \text{(Eq 7-1)}$$

where

σ_{Avg} = estimated standard error of an azimuth displacement at the offshore point

$\delta\alpha''$ = estimated angular tracking accuracy of the particular instrument used (assumed the same for both instruments) *b.* The RMS error (at either 1-σ or 95%) can be estimated using Equation 7-2:

$$RMS_{(1\text{-}\sigma)} = 1.414 \;.\; \sigma_{AVG} \;.\; \text{cosec } A$$

or at 95% confidence level;

$$RMS_{95\%} = 2.447 \;.\; \sigma_{AVG} \;.\; \text{cosec } A \qquad \text{(Eq 7-2)}$$

where *A* is the angle of intersection between the two transit/theodolite azimuths at the offshore point.

c. The above computation may also be performed graphically. The left page in Figure 7-5 depicts a sample field computation of the accuracy of a static intersected point (i.e., spudded dredge) using the above approximate formulas. The right page shows an alternate method of computing the RMS accuracy when the distances are simply averaged.

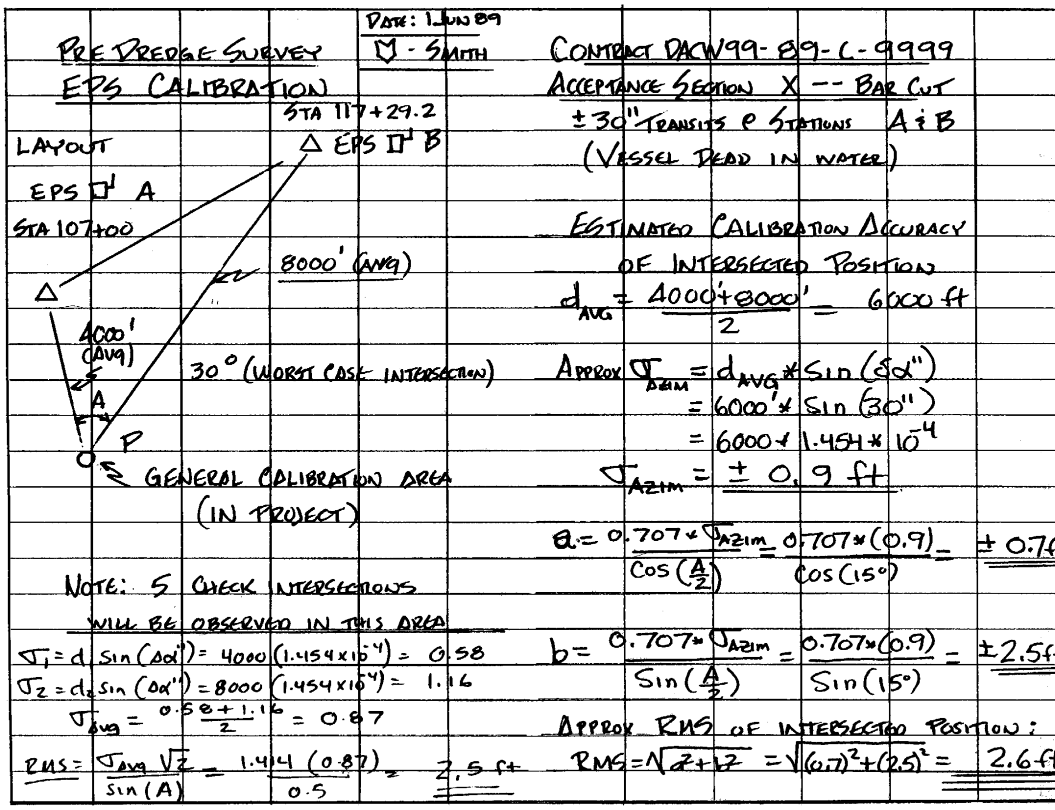


Figure 7-5. Field computation of intersected position accuracy

d. Multiple azimuth intersection techniques. To increase the accuracy of a triangulated point, additional shore stations are occupied in such a manner that each vessel position has three or more azimuth observations. This procedure provides redundancy and allows for an on-line assessment of the accuracy of the resultant position. Normally, a least-squares adjustment technique is performed on computers aboard the vessel. In aligning offshore structures during construction, or monitoring subsequent deformations, redundant theodolite azimuths are normally required. Theodolite (or total station) directions are repeatedly observed to increase accuracy. These azimuth alignments are combined with concurrent EDM or GPS distance observations in a properly weighted least-squares adjustment.

7-10. Quality Control and Quality Assurance

Periodic backsight checks should be made during the course of the survey. Like sextant survey methods, observer and plotter fatigue can impact quality. A third instrument provides the only semblance of an independent QA check on intersected point; however, this was rarely practical in practice.

Section III
Visual Positioning Methods

7-11. General Applications

Visual location relative to known shore features or flags was once a common hopper dredge positioning method. Few applications remain today, other than for construction--e.g., horizontal and vertical alignment of construction equipment, rigs, barges, etc. Dynamic hydrographic survey positioning by intersecting visible ranges and other identifiable objects is now rarely performed, given the wide availability of GPS control. Relative visual positioning is generally suitable only for non-navigation reconnaissance work where identifiable features on the furnished drawing, navigation chart, or map will be assumed to be accurate for this type of survey. These include navigational aids, beacons, day markers, bridges and other structures or map features. For some dredging and other investigative work, additional range poles, flags, and/or lasers are set ashore, as shown in Figure 7-6. Fixes are typically taken when the boat is abeam or lateral of an identifiable object and a constant speed is maintained to the next identifiable object or range intersection. Intermediate soundings are interpolated between the two fixes. The plotted features are presumed to be error-free, and a constant vessel speed is assumed to have occurred between the control features. Ranges established by sighting across such features or additional shore points may be intersected for position determination. Accuracies of such surveys are considered marginal, at best. All drawings depicting these surveys should caution users concerning the approximate nature of the data and warn against their use in design or construction.

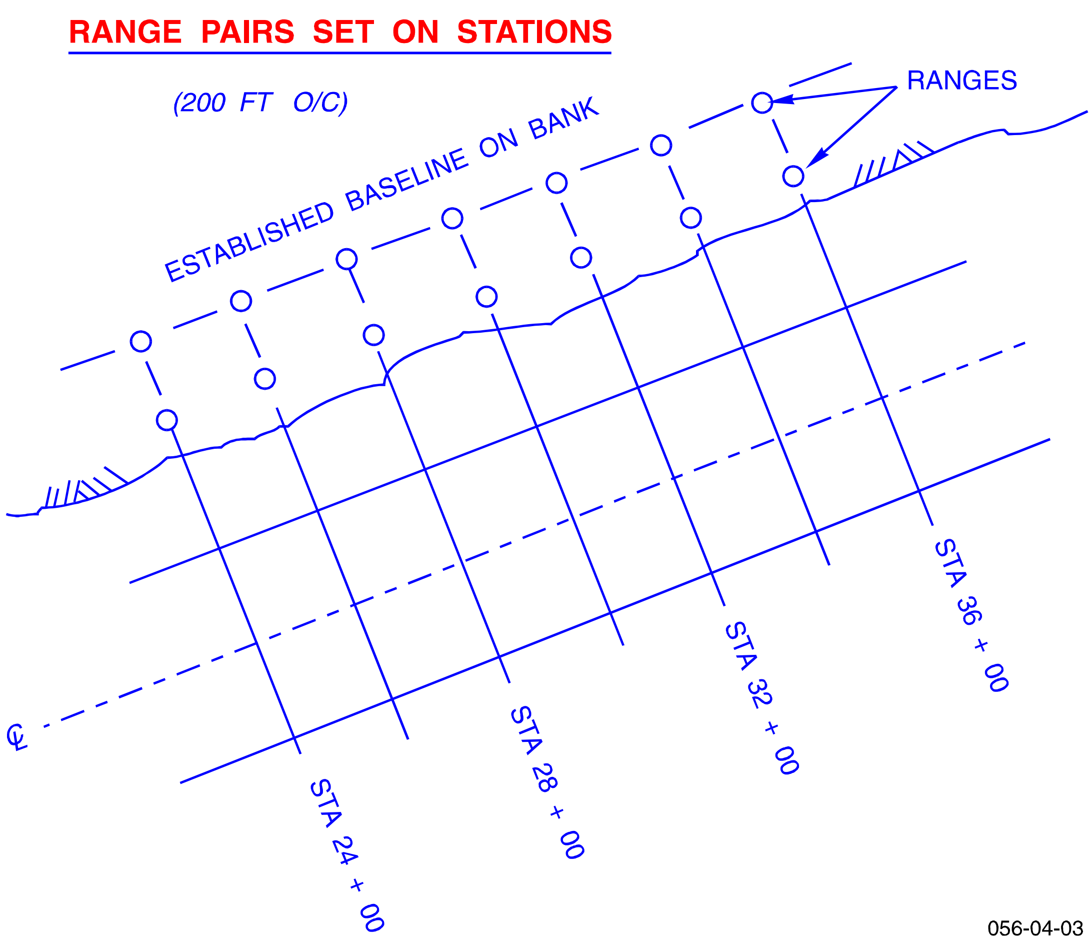


Figure 7-6. Typical visual dredging range configuration

7-12. Construction/Dredging Control Using Ranges

Offshore construction platforms, including dredges, can be effectively (and often accurately) controlled from visual ranges. Directional lasers are often used in place of range targets, and can provide both horizontal and vertical alignment to construction vehicles. In some hopper dredge work, alignment control is required only lateral to the project axis--see Figure 7-6. Sets of range pairs are typically set along a canal bank or bulkhead or at the projected end of the channel. Existing sailing ranges may also be used. Normally, range pairs are established at fairly dense intervals (e.g., 100 ft O/C). The limiting factor is the distance offshore relative to the range spread. A common rule-of-thumb is that the ratio should not exceed 10 to 1. For canal or other limited area construction projects, visual alignment accuracies can be quite accurate.

7-13. Uncontrolled Project Centerline Surveys

Approximate visual positioning was once commonly used in running centerline check surveys over uncontrolled recreational projects of relatively shallow project depth. The vessel is maintained relative to the approximate center of the project using local visual navigation aids, taken from a map or other source. The lateral error is a function of the ability of the boat operator to estimate the project's center. The accuracy of the resultant profile depends on the distance between identifiable features, chart scale, constant vessel velocity, and numerous other factors. Errors could approach 100 m. However, since these relative surveys are intended for reconnaissance purposes only, such inaccuracies may be tolerable. Any shoals encountered during these reconnaissance surveys that warrant a more detailed investigation would be developed using electronic or satellite positioning techniques. Survey data from visually controlled surveys are normally plotted in either plan or profile format, and not at a larger scale than that used to control the survey.

7-14. Accuracy and Quality Control

The accuracy of visual positioning techniques is difficult to access. Laser guided horizontal and vertical alignment can be highly accurate at reasonable distances from the target. Visual range-pair alignment accuracy is a function of the distance from the targets and the range pair spread. Positioning relative to existing map features varies with the map scale, interpolations, and feature accuracy. For these reasons, visual techniques are no longer used for navigation and dredging drawings. QA checks are rarely performed on visual positioning.

Section IV
Tag Line Positioning Methods

7-15. General Applications

Tag line positioning employs a calibrated wire rope stretched perpendicular from hubs on a baseline to the survey boat (Figure 7-7). Up until the 1970s dozens of Corps survey crews used tag line survey methods to monitor dredging progress of navigation projects. In addition to traditional channel cross-section surveys, tag lines were employed to position floating platforms (barges) used in subsurface investigation for channel obstructions, core borings, jet probings, and channel clearance sweep surveys. In the 1970s, tag line methods were largely replaced by microwave EDM and range-azimuth techniques, which in turn were replaced by GPS positioning in the mid-1990s. A few USACE districts have maintained a tag line survey capability for critical site investigation work; typically in areas where GPS signals are blocked, such as around berthing areas. Usually, however, an electronic total station is preferred for such surveys. A tag line survey requires no electronics or communication devices. Within limited distances off the baseline, and with proper execution, a tag line controlled survey is an accurate and stable method of performing hydrographic surveys and other investigative work for marine design and construction.

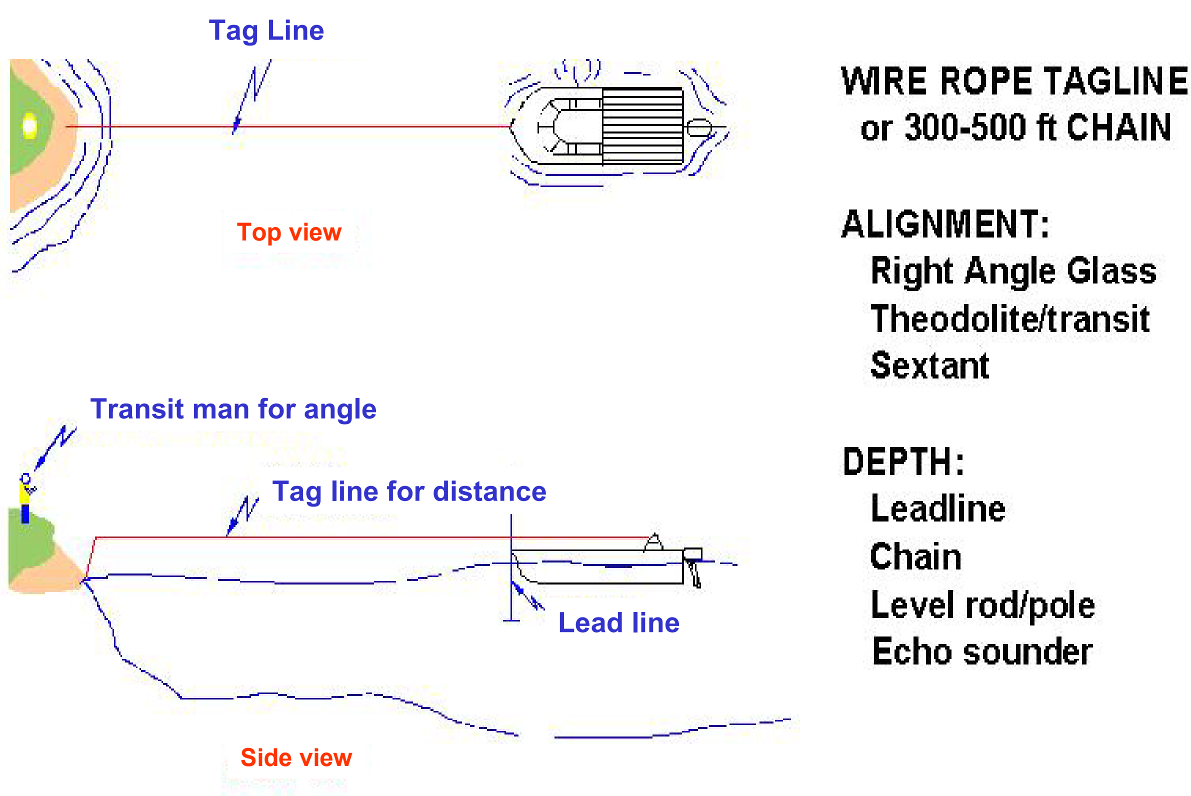


Figure 7-7. Tag line surveys

7-16. Tag Line Measurement Procedures

A tag line survey is simply a hydrographic method of running cross sections from a fixed baseline. Except for the boat and use of wire rope instead of chain, the same survey procedures are used as in highway cross-sectioning. The most accurate tag line distance measurements are conducted while the survey boat is stationary and holding constant tag line tension and alignment. Tag line surveys run dynamically (using echo sounders) are not as accurate as those conducted statically. Depths are observed with lead lines, sounding poles, level rods, or acoustically.

a. Static observations. Tag line length observations are made when the boat is properly aligned on the section and the wire is pulled taut to minimize sag. The zero end of the tag line must be firmly anchored on the baseline and held with a pole of sufficient leverage to withstand the pull from the boat. The tag line is payed out over the bow with the boat in reverse, and the winch clutch braked for each reading. The line is stopped when the interval mark is precisely at the depth measuring point on the boat (bow or transducer). The boat operator must maneuver the boat onto the proper cross-section alignment. This may be directed from ashore by hand signals or radio. Once on line, and with the tag line winch fully braked, the boat motor speed is regulated to hold the line taut out of the water and with only minimal apparent sag, at which time the depth is observed. Depending on the vessel power available and the weight of the line, the distance a tag line can be pulled fully taut will vary--pulls up to and exceeding 2,000 ft are possible. The accuracy of a tag line measurement will degrade drastically once the vessel is no longer able to provide sufficient power to suspend the line out of the water.

b. Dynamic or continuous tag line surveys. Some tag line surveys are conducted in a continuous (dynamic) mode using analog echo sounders. The boat is not stopped at tag line intervals, but the echo sounder is “fixed” at observed intervals as the reel pays out. Controlling alignment and tag line tension is not assured when this survey method is used.

c. Baseline boat tag line extension methods. Tag lines may be anchored to a floating vessel (baseline boat) that has previously been positioned by tag line or other means. Due to the compounding accumulation of error, such techniques are highly inaccurate. Since right angle prisms are typically used to hold the alignment of both the baseline boat and extended tag line boat, resultant positional errors of ±50 m or more are not uncommon.

d. Other tag line survey methods. A tag line may be used to maintain a constant range from the baseline hub. The line is held taut and the boat traverses along the constant tag line arc. Position fixes along the arc may be taken with a sextant or transit. Radial tag line surveys may be conducted from a single point on the baseline, with the survey vessel progressing outward along constant radials. Substituting an electronic ranging device for a tag line provides a better distance accuracy at extended ranges. In addition to normal cross-sectioning of harbors and canals, this survey method is commonly used in running-river cross sections and offshore sections for beach renourishment studies. The electronic positioning device and orientation instrument are moved to each incremental hub along the baseline. In some cases, a radial pattern may be run from one station. The survey vessel is guided along a constant azimuth in the same manner used in tag line work. Along-track (section) distance fixes are taken visually from an automated positioning system display. The accuracy of these distance readings is a function of the positioning system's stability, its update cycle, and the velocity of the boat. Higher accuracy surveys are obtained at slower velocities.

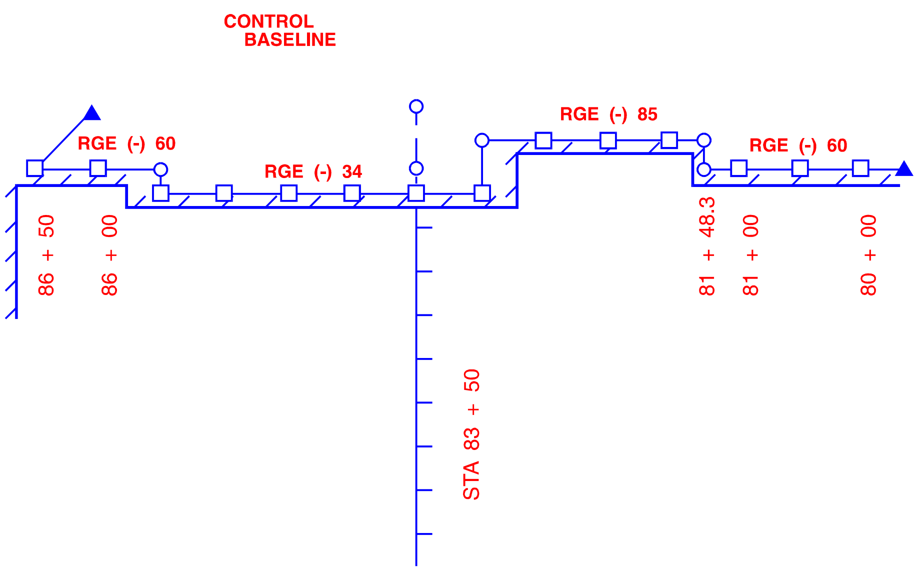


Figure 7-8. Typical baseline layout along bulkhead

e. Baseline layout for tag line surveys. Baselines for controlling tag line work are set using standard construction survey techniques and standards. Intermediate points (i.e., hubs) are surveyed at the line spacing required, usually 25, 50, or 100 ft O/C. These baselines should ideally be tied to USACE 3rd Order, Class II project control. However, 4th Order procedures may be used in setting intermediate control points along the baseline. Standard chaining or total station methods are used to lay out baselines. Baselines are normally aligned to the project's local coordinate system (station-range/offset) rather than a state plane system. See Figure 7-8.

(1) Intermediate points, or hubs, may be set for permanent or temporary use. Intermediate hubs can be marked by stakes, PK nails, flagging, or any other method. Back range hubs are established behind the baseline if needed. Project stationing and range offsets should be marked on the stakes and/or painted on bulkheads facing seaward for offshore identification. Baseline hubs must be located at points that are unobstructed to seaward and where the tag line end can be firmly secured.

(2) Baselines can be established in shallow water by staking with 2- by 2-in. wooden stakes, iron pipe, rebar, etc., for tagging locations. Baselines staked in shallow water can be used by small shallow-draft workboats (outboard motor or inboard/outboard motor propulsion). The chain/weight used on the end of the tag line forming a loop will hold the tag line at the base of the stake/pipe/rebar when tension is applied to the line by the motor and braking assembly on the power/manual reel or winch. In far offshore projects, piles have been driven adjacent to the channel in order to establish a baseline.

f. Tag line alignment methods. Lateral alignment control of the survey boat can be the weakest link in the performance of tag line surveys, especially if strong currents are present. The method used to project the desired cross-section alignment (usually 90 degrees) off the baseline is also critical. Poor alignment techniques will limit the distance that a tag line cross section can be reliably projected from the baseline. Methods for holding alignment include visual range flags, right angle prisms, transits, theodolites, sextants, and total stations. The use of visual range poles or flags presumes an adequate range base is established. Right angle prisms shall generally not be used beyond 200 or 300 ft unless only rough reconnaissance surveys are being performed.

g. Data recording procedures. Tag line survey and related depth measurements may be recorded on worksheets or in a standard field survey book (Figure 7-9). Survey data are plotted in either site plan or section formats.

STA. 16+00 CUT S-19

RGE.	SDG.	TIDE	RED.	TIME	
-75	7.2	+0.9	6.3	1:50	
-50	7.4		6.5		
-25	7.5		6.6		
0	7.6		6.7		
25	7.5		6.6		
50	11.7		10.8		
75	11.7		10.8		
100	11.7		10.8		
150	11.8		10.9		
175	11.9		11.0		
200	11.3		10.4		
225	8.0		7.1		
250	7.8		6.9		
275	7.8		6.9		
300	7.7		6.8		

STA. 37+65.94 CUT S-19

RGE.	SDG.	TIDE	RED.	TIME	
-75	7.0	+0.9	6.1	10:24	
-50	7.2		6.3		
-25	7.1		6.2		
0	8.6		7.7		W. LIMIT
25	9.3		8.4		
50	10.4		9.5		
75	11.2		10.3		
100	11.7		10.8		
150	10.8		9.9		
162	6.3		5.4		Rock
175	10.9		10.0		
200	7.7		6.8		
225	7.5		6.6		
236	7.4		6.5		E. LIMIT
250	7.4		6.5		
275	7.3		6.4		

Figure 7-9. Field book recording of depths at 25-ft tag line marks

h. Survey boats. Any size and type of boat may be used for performing tag line surveys. The most common types used in USACE are open workboats of rugged hull construction. Open boats provide ease and flexibility of tag line measurement and allow maintenance to the tag line power winches. Typical boat lengths range from 16 to 25 ft. Drafts of less than 1 ft are essential in order to work in shallow areas and to provide ease of beaching. Reinforced hulls are necessary since many tag line surveys are conducted adjacent to revetments, stone jetties, and other structures. An experienced boat operator is essential to the accurate and safe execution of a tag line survey. The operator must simultaneously maintain lateral alignment in currents, control the tag line tension, and, in some cases, operate the power winch mechanism. Lead line, sounding pole, or echo sounding depth observations are taken and recorded at the boat operator's signal. In cases in which tag line surveys are performed in navigable waters with heavy shipping traffic, the boat operator may have to release tag line tension to allow the wire to lower and rest on the channel bottom while a vessel passes.

7-17. Tag Line Equipment

Tag line surveys can be conducted using any type of continuous measuring device. Over short distances, tag line surveys may be performed using 50-ft cloth tapes or 100- to 300-ft surveyor's chains. Revolution-counting payout gages/meters are also employed. For greater distances, however, a lightweight, stainless steel (corrosion-resistant), braided cable, or wire rope (7 strand ($\pm$), 7/32-in. diameter or larger, depending on use of the tag line) is normally used. Wire rope tag line lengths vary from 500 ft to over 5,000 ft, and baseline boat tag lines from 5,000 ft to 15,000 ft long. A 2-ft loop of galvanized chain (5/8- to 3/4-in.) with a galvanized clevis and swivel should be used to connect the tag line wire to the chain.

a. Marking. The tag line cable is marked at any desired interval, usually every 25 ft. A variety of methods are used to mark and code the intervals along the tag line. Leather or plastic flagging or galvanized sleeves may be firmly crimped to the line using wire splicing/crimping tools--see Figure 7-11. Strands of polypropylene rope may also be inserted through the sleeves prior to crimping. Marks are coded by color and/or size. These marks and the coding system must be readily identified to prevent reading blunders, a common problem on tag line work.

b. Swivels. Corrosion-resistant swivels are inserted along the tag line at intermediate points, usually at the 100-ft mark, the 500-ft mark, and at subsequent 500-ft intervals thereafter. The swivels help in eliminating loops (pig tails) in the wire when continuous tension is not maintained. When the line becomes slack, wire rolls and loops appear, causing crimps and breaks in the wire. The swivels also serve as checks for incremental, even, 500-ft distances.

c. Power winches. Power winches are used to reel and control tag line payout. The winches are permanently mounted amidships and may be manually, electrically, or gasoline powered. Clutching and braking assemblies in the power winches regulate tag line payout. Line payout can be alternated over the bow or stern. A guide or fair lead is used for maintaining control during payout and reeling in of the line. Hand reels or manual winches are normally used on sounding boat tag lines because of the shorter or limited wire lengths deployed. Power reels/winches are commonly used on baseline boats due to the longer amounts of line involved. Power reels should have manual hand crank backup capability in case of power failure. Figure 7-10 depicts a typical installation of a power winch aboard an open workboat.

Figure 7-10. Tag line equipment aboard small 19-ft workboat (Jacksonville District)

7-18. Accuracy, Calibration, and Quality Control Requirements

a. Accuracy. Tag line surveys are highly accurate only within finite limits. Critical limitations include the length of extended line off the fixed baseline hub, the ability to measure and hold vessel alignment in strong currents, and the ability (power) of the boat to maintain a taut (sag-free) line over a given distance. The positional accuracy of a point positioned by tag line may be computed using the estimated accuracy of the alignment and distance measurements; similarly to that done with range-azimuth survey methods. Up to about 1,000 ft from the baseline, a tag line will maintain acceptable accuracy for dredging and navigation surveys; provided that it is pulled taut and accurate azimuth alignment is held.

b. Calibration. Flagged tag line intervals must be periodically calibrated every 3 to 6 months against a chained or EDM distance. The tag line should also be recalibrated after breaks have been respliced. Wire rope splicing must be performed so the original length is maintained as closely as possible. Calibration is done by comparing distances of the marked intervals with corresponding distances measured with a tape or instrument of higher accuracy (Figure 7-11). This is most easily performed along a pier or wharf where the tag line can be fully extended and compared with taped or EDM distances. At each marked interval on the tagline, a difference shall be observed and recorded in a field book.

c. Quality assurance. Independent checks on tag line surveys were rarely performed in practice. Occasionally, when baselines could be set on opposite canal banks, duplicate (overlapping) cross-sections could be run from opposing baselines as a check.

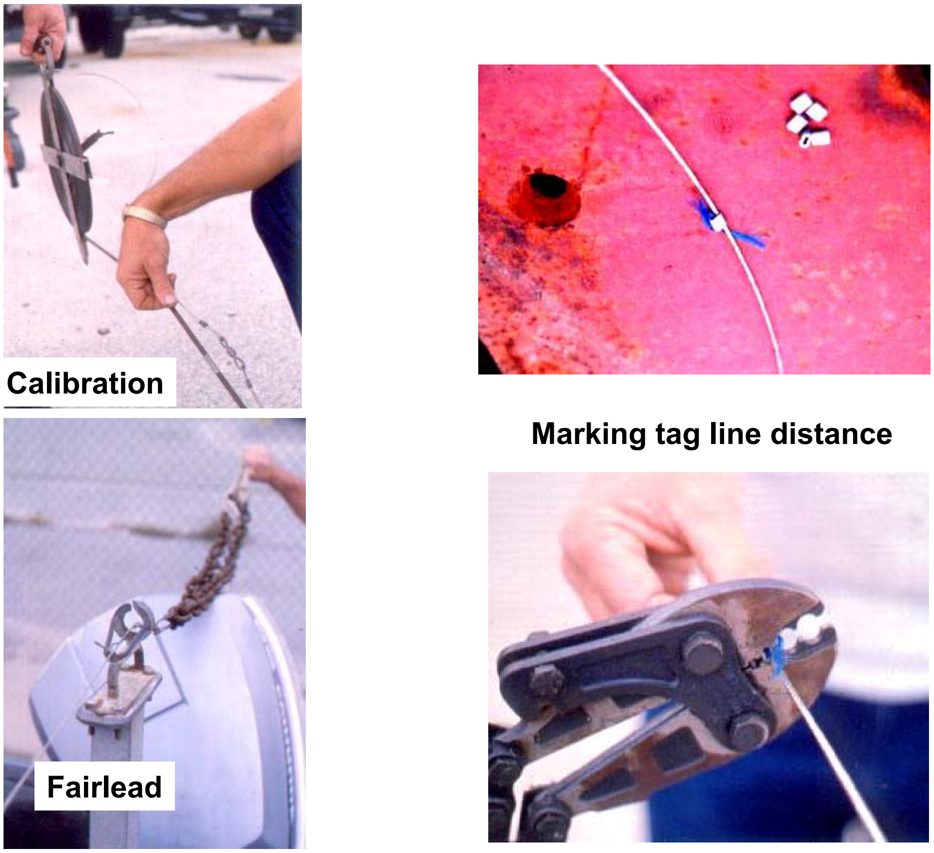


Figure 7-11. Tag line marking and calibration

Section V
Range-Azimuth Positioning Methods

7-19. General Applications

Range-azimuth positioning is most simply a forward traverse computation, based on the intersection of an angular and a distance observation, normally generated from the same shore-based reference station--Figure 7-12. Angular azimuth to the offshore vessel is observed by transits, theodolites, or manually or automated tracking total stations. The angular data can be manually observed and voice-relayed to the boat by radio or digitally recorded and transmitted to the boat. The distance measurement can be made by any number of EDM devices, such as microwave, laser EDM, and infrared light EDM. Although once a widely used positioning method, range-azimuth techniques are now employed only where GPS positioning cannot be obtained—usually due to satellite blockage. Today range-azimuth surveys are mostly performed using electronic digital theodolites--i.e., total stations. Range-azimuth positioning is typically used on projects located within four miles of a shoreline or riverbank. Depending on the type of equipment used, range-azimuth surveys have high relative accuracies. Because range-azimuth positioning is nonredundant, periodic calibration is essential. This survey method is relatively efficient. Only a two- or three-man crew is required to perform the survey. Any type of boat may be used, but open or enclosed workboats 17 to 26 ft long are common. This section covers hydrographic range-azimuth positioning methods where angles and distances are obtained visually or electronically, using alidades, transits, theodolites, EDM and full electronic total stations.

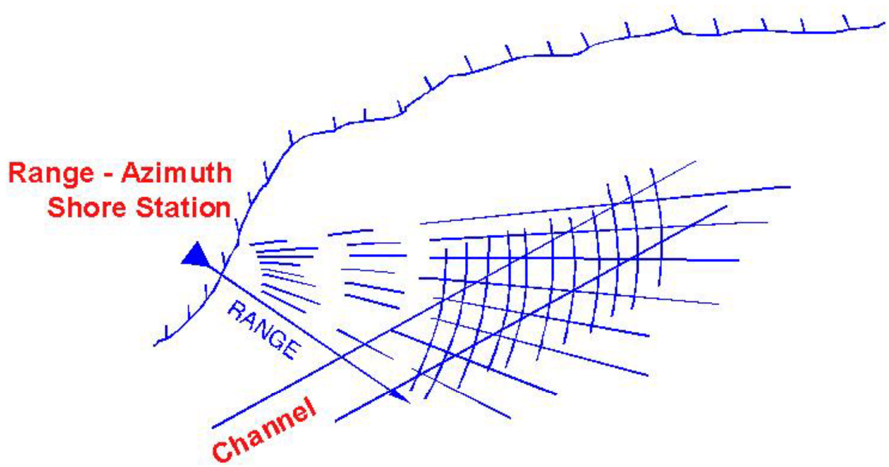


Figure 7-12. Range-Azimuth positioning

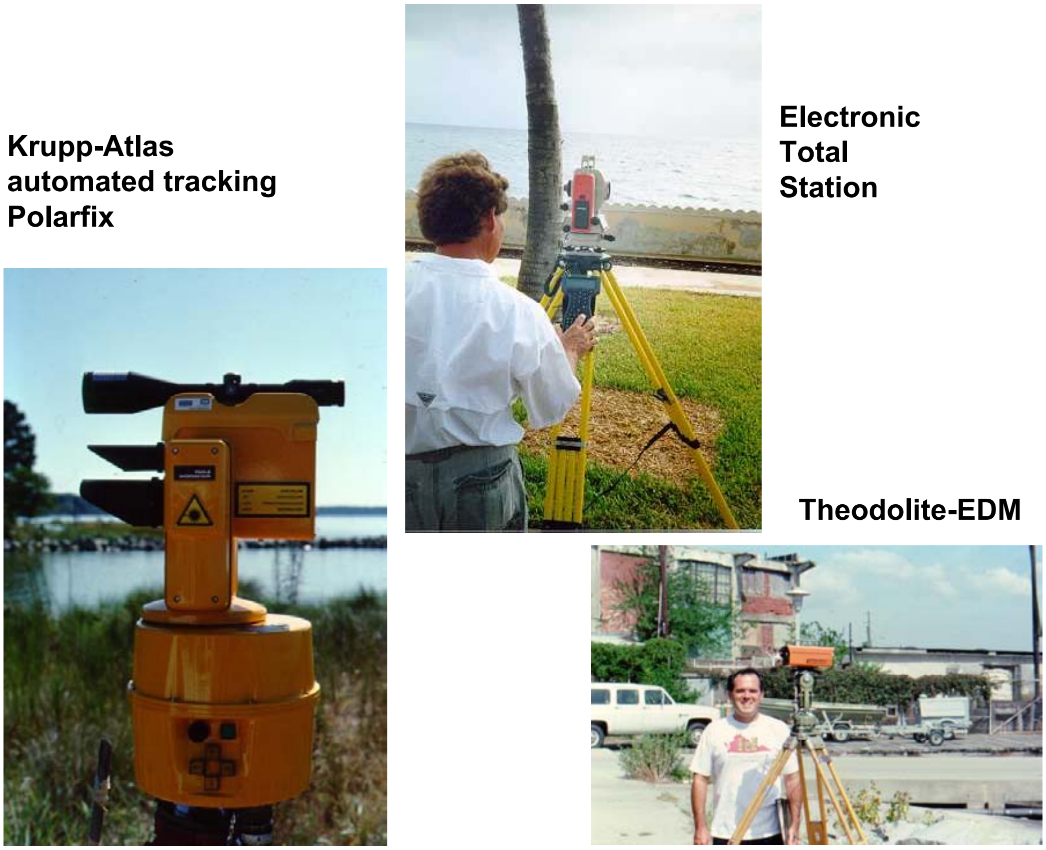


Figure 7-13. Various Range-Azimuth positioning instruments used in Corps (Norfolk District)

7-20. Range-Azimuth Survey Procedures

Total stations, theodolites, transits, or plane tables (i.e., alidades) are aligned on the local project datum in a manner similar to that described for triangulation intersection positioning (Section II). Thus, observed directions to the survey vessel are oriented in true grid azimuth reference for ease in plotting. Distances from the same point to the vessel are likewise observed, either visually (i.e., stadia) or electronically. Figure 7-13 depicts some of the systems used in the Corps.

a. Manual range-azimuth tracking procedures. It is usually easiest for the tracking instrument operator to call the shot or fix events to the survey boat. The analog echo sounder record is fixed at each shot and the azimuth recorded. Constant azimuth increments may be computed based on the distance offshore. The angular spacing should conform (roughly) to the desired position fixing interval, i.e., 50, 100, or 200 ft depending on the type/class of survey. These increments are usually rounded to a convenient even value (1 min of arc or 0.01 deg) for ease of setting in the instrument. The azimuth is set in the instrument, and the vessel is tracked only for the period it is within the scope. The fix is called to the survey boat when the boat's antenna crosses the vertical crosshair. Alternatively, the survey vessel may call the fix/shot; however, this procedure requires constant tracking by the instrument man.

b. Constant range tracking. Constant circular range arcs may be tracked with fixes taken at prescribed angular (azimuth) intercepts. The boat operator follows a constant range using the microwave system display. Ranges are incremented based on the line spacing coverage desired. Azimuth intercepts to the boat are either observed at regular angle intercepts or called for by the survey boat. The observer manually tracks the boat throughout the survey and calls the observed azimuths to the boat by radio.

Digital theodolites or total stations may be configured to telemeter the angular data directly to the boat. Angular intercept increments are designed to provide positions at roughly constant distances (e.g., every 100 ft) along the circular track. Thus, the angular increment will decrease as the distance offshore increases. Because the resultant data plot is along circular sections, which may not be aligned to the project, the data may not be suitable for quantity takeoffs unless DTM quantity-estimating techniques are available. This is, however, an excellent and efficient method of obtaining coverage over a given project area.

c. Separated range-azimuth reference points. The angular and distance measuring instruments need not be situated at the same point. For instance, a microwave system remote unit may be located on a sailing range structure and the tracking theodolite located at a more stable place ashore. The angle of intersection is no longer 90 deg in this case. To avoid degradation in geometry of intersection, the intersection angle should be kept larger than 45 deg within the project area. Manual tracking and positioning are accomplished in the same manner as described above.

d. Stadia distance measurement. Most traditional survey instruments are capable of determining slope/horizontal distances by tachymetric methods, i.e., using fixed cross-hair stadia intercepts. In many transits and levels with constant stadia intercept ratios, distances can be directly observed and rapidly computed by the instrumentman. Alidades typically reduce slope distances to horizontal--not required for most hydrographic applications. Visually observed stadia distances are relatively accurate over short distances--typically ± 5 to ±10 ft out to 300 foot distances on a dynamic platform. Beyond 300 ft to 500 ft, accuracy rapidly degrades. Ranges beyond 500 feet can be observed using "half-stadia" interval readings, and doubling the intercept value. Either level rods or painted "stadia boards" may be used for observing stadia distances. Level rod divisions are usually too difficult to read, so normally 8 to 12 foot long stadia boards are used. Boards are painted in with large black & white divisions, usually at 0.1-foot intervals, although larger intervals could be used if longer stadia distances are needed. The accuracy of observed stadia readings also degrades as vessel motion increases and visibility of the stadia board intercepts becomes obscured at longer ranges.

e. Data recording and plotting. Distances and azimuths are simultaneously observed by the instrumentman and recorded in a standard survey field book or electronic log by fix or time event. Radio contact with the vessel is maintained with the vessel normally calling for fix observations at prescribed intervals. The depth sounder is event-marked at the same time. Position data may be plotted either ashore or on the survey boat; or post plotted if real time navigation or coverage information is not required. Plane table observations are directly plotted ashore as observed. Transit-stadia observations may be plotted at either location, using drafting machines or preplotted range-azimuth sheets. If navigation guidance is needed aboard the survey vessel, then position data must be relayed to the vessel for on board plotting. The position update interval is limited by the instrument observer's and plotter's expertise in observing, transferring, and plotting. Typically, 45 to 60 second fix intervals are the best that can be performed in real time; thus, these methods are best for shot point depth observations under more static conditions. Total stations will typically compute and log vessel positions at a rapid update rate; however, in order to obtain real-time navigation aboard the vessel the position data must be relayed to the vessel. Manual plotting of range-azimuth surveys can be performed using a drafting machine and beam compass to lay out the azimuth and circular range arrays provided that the project area and reference station fall on the plotting sheet. If the project area is beyond the reach of these mechanical devices, the azimuth/circular array must be computed and drawn with spline curves. Angular position fixes are plotted along the constant range arc, and depth data are plotted relative to these points. Intermediate depth data points between fixes are interpolated between the fix events on the analog record. Range-azimuth position and depth data may also be encoded/digitized and plotted using automated techniques.

7-21. Total Station Range-Azimuth Surveys

Electronic total stations can be configured to provide highly accurate hydrographic positioning. The latest generation total stations can provide direct, real-time X-Y-Z coordinates on the vessel. If reflector-transducer offsets are applied, the X-Y-Z coordinate of the bottom can be computed/reduced in real-time. Robotic total stations can automatically track the vessel. A fully automated systems like the Krupp-Atlas Polarfix, contains a communications link that transmits the measured azimuth and distance to the boat. This communications data link is often the weak point in the system; care should be taken to ensure that there is no interference from other sources. These data are transformed to a local project coordinate system (station-offset, beach/river profiles, etc.) which is used for vessel operator steering guidance on a digital or analog left-right indicator. Topographic or construction total stations must be modified for hydrographic tracking applications if the beam width is not large enough to track the vessel. Philadelphia District has modified conventional topographic total stations for hydrographic survey purposes. Topographic total stations must also be configured to relay navigation data (via radio communication link) to the survey vessel processor for navigation and data logging purposes. Without on board navigation links, total stations are usually set up over established ranges--a common procedure for beach sections.

7-22. Range-Azimuth Accuracy

The accuracy of a range-azimuth position can be estimated from the following equation:

$$RMS_{95\%} = 1.73 \cdot sqrt[\, a^2 + (d \cdot \tan b)^2 \,] \qquad \text{(Eq 7-3)}$$

where

a = estimated standard error (1-sigma) of the distance measuring system (e.g., tag line, EDM, stadia)

d = distance offshore

b = estimated standard error (in arc-sec) of azimuth measuring system (e.g., total station, right angle glass, transit, sextant)

Within a few hundred feet from the instrument, theodolite/EDM/total station range-azimuth systems are highly accurate for dredging and navigation surveys. Microwave based EDM will rarely meet current 2 m or 5 m positional accuracy standards. Dynamic alidade or transit stadia distances are accurate to 5 meters within ranges of only 100-200 ft, depending on conditions.

7-23. Quality Control Requirements

a. Angular orientation. The tracking instrument should be referenced to the grid azimuth for the project. This is accomplished by setting the lower plate to the grid azimuth of the reference backsight. The farthest or most reliable point should be selected as the reference orientation. Additional reference points should be pointed on to verify orientation. All available visible control should be sighted on, and any error or discrepancy resolved onsite. All orientation checks (including grid azimuth computations) must be recorded on a worksheet or field book.

b. Periodic orientation checks. During the course of the survey, the initially set orientation should be periodically checked to ensure that no movement in the instrument has occurred. Periodic orientation checks should be noted in instrument operator's field book. These checks are normally done at the end of each survey line. The instrument should be readjusted and releveled as required during these checks. If significant movement has occurred, all work done since the last orientation check was made should be rejected and rerun.

c. Quality assurance checks. Like most visual survey positioning methods, independent positional checks on range-azimuth positions are rarely available. When the vessel can be maneuvered to another project control monument, a check on the position can be made. This should always be done for critical navigation surveys.

Section VI
Land-Based Electronic Positioning Systems

7-24. General Scope

Use of electronic distance measurement (EDM) techniques to position hydrographic survey vessels derived from hyperbolic aircraft navigation systems first developed during World War II. The Corps first began using hyperbolic and range-range electronic positioning during the mid 1950's--in Detroit and Norfolk Districts. A variety of systems have been used since that time; most of which became quickly obsolete when GPS became fully operational. However, the basic operating concepts behind land-based EDM and related trilateration positioning (including GPS) have not significantly changed. This section describes these electronic distance measurement and positioning principles of these older land-based electronic positioning systems; including procedural criteria for using such systems. Land-based (or terrestrial) positioning systems are distinguished from satellite (extra-terrestrial) positioning systems. All these systems use time difference and trilateration techniques to determine a position. The main focus of this section is on land-based microwave positioning systems as opposed to now nearly obsolete low- or medium-frequency hyperbolic systems such as LORAN-C.

7-25. Types of Electronic Positioning Systems

One method of classifying electronic positioning systems is by their operating frequencies. The frequency generally determines operating range and accuracy, and, in turn, a system's applicability for a particular type of work. Figure 7-14 lists some types of electronic positioning systems by their bandwidths. In general, the higher the frequency of the electronic positioning system, the more accurate the resultant position determination. Systems in the medium frequency range and below are typically hyperbolic phase/pulse differencing, and can reach far beyond the visible or microwave horizons. These systems were more suited for long-range navigation purposes or far offshore geophysical exploration work. Only those systems operating above the medium frequency bandwidth range had any practical application to USACE construction work. Microwave systems in the Super High Frequency (SHF) range were most commonly used to precisely control offshore survey vessels and dredges. Operating distances for these systems are generally limited to line of sight, which is adequate to cover most river, harbor, and coastal construction applications. Modulated lightwave and infrared spectrum electronic distance measurement instruments (e.g., electronic total stations) can be used over relatively limited distances, usually less than 3 to 5 miles offshore. These systems provide the highest distance accuracy measurements.

Bandwidth	Symbol	Frequency	System
Very Low Frequency	VLF	10-30 KHz	Omega
Low Frequency	LF	30-300 KHz	LORAN-C
Medium Frequency	MF	300-3000 KHz	Raydist, Decca
High Frequency	HF	3-30 MHz	Fundamental Earth Frequency 10.23 MHz
Very High Frequency	VHF	30-300 MHz	VOR Aircraft Navigation
Ultra High Frequency	UHF	300-3000 MHz	Del Norte
L-Band			NAVSTAR GPS
Super High Frequency	SHF	3-30 GHz	(Microwave EPS)
C-Band			Motorola
S-Band			Cubic
X-Band			Del Norte
Visible Light			EDM*
Laser Light			EDM
Infrared Light			EDM, Polarfix

*Electronic distance measuring instrument.

Figure 7-14. Frequencies of various positioning systems used for hydrographic surveying (1950 to date)

a. Medium-frequency positioning systems (RAYDIST/DECCA). Raydist and Decca positioning systems were first deployed by Corps districts in the mid 1950's and were used up to the early 1970's. They are no longer used. Systems in this frequency range operated by time/phase differencing methods--resulting in either circular or hyperbolic lattices (time differences). These systems required repeated calibration to resolve whole-wavelength (lane) ambiguities and continual monitoring during the course of the survey to resolve lane, or cycle, slips--no different than integer ambiguity determination requirements for modern day DGPS. Onsite calibration was essential to maintain accuracy. However, given the far offshore uses of these systems, calibration was often impossible. Many of the visual positioning techniques described in previous sections were used to calibrate these systems.

b. Low-frequency positioning systems (LORAN-C). LORAN-C is a low-frequency time-differencing hyperbolic system and has been the primary marine and airborne navigation system for over 40 years. It is suitable only for general navigation or reconnaissance surveys; and perhaps for general dredge/dump scow monitoring. Daily near-site or onsite calibration is critical if any semblance of absolute accuracy is to be maintained. (This is not the same as relative accuracy.) Without onsite calibration, absolute positional accuracy of LORAN-C is $\pm$ 0.25 mile at best. Recently developed differential Loran-C has a much higher accuracy. LORAN-C is expected to be decommissioned by the US Coast Guard in the early 2000's.

7-26. EDM Measurement Process

Most EDM systems operate either by resolving two-way travel phase delays of a modulated electromagnetic carrier pulse/wave between the offshore vessel and shore-based reference transmitter or by measuring the two-way travel time of a coded electromagnetic pulse between these points. GPS operates in a similar manner to the conventional systems except the travel distances from the satellites are one-way. Code-phase GPS is similar to microwave coded pulse systems, and carrier phase GPS operates on the carrier wave (phase differencing) used to transmit coded information. Phase differencing techniques are also used on land surveying EDM instruments, with the carrier being a visible laser or infrared light. Microwave pulsing type systems (Motorola, Del Norte, Micro-Fix, etc.) measure the round-trip travel time of a pulse generated at the offshore vessel, to the shore repeater station, and back to the vessel. The remote shore stations are variously referred to as transponders (XPDR), trisponders (TPDR), or responders (RPDR), depending on the manufacturer. They receive, process, and retransmit the signal. Some microwave systems use passive radar reflectors. For a pulsing system, the round-trip distance is computed by multiplying the measured elapsed time (less internal system time delays) by the assumed velocity of propagation of electromagnetic energy. The distance, or range, is computed by the following equation:

$$d \ (meters) = c \cdot (t_m - t_d) / 2 \qquad \text{(Eq 7-4)}$$

where

c = assumed velocity of propagation (m/sec)
t_m = measured round-trip travel time (sec)
t_d = internal system delays (sec)

a. Distance determination. Under ideal conditions, and with repeated measurements, the travel time (t_m) can be measured fairly accurately (to better than the 1-nsec (1-ft) level) and far more accurately (sub-centimeter) when modulated phase comparison techniques are employed, such as on infrared and some microwave systems. However, all three factors on the right side of Equation 7-4 are subject to both random and systematic errors. The only way to minimize these errors is by external and internal calibration of the equipment. Internal system delays (t_d) can be controlled relatively effectively on some modern pulsing systems. Such control is often termed "self-calibrating." The assumed velocity of propagation (c = speed of light) and other local anomalies or inherent system measurement instabilities cannot be controlled or corrected by the measurement system. Thus, an independent, on-site calibration must be performed if errors due to these sources become significant, which is normally the case (i.e., ambient project conditions different from nominal conditions). As a result, a calibrated microwave positioning system operating in a dynamic hydrographic survey environment can measure a range to an accuracy ranging between ± 3 m and ± 10 m (95% RMS).

b. Velocity of propagation variations. Variations in the velocity of propagation in air are caused by changes in air density due to temperature, humidity, and air pressure. The effect on land-based microwave positioning systems is more pronounced than on light waves. A factory-calibrated microwave system may be operated in atmospheric conditions differing significantly from the nominal calibration conditions. A change of 50 to 75 ppm could result, or 0.5 to 0.75 m in 10,000 m. Although such a variance may not be significant in operations 6 miles offshore, it is a systematic error, which could be compensated for by proper calibration. Assumed stability in the pulsing system time (t_m - t_d) or phase measurement process cannot be guaranteed. Periodic independent calibration is essential to check this stability. No independent calibration of positioning systems is totally effective unless it closely duplicates the actual operating ranges and conditions.

c. Microwave antenna considerations. Microwave propagation/refraction problems may exist in some areas during hydrographic surveys. Moving antennas a small distance (vertically or horizontally) sometimes eliminates the problem. Weather, especially humidity and temperature, affects microwave propagation through the air. Large ships, metal buildings, and even the water surface can create unwanted reflections of the microwave signals received at the antenna. Experience with microwave equipment problems and knowledge of the survey area will minimize the recurrence of these types of problems. Different antennas may be used to either boast a signal into a sector (sector antenna) or allow transmission over a full circle (omnidirectional) from the station. Circular polarization is another technique used to reduce multipath effects. Another technique used is antenna separation, which switches from one antenna to another to reduce multipath phenomena. GPS manufacturers use concentric metallic raised rings surrounding the antenna to reduce multipath effects.

d. Multipath effects. Signal multipath reflection is a major systematic error component for equipment operating in the microwave band. Errors due to this effect are difficult to detect. Most critically, they can gradually accumulate with vessel location and orientation relative to a particular remote reference station. An abrupt change due to multipath is usually readily apparent, as is total signal cancellation, termed "range holes." This gradual range increase of 1 m or more can cause what appears to be a course anomaly on a plot of the vessel's position, as if some erratic current displaced the vessel for a period of time. In addition, multipath may be present when the system is calibrated at a particular point. Consideration of multipath during antenna placement, enhanced antenna design (circular polarization, space diversity, etc.), and other internal electronic techniques and filters are required to identify and/or minimize multipath effects. None are totally effective in all cases. Antenna spacing or systems with circular polarization are recommended to minimize the possibility of these effects.

7-27. Microwave Range-Range Positioning Systems

These systems were first used by Corps districts in the early 1970's. The first systems were manufactured by Cubic Corporation, Motorola, and Del Norte Technology. They effectively replaced tag line and medium frequency (Raydist and Decca) positioning methods that had been used by districts since the 1950s. Up until the mid 1990's, microwave positioning systems were the primary positioning system in nearly every district. After 1992 when full coverage differential GPS became available, use of microwave systems rapidly declined. In 1998 only one or two districts were still utilizing microwave positioning--all the others have gone exclusively to GPS positioning. It is unlikely such systems will be in use much after 2000. Range-range positioning by microwave systems is accomplished by determining the coordinates of the intersection of two (or more) measured ranges from known shore control points--a process termed trilateration. When two circular ranges are measured, two intersection points result, one on each side of the fixed baseline connecting the reference stations. The ambiguity is usually obvious and is controlled by either initializing the computing system with a coordinate on the desired side of the baseline or referencing the point relative to the baseline azimuth. Prior to automated data acquisition systems, microwave ranges were visually observed and steered, with data logging and plotting performed manually. As automated data acquisition systems began to be used in the early 1970s, ranges and computed positions were electronically recorded and the resultant position sent to a track plotter and helmsman guidance display unit. These microwave range-range positioning methods used by the Corps during the period from about 1970 until 1999 are described below.

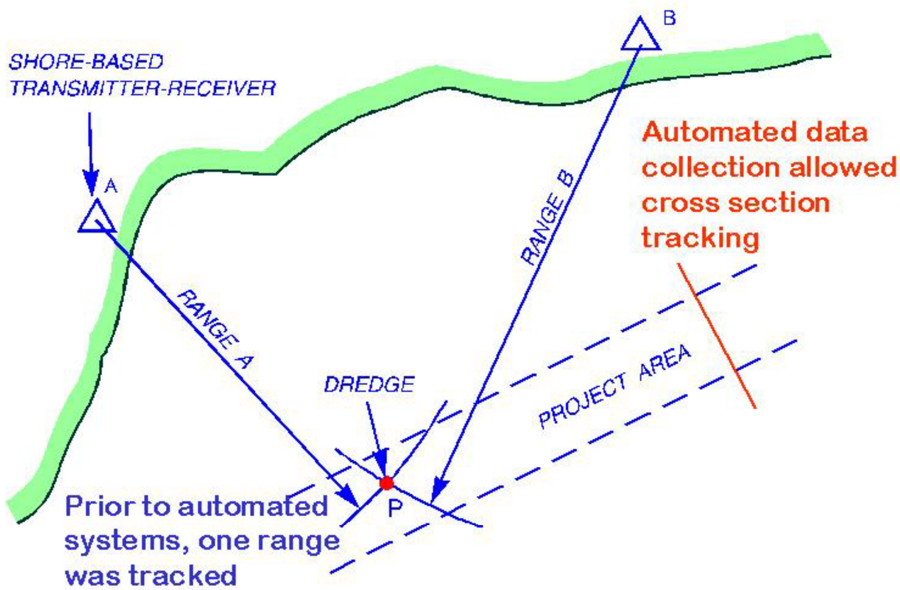


Figure 7-15. Range-Range intersection

a. Constant range tracking. Before automated data logging and processing systems were available, the survey boat was positioned by steering a constant range from one reference station and fixing at range intercepts from the other reference station (Figure 7-15). At higher vessel velocities, this is not an accurate positioning method, due to the need to estimate the intercept between range updates. In addition, the resultant survey lines are circular and are not aligned to the project coordinate system. This survey method provided a good backup capability when failures occurred in automated positioning and guidance systems. It was rarely employed, however.

b. Automated range-range tracking. When automated positioning and guidance systems were employed, the range intersection coordinates were automatically computed and transformed relative to the project alignment coordinate system (station-offset). This data was then fed to an analog or digital course indicator (or left-right track indicator), allowing any particular station/cross section or offset range to be tracked. Along-track position fixes were then taken by manually observing an along-track indicator or track plotter. The analog depth recording device is marked at each position. Normally, however, digitized depth data are correlated with positional data in an automated system at regular preset intervals by time or distance. Figure 7-16 shows typical electronic ranging and positioning equipment used by the Corps during the past 30 years.

c. Range-Range accuracy. The positional accuracy of a range-range intersection position is a function of the range accuracy and the angle of intersection of the ranges. The angle of intersection varies relative to the baseline so the positional accuracy varies as the survey vessel changes location. Assuming both ranges have equal value, the positional accuracy at any offshore point can be estimated from:

$$RMS_{95\%} = 2.447 \cdot \sigma \cdot \text{cosecant}(A) \qquad \text{(Eq 7-5)}$$

where

σ = estimated standard error of measured range distance (1-sigma)
A = angle of intersection of ranges at vessel (or angle from vessel to baseline stations)

Since the angle of intersection (*A*) has a major effect on positional accuracy, quality control criteria will restrict surveys within intersection tolerances--e.g., *A* must be between 45 deg and 135 deg. The accuracy of microwave ranges is difficult to estimate since it is not constant with distance from a shore station. Manufacturers typically claimed accuracies of $\pm$ 1 m (1-sigma), or $\pm$ 2 m (95% RMS). These estimates were for ideal (calibrated) conditions. More likely microwave range accuracies were on the order of $\pm$ 3 m. This would yield an average positional accuracy of about 8 m (95% RMS) at 60 deg range angle of intersection. Although an 8 to 10 m RMS error may seem excessive by today's DGPS standards, this represented a major improvement in the 20 to 50 m accuracies achieved by earlier positioning methods--especially on a project site 10 miles offshore.

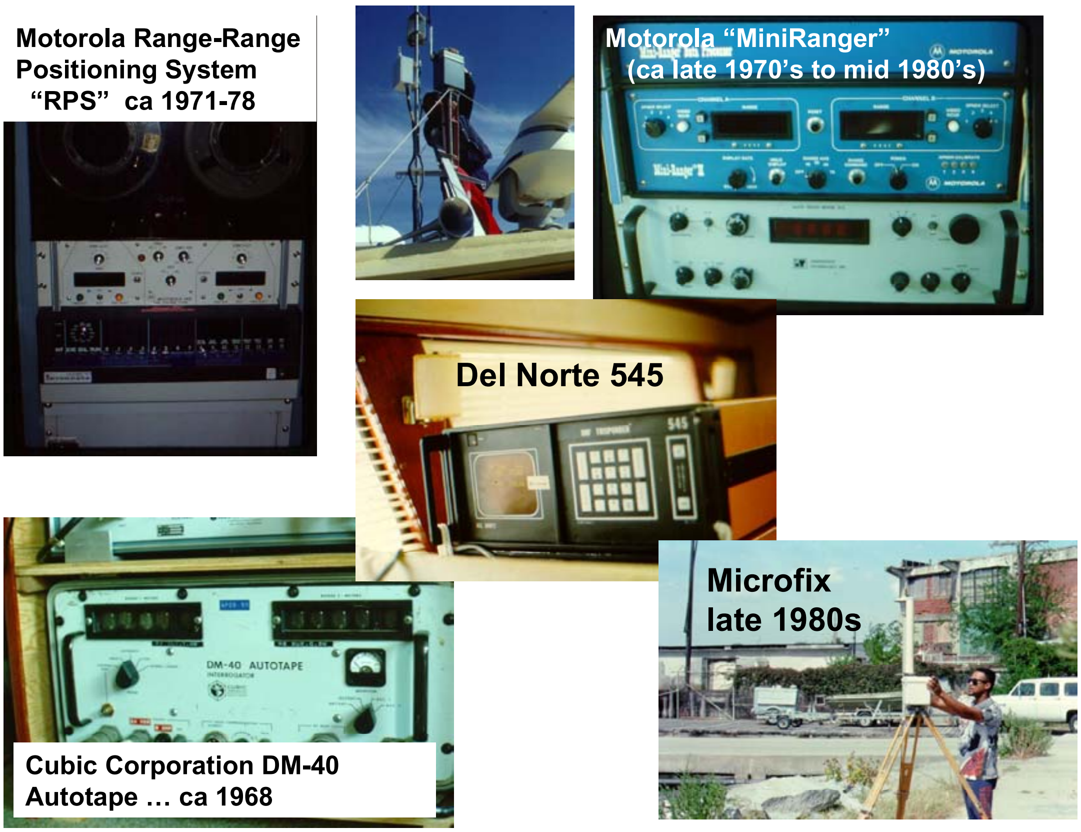


Figure 7-16. Range-Range positioning systems used in Corps (1970-1995)

d. Multiple range positioning techniques. This method is simply an expansion of the range-range method described above. Jacksonville District first developed this technique in 1979. In this case, three or more ranges are simultaneously observed, and a positional redundancy results. (The Racal Micro-Fix system allowed selection of up to 8 ranges from a total of 32 interrogated.) The position is determined from the computed coordinates of the intersections of the three or more range circles. Since each range contains observational errors, all the circles will not intersect at the same point. In the case of three observed ranges, three different coordinates result. Four ranges result in six separate coordinates. The final position is derived by an adjustment of these redundant coordinates, usually by a least-squares minimization technique. Some automated microwave positioning systems simply used the strongest angle of intersection as the "adjusted" position, and others take the unweighted average of all the intersecting coordinates. All adjustment methods were typically performed on-line at each range update cycle, normally every second. The positional data are then transformed to a project-specific coordinate system in a manner similar to that described for a two-range system.

(1) Using multiple ranging can minimize positional uncertainties. The coordinated position contains redundancy and can be adjusted. Such a process reduces the geometrical constraints and provides an opportunity to evaluate the resultant positional accuracy as the survey progresses. An on-line accuracy assessment is thus provided. This is accomplished by evaluating the positional misclosure which occurs when three or more position lines containing errors intersect, a so-called triangle of error for the simple case of three intersecting ranges, as shown in Figure 7-17. The position of the vessel is obtained by adjusting the three ranges to a best fit.

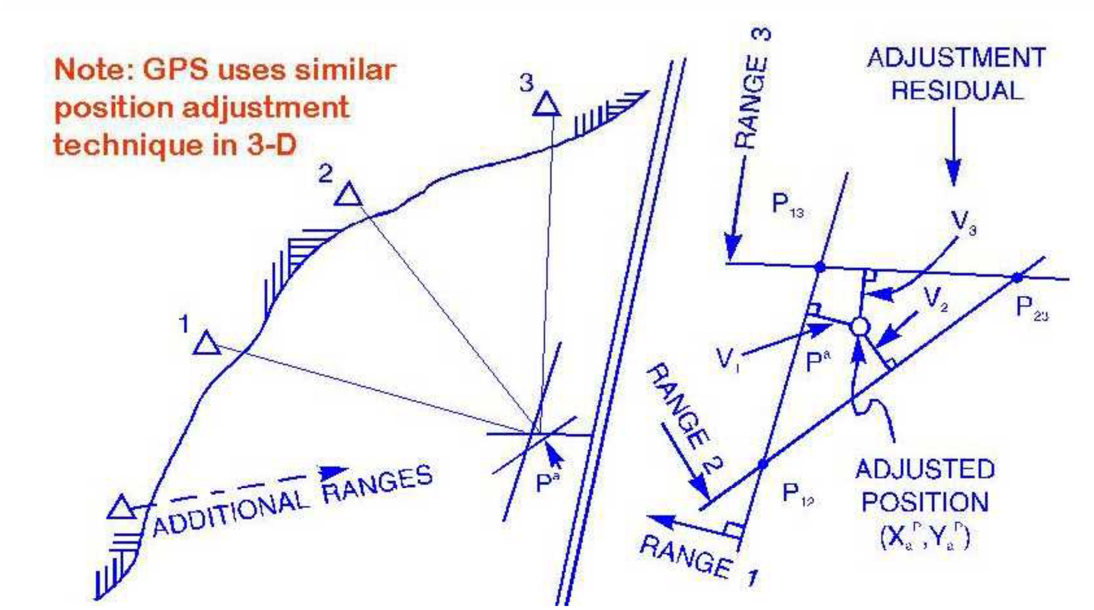


Figure 7-17. Multiple range positioning

(2) An assessment of the range measurement accuracy may be obtained by computing the residual range errors (*v*) for each position. These are the corrections added to each range so that all ranges intersect at the same point. When a least-squares type of adjustment is performed, the sum of the squares of the residual errors (*v*) is made a minimum. The magnitudes of these residual range corrections provide the statistics for an accuracy estimate of the observed distances or, more practically, an approximate quality control indicator. When a least-squares adjustment is performed, it is possible to obtain an accuracy estimate of the positional RMS error. Automated software can provide such data at each position update. If known, different weights may be assigned to individual range observations. This proved useful when different types of positioning systems were mixed during a survey (i.e., microwave and medium wave ranges).

(3) An on-line quality control indicator (e.g., 95% RMS error) can be computed. This can be directly obtained from the least squares adjustment matrix and computed from:

$$RMS\ Error_{95\%} = 1.73 \cdot sqrt\ (\sigma_x^2 + \sigma_y^2) \qquad \text{(Eq 7-6)}$$

where

σ_x *and* σ_y = estimated positional standard errors in x and y coordinates (from variance-covariance matrix)

Automated systems were designed to alarm when positional RMS accuracies fell outside the prescribed limits, indicating calibration problems. The initial standard error of the microwave ranges was usually assumed constant throughout the survey.

(4) Alternatively, the residual range errors (*v*), which result from comparing the observed distances with the inversed distances between the adjusted position and the remote shore transmitters, could be used to evaluate the accuracy of the range measurements. A variety of methods were used (on-line and/or off-line) to compute these residual errors. An approximate (unbiased) estimate of the range accuracy is obtained from the following:

$$Estimated\ Range\ Accuracy\ (1\text{-}\sigma) = sqrt\ [\ \Sigma(\ v^2\ )\ /\ (n\text{-}1)\ ] \qquad \text{(Eq 7-7)}$$

where

n = number of observed ranges
$\Sigma(\ v^2)$ = sum of the squared residuals

Adding redundant ranges will not necessarily make a significant improvement in the positional accuracy because the inherent random and systematic errors are still present. It will, however, help detect the existence of large systematic errors (and most critically, observational blunders) that might have otherwise gone undetected using a nonredundant range-range system.

(5) Figure 7-18 demonstrates the use of multiple ranging in an offshore location where no independent method of calibration at the job site was available. Figure 7-19 shows another project with six intersecting points, resulting from the four observed ranges. Error ellipses for each of the two-range intersections are shown. The on-line least-squares adjusted position is shown along with its (smaller) error ellipse.

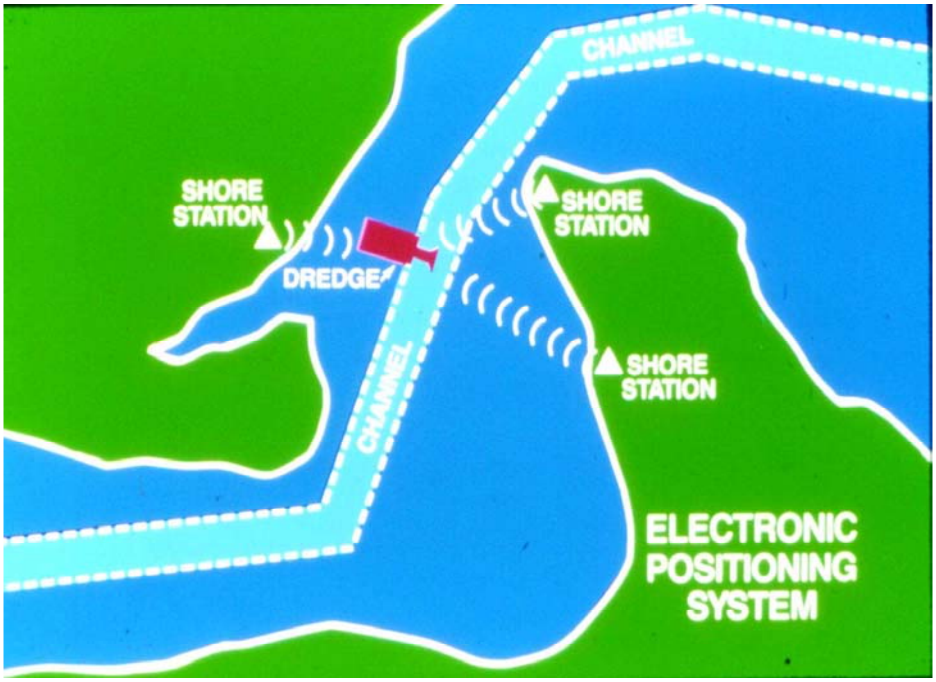


Figure 7-18. Three range microwave positioning scheme

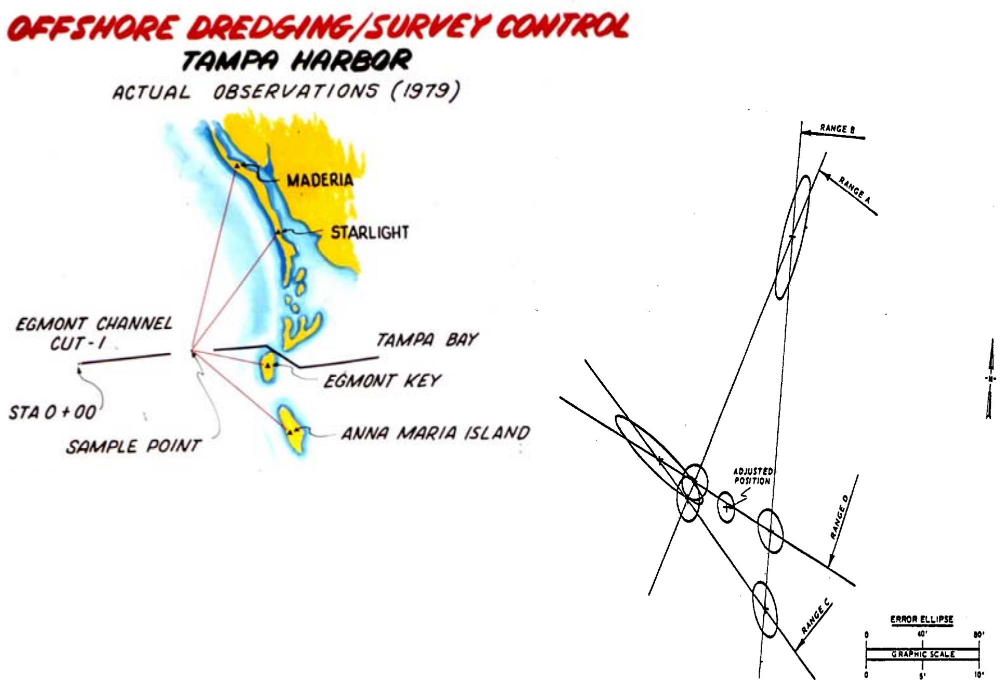


Figure 7-19. Four range intersection position solution (Tampa Harbor, Jacksonville District)

7-28. Microwave System Calibrations and Quality Control

A microwave system calibration processes basically involve an independent determination of the vessel's antenna location, followed by comparison of differences between the observed microwave ranges and the distances computed from the independent calibration. An independent calibration should be at least one order of magnitude more accurate than the microwave system being calibrated. Such systems would include: theodolite triangulation, total station observations, or EDM trilateration methods. If automated coordinates are observed rather than direct ranges, inverse coordinate computations will have to be made to determine the observed ranges. If a series of independent calibrations is made, the mean range difference over this series represents a correction to be applied to the system. This range correction is dialed in the microwave system range console or is stored for software application during the position computation. Given the instability of many microwave ranging systems, coupled with inaccuracies in the calibration process itself, determining whether a range correction is statistically valid is difficult. This problem frequently occurs when baseline comparisons are made at two (or more) different calibration points offshore.

a. Repeated calibrations. An advantage of EDM, total station, sextant, or triangulation intersection calibrations is that a series of 5, 10, or more independent calibrations may be obtained at various locations in the work area. If the calibration technique is performed accurately, the mean range difference correction may be statistically valid. Its validity is best estimated by computing the standard deviation from the mean of the series of range differences. Applying a calibrated range difference may often be debatable from a statistical standpoint. For example, assume that a microwave range is calibrated by five independent distance measurements. The accuracy of the calibration process is estimated at ±0.5 m and the range is presumed stable to ±0.5 m. The series of calibrations yields a (-) 0.3-m correction ±1.0 m. The ±1.0-m deviation contains the error budget of the microwave range, the calibration process, and other unknown factors (control, eccentricities, etc.). A (-) 0.3-m correction in this case would seem marginal. However, for consistency, it should be applied since no simple rule-of-thumb exists for deciding when such a correction is statistically valid.

b. EDM calibration. Direct ranges to the shore-based receiver stations may be observed using precise phase differencing laser/infrared electronic distance measurement instruments. Typically, the EDM is moved to the two or more receiver monuments, and the reflector prism is placed above or below the vessel's antenna. Depending on the type of EDM used, vessel stability is critical for maintaining lock on the reflector. A series of EDM distance readings is directly compared with the simultaneously observed microwave ranges, and corrections are assessed as described above. EDM observations are taken and corrected for slope and atmospheric refraction in accordance with standard survey methods. If control monuments other than the microwave remote receiver's are occupied, a trilaterated position of the vessel must be determined and inversed along the microwave ranges for comparison. This method is especially suitable for periodic calibration of dredges.

c. Baseline calibrations. Baseline calibrations are performed by locating the survey vessel alongside a known reference point and comparing the computed (inversed) distances with the ranges observed by the microwave system. This is the simplest and most common microwave calibration method. Any eccentricities between the vessel's antenna and the known monument must be corrected. This is usually done by observing an angle and taped distance from the reference point to the antenna and computing the grid coordinates of the actual antenna. A sextant bearing is adequate over short distances. In some instances, the vessel antenna may be removed from its mounting and placed directly over the known monument. Such a procedure may change antenna receiving characteristics and induce multipath error. Some automated systems allow input of the antenna coordinate and directly compute the distance comparisons or, alternatively, directly correct the observed ranges to agree with the fixed coordinate. (This latter method assumes only one calibration check will be employed--or the differences from different points are insignificant.) Such a process is useful on multiple ranging systems. Regardless of the method employed, a few minutes of observations should be recorded. Lengthy calibration observations at the same point serve no purpose other than measuring the system's precision (not accuracy) at that particular point. Range corrections are computed and assessed. For critical surveys, the same process should be performed at a second calibration point. Significant differences in the range corrections for each point may indicate problems with the control network, multipath errors, or both. The magnitude of the recorded range differences from each calibration point is another rough indicator of the quality of the survey. If the magnitude of these differences (or standard errors from the mean values) is significant, the source of the problem must be determined. This may require calibration at a third fixed point.

d. Total station instrument calibration. Since a typical total station EDM yields direct and accurate X-Y-Z coordinates of the remote point, it may be used to compare the coordinates of an automated positioning system. A total station may be set up at any known point with visibility to the offshore point (and within the operation ranges of both systems). With the vessel held as motionless as possible, the retro-prism is held adjacent to the microwave system antenna, and simultaneous total station and microwave system coordinates are observed at different locations. Inversed distances and microwave ranges are compared as shown in previous examples.

e. Triangulation intersection. Triangulation methods are suitable for areas where no onsite calibration points are available. This method is also particularly ideal for calibrating dredges and other large plants that cannot perform static or direct baseline calibrations. Triangulation methods are potentially the most accurate form of microwave calibration in that the process is performed in a dynamic (true working) environment. To attain this, however, excellent intersection geometry and visibility are necessary, and highly skilled theodolite tracking observers are essential. Vessel velocity must be kept at a minimum during the tracking process. For high-accuracy triangulation calibration, a third theodolite is added for redundancy. A series of 5 to 10 or more intersection fixes is made on a stable or slowly moving survey vessel or dredge at or near the work area. Microwave ranges are read at the time of each intersection fix. Triangulated positions are computed for each position, inversed, and compared with the observed range. Care should be taken to ensure that all computations and comparisons are based on grid distances. As described previously, based on the deviations in the range differences, a judgment must be made as to whether the mean range correction is statistically valid.

f. Sextant resection. Sextant resection calibrations are valid only when resection geometry is ideal, for nearshore projects where distinct sextant targets are clearly visible and vessel velocity is near dead slow or stopped. A series of 5 to 10 simultaneous sextant resection angles and microwave range observations should be made. The sextant observers must be centered about the microwave antenna to minimize eccentricities. On a stable or spudded platform, redundant angles should be observed. Resection computations should be performed manually or with standard software. Graphical resection (three-armed protractor plots) shall not be used. Resection software should provide an estimator or indicator of the quality of the resection based on the geometry and estimated standard error of the observed angles. Without such a quality estimate, the resection solution may be less accurate than the microwave solution. Resected grid coordinates are inversed and compared with the observed microwave ranges. Range differences for each position are computed and meaned. A standard error of each mean should be computed to judge whether applying a mean correction to the range is statistically appropriate. Large variances between the resected ranges and the microwave range indicate poor resectioning, unstable microwave ranges, or both.

g. General QC criteria for electronic positioning systems. Some basic criteria for performing positioning system calibrations are described below. Some of these factors are also applicable to GPS positioning techniques.

- The independent calibration procedure used must have an accuracy at least equal to or better than the system being calibrated. This is not always easily accomplished when dynamic calibrations are performed.

- Multipath effects may not be eliminated by calibration since they can depend on the antenna location (ashore and afloat) and the orientation of the offshore vessel.

- A static calibration does not simulate the dynamic survey condition. Thus, any errors due to vessel motion will not be picked up (e.g., electromechanical lags or lack of system synchronization--latency errors).

- Calibrations must simulate, to the maximum extent possible, the actual conditions existing in the project area. This requires calibration as close to the work site as possible.

- Measurement systems known to be relatively stable, such as infrared electronic distance measurement devices, "self-calibrating" or phase comparison microwave systems, total stations, and GPS, must also be independently checked, or verified, to prevent blunders. The frequency of such verification checks is more relaxed for these systems.

- Calibrations of pulsing microwave positioning systems are valid only for the particular range measurement system used. When antennas, receiver units, connecting cables, and the like are modified, moved, or swapped out, a full recalibration of the system must be performed. Calibration must be performed while the shore-based receivers are located at their actual sites and referenced to the permanently located vessel antenna. If not, some large systematic effects may not be properly compensated for.

- Calibration procedures must be consistent during the course of a project (i.e., both pre-dredge and after-dredge payment surveys). The same baselines and/or procedures should be employed.

- Remote points used to calibrate an established network must be adequately connected by surveys relative to the positioning network. This is especially important when calibrating from large offshore range structures which may not have been accurately positioned, or where the center point is not easily defined. This is especially applicable to long-range DGPS observations.

Section VII
Global Positioning System Techniques

7-29. General

The Global Positioning System (GPS) has rapidly become the standard surveying and navigation mode in USACE replacing microwave ranging and R/A systems. Visual R/A systems will be used only in isolated instances where GPS satellite coverage is obscured. Real-time GPS positional accuracies now exceed those of any other hydrographic survey positioning system. Most significantly, GPS does not require the time-consuming calibrations described for microwave equipment. Numerous public and private differential GPS systems now exist which allows for nationwide coverage. This section details USACE applications of current GPS technology.

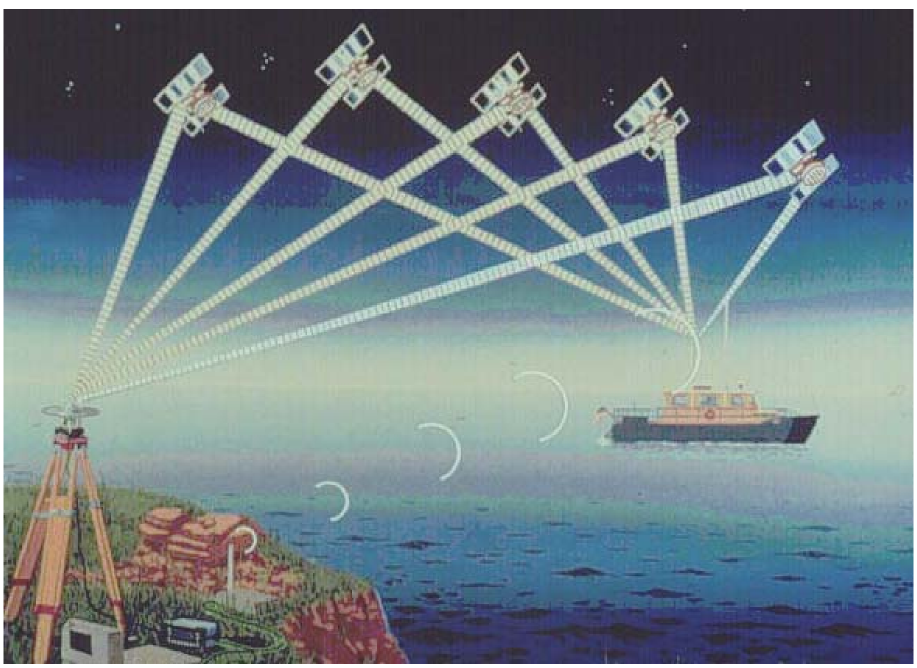


Figure 7-20. Differential GPS positioning of a hydrographic survey vessel

a. GPS is a real-time, all-weather, 24-hour, worldwide, 3-dimensional absolute satellite-based positioning system developed by the U.S. Department of Defense. This system consists of two positioning services: the Precise Positioning Service (PPS) and the Standard Positioning Service (SPS). PPS was developed for the U.S. military and other authorized users, uses the P(Y)-code on the L1 and L2 carriers, and provides an accuracy of 5-10 meters in absolute positioning mode. SPS is available to civilian users, uses the C/A-code on the L1 carrier, and provides accuracy of 10-20 meters in absolute positioning mode.

b. For many applications, absolute positioning does not provide sufficient accuracy. Differential GPS (DGPS) is a technique which can provide relative positioning with an accuracy of a few meters to a few millimeters depending on the DGPS method used. DGPS utilizing code phase measurements can provide a relative accuracy of a few meters. DGPS utilizing carrier phase measurements can provide a relative accuracy of a few centimeters. DGPS requires two or more GPS receivers to be recording measurements simultaneously. With two stations recording observations at the same time, GPS processing software can reduce or eliminate "common errors". If one of the stations is a survey control point, DGPS will determine a baseline between the stations and effectively establish the position of the other receiver in the same reference system as the survey control point. Both code and carrier phase DGPS can be performed in real-time thereby positioning moving platforms and survey vessels--see Figure 7-20.

c. The differential GPS technique has application to positioning USACE survey vessels, dredges, and other mobile platforms. When operating in a differential mode it is capable of providing real-time positional and navigational information at accuracies required for present-day hydrographic surveying and/or dredge positioning. Use of GPS has provided more accurate payment surveys and thus reduces disputes and claims arising from errors in survey measurements. Differential GPS is applicable for all USACE hydrographic survey and dredge positioning needs.

7-30. GPS Tracking Modes

a. There are basically two general modes, which are used to determine the distance, or range, between a NAVSTAR GPS satellite and a ground-based receiver antenna. These measurements are made by signal phase comparison techniques. Either the satellite's carrier frequency phase or the phase of a digital code modulated on the carrier phase may be used, or tracked, to resolve the distance between the satellite and the receiver. The resultant positional accuracy is dependent on the tracking method used. These two-phase tracking techniques are:

- Carrier phase tracking
- Code phase tracking

b. The GPS satellites actually broadcast on two carrier frequencies: L1 at 1575.42 MHz (19-cm wavelength) and L2 at 1227.60 MHz (24-cm wavelength). Modulated on these frequencies are the Coarse Acquisition (C/A) (300-m wavelength) and the Precise (P) codes (30-m wavelength). In addition, a 50-bps satellite navigation message containing the satellite ephemeris and health status of each satellite is transmitted. The C/A and P codes are both present on the L1 frequency. Only the P code is present on the L2 frequency. The higher frequency of the carrier signal (L-Band) has a wavelength of 19 and 24 cm from which a distance can be resolved through post-processing software to approximately 2 mm. The modulating code has a wavelength of 300 m and will only yield distances accurate to about 1 m. Both of these tracking methods have application in hydrographic and conventional surveying.

7-31. GPS Accuracies

The absolute range measurement accuracies obtainable from GPS are largely dependent on which code (C/A or P) is used. These estimated user range accuracies or deviations, when coupled with the geometrical relationships of the satellites during the position determination (i.e., dilution of position or geometrical dilution of precision), result in a three-dimensional (3-D) confidence ellipsoid that depicts uncertainties in all three geocentric coordinates. Given the changing satellite geometry and other factors, GPS accuracy is time/location dependent. Error propagation techniques are used to define nominal accuracy statistics for a GPS user. The user range errors/deviations will yield geocentric coordinates (*X-Y-Z*) and a covariance matrix. These can be transformed to a local datum (N-E-U or u-v-h). The 3-D covariance matrix defines the dimensions of the error ellipsoid, which can be assessed in any direction or coordinate system. The more common error measures used are described below.

a. Root mean square error measures. 2-D (horizontal) GPS positional accuracies are normally estimated using a RMS radial error statistic. A 1-σ RMS error equates to the radius of a circle in which the position will lie with an approximate probability of 63%. A circle of twice this radius (2-σ RMS or 2DRMS) represents a 98% positional probability circle. This 98% probability circle, or 2DRMS, is a common 2-D positional accuracy statistic used in GPS surveying literature. Occasionally, a 3DRMS, or 99+% probability circle, is used. USACE hydrographic survey accuracy requirements stated in this manual are given in terms of a 2-σ RMS error statistic.

b. Probable error measures. 3-D GPS accuracy measurements are most commonly expressed by Spherical Error Probable, or SEP. This measure represents the radius of a sphere with a 50% confidence or probability level. This spheroid radial measure only approximates (or averages) the actual 3-D ellipsoid representing the uncertainties in the geocentric coordinate system. In 2-D horizontal positioning, a Circular Error Probable (CEP) statistic is commonly used, particularly in military targeting. CEP represents the radius of a circle containing a 50% probability of position confidence. Another 2-D measure occasionally used is the radius of a 95% confidence circle.

c. Accuracy comparisons. It is important that GPS accuracy measures clearly identify the statistic from which they are derived. A "100 meter" or "3 meter" accuracy statistic is meaningless unless it is identified as being 1-D, 2-D, or 3-D, along with an applicable probability level. For example, a PPS 16-m 3-D accuracy is, by definition, SEP (i.e., 50%). This 16-m SEP equates to a 28-m 3-D 95% confidence spheroid, or when transformed to 2-D accuracy, roughly 10 m CEP, 12 m RMS, 24 m 2DRMS, and 36 m 3DRMS. In addition, absolute GPS point positioning accuracies are defined relative to an earth-centered coordinate system/datum. This coordinate system will differ significantly from local project or construction datums. Nominal GPS accuracies may also be published as design or tolerance limits, and actual accuracies achieved can differ significantly from these values.

d. Relative accuracy measures. Engineering, construction, and dredging surveys are not so concerned with absolute positions (φ-λ-*h*) as with local project coordinates (*X-Y-h*), and with insuring high accuracy within a local construction project. Thus, relative project accuracy is far more important than absolute (world-wide) positional accuracy. Standard surveying and differential GPS (DGPS) linear baseline accuracy is therefore normally expressed by a relative accuracy measure--typically in parts per million (ppm) as a function of the distance between two points or receivers. This measure is usually given at the one-sigma standard error (or standard deviation) level--a 68% probability measure. DGPS system accuracy definitions of 3 m and 0.1 m are, in effect, maximum 1-σ 3-D baseline vector errors relative to the fixed reference point.

e. Dilution of precision. The final positional accuracy of a point determined using absolute GPS survey techniques is directly related to the geometric strength of the configuration of satellites observed during the survey session. GPS errors resulting from satellite configuration geometry can be expressed in terms of Dilution of Precision (DOP). In mathematical terms, DOP is a scaler quantity used in an expression of a ratio of the positioning accuracy. It is the ratio of the standard deviation of one coordinate to the measurement accuracy. DOP represents the geometrical contribution of a certain scaler factor to the uncertainty (i.e., standard deviation) of a GPS measurement. In a statistical sense, DOP is equivalent to the square root of the sum of the squares of the confidence region axes corresponding to the parameters being assessed in an error ellipse.

f. Reference datum. Since differential survey methods are concerned only with relative coordinate differences, disparities with a global reference system used by the NAVSTAR GPS are not significant for USACE purposes. Therefore, GPS coordinate differences can be applied to any type of local project reference datum (i.e., NAD 27, NAD 83, or local project grid and/or dredging reference system). However, it is recommended that the NAD 83 datum be used to avoid mistakes, since most maps and charts produced today use this datum. In order to obtain accurate NAD 83 coordinates for the reference stations, static GPS surveys can be performed. If this is not feasible, then CORPSCON can be used to convert NAD 27 coordinates to NAD 83.

7-32. GPS Error Sources

Table 7-1 lists the GPS modes and QC standards for hydrographic surveying positioning. The accuracy of GPS is a function of errors and interferences on the GPS signal and the processing technique used to reduce and remove these errors. The same types of phenomena as range-range microwave systems affect GPS signals. Both types of systems are highly affected by humidity and multipath. In addition, the GPS signals travel from 20,000 km out in space through ionosphere and troposphere layers of the earth that delay the satellite signals. Satellite signals can be altered for national security reasons by S/A and AS. Surveying in differential mode close to the reference station can eliminate most of these errors. The further the remote operates from the reference station, the less similar will be the errors received by both receivers. Consequently, less error is being eliminated by the pseudo-range corrections sent over the data link.

a. Tropospheric error. Humidity is included in this error. Humidity can delay a time signal up to approximately 3 m. Satellites low on the horizon will be sending signals across the face of the earth through the troposphere. Satellites directly overhead will transmit through much less troposphere. Masking the horizon angle to 15 deg can minimize the tropospheric error. If this blocks too many satellites, a trade-off down to 10 deg may be necessary. Manufacturers model the tropospheric delay through software. Tests have determined that the tropospheric models used by software manufacturers works reasonably well.

b. Ionospheric error. Sun-spots and other electromagnetic phenomenon cause errors in GPS range measurements of up to 30 m during the day and as high as 6 m at night. The errors are not predictable but can be estimated. The ionospheric error is assumed to be the same at the reference receiver as at the vessel receiver. This assumption is sound for GPS formulations where the stations are separated by a few nautical miles. Ionospheric models have been implemented for dual frequency receivers.

c. Multipath. Multipath is a reception of a reflected signal in lieu of a direct signal. The reflection can occur below or above the antenna. Multipath magnitude is less over water than over land, but it is still present and always changing. The placement of the GPS receiver antenna should avoid areas where multipath is more likely to occur (e.g., rock outcrops, metal roofs, commercial roof-mounted heating/air conditioning, buildings, cars, ships, etc.). Increasing the height of the antenna is one method of reducing multipath at a reference station. The multipath occurrence on a satellite range can last several minutes. Masking out satellite signals from the horizon up to 15 deg will also reduce multipath.

d. Selective availability (S/A). S/A purposely degrades the satellite signal to create position errors. The error can be in excess of 100 m; typically, S/A will be below 100 m 95% of the time according to the Federal Radionavigation Plan. Differential operation can eliminate S/A (under current GPS operations). As of May 1, 2000 S/A has been turned to zero and therefore eliminated its affects on the GPS signal. Even with S/A set to zero DGPS is still needed for most hydrographic surveying applications.

e. Other errors. Other GPS errors are discussed in detail in EM 1110-1-1003.

f. Calibration requirements (checklist). Unlike microwave or R/A systems, DGPS operation has no prescribed calibration requirements. The major items to check for are blunders such as:

(1) Incorrect project datums or geodetic reference datums.

(2) Incorrect master station coordinate values.

(3) Incorrect antenna measure-up values (master and remote heights).

(4) DGPS mode not selected in the unit.

(5) RTCM-104 input/output format not selected in both units for USACE activities.

7-33. GPS Positioning Methods

There are two general operating methods by which GPS derived positions can be obtained:

- Absolute point positioning
- Relative (Differential) positioning (DGPS)

Each of these positioning methods has a variety of survey and navigation applications. In general, absolute point positioning involves only a single passive receiver and is not sufficiently accurate for precise surveying or hydrographic positioning uses. It is, however, the most widely used military and commercial GPS positioning method. Relative (Differential) positioning requires at least two receivers and can provide the accuracies required for basic land surveying and offshore positioning.

a. Absolute Point Positioning (Pseudo-Ranging). When a GPS receiver user performs a navigation solution, only an approximate range, or "pseudo-range," to selected satellites is measured. By pseudo-ranging, the GPS user measures an approximate distance between the antenna and the satellite by correlation of a satellite-transmitted code and a reference code created by the receiver, without any corrections for errors in synchronization between the clock of the transmitter and that of the receiver. The distance the signal has traveled is equal to the velocity of the transmission of the satellite multiplied by the elapsed time of transmission. Tropospheric and ionospheric conditions cause additional delays (errors), which can affect positional accuracy. Four pseudo-range observations are needed to resolve a GPS 3-D position. (Only three pseudo-range observations are needed for a 2-D location.) This is due to the need to resolve the constant clock biases (Δt) contained in both the satellite and the ground-based receiver. Thus, in solving for the *X-Y-Z* coordinates of a point, a fourth unknown (i.e., clock biases) must also be included in the solution. The solution of the 3-D position of a point is simply the solution of four pseudo-range observation equations containing four unknowns: X, Y, Z, and Δt.

(1) The above solution is highly dependent on the accuracy of the known coordinates of each satellite (i.e., X^s, Y^s, and Z^s), the accuracy of the modeled atmospheric delays (d), and the accuracy of the resolution of the actual time measurement process performed in a GPS receiver (clock synchronization, signal processing, signal noise, etc.). As with any measurement process, repeated and long-term

observations from a single point will enhance the overall positional reliability. The accuracy of an absolute point position is a function of the range measurement accuracy and the geometry of the satellites. A description of the geometrical contribution to uncertainty in a GPS-determined point position is termed Dilution of Precision, or DOP. DOP is roughly related to the physical orientation of the satellites relative to the ground receiver along with the range measurement accuracy. Repeated and redundant range observations to the satellites at varying orientations will improve the positional accuracy. In a static mode (meaning the GPS antenna stays stationary), range measurements to each satellite may be continuously remeasured over varying orbital locations of the satellite(s). The varying satellite orbits cause varying positional intersection geometry. In addition, simultaneous range observations to numerous satellites can be adjusted using weighting techniques based on the strength of intersection and pseudo-range measurement reliability.

(2) Two levels of absolute positioning accuracy may be obtained from the NAVSTAR GPS satellite system. These are called the (a) Standard Positioning Service and (b) Precise Positioning Service.

(a) Standard Positioning Service (SPS). The SPS user is capable of achieving real-time 3-D absolute positional information on the order of 10-20 m. DOD has implemented Anti-Spoofing (AS), which interchanges the P code with a classified Y code, therefore denying the SPS user the higher P code accuracy. This DOD security action does not significantly affect a hydrographic user operating in a differential positioning mode.

(b) Precise Positioning Service (PPS). The non-military PPS user must be authorized by DOD to have a decryption device capable of deciphering the encrypted GPS signals. This authorization must be obtained from the National Security Agency (NSA). USACE is an authorized user; however, actual use of the equipment has security implications. The PPS user can attain real-time absolute 3-D positional accuracy on the order of 16 m SEP. Again, access to the PPS is not essential to differential positioning.

(3) Since absolute positioning will only provide real-time absolute positional accuracies of, at best, 5-10 m, this method will not satisfy the majority of USACE hydrographic surveying requirements. Exceptions may involve rough reconnaissance surveys that are not used for detailed design or construction. Absolute positioning does have general navigation application and will eventually replace LORAN-C and other satellite navigation systems for ships and aircraft.

b. Relative (Differential) Positioning (DGPS). Relative surveying is the positioning of one point in reference to another. Differential positioning is the technique or method used to position one point relative to another. Differential positioning is not so concerned with the absolute position of the user as with the relative difference in position between two users, who are simultaneously observing the same satellites. Since errors in the satellite position (X^s, Y^s, and Z^s) and atmospheric delay estimates (d) are effectively the same at both receiving stations, they cancel each other to a large extent. Differential positioning can be performed by using code or carrier phase measurements and can provide results in real-time or post processed.

(1) DGPS (Code Phase). Because of the effects of AS on the P-Code, the discussion of code phase DGPS will focus on using the C/A code. Code phase DGPS consists of 2 GPS receivers, one set up over a known point and one moving from point to point or placed on a moving platform, measuring pseudo-ranges to at least 4 common satellites. Since the satellite positions are known and one of the receivers is over a known point, a "known range" can be computed for each satellite observed. This "known range" can then be subtracted from the "measured range" to obtain a range correction or pseudo-range correction (PRC). This PRC is computed for each satellite being tracked at the known point. The

PRC can then be applied to the moving or remote receiver to correct its' measured range. Code phase DGPS has primary applications to real-time positioning systems where accuracies at the meter-level are tolerable. Given these limitations, engineering/construction survey applications of code phase DGPS are limited. However, DGPS is applicable to hydrographic survey and dredge positioning, since meter-level positioning suffices for the vast majority of these applications.

(2) DGPS (Carrier Phase). Differential positioning and surveying using the carrier phase is the most accurate GPS survey method. The relative positional accuracies are on the order of two to five parts per million (ppm) between two GPS receivers -- one at a known reference point and the other at the unknown location (aboard a vessel, vehicle, aircraft, etc.).

(a) Differential positioning using carrier phase tracking uses a similar formulation of pseudo-ranges used in code phase tracking systems described above. The process becomes somewhat more complex when the carrier signals are tracked. In carrier phase tracking, the short wavelength, 19 cm, necessitates adding an ambiguity factor to the solution equations to account for the unknown number of whole carrier cycles over the pseudo-range.

(b) Carrier phase tracking provides for a more accurate range resolution due to the short (19 cm) wavelength and the ability of a receiver to resolve the carrier phase down to about 2 mm. This method, therefore, has primary application to engineering, topographic, hydrographic, real estate, and geodetic surveying, and may be employed with either static or kinematic receivers. Methods for resolving the carrier phase ambiguity in a dynamic, real-time mode have been developed and implemented by several GPS receiver manufacturers for real-time positioning and are readily available today. These methods are referred to as real-time kinematic or RTK and provide 3D positions accurate to a few centimeters over a range of approximately 20 kilometers (12 miles).

(3) One advantage of the code phase over the carrier phase is the wavelengths are much longer than the carrier wavelengths, eliminating the ambiguity problem. However, the longer wavelengths decrease the system accuracy and are more affected by signal multipath.

7-34. Real-Time Code Phase DGPS Concept

The code phase tracking differential system is currently a functional GPS survey system for positioning hydrographic survey vessels and dredges. A real-time dynamic DGPS positioning system includes reference station (master), communications link, and user (remote) equipment. If results are not required in real-time, the communications link could be eliminated and the positional information post-processed; however, such an operation is not practical for most construction support activities where immediate results are necessary. Since there are several DGPS services (USCG, Commercial Subscription Services) that provide real-time pseudo-range corrections, it is recommended that these services be used before installing or using a local DGPS system. Only in circumstances where these services do not provide coverage should a local DGPS system be used.

a. Reference Station. The reference station measures timing and ranging information broadcast by the satellites and computes and formats range corrections for broadcast to the user equipment. The reference receiver consists of a GPS receiver, antenna, and processor. Using the technology of differential pseudo-ranging, the position of a survey vessel is found relative to the reference station. The pseudo-ranges are collected by the GPS receiver and transferred to the processor where pseudo-range corrections are computed and formatted for data transmission. Many manufacturers have incorporated the processor within the GPS receiver, eliminating the need for an external processing device.

(1) Reference station placement. The reference station is placed on a known survey monument in an area having an unobstructed view of the sky for at least 10 deg above the horizon. The antenna should not be located near objects that will cause multipath or interference. Areas with antennas, microwave towers, power lines, and reflective surfaces should be avoided.

(2) Reference station processor. The reference station processor computes the pseudo-range corrections (PRCs) and formats the corrections for the communications link to transmit to the offshore vessel. The recommended data format is that proposed by the Radio Technical Commission for Maritime Services (RTCM) Special Committee 104 v 2.0. The reference station processor also performs quality assurance. This routine is required to determine the validity and quality of the computed PRCs. The reference station processor should be capable of computing and formatting PRCs every 1 to 3 sec. Most GPS receivers have processors built into them for computing pseudo-range corrections.

(3) Algorithm description. For a detailed algorithm description, refer to EM 1110-1-1003.

b. Communications Link. The communications link is used as a transfer media for the differential corrections. The main requirement of the communications link is that transmission be at a minimum rate of 200 bits per second (bps). The type of communications system is dependent on the user's requirements.

(1) Ultra high frequency (UHF) and very high frequency (VHF). Communications links operating at UHF and VHF are viable systems for the broadcast of DGPS corrections. VHF and UHF can extend out some 20 to 50 km, depending on local conditions. The disadvantages of UHF and VHF links are their limited range to line of sight and the effects of signal shadowing (from islands, structures, and buildings), multipath, and licensing issues. USACE is limited to using VHF 164-172 MHz for the transmission of PRCs since USACE has already been authorized to these frequencies.

(2) Frequency authorization. All communications links necessitate a reserved frequency for operation to avoid interference with other activities in the area. Transmitters with power outputs below 100 milliwatts (mW) do not require a frequency allocation and license for operation in the United States. Frequency authorization for the USACE must be obtained through the National Telecommunications and Information Administration (NTIA) of the U.S. Department of Commerce for transmissions that exceed 100 mW. A district's frequency manager responsible for the area of application handles allocation of a frequency. No transmission can occur over a frequency until the frequency has been officially authorized for use. This procedure applies to all government agencies.

(3) Satellite communications. There are several companies that sell satellite communications systems, which can be used for the transmission of the PRCs. These systems are not as limited in range as a UHF/VHF system can be, but are usually higher in price.

c. User Equipment. The user equipment is the most flexible facet of the real-time code phase tracking DGPS. The remote receiver should be a multichannel single frequency (L1) C/A code GPS receiver. The receiver must be able to accept the differential corrections from the communications link in the Radio Technical Commission for Maritime Services Special Committee No. 104 (RTCM SC-104) v.2.0 format and then apply those corrections to the measured pseudo-range. The critical portion of the user equipment is the receiver update rate. The update rate for payment surveys must be 1 to 3 sec. Specific requirements will vary with different manufacturers and with the distance from the reference station. The output from the rover receiver should be in the NMEA-183 sentencing format, because it is the most widely used for input into a hydrographic survey software package. The user equipment also must be capable of maintaining positional tolerances for surveys at speeds of 7 to 10 knots. A DGPS receiver must not bias the position during vessel turns due to excess filtering.

d. Separation Distances. The maximum station separation between reference and remote station, in order to meet hydrographic surveying standards of 2 m, can be maintained up to a distance of 300 km, provided that differential tropospheric and ionospheric corrections are used. These corrections are not presently applied to internal solutions of most GPS receivers. The unaccounted tropospheric and ionospheric errors contribute to horizontal position error on an average of 0.7 m per every 100 km. A limiting factor of the separation distance is the type of data link used. If a DGPS is procured for hydrographic surveying, the reference station should be capable of being moved from one point to another. This will allow the user to move the reference station so that the minimum distance separation requirements are maintained.

e. Satellite Geometry. In code phase DGPS, the Horizontal Dilution of Position (HDOP) is the critical geometrical component. The HDOP should be < 5 for dredging and navigation hydrographic surveys. The final GPS constellation (24 Block II satellites) will maintain a HDOP of approximately 2 to 3 most of the time.

7-35. USCG DGPS Radiobeacon Navigation Service and Commercial DGPS Services

Real-time, meter-level DGPS correctors can be obtained from the USCG radiobeacon navigation service or from a variety of commercial wide-area augmentation systems (WAAS). This section primarily focuses on the USCG radiobeacon system; however, a number of commercial augmentation systems are capable of providing comparable survey positioning capability. Calibration guidance is applicable to all these augmentation systems.

a. USCG DGPS Radiobeacon System. One function of the U.S. Coast Guard (USCG) is to provide aids to navigation in all navigable waterways. In the past, Loran-C and Omega systems were used as the primary positioning tools for marine navigation. Today, the USCG is making use of the full coverage from GPS for a more accurate positioning tool for marine navigation. Utilizing DGPS and marine radiobeacon technology, the USCG has designed a real-time positioning system for the coastal areas and Great Lakes regions of the U.S. The USCG has also partnered with USACE and other government agencies to expand this coverage to inland waterways and eventually over the entire nation. The system consists of a series of GPS reference stations with know coordinate values based on the North American Datum of 1983 (NAD 83) datum. GPS C/A-code pseudo-range corrections are computed based on these known coordinate values and transmitted via a marine radiobeacon. A user with a marine radiobeacon receiver and a GPS receiver with the ability to accept and apply pseudo-range corrections can obtain a relative accuracy of 0.5-3 meters. This accuracy is dependent on many factors including the design and quality of the user's GPS receiver, distance from the reference station, and the satellite geometry. This service can be used for all USACE hydrographic surveys and dredge positioning requiring an accuracy of 0.5 to 3 meters.

b. Site Set-up and Configuration. Each USCG radiobeacon site consists of two GPS L1/L2 geodetic receivers (as reference station receivers) with independent geodetic antennas to provide redundancy and a Marine Radiobeacon transmitter with transmitting antenna. The site is also equipped with two combined L1 GPS / Modulation Shift Key (MSK) receivers which are used as integrity monitors. Each combined receiver utilizes an independent GPS antenna and a MSK near-field passive loop antenna.

(1) Site Location. The location of the reference station GPS antennas are known control points within the North American Datum of 1983 (NAD 83) and International Terrestrial Reference Frame

(ITRF). The geodetic coordinates for these positions were determined by NGS. DGPS corrections are based on measurements made by the reference receiver and the NAD 83 known antenna coordinates. These corrections are then transmitted via a marine radiobeacon to all users having the necessary equipment.

(2) Data Transmission (data types). The corrections are transmitted using the Type 9-3 (three satellite corrections) message of the Radio Technical Commission for Maritime Services Special Committee 104 (RTCM SC-104) version 2.1 data format. Other RTCM SC-104 message types transmitted to the user include Type 3 (contains the NAD 83 coordinates for the broadcast site), Type 5 (provides information if a GPS satellite is deemed unhealthy), Type 7 (information on adjacent radiobeacons), and Type 16 (alerts the user of any outages). More detailed descriptions of these message types are explained in the Broadcast Standard for the USCG DGPS Navigation Service, COMDTINST M16577.1, April 1993 that can be downloaded from the USCG Navigation Center (NAVCEN) web site (www.navcen.uscg.mil).

(a) Corrections are generated for a maximum of nine satellites tracked by the reference station GPS receiver at an elevation angle of 7.5 degrees or higher above the horizon. Satellites below a 7.5-degree elevation mask are highly susceptible to multipath and spatial decorrelation. If there are more than nine satellites observed at the reference station above 7.5 degrees, than the corrections broadcast are based on the nine satellites with the highest elevation angle.

(b) The sites transmit these corrections at a 100 or 200 baud rate. Since a type 9-3 message is 210 bits (includes header information and corrections for three satellites), the latency of the data is 2.1 seconds for a site transmitting at 100 baud. For stations transmitting at 200 baud, the latency would be half, 1.05 seconds. The user can expect a latency of 2-5 seconds for all of the corrections for a group of satellites observed at the reference station to reach them. A correction can be considered valid for a period of 10-15 seconds from generation (the USCG limit is 30 seconds). Using corrections beyond this period of time, especially for positioning of a moving platform, may cause spikes in the positional results.

c. Availability and Reliability of the System. The system was designed for and operated to maintain a broadcast availability (i.e., transmitting healthy pseudo-range corrections) that exceeds 99.7 percent (in designed coverage areas) assuming a healthy and complete GPS constellation. The signal availability, in most areas, will be higher due to the overlap of broadcast stations. The USCG monitors each site within the entire system for problems or errors 24 hours a day. Each site is equipped with two integrity monitors (i.e. a GPS receiver with a MSK radiobeacon) that are mounted over known positions. The integrity monitors receive the pseudo-range corrections from that site and compute a position. The computed or corrected position is compared to the known location to determine if the corrections are within the expected tolerance. The corrected positions calculated by the integrity monitors are sent via phone lines to the control monitoring stations. For the stations east of the Mississippi River, this information is sent to USCG's NAVCEN in Alexandria, Virginia. Sites west of the Mississippi River send their corrected positions to the NAVCEN Detachment in Petaluma, California. Users are notified via the type 16 message of any problems with a radiobeacon site within 10 seconds of an out-of-tolerance condition.

d. Coverage. The system was designed to cover all harbors and harbor approach areas and other critical waterways for which USCG provides aids to navigation. Each site has a coverage area between 150 to 300 miles, depending on the transmitter power, terrain, and signal interference. Since the sites utilize an omnidirectional transmitting antenna, some areas have overlapping coverage. Currently the system covers all U.S. coastal harbor areas, the Mississippi and part of the Missouri and Ohio Rivers, and the Great Lakes Region. Additional areas within the Midwest U.S. and other non-coastal areas are being added to provide nationwide coverage. Figures 7-21 and 7-22 depict existing and planned radiobeacon coverage as of 1999. An updated map of the coverage area can be found at the NAVCEN web site under the DGPS section.

e. User Requirements and Equipment. To receive and apply the pseudo-range corrections generated by the reference station, the user needs to have a MSK Radiobeacon receiver with antenna and, at a minimum, a L1 C/A code GPS receiver with antenna. The MSK receiver demodulates the signal from the reference station. Most MSK receivers will automatically select the reference station with the strongest signal strength to observe from or allow the user to select a specific reference station. A MSK receiver can be connected to most GPS receivers. The costs of radiobeacon receivers range from $500 to $2000. The GPS receiver must be capable of accepting RTCM Type 9 messages and applying these corrections to compute a "meter level" position. Since the reference station generates corrections only for satellites above a 7.5 degree elevation, satellites observed by the user's GPS receiver below a 7.5 degree elevation will not be corrected. Some receiver manufacturers have developed a combined MSK radiobeacon and GPS receiver with a combined MSK and GPS antenna. For a combined radiobeacon/GPS receiver, prices range from $2,000 to $5,000.

Figure 7-21. USCG Radiobeacon DGPS coverage including USACE coverage in inland navigation system (1999)

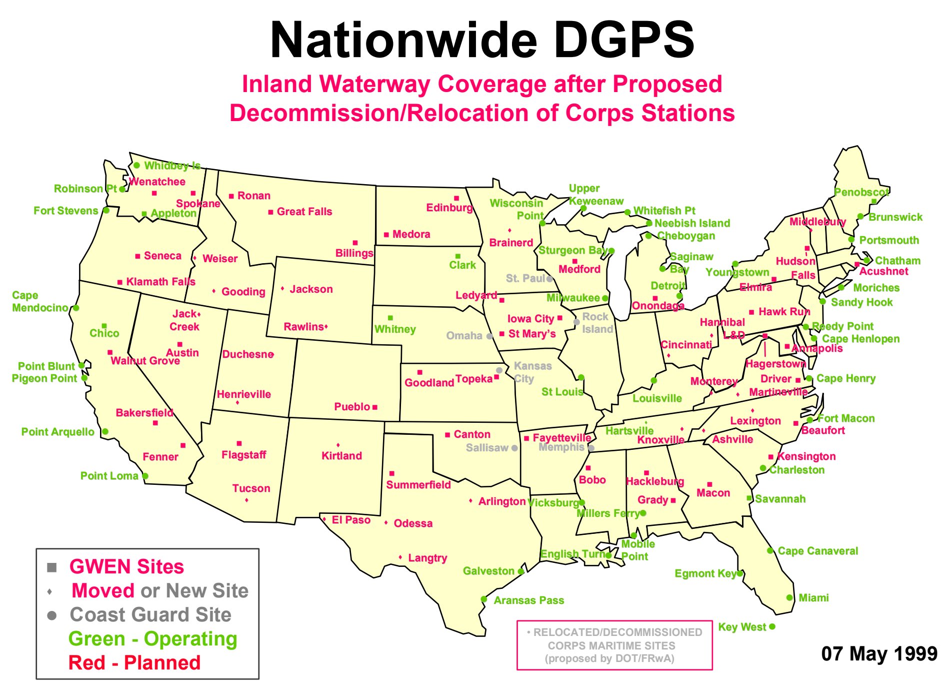


Figure 7-22. Proposed nationwide coverage of USCG radiobeacon network (May 1999)

f. Position QC Tolerance Checks. Most precise DGPS augmentation systems are capable of providing sub-meter accuracies at reasonable distances from the nearest reference station. However, at increasing distances spatial decorrelation errors (due to differing ionospheric/tropospheric conditions) can induce systematic positional biases. In general, under nominal atmospheric conditions, a 2-meter RMS (95%) positional accuracy may be achieved at distances upwards of 150 miles. To confirm a positional accuracy is within this 2-meter tolerance, it is strongly recommended that a static check position be obtained at some known survey point near the project. When operating with the USCG radiobeacon system, static positions should be observed from different radiobeacon reference stations to ascertain if positional systematic biases are present--and select the beacon with minimal biases. In practice, this would normally be the closest beacon. If no fixed survey point is available, then a static comparison of different beacon positions should be observed; however, any large biases between beacon positions may be ambiguous. When large or ambiguous positional biases occur in a project area, it may be necessary to establish a local DGPS network (code or RTK carrier) if high positional accuracy is critical to the project. Commercial WAAS systems should be checked in a similar manner.

7-36. Real-Time Carrier Phase DGPS Concept

a. General. The carrier phase system for hydrographic survey vessels and dredges is capable of centimeter accuracy both horizontally and vertically. This technology will provide real-time elevations of survey vessels and other moving platforms. If adequate motion compensation equipment is used, and project tidal datum modeling has been accomplished, real-time bathymetry (depths) can be directly obtained from the soundings. This positioning system is based on DGPS carrier phase technology similar to the kinematic techniques. In the past, kinematic surveying procedures allow for the movement of a GPS receiver only after the initial integer ambiguity (i.e., whole number of wavelengths) between satellites and receiver had been resolved. Current kinematic techniques allow for the ambiguities to be resolved while the moving receiver(s) is in motion and provides accuracies in the range from 2 to 5 cm. This method of carrier phase positioning is commonly referred to as real-time kinematic or RTK surveying.

b. Reference Station. The carrier phase positioning system is very similar to the current code phase tracking technology previously described. A shore GPS reference station must be located over a known survey monument; however, the reference station must be capable of collecting both pseudo-range and carrier phase data from the NAVSTAR satellites. The reference station will consist of a carrier phase, dual frequency full wavelength L1/L2 GPS receiver with its associated antenna and cables, processor, and communications link. The receiver should be capable of a 1-sec update rate. The location of the reference station will be the same as for a code phase tracking DGPS system. The processor used in the reference station will measure the pseudo-range and carrier phase data and format the data for the communications link. The data will be formatted in the RTCM SC-104 v.2.1 format for transmission to the remote user.

c. Communications Link. The communications link for the carrier phase positioning system differs from the code phase tracking DGPS system in the amount of data that has to be transmitted. The carrier phase positioning system requires a minimum data rate of 4800 baud, as compared to a baud rate of 300 for the code phase tracking DGPS system. This high data rate eliminates many of the low-frequency broadcast systems and limits the coverage area for high-frequency broadcast systems. VHF and UHF frequency communications systems are well suited for this data rate. As satellite communications become more cost-effective, can handle higher baud rates, and employ smaller terminals, this communications option will be used for carrier phase positioning systems.

d. User Equipment. The user equipment on the survey vessel or dredge consists of a carrier phase dual-frequency full-wavelength L1/L2 GPS receiver with a built in processor and associated antenna. The built in processor must be capable of resolving the integer ambiguities while the platform (survey vessel or dredge) is moving. Using a "geodetic quality" GPS antenna will reduce the effects of multipath on the GPS signal. A communications link is needed on the dredge or survey vessel to receive data from the reference station. Frequency approval may be necessary for communication link broadcasts using a power source in excess of 1 watt. The RTK system is not designed to be used for surveys in excess of 20 km from the reference station. The position output for the helmsman is code phase tracking using pseudo-ranges (accurate at the meter level) for vessel navigation in real time. The carrier phase DGPS data will be timed/tagged to allow for recording the true vessel position needed for survey processing. The minimum update rate from the reference station to the vessel(s) is 1 sec.

e. Ambiguity resolution. High-precision kinematic positioning is available from the system once the receiver's processor resolves integer ambiguities. As long as the system remains in the RTK mode, real-time sub-decimeter positioning in three dimensions is available at the (mobile) remote station or platform. To remain in this RTK mode requires both reference station and the remote station receivers to maintain lock (continuous GPS data) on at least four satellites. If that number drops to below four, the ambiguities will again be resolved after the system reacquires lock on a sufficient number of satellites. It will also trigger reinitialization if quality factors based upon residuals fail to meet certain predefined limits.

Section VIII
Summary of Positioning System Quality Control Standards

7-37. Calibration Criteria

All visual, mechanical, and electronic positioning systems must be periodically calibrated (or checked) to minimize systematic errors and/or to eliminate blunders that may be present in the measurements. Failure to perform and record calibrations represents poor quality control performance and, in the case of construction measurement and payment work, can lead to contract disputes and claims over equitable payment. The amount of calibration needed for each type of positioning system varies considerably. Transits and total stations require periodic back sight checks. Microwave distance measurement systems require daily comparisons with independent higher accuracy EDM. GPS has far fewer calibration requirements than other positioning methods. It is mandatory that calibration observations (and related computations and adjustments) must be officially recorded either in a standard field survey book or on a prescribed worksheet and that these records be maintained as part of the project/contract files.

7-38. Quality Control Criteria for Positioning Methods

Table 7-1 resents a summary of minimum QC standards to be followed when using the various positioning systems described in this chapter. These criteria apply only to dynamic hydrographic survey applications, not to observations made to locate or calibrate a stationary platform or structure.

Table 7-1. Summary of QC Standards for Hydrographic Survey Positioning

	PROJECT CLASSIFICATION		
	Navigation & Dredging Support Surveys Bottom Material Classification		Other General Surveys & Studies (Recommended Standards)
	Hard	Soft	
SEXTANT RESECTION			
Allowable procedure	No	No	Yes
Calibrate sextant every	N/A	N/A	30 min
TRIANGULATION/INTERSECTION			
Allowable procedure	No	Yes	Yes
Check backsight	N/A	1/hr	1/hr
VISUAL POSITIONING			
Allowable procedure	No	No	Yes
TAG LINE POSITIONING			
Allowable procedure	Yes	Yes	Yes
Distance from baseline NTE	500 ft	1,500 ft	3,000 ft
Calibrate tag line	project	monthly	annually
Accuracy-nearest	1 ft	1 ft	2 ft
Allowable alignment methods (see Range Azimuth below)			

Table 7-1. Summary of QC Standards for Hydrographic Survey Positioning (Contd)

	PROJECT CLASSIFICATION Navigation & Dredging Support Surveys Bottom Material Classification		Other General Surveys & Studies (Recommended Standards)
	Hard	Soft	
RANGE-AZIMUTH			
Allowable procedure	Yes	Yes	Yes
Distance from observer NTE:			
Stadia	200 ft	500 ft	1,000 ft
Microwave EDM	(0 ft)	5,000 ft	----
Total Sta EDM	(Inst range)	(Inst range)	(Inst range)
Alignment method:			
Right angle glass	100 ft	200 ft	500 ft
Sextant	500 ft	1,000 ft	2,500 ft
Transit/Theod/Tot Sta	(Inst range)	(Inst range)	(Inst range)
Check orientation	2/hr	1/hr	1/hr
Real-time data quality indicator	Recommended	Recommended	Recommended
Alarm at 95% RMS exceeding	2 m	2 m	5 m
MICROWAVE RANGE-RANGE			
Allowable procedure	No	No	Yes
Calibrate	N/A	N/A	monthly
Range calib accuracy	N/A	N/A	± 3 m
Calib point at worksite	N/A	N/A	Recommended
Angle of intersection	N/A	N/A	30-150 deg
Real-time data quality indicator	N/A	N/A	Recommended
Alarm at 95% RMS exceeding	N/A	N/A	5 m
GLOBAL POSITIONING SYSTEMS			
Allowable mode			
SPS/PPS	No	No	Yes (marginally)
DGPS (Local Code)	Yes	Yes	Yes
DGPS (USCG/WAAS)	Yes (marginally)	Yes	Yes
DGPS (Carrier/RTK)	Yes	Yes	Yes
Maximum distance from ref sta			
SPS/PPS	N/A	N/A	N/A
DGPS (Local Code)	1 mile	10 miles	50 miles
DGPS (USCG/WAAS)	100 miles	150 miles	200 miles
DGPS (Carrier/RTK)	10 miles	10 miles	20 miles
Position check required	1/day	1/project	1/project
Tolerance check	1 m	2 m	5 m
Real-time data quality indicator	Mandatory	Recommended	Recommended
Alarm at 95% RMS exceeding	2 m	2 m	5 m
RTK vertical check with gage	Mandatory	Mandatory	Recommended

7-39. Mandatory Requirements

The criteria in Table 7-1 for positioning dredging and navigation surveys are considered mandatory.

Chapter 8
Manual Depth Measurement Techniques

8-1. General Scope and Applications

Manual depth measurement techniques are used for many under water engineering and construction applications. These methods include use of hand lead lines, topographic level rods, and sounding poles. Manual methods are generally used where more efficient acoustic methods cannot provide adequate depth data or sufficient detail. Examples include: surveys of areas adjacent to piers, bulkheads, and offshore pile structures; near locks, dams, power plants, and river control structures subject to turbulence; detailed surveys of rock jetties and breakwaters; beach and dune profile surveys; surveys in shallow detention or retention ponds or water conservation pools; surveys in shallow wetland areas with thick bottom vegetation or mangrove; and surveys in areas where unconsolidated sediments are present. Manual depth measurement techniques are simply a variation of conventional topographic survey methods. However, unlike land-based topographic surveys, the geophysical properties of the bottom are not always visible or consistent. Any type of positioning method may be used to locate the depth measurement device--total stations and DGPS now being the most common. This chapter provides general guidance and procedural criteria for manual hydrographic survey depth measurements on engineering and construction projects.

8-2. Lead Line or Sounding Disk Measurement

Prior to the accepted use of acoustic depth sounding methods in the 1950s, lead lines were the Corps standard for hydrographic survey depth measurement, as illustrated in Figure 8-1. At one time they were used as the calibration reference for acoustic soundings. Lead lines are simply surveyor tapes (chains) with a weight attached to the end. The length of these lines was usually less than 100 ft, or near project depth; however, much longer lines were used for deep-water surveys. Lead lines may be operated by hand, suspended from a bicycle wheel, or operated by a power winch apparatus--see Figure 8-2. The water surface is used as the reference datum for the observations, as shown in Figure 8-1.

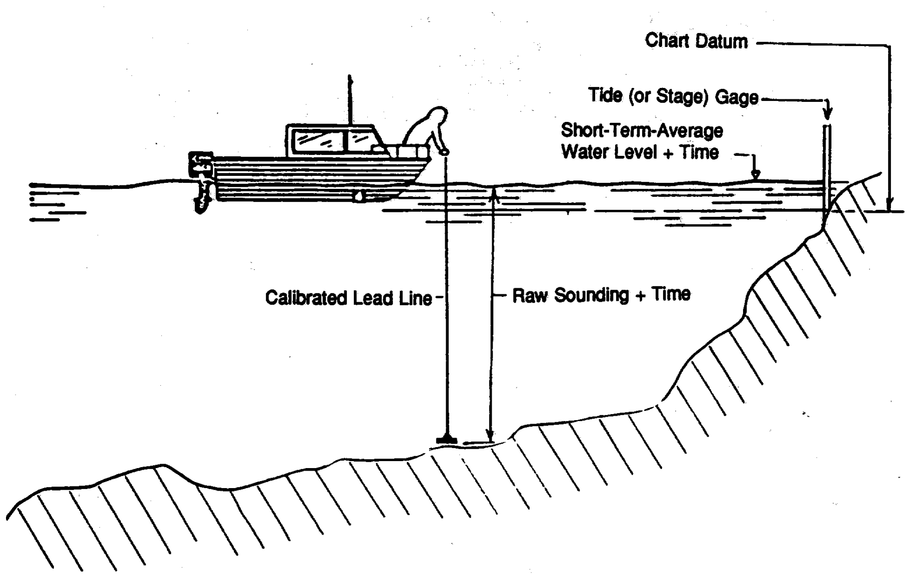


Figure 8-1. Lead-line depth measurement

a. General uses. Lead lines are to be used in situations where use of electronic sounding would be impractical, impossible, or give faulty results. Lead line sounding is especially suited for underwater investigation of rock or concrete placement; on the slopes of jetties, groins, and revetments; and near bulkhead construction. In such areas, echo sounding may be inaccurate or contaminated with noise from side echoes. Lead lines are to be used in conjunction with acoustic or nuclear density techniques to corroborate echo soundings. Also, for silty bottoms containing "fluff" that would give questionable echo sounding readings, a lead line may be required in a construction contract.

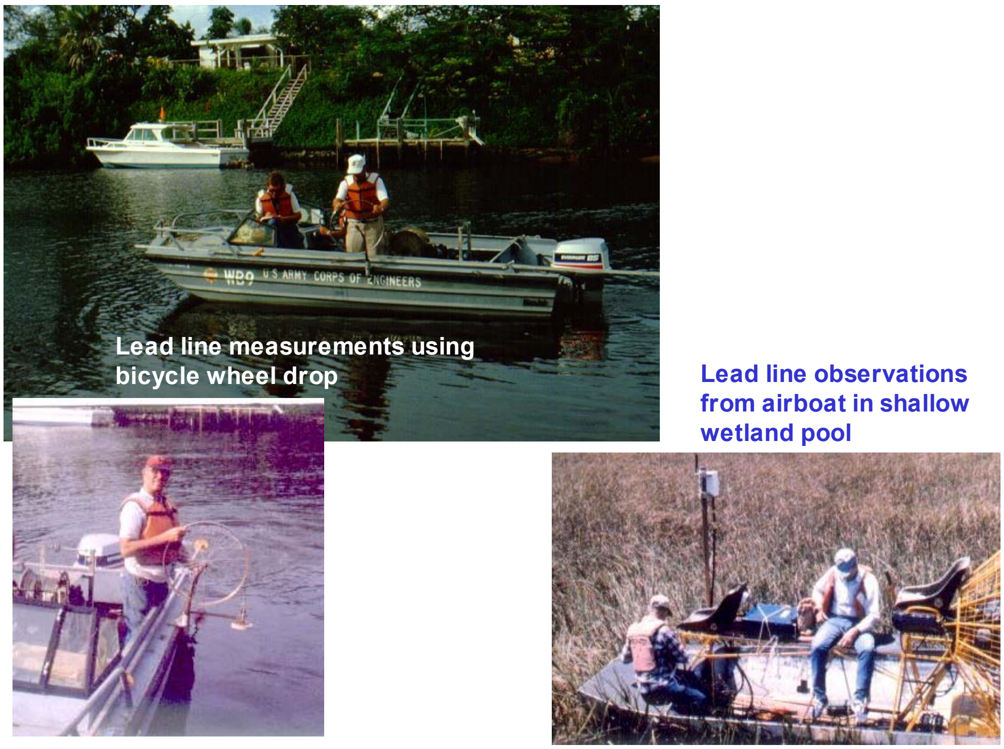


Figure 8-2. Lead line measurements (Jacksonville District)

b. Line materials and dimensions. A variety of flexible metallic materials can be used to suspend a sounding lead. All must exhibit minimal stretch while under tension. Braided rope is never used for this reason. Standard 100-ft surveyor's chains/tapes have been configured into lead lines. Stainless steel wire rope, piano wire, and rubber-shielded electrical wire are often used. Since a lead line is rarely used in depths exceeding 50 ft, line stretching due to tension should be minimal. However, this should be checked when any type of braided material is used. For most USACE applications, lines need not be made any longer than 50 to 75 ft. Shorter lines may be made when used primarily on shallow-draft projects.

(1) The Coast and Geodetic Survey recommends use of a mahogany-colored tiller rope with a phosphor-bronze wire center (size 8 line --0.24-in. diameter). This type of braided line is suitable for continuous hand operation since the tightly woven cotton shroud prevents broken wire strands from protruding and causing hand injury. Procedures for seasoning and calibrating this type of line are covered in the NOAA Hydrographic Manual (1976).

(2) Flexible wire lines are best suited for mechanically reeled lead lines. A bicycle wheel rim (Figure 8-2) or other large-diameter drum provides a rapid line payout velocity. A thin braided or solid core flexible wire is used for such devices.

c. Line marking. For Corps applications, lines are marked at 0.1-ft intervals throughout their length. The zero reference is the bottom crown of the mushroom anchor or sounding disk, and the marking interval begins above the connection to the sounding line. The anchor/disk shank is not marked. Marking the 0.1-ft intervals is performed using a standard 100-ft surveyor's chain. These marks must be easily read. Care must be taken to ensure that the ring/swivel and shackle connection is free and clear and that the line is under adequate tension. Types of marks used depend on the line. Marks may be seized onto the line with small cord. Seizings should penetrate the wire braids to prevent slippage. Marks may be directly crimped onto braided or solid wire using standard wire rope crimping equipment, and identified by color-coded seizing cord or seized leather flags.

d. Lead type and dimensions. A Corps-wide standard lead line weight shall be either a mushroom anchor or a flat sounding disk. A standardized weight will help ensure uniformity of contract payment, especially in areas subjected to high-suspended sediment concentrations. These two optional standardized weights should not be interchanged on the same project.

(1) *Mushroom anchor.* The USACE standard mushroom anchor type lead weighs 7-lbs. and has a 6-in. diameter crown. This type of anchor may be purchased at most marine supply outlets. The lower end of the line should be attached to the anchor ring with a freely pivoting shackle. In some cases, a permanent bight in the line may be end-spliced around the anchor ring's eye. Any variation from this standard lead weight shall be indicated in construction contract specifications. In some high-turbulence areas, a heavier lead may be required. Lead weights in excess of 100 lb. have been used to investigate scour rates below control structures.

(2) *Sounding disk.* The standard sounding disk is a 6-in.-diameter circular stainless steel plate. A connecting shank (4- to 8-in. length) and swivel shall be welded to the center of the plate. Four 1-in.-diameter holes shall be drilled symmetrically around the plate. Total weight, including shank and attachment swivel, shall be 8 lb. Again, any variation from this standard lead weight shall be indicated in construction contract specifications.

e. Operational procedures. Normally, measurement is made upon free-fall to apparent refusal on the bottom. Proper care shall be taken to minimize line angle from the vertical due to strong currents or tidal flow. A bicycle wheel should be employed when rapid drops are necessary such as in project depths exceeding 40 ft with strong surface or subsurface currents are present. In soft-bottomed materials, the reading should be taken at apparent refusal or within some specified time (normally 5-sec) after apparent initial penetration. In payment areas where a lead continues to fall under its own weight, it is essential that contract specifications (or subsequent agreement) indicate the elapsed time before reading. To ensure consistency and equity of payment, the same lead line and leadsman operator should be used for both pre-construction and post-construction surveys. Leads should be thrown or mechanically dropped adjacent to the tag line mark or positioning reference. If lead casts are made to port/starboard and/or forward/aft of the positioning reference, an eccentric correction must be applied. The lead line is held taut for sufficient time to visually mean any sea state variation. Observed depths are recorded to the nearest 0.1 ft either in a surveyor's field book, on a worksheet, or directly into a portable data-logging device. Buffalo District has developed a system whereby lead line observations are input into HYPACK along with observed DGPS positions. Subsequent corrections are made for river/pool stage or tidal datum. Corrections resulting from periodic calibrations are also applied.

f. Calibration. Each lead line should be calibrated at intervals of time not exceeding those listed in Table 8-1. Contractors are free to request that the lead line be checked before any payment survey. Calibration should be performed by comparison of marked intervals with a steel tape. Calibration data should be recorded in a standard field survey book or on a worksheet. Differences between true and marked intervals should be computed. Measurements in the interval band should be corrected accordingly. Maximum errors should not exceed the indicated allowable values. If so, marks exceeding this value shall be reset. If a constant index error is present, the line-anchor connecting assembly should be modified to remove the error.

8-3. Sounding Pole

a. Uses. A sounding pole is basically a level rod which uses the water surface instead of a differential leveling instrument for reference. Depths are observed relative to the water surface. If a total station is used, direct absolute elevations may be observed and reduced to the water surface datum. Standard expandable level rods are often used for sounding poles. Sounding poles, like lead lines, are useful in certain situations in which an electronic echo sounding system is not practical or accurate. For example, areas with dense bottom vegetation or irregular jetty stone may give false signals electronically and must be sounded by hand. Next to instrumental leveling, a sounding pole is perhaps the most accurate hydrographic measuring device in shallow water depths. It is especially suitable for subsurface rock and concrete placement. Its light weight is useful in fluff areas where free-fall penetration must be minimized. Its uses are generally restricted to depths not exceeding 15 to 20 ft. Figures 8-3 and 8-4 are illustrations of the use of a sounding pole.

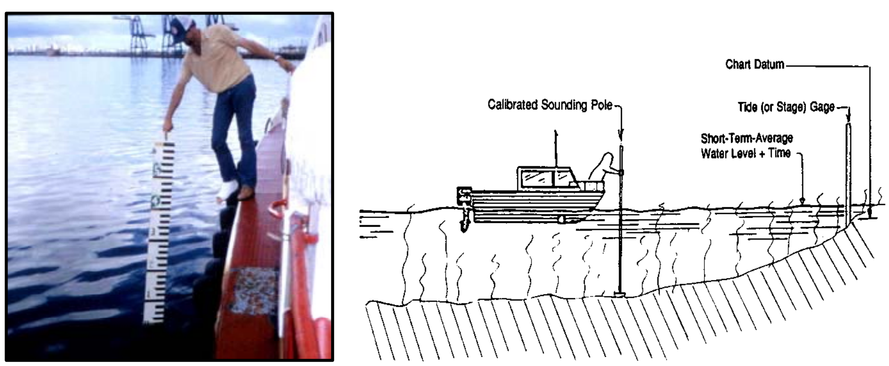


Figure 8-3. Sounding pole depth measurement

b. Dimensions. Poles should generally not exceed 20 ft in length. A 12- to 15-ft-long pole is optimal for ease in handling and maintaining verticality. Wood or square tubular aluminum poles (1-in. dimension) are commonly used. Standard wooden/metallic and fiberglass level rods are also employed as sounding poles. For other than subsurface rock, packed sand, concrete, or other hard bottom material depth measurement, the pole should have a 6-in.-diameter circular plate attached to the base of the pole. Overall weight of the pole (including base plate) should be less than 8 lb. As with a lead line, use of a particular pole should remain consistent throughout the duration of a contract/project. When conventional level rods or fiberglass rods are used, the base plate characteristics and overall weight should conform to the above standard. Any deviation for a particular project shall be noted in the contract specifications.

Figure 8-4. Sounding pole measurement from small work boat (Jacksonville District)

c. Marking. Sounding poles are marked at 0.1-ft intervals. Rod divisions are referenced to the bottom of the base plate. Marks are usually painted and annotated in a manner identical with that used to paint and annotate conventional level rods.

d. Calibration requirements. Each sounding pole should be calibrated at periodic intervals and recorded in a standard field survey book. Pole calibration should be done by comparison with a steel tape or level rod whereby marked intervals are measured and recorded.

e. Operational procedures. In projects with hard bottom material, readings shall be taken at apparent refusal. In soft-bottomed materials, the reading shall be taken at apparent refusal or within some specified time (normally 5 seconds) after apparent initial penetration. In extreme low-density areas where the pole continues to fall under its own weight, it is essential that contract specifications (or subsequent agreement) indicate the time of reading. It is critical that no pressure be exerted in areas of highly suspended sediments. Observations are referred to the water surface and are corrected to the final datum by applying appropriate corrections, including calibration corrections, if any. The pole must be kept as nearly vertical as possible especially in strong currents. A standard bulls-eye rod level may be attached to the pole if necessary. Depth measurements must be reduced for any horizontal eccentricities as described for lead line measurements.

8-4. Manual Depth Measurement Accuracy and Quality Control Criteria

Manual depth measurement accuracy depends on a number of factors: water depth, currents, sea state, and bottom consistency. In general, these devices are highly accurate in calm, shallow water where the device can quickly reach the bottom and depth readings can be easily interpolated from the water surface undulations. Accurate measurements require rapid estimation of the average wave action. Where feasible, direct total station elevation observations on the rod can eliminate the water surface interpolation error. However, this is usually not practical at distances beyond 500 ft from the instrument, and the water surface must be used as the reference elevation. Currents can adversely effect both lead line and sounding pole measurements, causing slope distances to be observed. In soft sediments, the reading accuracy is dependent on the ability to judge a point of refusal. This is likewise true in dense bottom vegetation or where mangrove roots are present.

a. Depth limitations. In general, the accuracy of manual depth measurement methods is limited to water depths of approximately 15 to 20 ft. This is based on the performance standards shown in Table 3-1 for mechanical observations at these depths--i.e., ± 0.25 ft RMS (95%). Deeper measurements may be justified only in extremely calm, current-free, protected waters, with a nearby reference gage.

b. Quality control and assurance. QC techniques are basically limited to periodic calibrations of the line or rod intervals, restricting observation conditions (depth, current, sea state, etc.), and verifying tide/stage gage readings. Independent QA testing is not usually performed on manual survey methods; thus, adequate QC is essential. If distances from the reference tide/staff gage are significant, then comparisons and/or interpolations should be made from a second gage. A "significant" difference in gage observations would be water surface slope errors exceeding 50% of the required elevation accuracy--i.e., approximately ± 0.12 ft for dredging and navigation surveys in less than 15 ft of water. Refer to Table 3-1.

c. Criteria. Table 8-1 describes general criteria for depth measurement observing, recording, and accuracy evaluation.

Table 8-1. Manual Depth Measurement Quality Control Criteria

	PROJECT CLASSIFICATION		
	Navigation & Dredging Support Surveys Bottom Material Classification		Other General Surveys & Studies (Recommended Standards)
	Hard	Soft	
Recommended maximum depth	15 ft	20 ft	50 ft
Read/record/plot soundings to nearest	0.1 ft	0.1 ft	0.1 ft
Maximum currents generally NTE	1-3 kts	4-5 kts	N/A
Reference water surface accuracy for depths < 15 ft	± 0.12 ft	± 0.12 ft	± 0.25 ft
Calibrate line/pole/rod to tape every read to nearest	week 0.05 ft	month 0.05 ft	annually 0.05 ft
Standard lead line weight	[7 lb mushroom anchor] [8 lb -- 6-in sounding disc]		optional optional
Standard pole/rod disc size Total weight	6-in diam 8 lbs	6-in diam 8 lbs	optional optional

8-5. Mandatory Requirements

The criteria in Table 8-1 are considered mandatory.

Chapter 9
Single Beam Acoustic Depth Measurement Techniques

9-1. General Scope and Applications

Single beam acoustic depth sounding is by far the most widely used depth measurement technique in USACE for surveying river and harbor navigation projects. Acoustic depth sounding was first used in the Corps back in the 1930s but did not replace reliance on lead line depth measurement until the 1950s or 1960s. A variety of acoustic depth systems are used throughout the Corps, depending on project conditions and depths. These include single beam transducer systems, multiple transducer channel sweep systems, and multibeam sweep systems. Although multibeam systems are increasingly being used for surveys of deep-draft projects, single beam systems are still used by the vast majority of districts. This chapter covers the principles of acoustic depth measurement for traditional vertically mounted, single beam systems. Many of these principles are also applicable to multiple transducer sweep systems and multibeam systems. This chapter especially focuses on the critical calibrations required to maintain quality control in single beam echo sounding equipment. These criteria are summarized in Table 9-6 at the end of this chapter.

9-2. Principles of Acoustic Depth Measurement

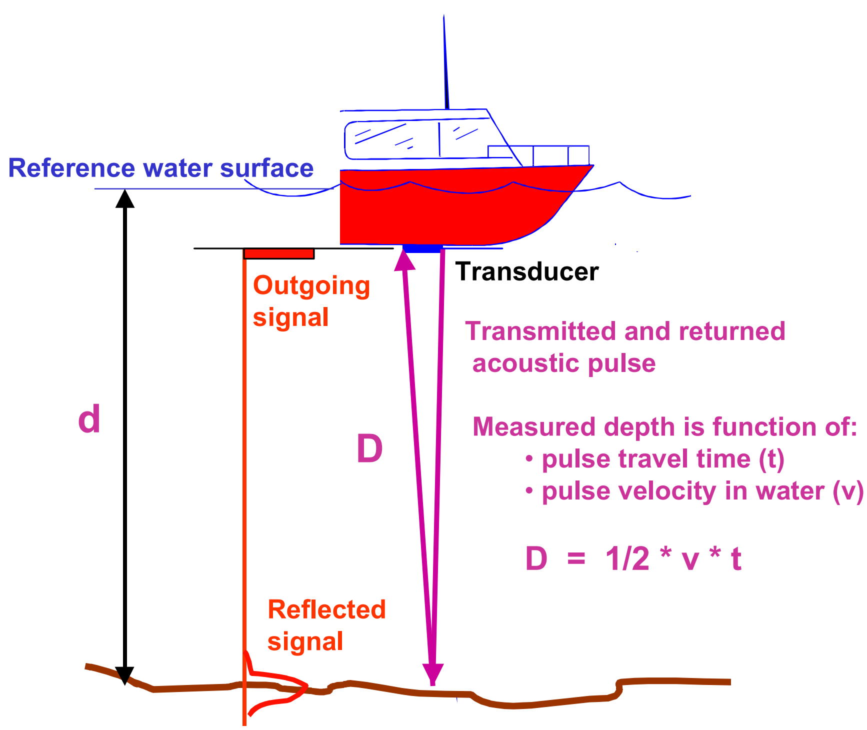


Figure 9-1. Acoustic depth measurement

a. Basic principle. Acoustic depth measurement systems measure the elapsed time that an acoustic pulse takes to travel from a generating transducer to the waterway bottom and back. This is illustrated in Figure 9-1 where the measured depth (D) is between the transducer and some point on the acoustically reflective bottom. The travel time of the acoustic pulse depends on the velocity of propagation (v) in the water column. If the velocity of sound propagation in the water column is known, along with the distance between the transducer and the reference water surface, the corrected depth (d) can be computed by the measured travel time of the pulse. This is expressed by the following general formula:

Depth corrected to referenced water surface $d = \frac{1}{2}(v \cdot t) + k + d_r$ (Eq 9-1)

where:

d = corrected depth from reference water surface
v = average velocity of sound in the water column
t = measured elapsed time from transducer to bottom and back to transducer
k = system index constant
d_r = distance from reference water surface to transducer (draft)

The parameters v, t, and d_r cannot be perfectly determined during the echo sounding process, and k must be determined from periodic calibration of the equipment. The elapsed time, t, is dependent on the reflectivity of the bottom and related signal processing methods used to discern a valid return. The shape, or sharpness, of the returning pulse shown in Figure 9-1 will play a major role in the accuracy and detection capabilities of depth measurement.

b. Velocity of sound in water. Determining the sound velocity, v, is perhaps the most critical factor in using acoustic depth sounders. The sound velocity varies with the density and elastic properties of the water. These properties are, for typical river and harbor project depths, primarily a function of the water temperature and suspended or dissolved contents, i.e., salinity. Due to these effects, the velocity (v) can range from 4,600 to 5,000 ft/sec. Since most river and harbor projects can exhibit large variations in temperature and/or salinity with depth, the velocity of the projected sound wave will not be constant over the distance from the boat's transducer to the bottom and back. The effect of this variation is significant. A temperature change of 10 deg F will change the velocity by as much as 70 ft/sec, or 0.8 ft in 50 ft of water. A 10-ppt salinity change can vary the velocity by some 40 ft/sec, or 0.4 ft in 50 ft. For practical single beam echo sounding work in shallow water, an average velocity of sound is usually assumed (by calibration). Use of an average sound velocity may not be valid in coastal projects subject to freshwater runoff nor will it be constant over the entire project area surveyed. If large variations in velocity occur over the water column, the average sound velocity used should be that at or near the average project survey depth, not over the entire water column. The sound velocity may be measured directly using a velocity probe or indirectly by a bar check calibration. The velocity probe can measure sound velocities at each point in the water column (e.g., every foot). These data can be used to compute an average velocity over the entire column, or use the velocities at each increment to correct depths. The bar check measures actual depths relative to the recorded depths on the echo sounder with an assumed average velocity. Sound velocity determination is much more critical on multibeam systems--especially on the outer beams. Thus, more frequent and accurate sound velocity measurements using probes are required for multibeam systems.

c. Transducer draft and index constant. The transducer draft and index constant must be applied to the reduced time distance to obtain the corrected depth from the reference water surface. The index constant contains any electrical and/or mechanical delays inherent in the measuring system, including return signal threshold detection variations. It also contains any constant correction due to the change in velocity between the upper surface level and that used as an average for the project depth range. For this reason, the apparent "draft" setting or reading on a digital or analog record is *not* necessarily the actual draft of the transducer, as would be obtained by physical measurement between the water surface and transducer. Also, the vessel draft is not the same as the transducer draft because the vessel draft may be measured relative to skegs or other points on the hull. The only effective method of determining the combined constants in Equation 9-1 is by a bar check calibration.

d. Other corrections to observed depths. The depth in Equation 9-1 must subsequently be corrected for short-term vessel draft variations due to loading changes, squat, settlement, heave, pitch, roll, etc. The reference water surface must then be reduced to the local vertical datum based on real-time river/lake stage, pool, or tidal observations. The various corrections required in an acoustic depth measurement are generalized in the sketch shown in Figure 9-2 and are discussed in subsequent sections in this chapter.

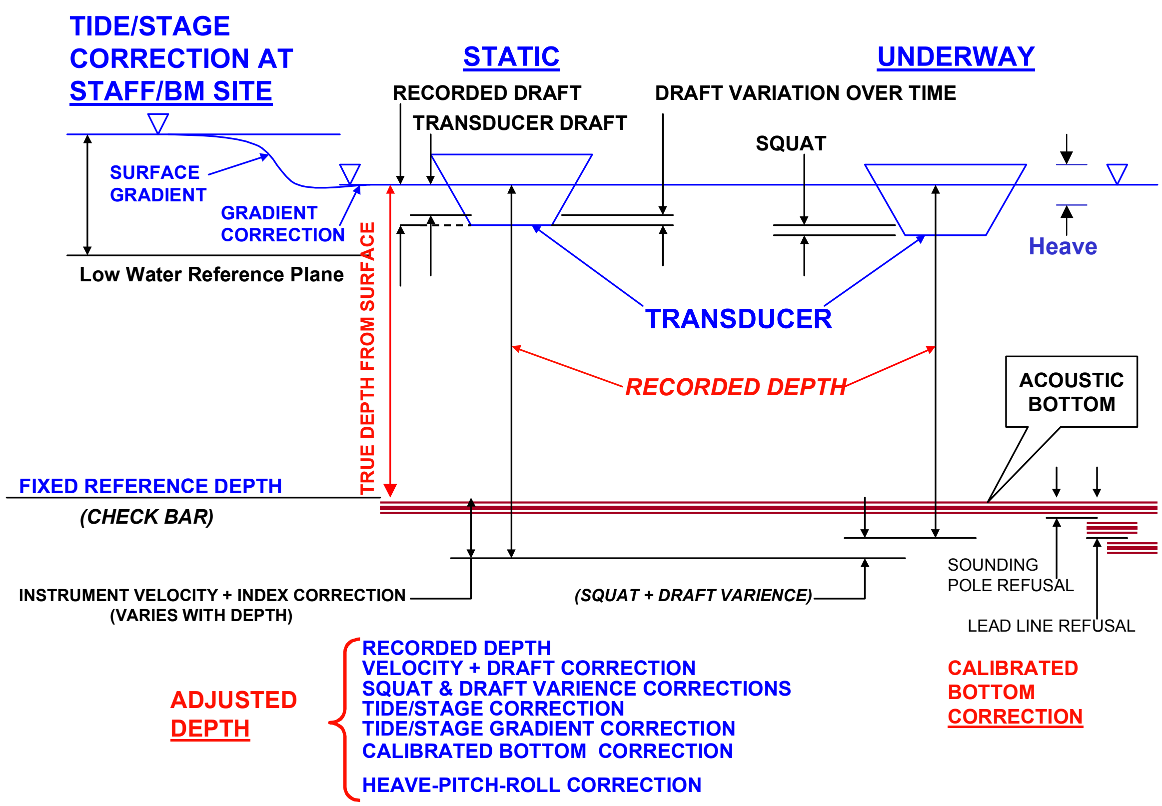


Figure 9-2. Corrections to observed echo soundings

e. Sounding instrument accuracy. The travel time of the sound pulse is measured either electronically in a depth digitizing device or mechanically (graphically) on an analog recording type instrument. The accuracy of the absolute time measurement generally varies with depth. This is due to signal attenuation, noise, and the ability of the measurement circuitry to correlate the outgoing and incoming pulses. In addition, the acoustic reflectivity characteristics of the target, i.e., size, shape, orientation, material, etc., can significantly impact the returning pulse. Variations in return signal strength and sharpness will affect the depth measurement accuracy. The irregularity of the reflected pulse causes uncertainty in the overall time measurement process. There is no practical calibration process for minimizing this error. The *nominal* accuracy of echo sounding time measurement is usually rated by manufacturers at ±0.1 ft plus 0.1 to 0.5 percent of the depth. This equates to a precision range of ±0.15 to ±0.35 ft in 50 ft and is independent of the acoustic reflection characteristics. Digitally measured elapsed times are more accurate than those performed on older mechanical recording devices.

9-3. Transducer Frequency Specifications

A transducer converts electronic energy to acoustical pulses and vice versa. The type of transducer used is a major determining factor in the adequacy of a depth measurement. The optimum transducer frequency is highly project- or site-dependent. Throughout USACE river and harbor projects, a variety of frequencies have been used. These frequencies generally range between 20 kHz and 1,000 kHz. Each frequency/transducer has physical characteristics that particularly suit it to an individual application or project site. The response (i.e., sounding) of the transducer is dependent on the frequency, project conditions, array gain, and beam pattern as is generalized in Figure 9-3. Sensitivities are measured at the - 3 dB half-power points. In general, higher frequency transducers (100 kHz to 1,000 kHz) will provide more precise depth measurement, due to both the frequency characteristics and more-concentrated (i.e., narrow) beam widths. Narrow beam transducers (i.e. less than 8 deg) may require roll and pitch correction since the more-focused beam will measure a slope distance at non-vertical points. However, the side lobes shown in Figure 9-3 could provide a vertical return in shallow water. Narrow beam transducers should be obtained with minimum side lobes. Lower frequency transducers (below 40 kHz) tend to have larger beam widths, which can cause distortion and smoothing of features in irregular bottoms or on side slopes. However, lower frequencies are less subject to attenuation, which allows greater depth measurement and penetration of suspended sediments. Although greater depth measurement is not required for river and harbor projects, the ability to penetrate suspended sediment is a decided asset, especially in performing surveys for dredging projects. A major disadvantage of higher frequency transducers is that there is high signal attenuation with depth, and low specific gravity suspended sediments (fluff) or bottom vegetation will readily reflect the signal. High frequency transducers are not recommended in areas where suspended sediment layers commonly occur, or where bottom vegetation may obscure the desired "pay" grade. In such areas, frequencies ranging between 20 kHz and 50 kHz are typically employed for payment determination.

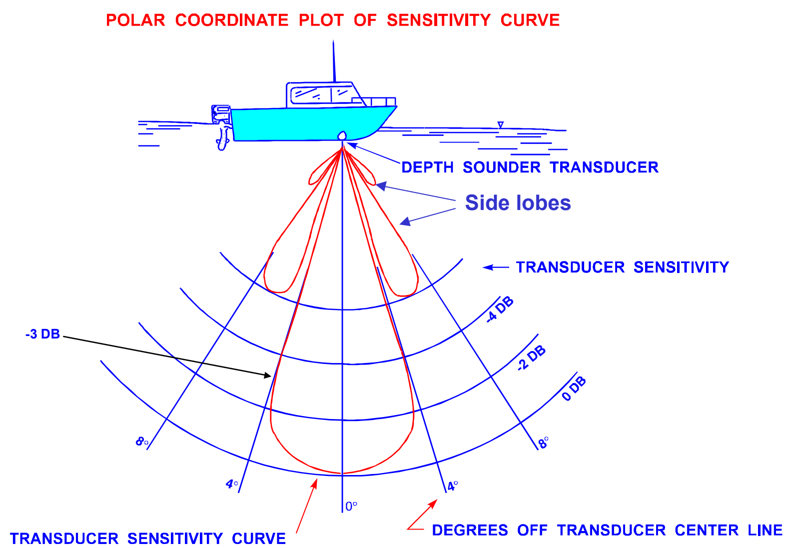


Figure 9-3. Transducer beam angle

a. Ensonification coverage. Each transducer ping ensonifies an area of the bottom. The size of this ensonified area is a function of the transducer beam width and transducer characteristics (i.e., side lobes). The narrow beam transducers used in the Corps ensonify a smaller area of the bottom; resulting in less distortion or smoothing of bottom features within this area. However, only a small portion of a channel is ensonified by narrow beam transducers. The approximate bottom footprint size of a transducer can be computed as follows:

$$\textit{Linear coverage (ft)} = 2 \cdot D \cdot \tan(a/2)$$

$$\textit{Footprint area coverage (sq ft)} = 3.14 \cdot D^2 \cdot \tan^2(a/2) \qquad \text{(Eqs 9-2)}$$

where,

D = Depth in ft
a = Beam width in deg

Table 9-1 illustrates the lineal coverage for typical USACE transducers. Table 9-2 computes the resultant area footprint coverages.

Table 9-1. Approximate lineal coverage for different beam width transducers

		BEAM WIDTH		
Project depth	1.5 deg	3 deg	8 deg	20 deg
10 ft	0.3 ft	0.5 ft	1.4 ft	3.5 ft
25 ft	0.7 ft	1.3 ft	3.5 ft	9 ft
50 ft	1.3 ft	2.6 ft	7 ft	18 ft
75 ft	2 ft	4 ft	10 ft	26 ft

Table 9-2. Approximate footprint coverage for different beam width transducers

		BEAM WIDTH		
Project depth	1.5 deg	3 deg	8 deg	20 deg
10 ft	< 1 sq ft	< 1 sq ft	< 2 sq ft	10 sq ft
25 ft	< 1 sq ft	< 2 sq ft	10 sq ft	60 sq ft
50 ft	< 2 sq ft	5 sq ft	40 sq ft	250 sq ft
75 ft	3 sq ft	10 sq ft	90 sq ft	550 sq ft

Table 9-2 clearly indicates that bottom coverage is small for narrow beam transducers. Thus, when cross-section surveys are performed, only a very small portion of the channel is ensonified. The total amount of ensonified coverage for typical cross-section surveys at 100-ft and 200-ft spacings is shown in Table 9-3.

Table 9-3. Approximate percent bottom coverage for cross-section surveys

	100-ft Cross-Sections			200-ft Cross-sections		
Project depth	1.5 deg	3 deg	8 deg	1.5 deg	3 deg	8 deg
10 ft	0.3%	0.5%	1.4%	0.1%	0.2%	0.7%
25 ft	0.7%	1.3%	3.5%	0.3%	0.6%	2%
50 ft	1.3%	2.6%	7%	0.6%	1%	4%
75 ft	2%	4%	10%	1%	2%	5%

Table 9-3 indicates that only 1% to 5% of a channel bottom is typically ensonified by single beam cross-section surveys. From this small data sample, shoaling conditions are projected and material quantities are estimated using end area projection methods. In effect, quantity take-off computations and shoaling estimates are "extrapolated" over 95-99% on the channel that is not surveyed. These estimates have normally been adequate for engineering and construction purposes; plus they were deemed practical given the high cost of data collection per cross-section. In the past this rationale was valid; however, multi-transducer sweep systems and multibeam systems can now easily collect 100% bottom coverage.

b. Single beam roll and pitch correction. The transducer measures depth from the first echo return. The wider the beam, the less effect vessel roll or pitch will have since the transducer beam width falls within the vertical. For narrow beam transducers a slope rather than vertical distance is measured. If roll and pitch is severe--e.g., a 10-15 deg roll--the recorded depth will be a longer slope distance. This measurement should either be rejected due to excessive roll/pitch or corrected for slope-to-vertical given the observed roll/pitch angle from a motion sensor. Processing software such as HYPACK provides pitch/roll slope-to-vertical depth correction in addition to correcting for the positional (X-Y) eccentricity or the transducer relative to the positioning antenna.

c. Shoal or object strike detection. Far more complex is the effect of frequency on the detection of certain-size objects on the bottom. Detection of blasted rock fragments or other hazardous objects above project grade is a difficult process with traditional echo sounders, regardless of the frequency used. Generally, lower-frequency, wider-beam transducers may be more suited for strike detection than higher-frequency, narrow-beam transducers. However, the sounding system's threshold detection settings, gate settings, display methods, etc., are also critical to strike detection. Vertically mounted, narrow-beam transducers (either single hull-mounted or boom “sweep” systems) may not be the best configuration for providing optimum energy return from small underwater strikes; notwithstanding their small acoustical footprint. Side-looking multibeam systems and side-scanning sonar may provide better returns from such objects. In addition, many “charting” type echo sounders used in USACE are not designed (or optimized) for strike detection work.

d. 200 kHz standard frequency. The most commonly employed transducer frequency in USACE river and harbor navigation projects is 200-208 kHz. Transducers operating at this frequency are usually narrow-beamed (between 1.5 deg and 8 deg at the -3 dB points) to provide more accurate bottom detailing. Narrower beams are recommended for projects with relatively hard, smooth grades, such as rock cuts or sand bottoms. A 3 deg transducer will provide a slightly higher depiction of small bottom features. The 200-208 kHz (± 10%) frequency is *not* a mandatory USACE frequency standard, nor is any particular beam width. Lower or higher frequency transducers, ranging between 20 kHz and 1,000 kHz, and with varying beam widths, are allowable for any class of survey or type of acoustic measurement system (e.g., single, sweep, or multibeam systems). Local conditions and unique project requirements will dictate the optimum type of survey system and frequency to be used. However, for navigation and dredge payment surveys, the acoustic survey system and/or transducer frequency should be constant throughout the project duration--and clearly identified in construction specifications. Multiple frequency systems may be used for analyzing sediment layers of varying densities-- typically using 200 kHz and 28 kHz dual frequency sounders.

e. Single beam transducer mounting. The transducer for a single beam echo sounder should be mounted nearly amidships and as near as possible to the vessel's fore and aft center of rotation. The transducer should be permanently located in a frame or transducer well adjacent to the vessel's keel. Over-the-side, bow, and stern mounts are permitted only if heave-pitch-roll roll motion and location eccentricities are compensated. The positioning system's antenna should preferably be located directly over the transducer--any X-Y-Z offsets must be accurately measured and input into processing software.

9-4. Single Beam Echo Sounding Equipment and Procedures

Prior to the 1970s, most districts employed mechanical analog depth recorders. The most common models used were Bludworth and Raytheon 719. These devices marked the continuous depth profile on a pre-printed graph paper using a rotating stylus mechanism. The speed of the rotating mechanical stylus was a function of water depth and velocity of sound. Unfortunately, the rotational velocity of the mechanical recorders was often unstable and required constant calibration and alignment. Few of these mechanical analog recording systems are still used in the Corps. Figure 9-4 depicts an older Raytheon DE 719 along with a typical cross-section record. In the 1970s, districts began to acquire digital depth recording systems. These systems marked analog (profile) depths directly on blank thermal recording paper; thus eliminating most of the errors in mechanical recorders. Digital depth data could also be sent to a data logging device where it was correlated with positioning data input. Newer generation systems record data on disc or WORM drives for real-time screen viewing and/or off line printing. All modern depth measurement systems can be configured to output measured depths to data recording devices, where they can be time tagged with position and motion sensing data.

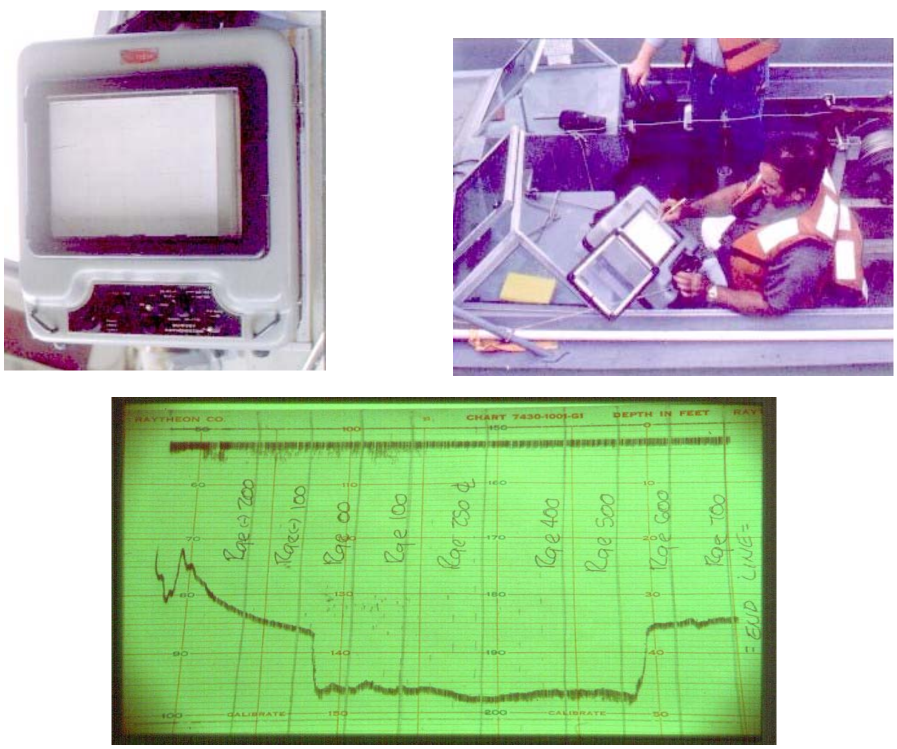
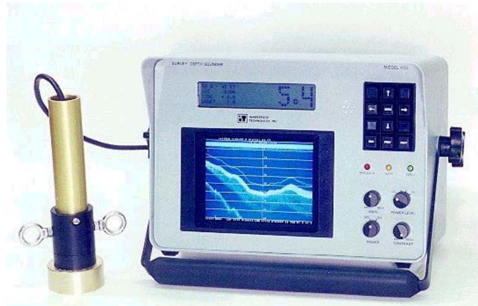


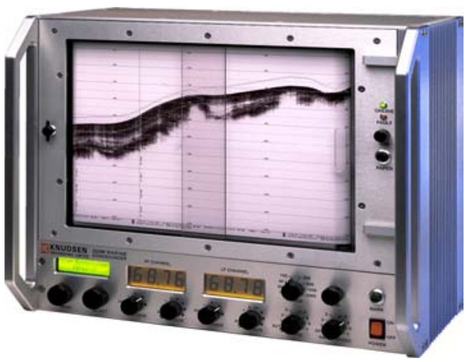
Figure 9-4. Raytheon DE 719 analog-recording portable echo sounder (Jacksonville District)

a. Single beam echo sounders. Figure 9-5 depicts some of the more common digital sounding units currently used by Corps districts. A brief description of the specifications for some of these units follows. These specifications were obtained directly from the manufacturer's operating manuals and/or other literature--see the references at the end of this chapter for more details.

Ross Laboratories Smart Sounder



Innerspace Model 455 Depth Sounder



Knudsen 320M Echosounder

Odom Echotrak DF3200 Mk II

Figure 9-5. Typical single beam echo sounders used in Corps

(1) Innerspace Technology, Inc. Model 455 and Model 448. The Model 455 shown in Figure 9-5 provides analog and digital depth on separate high resolution LCD display screens. The small, lightweight, portable unit is designed for use on reconnaissance vessels and small workboats. Optionally, analog screens can be printed on a computer printer or stored internally for future reference or hard copy printout. The menu is controlled via up / down, left / right arrows; no numerical entries are required. The analog LCD provides a continuous, high-resolution, bottom profile with alphanumerical annotation of pertinent information. Significant features include:

- Range gated autotracking digitizer
- Variable speed-of-sound adjustment (feet & meters)
- Power output adjustment (four level)
- VGA, parallel, serial (three), floppy, keyboard ports
- VGA, transflective monochrome LCD with contrast control (daylight readable) optional-color LCD TFT VGA 500NIT with index filtering for daylight viewing
- Resolution, 0.1 feet or 0.01 meter, digital and analog
- Audible shallow depth alarm

- Mission storage of charts on 48 MB solid state flashRAM; two days of continuous screen capture
- Analog chart files are in PCX format for color presentation on standard computer equipment
- 40 character chart annotation from external computer
- GPS input for latitude/ longitude chart annotation.
- Built in multiplexer. Digital depth and GPS position can be internally multiplexed then outputted as a single NMEA data string to a single port, data logging computer
- Complete transducer and GPS antenna mounting accessories for small boats

The Innerspace Model 448 Thermal Depth Sounder Recorder (not shown in Figure 9-5) is used in some 18 Corps districts. The 448 provides survey precision, high resolution depth recordings using solid state thermal printing. The lightweight, portable unit is designed for use in small boat surveying as required for engineering surveys, harbor and channel maintenance, pre and post dredge surveys, etc. Some of the features of the 448 advertised by Innerspace Technology include:

- Thermal Printing fixed head - no stylus to replace-no carbon residue-no rotating stylus-no arcing-odorless operation - no burned paper
- Large viewing area with sliding window
- Large chart - high resolution
- Blank Paper is high contrast black on white
- Portable and lightweight for small boat operation
- Microprocessor controlled
- Scale selected is the only one printed
- Feet or meters operation - switch selectable
- Thumbwheel settings for speed of sound, tide and draft
- Annotation of all parameters appear on recordings in chart margin Speed-of-sound, Tide, Draft, Event, Time and Mode of operation
- TVG (time varied gain) minimizes gain adjustments
- Internal micro controlled depth digitizer
- No adjustments for zero line or cal line are required
- Motion compensation interface

(2) Knudsen Engineering Limited Model 320M or 320M/P Echosounder. Models 320M or 320 M/P are single or dual-frequency recorders. Using either the high or low frequency channel, or both simultaneously, the 320M and M/P produce a high resolution record accurately depicting bottom profiles and sediment layers with 32 shades of gray. The thermal printer uses 8.5 inch plastic film for permanent, high-quality archival records. The annotated depth grid is printed with reverse shading for clarity.

- Digitized water depths is shown on two large 4-digit LCD displays, visible in direct sunlight and backlit for night operation. Serial RS232 depth data is continuously available in NMEA format as well as user-defined string formats, and in operator-selectable time and position tagged formats.

- A LCD menu display with 2-button control provides access to parameters such as sound velocity, draft, TX blanking, serial port assignment, time and date setting, and testing features. All settings are retained in non-volatile memory and recalled on power-up.

- Three RS 232 ports support communication with personal computers, NMEA input and output devices, GPS receivers, sound velocity sensors, heave sensors, remote depth display, and survey data loggers. An optional upgrade allows the 320M or 320 M/P to be operated remotely through the built-in SCSI interface and Windows application software. This SCSI interface provides the ability to transfer the entire gray scale image data (32 gray scales) as well as the binary files to disc for future archive.

- Technical specifications (selected). Frequencies: 3.5 kHz to 250 kHz (12, 24, 26, 28, 30, 33, 38, 40, 41, 50, 100, 120, 150, 200, 208, and 210 kHz). Units: meters, feet, or fathoms. Weight: 40 lbs. Power: 12 or 24 VDC nominal. Resolution: 1 cm over 0-100 meter range.

- The 320M series provides a depth range capability from extremely shallow (12 inches or less) to full ocean depth, depending on frequency/transducer options.

(3) Odom Hydrographic Systems, Inc. Echotrac Model DF3200 MKII. The Echotrac MKII Recorder/Digitizer/Transceiver utilizes highly integrated digital and analog circuitry, display technology, and thermal printing techniques. System response is achieved by employing techniques such as digital signal processing, task sharing, asynchronous event processing, and multiple scan buffering.

- Dual Frequency Operation: Two frequencies are selectable from the following: Low (12 kHz to 50 kHz), High (100 kHz to 1 MHz), Standard frequencies are 24 kHz and 200 kHz.

- Printer mechanism: The high-resolution thinfilm thermal print head (216 mm (8.5") wide, 8 dots per mm (203/in.)) prints up to 16 gray shades.

- Display: Film Super Twisted Nematic (FSTN) Dot Matrix LCD Module (320 x 200 pixels, 0.38 mm x 0.52 mm dot pitch), Six inch (156.4 mm) diagonal measure, on board controller and Fluorescent Back Lighting (CFL). The paper white display has visibility in all light conditions--from bright sun to darkened wheel house.

- Remote Operation: All system controls are accessible to a remote computer via one of the three serial ports. The sounder in completely interactive with motion and positioning systems and provides unlimited header and event annotation input capability generated either internally or by the computer.

- Keypad: The 16 key Nema 12 sealed unit has full travel and tactile feel. The keypad is used by the operator for direct parameter entry and functional control of the unit from the front panel.

- Receive: The system incorporates both TVG and AGC Sensitivity and AGC are continuously variable by front panel mounted potentiometers. Automatic gain control can be disabled by setting the front panel mounted potentiometer to the minimum detect position. The TVG curve is internally accessed.

- Transmit: Transmit frequencies are digitally synthesized and based on the stable frequency characteristics of a crystal controlled clock oscillator. Transmitted power for both high and low channels is individually adjustable via front panel mounted controls. Power is adjustable from the minimum of less than 20 watts in high frequency shallow water applications to over 1600 watts in low frequency deep water versions. Transmit Pulse Width is variable either automatically (actual value dependent on frequency and depth) or manually by keypad entry.

(4) Odom Hydrographic Systems, Inc. HYDROTRAC. The Hydrotrac is a single frequency, Recorder/Digitizer/Transceiver and is a highly integrated digital and analog sounder packaged into a small, waterproof housing. The thermal printer is identical to that used in the Echotrac MKII sounder.

Many of the features in Echotrac are carried over into the Hydrotrac including; digital signal processing, task sharing, asynchronous event processing, and multiple scan buffering.

- Single Frequency Operation: The frequency agile Hydrotrac allows connections to a variety of transducers ranging between 33 kHz and 200 kHz.

- Printer Mechanism: The high-resolution thin film thermal print head (216 mm (8.5") wide, 8 dots per mm (203/in.) prints up to 16 gray shades. Help instructions are printed on the chart and standard fax paper can be used in emergencies.

- Display: Backlit dot matrix LCD module with scrolling menu for parameter setting and large character "depth" reading. All settings are stored in non-volatile internal memory.

- Keypad: The sealed, 10 key, tactile feel keypad is waterproof and used by the operator for direct parameter entry and functional control of the unit from the front panel.

- Remote Operation: All system controls are accessible to a remote computer via one of the two serial ports. The sounder in completely interactive with motion and positioning systems as described for the Echotrac MKII.

- Receive: The system incorporates both Sensitivity and TX Power controls on the front panel.

- Transmit: Transmit frequencies are digitally synthesized and based on the stable frequency characteristics of a crystal controlled clock oscillator.

- System upgrades: Remotely installed in flash memory via the Internet.

- DGPS Receiver: (Optional) Incorporated inside the waterproof housing of the Hydrotrac, provides XYZ chart annotation and combined NMEA output string.

(5) Odom Hydrographic Systems, Inc. Echotrac Model DF3200 MKIII. The Echotrac MKIII Recorder/Digitizer/Transceiver utilizes Multiple DSP and RISC technology to provide a portable, dual frequency sounder that is mission configurable. With an interchangeable chart panel, the surveyor can elect to have a standard paper chart recorder or a paperless, full color LCD presentation. In either case, data, parameter settings, sensor input, etc. are stored on a removable PCMCIA card for later playback or chart printing on the recorder or directly on a computer.

- Dual Frequency Operation: Frequency and Impedance agile to match a variety of transducers ranging in frequency from 24 to 210 kHz.

- Printer Mechanism: Interchangeable, high-resolution thin film thermal print head (216 mm (8.5") wide, 1600 dots per scan, printing up to 32 gray shades. Standard fax paper can be used in emergencies.

- Display: Active matrix, high intensity color LCD (1500 NITS) for data, setup, and graphical user interface.

- Remote Operation: All system controls are accessible to a remote computer via one of the three serial ports. The sounder in completely interactive with motion and positioning systems and provides unlimited header and event annotation input capability generated either internally or by the computer.

- Keypad: The 16 key Nema 12 sealed unit has full travel and tactile feel. The keypad is used by the operator for direct parameter entry and functional control of the unit from the front panel. All operator settings are stored in non-volatile internal memory.

- Storage Media: Removable PCMCIA memory card – compatible to PCMCIA readers for direct download to computer or other Echotrac units – with 10 hour logging range.

- Receive Section: Incorporates both Sensitivity and AGC controls via the front panel.

- Transmit Section: Frequencies are digitally synthesized and based on a crystal controlled clock oscillator. Transmitted power and pulse width for both high and low channels are individually adjustable via front panel mounted controls.

- Communications: Four Serial RS232 ports plus USB port for analog feed to computer for real-time chart display on monitor.

- Power Agile: AC or DC power supply.

(6) Ross Laboratories Series 850 Smart Sounder. It is a paperless recorder (all electronic) which automatically stores a Sonogram to operator-selected media on the data collection computer. This is used for playback and for editing purposes. The sonograms are also archived on a Zip drive or CD ROM. Hard copies may be printed out on a color printer also. The display is a high visibility (900 NIT) active matrix TFT display.

- Hardcopy. The 850 can print the analog signal levels graphically in color or gray scale, in real time or post-survey. Printing after the survey is accomplished by connecting a printer to the 850 or transferring the analog data to a computer for printing.

- Heave Correction. Direct serial communication with the TSS Heave Compensator is standard. The heave is placed in scale anywhere on the analog display. Heave corrected depth data can be superimposed as a line on the color display.

- Serial Output. Custom NMEA-0183 output string includes feet and meters, and if connected, heave corrected depth in both feet and meters.

- Digital Data Logging. Digital depth can be logged to a file on any one of the 850’s disk drives. This text file can be exported to a spreadsheet or any other application that reads comma delimited text files.

- Color Display. The display shows the digitized signal levels in different colors. The color display provides enhanced bottom and sub-bottom detail using active TFT color display, which is effective in bright sunlit applications. The entire sonogram (received echo) is stored on magnetic or optical media for future playback and printing. The playback of the data can be done on the 850 or using an MS-DOS based personal computer. Playback software is used for display and editing of the soundings. The transfer of the data to a second computer is done by floppy or removable ZIP drive. The recording time of the data varies--the storage of the entire sonogram is typically 1.7 megabytes per hour for a 200 kHz system on a 50-foot range. This varies due to bottom dynamics and depth range.

- Model 850C. The 850C is the basic machine that includes a standard 3.5 inch floppy drive and a software compression utility (pkzip.exe) for the transfer of the sounding data to a PC compatible computer. The 850C also has a removable ZIP drive for large data transfers and backup storage of the sounding data.

- Model 851C. The 851C can permanently archive the sounding data on a removable optical media. This optical media is intended to be the legal record of the survey.

b. Single beam surveying methods. Single beam surveys are run either normal to (i.e., cross-sectioned) or longitudinal with the channel alignment. Cross-sections for dredge payment surveys are usually spaced between 50 and 200 ft, depending on the bottom consistency between sections and need for shoal or strike detection. Cross-sections are extended up the channel sides. Condition survey lines are typically run longitudinal with the channel alignment--inside the channel toes. The spacing of lines is typically between 50 and 250 ft, again depending on project-dependent channel shoaling patterns.

c. Marking position events on hard-copy depth profile records. Horizontal positioning event marks (or fixes) are made on analog or digital hard-copy recorders. When channel cross sections are run, the position fixes may be keyed to specific channel offset ranges. Position fixes may also be keyed by time or distance traveled along a cross-section. The horizontal fix events should be spaced at close intervals so that positions can be accurately interpolated between event marks. A fix should be taken at channel toe ranges. The vertical event line in the recorded profile may be manually “fixed” or automatically generated from the positioning system. On older mechanical systems (e.g., Raytheon 719) excessive stylus wobble during an event must be prevented. Fully automated survey systems that tag each recorded depth with a position can be configured to annotate periodic event marks on the analog record. This period will be much longer than the digitized depth sample rate. Special care must be taken to ensure that the event corresponds exactly with the position update. Otherwise, severe systematic latencies due to electrical and/or mechanical delays can result. These latencies are exhibited by apparent shifts on alternately run cross sections.

d. Retention of hard-copy depth records. Real time, hard copy depth profile records of navigation and dredging surveys are still used in the field to visually evaluate project condition and clearance. This may be done using hard-copy (paper) depth recordings or digital play-back recordings. Retention of real-time (or near real-time) profile depth records is still required for contract measurement and payment surveys since these analog records contain bar check calibration data as a continuous part of the record. These data can be retained either in hard-copy form or on a "write-once" type of digital record that cannot be edited. Recording to rewritable discs is optional for project condition surveys.

9-5. Depth Collection Density and Bottom Coverage

Single beam echo sounders typically collect depth data at a rate of 5 to 20 soundings per second. Data acquisition systems can be set to acquire some or all of these data points each second. If continuous bottom coverage along the cross-section is required, then the update rate should be adjusted such that each portion of the cross-section is ensonified. This update rate is a function of the average or project depth, vessel speed, and transducer beam width. An approximate computation of this update rate can be made from the following equation:

$$Update\ rate\ (milliseconds) = 1185 \cdot (D / v) \cdot \tan(a/2) \quad \text{(Eq 9-3)}$$

where

D = Average or project depth
v = Velocity in knots
a = Transducer beam width

Since all these parameters can vary during a survey, the minimum practical update rate should be used. For example, given a project depth of 43 ft and an 8-deg transducer, the required update rate would be 400 millisecs at 5 kts, and 200 millisecs at 10 kts. Thus, a 200 millisec rate (i.e., 5 depths/sec) would be adequate for all speeds less than 10 kts. However, if the project depth were only 20 ft, a 100 millisec collection rate would be needed to obtain full along section coverage if the vessel runs up to 10 kts. In general, a 100 millisec update will be adequate for most surveys. Setting too large an update rate could leave data gaps. Higher densities (i.e., every 50 to 100 milliseconds) might be collected in rock-cut channels to give a more accurate representation of the bottom and to detect strikes above grade. A high density of depths may also be needed to confirm multiple hits on strikes. Data collection software allows input of the desired depth collection rate. As high-density depth data is recorded, it is time tagged to interpolated positions taken at a lower update rate. Dredging contracts should specify depth data collection density used in payment computations, and distinguish the process by which depths are thinned or generalized for plotting purposes (i.e., sorting, binning, or gridding techniques).

9-6. Effects of Vessel Heave, Roll, Pitch, and Yaw on Single Beam Systems

Correcting observed depths for the superimposed effects of vessel roll, pitch, yaw, and heave was once perhaps the most difficult aspect of hydrographic surveying. Along with tide/stage, these effects are a major error component in hydrographic surveying. Vessel heave is the major error component of the four listed motions. Since the mid 1990s, affordable and accurate motion compensation instruments have significantly reduced these errors. Many districts have now incorporated motion compensation into single beam systems. Since vessel roll, pitch, yaw, and heave conditions can occur simultaneously and at different periods, either visual or automated interpretation of a single beam analog profile record to reduce these errors is an imprecise process, at best. Motion compensation (heave-pitch-roll) is mandatory on critical dredging measurement and payment surveys and strongly recommended for all other surveys where adverse sea conditions can affect the quality of the recorded data.

a. Interpretation of single beam recorded depths without motion compensation. The impact of lateral vessel roll and fore-and-aft pitch of the vessel are more pronounced when narrow-beam transducers are employed because the sounding cone becomes non-vertical and measures a longer slope distance. Up and down vertical heave reflects the wave height. Heave is superimposed with roll and pitch on the observed depth. Heave values typically can range up to 2 to 4 ft whereas roll/pitch depth errors are much smaller--e.g., less than 1 ft. Interpretation of the effects of all three potential motions on an analog recording requires skill and experience with the vessel motion at the time of the survey. The apparent smoothing of undulations on the graphical record are not always interpolated correctly, depending on the vessel's course relative to the seas, vessel size, vessel characteristics, and wave height. On an irregular bottom, it is extremely difficult to separate vessel motions from the bottom undulations. Digitally recorded depths do not allow for any human interpretation or smoothing of undulations due to heave, pitch, and roll.

(1) Unless reliable heave-pitch-roll (HPR) motion compensation devices are used, the only practical method of minimizing vessel motion effects is to limit the maximum allowable sea states under which a particular type of survey may be performed. Such limitations are highly subjective and can have significant economic impacts, due either to delayed survey work or to inaccurate payment when a survey is performed under adverse conditions. Maximum sea state limitations must also factor in the size and relative stability of

the survey vessel, along with the effects of the prevailing wave direction relative to the survey lines or cross sections. Procuring larger vessels to minimize roll, pitch, and heave is likewise no longer economically justified given the small cost of HPR compensators. Thus, a simple maximum allowable wave height criterion is difficult to definitively specify.

(2) An on-site assessment of the potential data adequacy must be performed since so many variables are involved. If the effects of vessel motion appear to be degrading the desired (and acceptable, from a contract performance measurement standpoint) survey quality after the on-site assessment is performed, the on-site survey party chief should make the decision to postpone the survey. Such a decision should be made with the concurrence of the government's Contracting Officer Representatives (COR) and/or contractor representatives present aboard the survey boat, or as otherwise defined in the contract provisions.

(3) A subjective judgment on the effects of excessive vessel motion to a survey's adequacy must also consider the type of survey. One-half-foot seas may be the maximum tolerable limit for performing a final acceptance survey or sweep on high-unit-price rock excavation work, whereas 1-ft seas or larger might have been tolerable for the initial pre-construction survey of this same project. Any workable sea state may be tolerated for an intermediate progress payment survey of this project. No maximum sea state limits need be imposed on performing less critical non-navigation surveys--the only tolerance to be considered is the ability of the vessel, equipment, and personnel to collect reliable data.

(4) Based on the above discussion, use of HPR motion compensation instruments for single-beam surveys is recommended in order to maximize data quality and production.

b. Motion stabilization for single beam systems. To best minimize the adverse effects of vessel motion, single beam systems used for dredging and navigation surveys in rough sea states should be equipped with automated heave sensors, and also pitch and roll sensors. Motion compensation should be required if the effects of heave, roll, or pitch generate depth errors exceeding $\pm$ 0.2 ft. Yaw compensation may or may not be required. Motion compensation may not be necessary in confined, calm waters, such as inland rivers or reservoirs; presuming these corrections are less than $\pm$ 0.2 ft. Motion compensation systems are configured to operate in line directly with depth recorders or independently as a real-time input to the survey data acquisition and processing system. Nearly all systems display heave, pitch, and roll information in real-time; allowing for operator assessment of the data quality. Motion compensation is then applied either in real-time or during post-processing of data. Raw observed data can be independently corrected for heave (e.g., Figure 9-6), roll, and/or pitch, depending on the magnitude of these correctors.

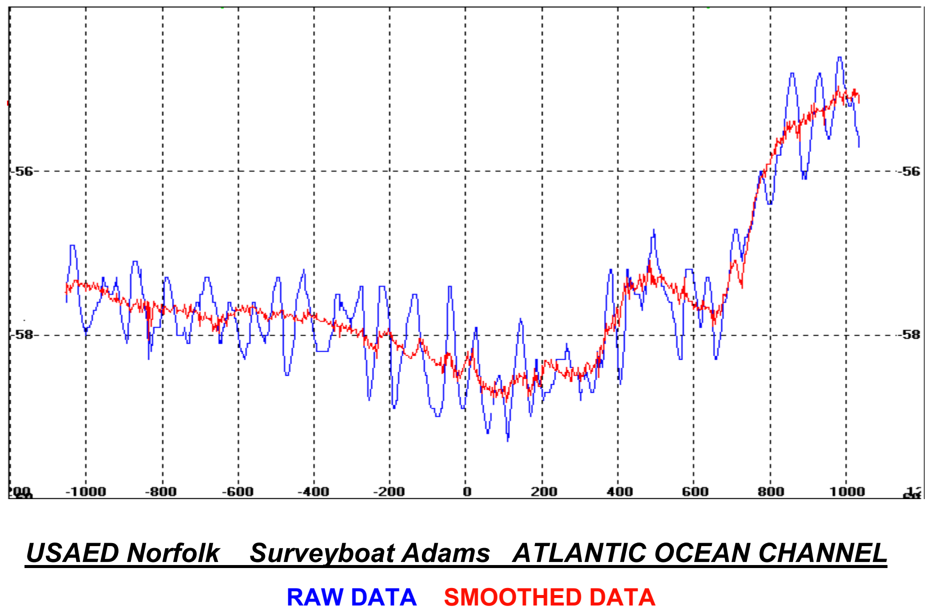


Figure 9-6. Heave compensation on typical offshore channel (Norfolk District)

c. Heave compensation. The major depth error component is heave--the long-period up and down motion of the vessel due to wave motion, other vessel wakes, etc. Heave is basically a function of wave swell and period. Heave errors are normally excessive at coastal entrances and on offshore approach channels--large 65-ft survey boats can typically work in swells up to 3 or 4 feet. Modern heave compensators can effectively record heave movement and smooth out these effects. Heave compensators require internal alignment and stabilization calibrations specified by the manufacturers. Since heave compensators can be subject to constant drifts, continuous monitoring during surveys is required.

d. Roll and pitch compensation. Excessive roll and pitch can introduce bias error in depth, resulting in a deeper reading over a level bottom. Excessive roll and pitch can also inject position errors in the measured depth. This is caused by the motion of the positioning system antenna relative to the transducer. If the distance between the units is large, roll and/or pitch displaces the transducer. This is usually not significant for most applications but can be corrected with roll/pitch and antenna-transducer offset data.

(1) Roll-pitch effects. On larger vessels--i.e., greater than 26 ft--roll and pitch are usually not excessive under normal working conditions--typically less than 5 deg . However, on smaller vessels (e.g., less than 26 ft) roll or pitch can easily approach or exceed 10 deg in rough seas. The correction for roll and pitch varies with the angle of rotation and depth--see Figure 9-7. However, the beam width of the transducer may be greater than the overall roll or pitch, resulting in the first return still being near vertical. Figure 9-8 shows a starboard roll (looking from aft). Rotation is about the point "O". The transducer is rotated slightly higher relative to the reference surface. In theory, the measured depth without roll--"D_0"--would be slightly less than that measured at the indicated roll-- "D_1". If the roll angle is within the beam width, as shown, then the correction would be negligible. However, if the roll is excessive--say greater than 10 deg-- then observed depths would be greater. Corrections for roll-pitch should be applied for high frequency narrow beam transducers--similarly to that applied to narrow beams formed by multibeam arrays.

ROLL/PITCH ERROR ON NEAR-VERTICAL BEAM

Roll/Pitch	Error at Depth 10 ft	25 ft	50 ft
0 deg	0 ft	0 ft	0 ft
1	0	0	0.01
5	0.04	0.10	0.19
10	0.15	0.39	0.77
15	0.35	0.88	1.76
20	0.64	1.6	3.2

MAXIMUMLALLOWABLE ROLLL/PITCH ANGLE TO MAINTAIN +/- 0.2 FT ERROR

Project Depth	Max Angle
10 ft`	11 deg
25 ft	7 deg
50 ft	5 deg
75 ft	4 deg

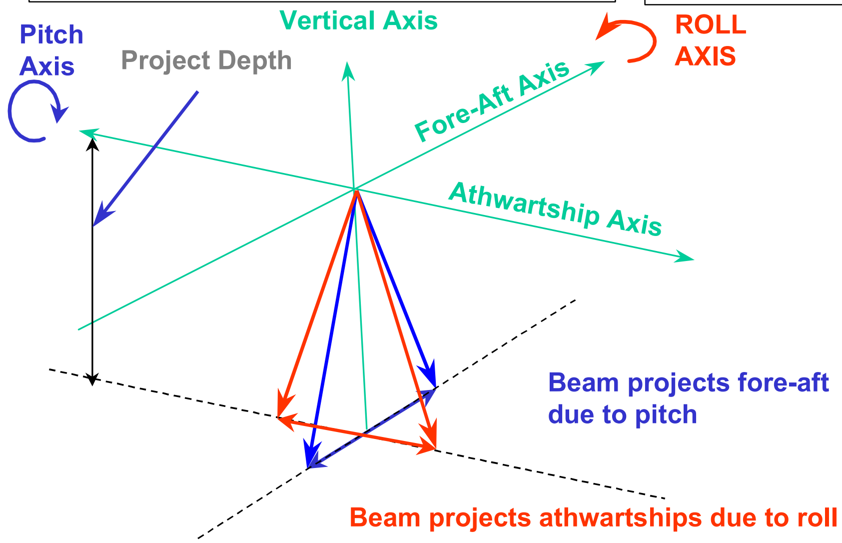


Figure 9-7. Roll and pitch effects on a single beam depth

(2) Roll-pitch position displacement correction. Single beam processing systems (e.g., HYPACK) correct for depth and position variations due to roll or pitch. Using roll-pitch data, HYPACK does allow correction of the depth's X-Y position due to rotation of the antenna-transducer axis, and optionally to compute the X-Y coordinate of the center of the projected (i.e., steered) beam on the bottom--point D_1 in Figure 9-8. On a large survey vessel with an antenna located 30 ft above the transducer subject to a 10 deg roll or pitch, this would amount to a 5 ft horizontal displacement of the transducer. In a 30-foot project, the center of the beam on the bottom would also be displaced by another 5 ft (approximately) relative to the transducer. The total horizontal displacement of the depth relative to the antenna would then be about 10 ft. A displacement of this magnitude (3 m) is outside the 2 m RMS positional tolerance for dredging and navigation surveys, so it should be applied to all observed depths. A smaller survey boat would normally have a much smaller antenna height (< 10 ft) so the horizontal displacement between the antenna and beam-steered bottom depth would be smaller. If cm-level RTK DGPS positioning is being observed, then the antenna-depth displacement is especially significant and should be applied on all work. In shallow draft projects (< 15 ft) using meter-level code-phase DGPS positioning, this displacement correction is usually not significant and need not be applied as long as the displacement does not exceed 1 meter.

(3) Roll-pitch slope to vertical depth correction. In addition to the antenna-transducer-bottom depth positional displacement correction, the slope-to-vertical correction to depth may also be computed and applied to the observed depth. The slope-to-vertical depth correction is usually small for typical roll-pitch conditions. As indicated in Figure 9-7 it is generally insignificant (i.e., < 0.2 ft) for project depths less than 20-25 ft. Full roll and pitch corrections are performed in HYPACK processing software at ADVANCED READ PARAMETERS\MRU\STEER SOUNDING BEAM.

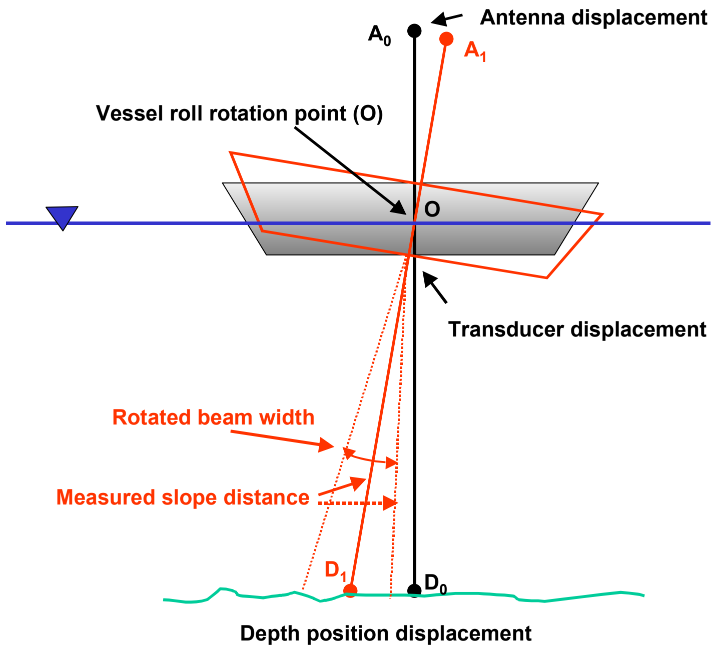


Figure 9-8. Depth correction due to roll (starboard roll viewed from aft)

(4) Constant pitch bias test and gyro stabilized transducers. Transducers are mounted vertically in a vessel at rest trim. When underway, excessive vessel roll and pitch can deflect the transducer from vertical. A constant forward pitch offset angle could be induced if a vessel's trim changes while underway--causing all depth to be measured over slope ranges rather than vertically. Given the typical beam width of a transducer, this misalignment is usually not significant unless pitch exceeds the beam width, which could occur for an extremely narrow beam transducer. A constant pitch bias can be checked similar to that for multibeam systems--i.e., running two pairs of reciprocal lines run over a slope at two different speeds. The important characteristic of pitch offset is that the along-track displacement caused by pitch offset is proportional to water depth. Thus, the deeper the water, the larger the offset. If a constant pitch bias is indicated in a single beam transducer, then a slope-vertical correction might be required. (Refer to the chapter on Multibeam Systems for more details on the pitch bias test). Alternatively, the transducer could be realigned to point vertical at typical sounding speeds. Gyro stabilized transducers can also be utilized to correct for these errors if work must be performed in heavy seas.

(5) Roll-pitch tolerances for single beam systems. Ideally, roll-pitch depth errors should be kept within tolerable limits--say not greater than 0.2 ft. As indicated in Figure 9-7, this can be achieved if maximum allowable roll or pitch is kept less than 10 deg when using a typical 8 deg beam width transducer. On critical deep-draft projects, 5 deg roll-pitch limits would be recommended. In general, roll-pitch exceeding 10 deg is a degraded working environment and overall acoustic data quality is marginal. The table in Figure 9-7 also indicates that roll-pitch slope-vertical corrections are insignificant on project depths of less than 20-25 ft; thus, slope-vertical depth corrections would (usually) only be significant on deeper draft projects.

(6) Testing roll-pitch magnitudes. For a particular beam width transducer, the effect of roll and pitch can be roughly tested to determine if roll-pitch slope-vertical corrections are necessary or significant. A pole-mounted transducer can be hung over the side by hand in deep (i.e., typical project

depth), smooth-bottom water. Rotate the transducer and observe the rough angle where the recorded depth begins to increase. If relatively large rotations are required to detect significant depth increases, then slope-vertical corrections with this transducer's beam width are probably not justified. If relatively small angular deflections cause discernible increases in depth, then this narrow beam transducer should have full roll-pitch corrections applied.

e. Yaw. Yaw (or vessel heading) rotation error is not significant for vertical single beam systems if the transducer and positioning system antenna are co-located vertically. If these units are not located vertically, then offset corrections must be applied using vessel heading information. This translates the position to the transducer--it has no effect on the measured depth. A variety of techniques can be used to measure real-time heading: magnetic fluxgate compasses, fiber optic gyro compasses, inertial systems, and carrier-phase DGPS. Refer to the chapter on multibeam systems for more details on yaw/heading offset corrections.

9-7. Calibration of Single Beam Echo Sounders

Calibration of acoustic sounding instruments is absolutely critical (and mandatory) in maintaining quality control of depth measurements. This is primarily due to instabilities or variances in the water column, or to a lesser extent, in the equipment. All navigation and dredging surveys for contract measurement and acceptance require, *as a minimum*, twice daily calibration at the project work site. Failure to perform adequate calibrations, including documentation/certification thereof, can lead to total unacceptance of the survey and any payment associated with it. This section describes the various methods used to calibrate single beam depth measurement equipment. The calibration procedures in this section also apply to multiple transducer sweep systems and, to a lesser extent, multibeam systems. Independent quality assurance procedures are also detailed.

a. Bar check calibration. The primary depth calibration procedure used in USACE is the "bar check." The bar check is recognized throughout the Corps and dredging industry as the standard reference system for acoustic depth measurements. The bar check is a quality control procedure. It is not a quality assurance procedure. The bar check is a flat bar or plate suspended by two precisely marked lines to a known depth below the water surface and under the transducer. A series of depth intervals are observed during a bar check, down to the project depth. Any difference between the reference bar depths and the recorded depths represent corrections to be made to any subsequently recorded soundings. The bar check represents the only recognized check on the quality of a depth recording system. In reality, the bar check may not exhibit the same acoustic properties as the bottom; however, in practice, any such differences are ignored. This primary reference device is also used to periodically check secondary calibration devices, such as a velocity meter and a ball check. Figure 9-9 characterizes the operation of suspending the bar a known distance below the waterline using calibrated chains. Both a single line calibration plate and a dual line (full beam) bar check device are shown. Bar checks correct for velocity variations, draft variations, and index errors in the echo sounding system--reference Equation 9-1. The effect of a varying velocity of sound propagation is measured by performing a bar check. The actual velocity need not be computed as part of a bar check. The bar check must be taken at sufficient intervals to develop the variation. Normally intervals of 5 to 10 feet are adequate, unless the velocity of sound is highly variable. If a bar check were performed at 1-ft increments throughout the water column, a correction would be available for any observed depth falling within that those 1-ft intervals. Draft and index variations are also compensated through the use of a bar check calibration. It is again emphasized that a bar check will not correct for variations in acoustic reflectivity, either between the bar and bottom material or between different bottom materials within a project area. The bar check is also not a totally independent reference in that it may contain errors within itself--e.g., water surface smoothing, line markings.

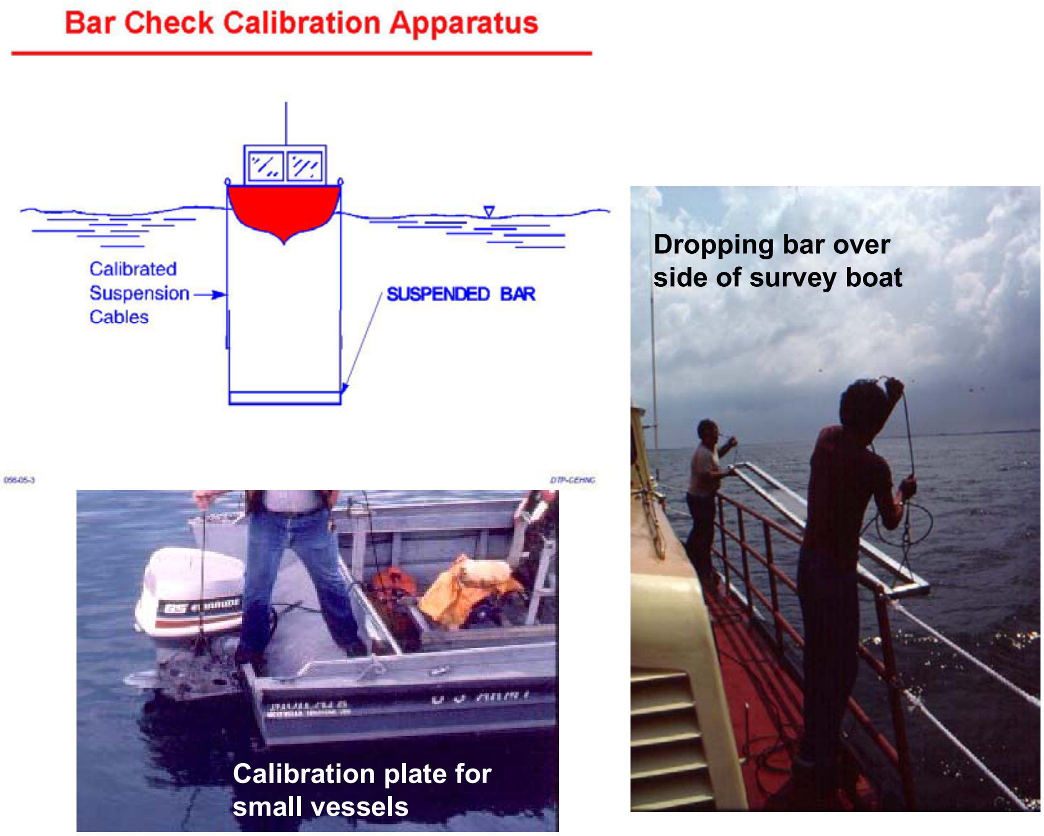


Figure 9-9. Bar check calibration (Jacksonville District)

b. Ross ball check. As a substitute to a full-beam bar check, many districts use a center-mounted, spherical calibration ball with a flat top in lieu of a calibration bar. This device was designed and developed by Wayne Ross of Ross Laboratories. The ball is suspended on a cable from the interior of the boat by a hand crank-lock mechanism. The line is marked and calibrated in a manner similar to that used for a bar or lead line; however, the reference water surface is not. Therefore, any index error or draft line variation must be calibrated using a standard bar check method. An interior water level gage may also be used to measure/monitor the line indexes. Details regarding installation and operation of this calibration device can be obtained from the manufacturer (Ross Laboratories, Inc.). See Figure 9-10.

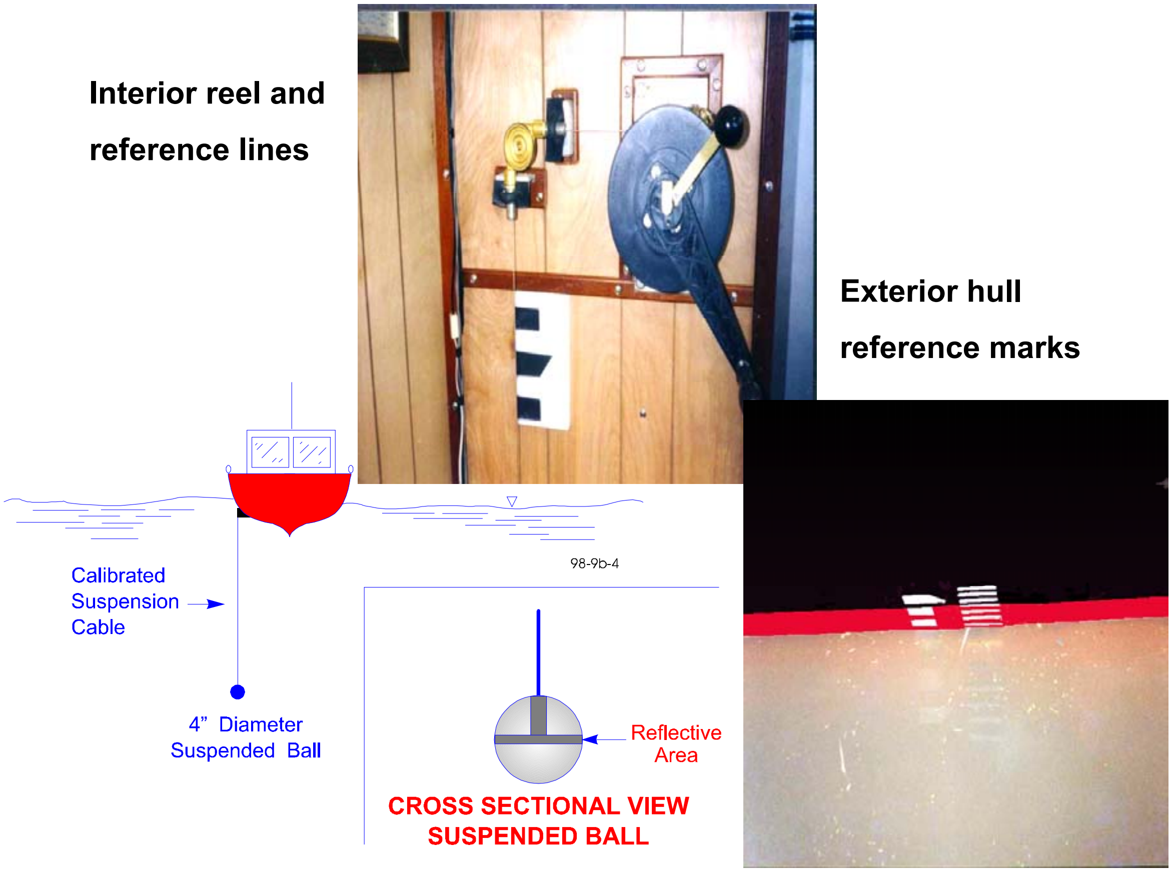


Figure 9-10. Ross Ball Check (Surveyboat Adams, Norfolk District)

c. Velocity probe calibration. In lieu of a bar check calibration, the velocity of sound may also be directly measured using a velocity probe instrument. A velocity probe measures the speed of sound at various depth intervals. A velocity probe must still be periodically calibrated, both internally and externally. A bar check is necessary to perform the external calibration, since a velocity probe measurement will not determine the constant terms in Equation 9-1.

9-8. Bar or Ball Check Calibration Procedures

The bar check effectively measures for the following systematic errors inherent in depth recording systems: instrumental errors—index, mechanical, and electrical; velocity of sound errors due to temperature, salinity, or other suspended or dissolved sediment variations; and static draft fluctuations resulting from varying vessel displacement caused by fuel and personnel loads.

a. Bar check apparatus. The suspended bar is constructed of flat stainless steel or aluminum plate welded or bolted to any standard supporting crosspiece section. The plate should be of sufficient width (typically 8 to 12 in.) to provide an adequate return down to project depth. The bar should be approximately 1 ft longer than the vessel beam (on the measuring deck). The reflecting plate need not extend the full length of the bar. Both ends of the bar are rigged with universal-type swivel joints to attach the supporting lines. Each line is zero-referenced from the top of the plate and is marked at either 1- or 5-ft increments. The top surface of the bar plate may optionally be coated with foam, rubber, or other like material that better simulates the acoustic reflectivity properties of the channel bottom. A small

(12-in.-diam) steel plate can be used to calibrate over-the-side mounted transducers. The plate is suspended by a standard single bar check line or lead line. Calibration and/or adjustment is performed in a manner identical with that used for bar check. Special caution must be taken not to change the vessel draft when performing a check on one side or end of the boat.

b. Bar weight. The weight of the bar will be dependent on the types of currents experienced, project depths, and beam of the vessel. A typical bar will range between 40 and 100 lb. In deep-draft projects with large currents, a heavy bar is essential because subsurface currents will pull too light a bar away from the transducer's vertical plane, causing loss of acoustic return or slope error in the check lines. Provisions for adding additional weight to the bottom base of the bar ends may also be needed in strong currents. Increased bar weight may necessitate additional personnel to perform the bar check.

c. Bar check procedures. On a larger vessel, the bar is usually deployed off the bow and each end walked aft until abeam of the transducer. Both lines are held at the desired fixed depth increment (visually meaning vessel and water surface motion), and the depth recorder is simultaneously observed, annotated, and/or recalibrated. Vessel alignment must be held toward the sea to minimize roll. Under adverse wind and current conditions, coupled with a narrow-beam transducer, maintaining vertical alignment of the bar and lines becomes extremely difficult, especially at greater bar depths. In such cases, the skill and experience of the boat operator to maneuver the vessel over the suspended bar becomes critical to the process. On smaller vessels, personnel movement during a bar check may affect the nominal (underway) trim of the boat. Care must be taken to ensure that this variation is minimized.

d. Calibration increments. Static bar comparisons should be taken at 5-ft intervals throughout the project or dredging excavation range. If the recorder is adjusted to display actual bar depths, subsequent bar check readings need to be taken only at the upper, intermediate, and lower project levels to verify stability. A sample bar check is shown in Figure 9-11.

e. Data corrections. Stage/tidal corrections, vessel squat corrections, draft loading variances, calibration line graduation errors, or any other correction should never be “dialed” into the depth recording device. These corrections are always applied off-line (manually or automatically) or in data reduction software on an onboard processor. Recorded depth data must be “original” relative to the calibration process. Adding other time/speed variable corrections makes reconstruction of original survey data difficult and indefensible in the case of a contractual dispute or claim over the data adequacy.

f. Frequency of bar check. For critical navigation and dredging support surveys, two bar checks are required each day--one before work and one after completing a day's activity. Additionally, if a mechanical analog recorder that does not contain a zero/calibration event line(s) is turned off, or the paper or stylus is replaced, a new bar check must be performed before proceeding with the survey.

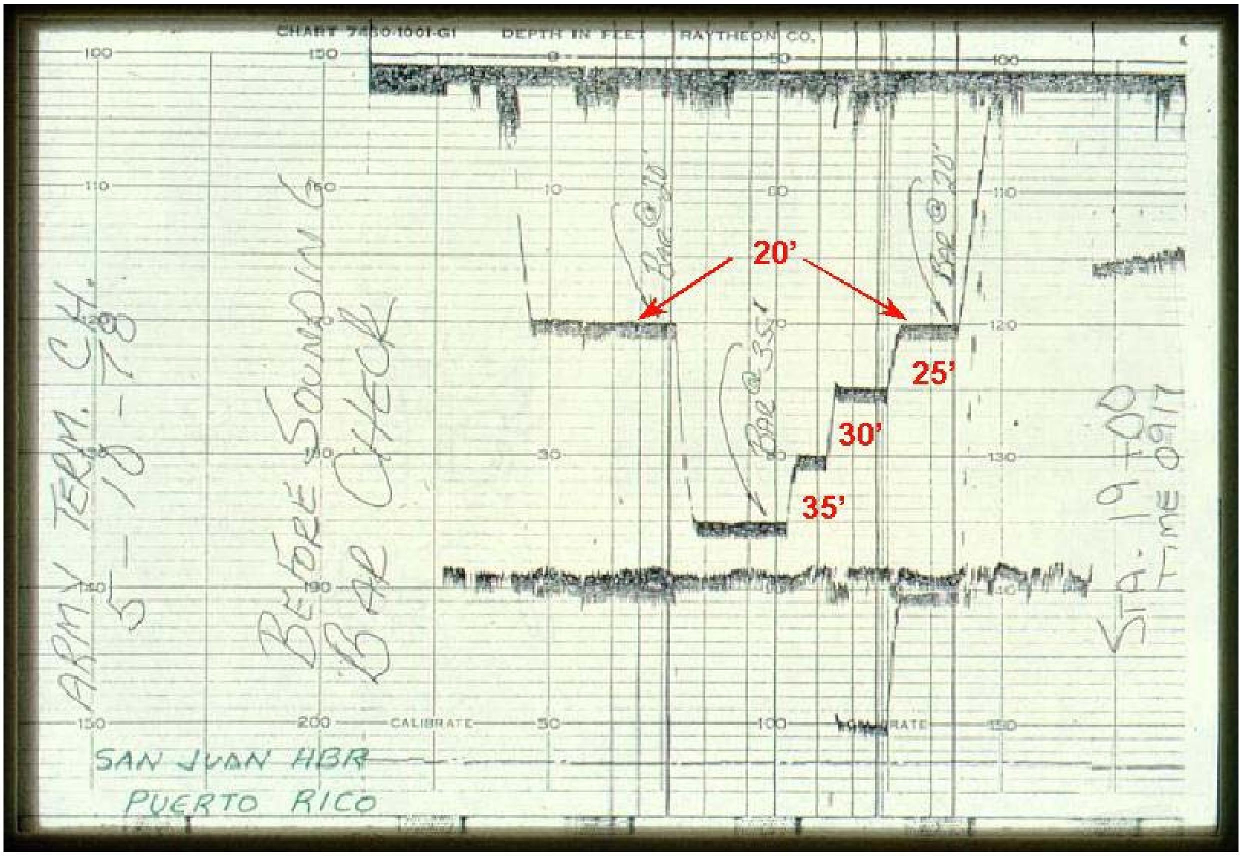


Figure 9-11. Example of bar check in deep-draft navigation project (Jacksonville District)

g. Location of bar checks. Due to the high potential for local temperature and/or salinity variations in typical USACE river and harbor projects, the resultant effect on the velocity of sound must be measured directly at the work site. This is a mandatory requirement for payment surveys. Failure to perform a bar check calibration within the project area will be sufficient reason for rejection of the survey. If an area is known to be subject to extreme temperature/salinity variations, additional bar checks in these areas may be warranted. In extremely adverse conditions where it is physically impossible to perform a bar check at the project site (due to high winds, currents, and/or sea states), a velocity probe may be used to determine the sound velocity at the project site--see paragraph 9-10. However, on critical projects, both a bar check and velocity probe should be simultaneously performed in a protected area near the project vicinity. The velocity derived from the bar check should agree within 5 fps with the probe's average velocity in the protected area. The echo sounder draft would be set from the bar check and the velocity would be readjusted based on the probe velocity measured later at the actual project site.

h. Bar check recording. Bar check data for digital data shall be recorded in a standard field survey book or on a form. Bar check data are obviously visible on analog hard copy recording media and must be immediately adjacent (on the graphical record) to the actual survey. For dredging payment surveys in which analog backup recordings must be maintained, digital bar check data may be recorded on the analog record for comparative purposes. When no analog recorded is used, digitally recorded bar checks shall be recorded on a write-only type of media. It is a recommended practice to maintain a continuous record of all bar check calibrations in a bound survey field book. This record should include draft and velocity settings, along with other instrumentation calibration and alignment records. Figure 9-12 shows pre-sounding and post-sounding calibrations in which both a bar check and velocity probe are performed simultaneously.

SURVEY VESSEL "PAJ" - DAILY REPORT OF ON-LINE OPERATIONS

PRESOUNDING CALIBRATION CHECK:
Bar Check at 0922 hours
Digibar Velocity Reading 4778 FPS
Recorder Velocity Set at 4778 FPS
Bar at 30.0 feet
Monitor Reads 30.1 / 30.0 feet
Sounder Trace Reads 30.1 / 30.0 feet
Sounder Digitizer Reads 30.1 / 30.0 feet
Bar at 20.0 feet
Monitor Reads 20.1 / 20.0 feet
Sounder Trace Reads 20.1 / 20.0 feet
Sounder Digitizer Reads 20.0 feet

POSTSOUNDING CALIBRATION CHECK:
Bar Check at 1311 hours
Digibar Velocity Reading 4776 FPS

Bar at 30.0 feet
Monitor Reads 30.0 / 30.1 feet
Sounder Trace Reads 30.0 / 30.1 feet
Sounder Digitizer Reads 30.0 feet
Bar at 20.0 feet
Monitor Reads 19.9 / 20.0 feet
Sounder Trace Reads 19.9 / 20.0 feet
Sounder Digitizer Reads 20.0 feet

Figure 9-12. Bar check and velocity meter records (Detroit District)

i. Agreement between successive bar checks. The two bar checks for a work day must be compared for excessive differences. Adjustments are *never* made to the final (end-of-day) bar check. Results are logged at the same check increments used during the initial calibration. Any known draft variation due to loading should be applied to the final readings before comparison. Otherwise, the draft variation may be taken from markings on the vessel hull. Failure to obtain consistent agreement between successive bar check calibrations may be due to any number of physical or electronic causes and must be located. The frequency of calibration may have to be increased. The mean value of the calibrations may be used to correct the recorded data. Differences exceeding the limits shown in Table 9-6 may be grounds for rejection of the survey.

j. Calibration of bar check lines. The bar check suspension lines must be periodically checked to ensure the accuracy and stability of the graduated marks on the lines. The frequency of this independent calibration is indicated in Table 9-6. Periodic calibration data shall be recorded on a worksheet or in a standard field survey book. Any errors in the graduated marks must be physically corrected (removed) at the time of calibration.

9-9. Depth Corrections Based on Bar Check Data

There are several methods of performing bar checks and arriving at corrections to apply to observed depths. Three methods are commonly used in USACE and are described below. Each of these methods is acceptable on any type of survey. Typical results of a bar check calibration are shown in Table 9-4 below. The differences between the bar depth and recorded depth indicate the presence of both a constant index error and a velocity error in the recorded data. The velocity change is exhibited by the increasing differences below 20 ft where a change in the water's sound velocity has occurred. The constant 0.2-ft index error indicates that the presumed 3.0-ft draft measurement must be independently checked. Three different methods for correcting soundings are described below.

Table 9-4. Sample results of a bar check calibration

Initial velocity set at 5,100 ft/sec   Initial draft = 3.0 ft   Project depth range: 20 to 40 ft

Depth of Bar (ft)	Recorded Depth (ft)	Difference (ft)	Notes
5	5.2	0.2	0.2 ft index error indicated
10	10.2	0.2	
15	15.2	0.2	
20	20.2	0.2	
25	25.3	0.3	Change in water column velocity occurs
30	30.4	0.4	
35	35.5	0.5	
40	40.6	0.6	
45	45.7	0.7	
50	50.8	0.8	

a. Incremental bar check readings and correction formula. Recorded depths may be directly and individually corrected mathematically without making any adjustments to the draft or velocity settings on the recording device. All recorded depths are adjusted according to the bar check data, such as that recorded in Table 9-4. This reduction can be made on-line when an automated data acquisition system is used or off-line during the post-processing phase. The results of a sample calibration shown in Table 9-4 are used directly for this process; however, a table combining the before and after survey bar checks may also be used. A corrected depth is then computed by:

$$d_c = [[(bar_i - bar_{i+1}) \div (rec_i - rec_{i+1})] \cdot (d_0 - rec_i)] + bar_i \qquad \text{(Eq 9-4)}$$

where:

d_c	=	corrected depth
d_o	=	any observed/recorded depth to be corrected for speed of sound and index error
bar_i	=	bar depth at checkpoint i
bar_{i+1}	=	bar depth recorded at point $i+1$
rec_i	=	recorded depth at bar depth i
rec_{i+1}	=	recorded depth at point $i+1$
$i, i+1$	=	any two successive calibration depth points and $rec_i > d_o < rec_{i+1}$

An observed depth is corrected between its closest range of calibration data. For example, if a 43.5-ft sounding is recorded, it is corrected relative to the calibration data in Table 9-4 at the 40- and 45-ft levels.

From the calibration table:

bar_i = 40 rec_i = 40.6
bar_{i+1} = 45 rec_{i+1} = 45.7

From Equation 9-4,

$$d_c = \frac{(40 - 45)}{(40.6 - 45.7)} \cdot (43.5 - 40.6) + 40$$

$$d_c = \frac{(-5)}{(-5.1)} \cdot (2.9) + 40$$

$$d_c = 0.9804\ (2.9) + 40 = 2.8 + 40 = \underline{42.8}$$

Given a bar check calibration table, all subsequent observed depths may be corrected using the above-described procedure. Such a procedure may be performed either on-line or in an off-line mode. Correcting non-digital depth data by this method is obviously not very practical unless that data can be digitized into a database. The Correction Table/Formula method works well in areas of salt wedges or places where the water has distinct temperature differences.

(1) This method may be preferred in the vicinity of power plants where the plant cooling water effluent has a much higher temperature than the surrounding water. This will cause the speed of sound to increase slightly if the water is turbulent and thoroughly mixed. In most cases the effluent will not thoroughly mix with the surrounding water. This will cause the temperature to be different through the depth layers. The result to the surveyor will be a significant increase in the speed of sound in these depth layers (shallow soundings). If the bar check table does not reflect this phenomenon, the survey may erroneously indicate extreme shoaling in the area of the power plant outfall. A separate bar check should be recorded in these areas.

(2) Since the speed of sound is normally fairly stable over most river and harbor projects, it is usually desirable and more practical to base the above-described correction over a wider interval than 5 ft. Given the sample project data in Table 9-4 with excavation depths ranging between 20 and 40 ft, a single correction factor may be computed over that range, since the differences over that 20 to 40-ft range in Table 9-4 are linear.

For example:

bar_i = 20 rec_i = 20.2
bar_{i+1} = 40 rec_{i+1} = 40.6

From Equation 9-4,

$$d_c = \frac{(20 - 40)}{(20.2 - 40.6)} \cdot (d_0 - 20.2) + 20$$

$$d_c = 0.9804\ d_0 + 0.2$$

The above factor may be used to correct any depth ranging between 20 and 40 ft and may be practically extended to a range of 15 to 45 ft. Such a correction procedure is valid as long as the calibration data are linear over this range.

(3) The constant term (0.2 ft) represents the index correction. The ratio (0.9804) represents a velocity correction between that set in the recorder (5,100 ft/sec) and that actually occurring in the water medium over this range, or approximately (0.9804) · (5,100 ft/sec) = 5,000 ft/sec. Readjusting the recorder to 5,000 ft/sec and modifying the draft line to 2.8 ft (3.0 - 0.2 ft) will *not* graphically correct the depths over this range.

b. Graphical bar check calibration method (Jacksonville District). The computational method described above may not always be suitable in practice, since the displayed depth cannot readily be related (i.e., on-site) to a required excavation grade. Performing the computations and then applying other required corrections (squat, draft loading variances, and stage/tide corrections), requires automated processing capabilities. Such equipment may not always be available aboard small work boats. Since most construction payment/acceptance work depends on immediate on-site assessment of the recorded data, the computations must be minimized. This is accomplished by changing the velocity and draft settings in the analog/digital recording device so that the recorded depth equals that calibrated during the bar check. In essence, the recording mechanism is reoriented and rescaled by appropriate adjustment of the velocity and index/draft. This procedure is performed *only* during the initial bar check of the day, *never* during the final check. The procedure for making these adjustments is described below and graphically illustrated in Figure 9-13.

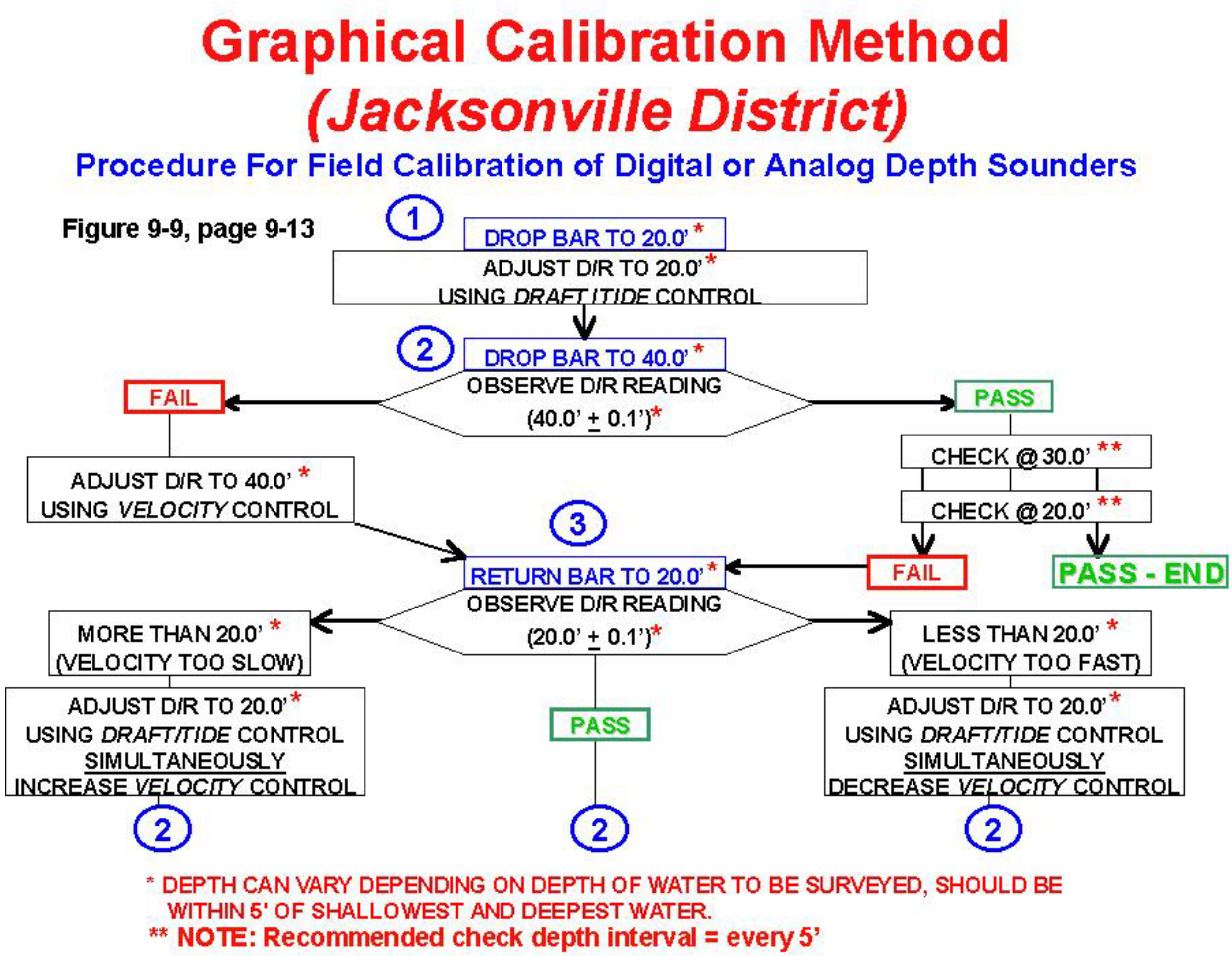


Figure 9-13. Jacksonville District calibration method

Calibration is a sequential process performed by trial and error so that the index/draft and the sound velocity errors are simultaneously minimized. Two depths, for example, 20 and 40 ft, are chosen that correspond to the maximum and minimum project depths. The bar is lowered to the lesser depth, and the depth recorder display is adjusted with the index controls to read that depth value. The bar is then lowered to the greater depth, and the reading is adjusted to that depth using the speed of sound control only. When the bar is returned to the first depth, the reading is observed. If the display reads low (i.e., 19.9 ft), velocity is too high. The display should be adjusted to the proper reading (20 ft) with the index control while simultaneously decreasing the speed of sound control. Reverse the adjustments for a high reading (i.e., 20.1 ft). The entire process is then repeated by lowering the bar to the greater depth, then back to the first depth for inspection of the display until the correct reading is produced at all three steps (within ±0.1 ft). Intermediate readings should then be checked to compare displayed value with the known length of bar lines.

Once set, the velocity and draft settings will usually remain fairly stable for a given project area. The primary advantage of the method described above is that a recorded depth can be easily referenced to a required excavation grade. If the velocity of sound is not relatively constant throughout the working depth range, it will not be possible to adjust the instrument so that it reads equal to the bar check at each depth increment. In such cases, the data will have to be corrected by linear interpolation as described previously.

c. Modified graphical bar check calibration method (Norfolk District). This method is similar to the graphical method except that the draft setting on the recorder is not modified. The bar is placed close to the maximum project depth (40 ft in this example), and *only* the speed of sound control is adjusted so that the observed bar equals the actual bar depth. The bar is then raised at 5-ft intervals throughout the range of project depths, and observed bar readings are recorded. Any significant variation will be corrected in the office data-processing program using the computational procedures described previously. This method only minimizes the error near the lower level at which the sound velocity control was adjusted. The recorded values at other depths will be proportionately in error. In the sample data from Table 9-4, at the 20-ft bar check level the recorder will read 19.9 ft, a 0.1-ft error. Near the project excavation grade the instrument is adequately calibrated. However, this is not true up the side slopes.

9-10. Velocity Meter Calibration Method

A velocity meter is a portable, hand-deployed instrument that directly measures sound velocity. A velocity meter may be used to correct sounding data for dredging payment surveys provided independent external/internal calibrations are periodically conducted using a traditional bar check--see paragraph 9-8g for recommended procedures. Velocity measurements are always taken at the project work site. Two types of velocity meters are shown in Figure 9-14.

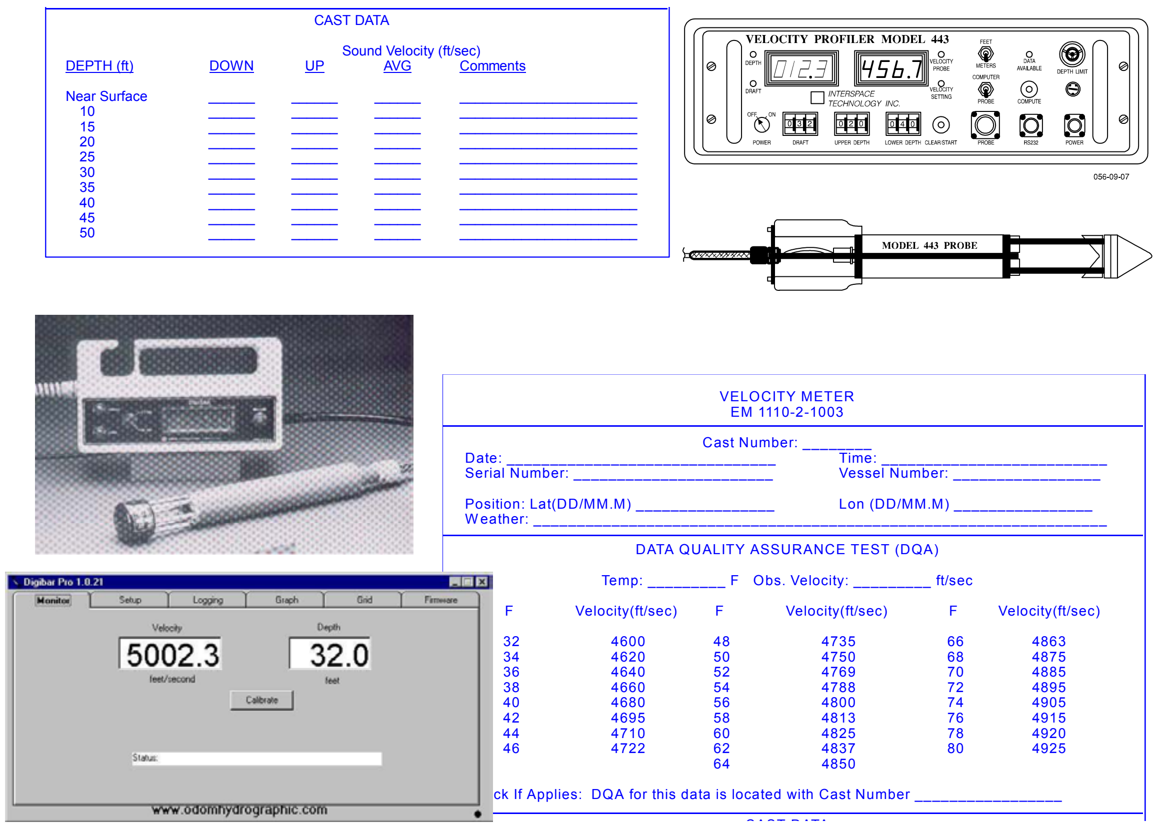


Figure 9-14. Innerspace Technology Model 443 and Odom DigiBar Velocity Profilers

a. General description of velocity meters. Velocity meters generally consist of a probe attached by cable to a waterproof, hand-held control unit powered by internal batteries. The cable is numerically labeled at 5-m intervals and marked in 1-m intervals, or labeled at 10-ft intervals and marked at 5-ft (or more frequent) intervals. Some models use a pressure sensor for depth determination, thus minimizing cable slant range errors. Velocity meter output is typically speed of sound as a function of water depth. Sound velocities should be recorded at 1 to 5 ft depth intervals. Readings should be made to the nearest 1 foot per second (fps). Where velocity of sound is not constant over the water column (e.g., Table 9-4) a correction table should be developed in processing software. This is especially critical for multibeam systems where velocity variations can refract outer beams. Software processing systems, such as HYPACK (PROCESSING\SOUND VELOCITY), provide a sound velocity correction table based on velocity readings at incremental depths (Figure 9-15). It is absolutely essential that velocity meter data be periodically checked with a standard bar check. The following paragraphs describe some of the basic specifications of two velocity meters. Additional information can be obtained directly from the manufacturers listed at the end of this chapter.

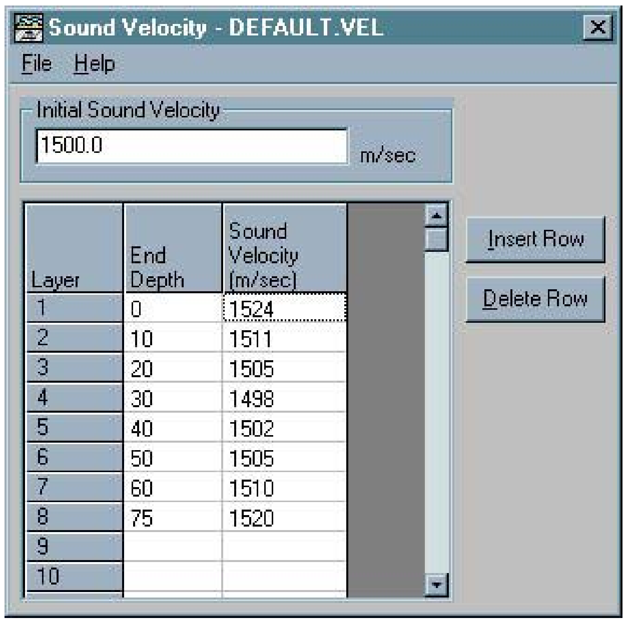


Figure 9-15. HYPACK sound velocity correction

(1) Innerspace Model 443. The Model 443 Velocity Profiler (Figure 9-16) measures and records an accurate speed-of-sound for each foot of the water column automatically as the probe is deployed. It then computes and displays sound speed and draft values for use in the depth sounder for calibration. Since depth is determined by a sensor in the underwater probe, the length or angle of the cable paid out is unimportant, thus enabling the sampling of data while underway. Since the Innerspace 443 provides precise speed-of-sound for each foot of the water column, this data can also be used to correct acoustical transmissions from any underwater ranging device, such as transponders used in oil exploration and other devices such as multibeam sonar. Via the RS232 front panel connector, the speed-of-sound/depth values can be sent to a computer for further analysis of the water column speed-of-sound gradient. For multibeam sounding, an acoustic speed-of-sound can be logged for each foot of the water column. This information can be sent to a computer where it can then be used to apply different speeds-of-sound to different segments of the water column for more accurate velocity corrections when processing multibeam sonar data. The Innerspace Model 443 additionally computes and displays the average sound velocity over the measured water column and the draft/index corrections. This process effectively provides a correction equation for speed of sound in the water column.

Figure 9-16. Innerspace Model 443 velocity profiler

(2) Odom Digibar Pro velocity meter. DIGIBAR-PRO (Figure 9-17) is a velocimeter that employs the sing-around method of sound velocity determination. Mounted near the end of the sampling probe is the high frequency "sing-around" transducer and its associated reflector. This precisely spaced pair is used to measure the velocity of sound in water by transmitting and receiving a signal across their known separation distance. After the first transmission, the received echo is gated and introduced into the feedback loop of an oscillator that re-triggers the transmitter and begins the cycle again. The frequency resulting from this regenerative feed-back loop is determined by the distance the signal travels (transducer to reflector and back) and is directly proportional to the velocity of propagation of the sound pulse through the measured medium (in this case water). This method of direct sampling means that all factors that influence the speed of sound, including salinity, pressure, and temperature, are taken into account. An embedded RISC processor in the probe digitizes the sing-around frequency and depth information, sending that data along with temperature and calibration constants in ASCII format via a 2 wire current loop up the cable to the hand-held control unit at a 10 Hz rate. In the control unit, another microprocessor accepts data from the probe, converting the frequency information to sound velocity, and the pressure data into depths, storing them in internal memory. In addition to converting both values to usable units, the control unit provides an operator interface. The multi-line display and system of menus guide the operator through the steps required to complete a velocity cast. Other features of the control unit include, data storage space, interfacing circuitry for transmission of collected data to a PC, and a power source (three Alkaline C-cells) for driving both the probe and its own internal circuitry. The velocity and depth information collected from up to 10 casts can be stored in DIGIBAR-PRO's internal memory. The average velocity value of each cast can be calculated, or the entire velocity profile of the cast can be up-loaded to a PC, in spreadsheet format, for subsequent use in ray-bending calculations. The unit not only samples, displays, and stores values for the speed of sound in water, but it also ties each collected value to a precise depth. The instrument is made up of a hand-held controller (splash rated to IP-65), a Kevlar reinforced cable (with a 400 lb. breaking strength rating), and a marine grade stainless steel probe. The velocity of sound and depth values displayed on the DIGIBAR-PRO front panel are measured, stored in memory, and displayed by the system's internal

microprocessor and its associated circuitry. The processor applies Del Grosso's formula to the sing-around frequency calibration constants, yielding accurate and traceable velocity results. The meter has a pressure sensor to determine depth of the probe. The precise profiling capabilities allow multibeam sounders to utilize the output of the DIGIBAR-PRO directly in their critical ray-bending calculations.

Figure 9-17. Odom DIGIBAR PRO velocity meter

b. Velocity probe quality control test. A quality control test must be performed one time each week that the velocity meter is used to determine sound velocity corrections. These tests may vary depending on the manufacturer's recommendation. The following equipment is typically needed for data quality assurance tests of velocity probes:

- Calibrated thermometer
- Clean fresh water
- Clean vessel (plastic bucket) large enough for the probe.

Fresh water is needed because its salinity (parts per thousand) is less than that of sea water. In some cases the fresh water salts, pollutants, or other particles in suspension may affect the water density or the elasticity. Distilled water should be used if this is the case. Reduction of salinity and pressure effects leaves the elastic water property a function of temperature only for practical purposes. This determines the average sound velocity through the layers in the water column. Using the manufacturer's chart, the propagation velocity can be computed with known temperature. A worksheet similar to that shown in Figure 9-14 may be used as a record of the test. This worksheet was constructed for the Odom velocity meter. Computer programs are also available from the manufacturers for this calibration.

c. Velocity meter corrections/calibrations. The velocity probe measures the actual sound velocity over the entire depth measurement range. From these data, a correction algorithm can be devised for on-line or post-processing data reduction. If velocity probe data are used to obtain an average sound velocity over a given range, then this average velocity (or velocities) may be used to adjust the digital or analog recording device as is done with a bar check calibration. The average velocity from a probe will be the same as the indirect velocity determined by a bar check. A velocity probe calibration does *not* confirm/check the index/draft setting on the analog/digital recorder. This *must* be done with a standard bar check.

d. Index correction. The application of the probe's average velocity data depends on the type of probe system used and any software included with that system. The Innerspace 443 probe system used by some USACE districts automatically determines the average velocity (v_1) of the layer between the surface and the upper project depth (UD) and the average velocity (v_2) between the UD and lower project depth (LD). The average velocity is dialed into the depth recorder (digitizer), and the index setting is computed from the following equation and set into the recorder:

$$Index\ Correction = [\ UD\ (v_1\ -\ v_2\ )\ )\ +\ Draft \cdot v_2\ ]\ \div\ v_1 \qquad \text{(Eq 9-5)}$$

Where:

UD	=	upper project depth
v_1	=	average velocity -- surface to UD level
v_2	=	average velocity -- UD to LD levels
Draft	=	measured draft of vessel

A major advantage of a velocity probe check over a bar check is the ability to perform rapid calibrations in heavy seas or currents. Calibrations are thus more easily (and frequently) performed directly at the project site. If repeated comparisons between the velocity probe and bar check yield consistent velocity measurements, then the velocity probe can be used with confidence. It is important to remember that the velocity probe measures only the "*v*" term in Equation 9-1. Therefore, a conventional bar check must be periodically performed in conjunction with a velocity probe measurement to calibrate system indexes and draft corrections. Those velocity probes that additionally derive the draft and index constants in Equation 9-1 must also be verified with a bar check device. These corrections may also prove to be relatively stable over the long term, as has been indicated by field results.

9-11. Squat and Settlement Calibration Test

As a vessel's velocity increases, it generally settles or squats into a lower profile in the water, causing an error in depth measurement that must be corrected--Figure 9-18. A squat test should be performed at least annually to determine the relation between boat speed and transducer height above or below the static sounding reference plane. Report results of this calibration test using a standard field book. Squat correction tables/curves should be permanently posted aboard the vessel--see example in Table 9-5. Without squat correction, channels may be actually dredged deeper than the drawings indicate. RTK DGPS systems which provide direct (absolute) antenna-transducer elevation eliminate the need for the squat correction, as the antenna height will record the squat in real-time. However, if the RTK DGPS system is set up to provide only the antenna height and is not configured to resolve the transducer elevation, then the squat correction must still be applied.

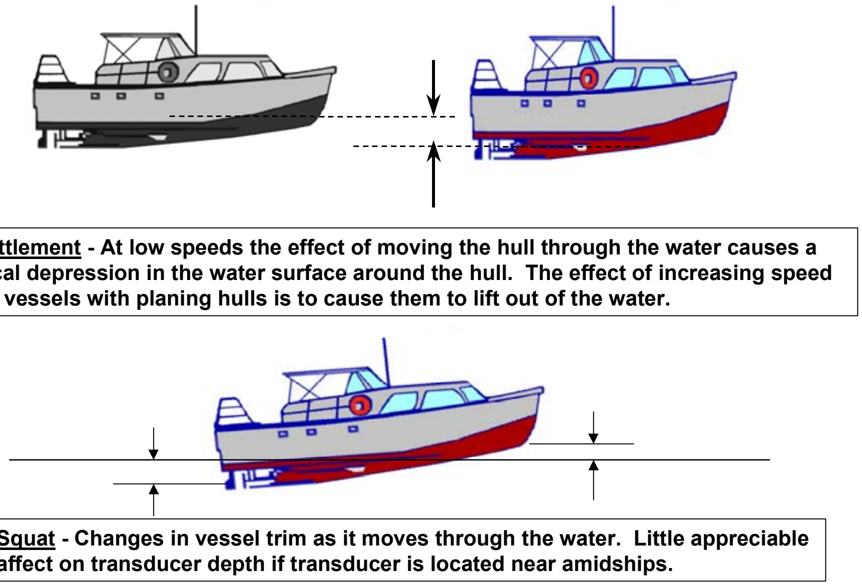


Figure 9-18. Squat and settlement effects on vessel draft (from NOAA)

Table 9-5. Squat and Settlement Calibration (65-ft Surveyboat Florida, Jacksonville District)

Conducted 29 May 1998, St. Johns River, Jacksonville, FL

Engine RPM	Upstream Rod	Downstream Rod	Tide	Squat	HYPACK Entry
Dead in water	0.70	--	1.12	0.00	
800	0.73	0.73	1.19	-0.10	+ 0.10
1000	0.65	0.63	1.33	-0.15	+ 0.15
1200	0.62	0.58	1.43	-0.21	+ 0.21
1500	0.58	0.58	1.50	-0.26	+ 0.26
1800	0.43	0.41	1.60	-0.20	+ 0.20

a. Conventional differential leveling techniques are utilized to measure the required calibration constants under normal loading (fuel/personnel) conditions. A level is set up on a pier or bulkhead with the boat in a static position in calm water, and elevations are taken at a point on the boat directly over the transducer, i.e., amidships (see Figure 9-19). With a stadia board or level rod held at this point, the boat is driven past the instrument at various speeds, and elevation differences are noted at each speed. In moving bodies of water (wind and/or current), this procedure must be run both up and down current to obtain the mean speed/squat. Boat velocities and observed rod readings are recorded on the form. A subtraction of rod readings after due correction for tide differences gives the squat corrections at each velocity.

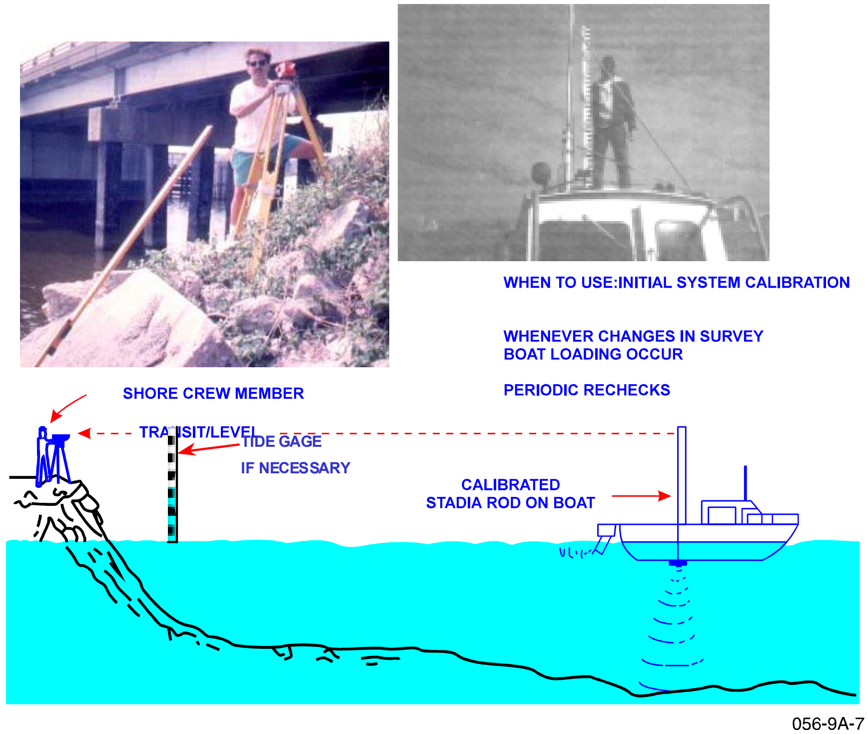


Figure 9-19. Squat and settlement test procedure with differential leveling

b. Corrections are added to the soundings to refer them to a static state. Squat corrections are therefore considered positive quantities as the transducer depresses (squats) deeper into the water at increased speeds. In this case, a *positive* squat is *added* to the raw observed/recorded depth. A *negative* squat may occur with high-speed planing, surface effect, or hovering type vessels. For these types of survey vessels, a squat test is especially critical and must be performed more frequently.

9-12. Miscellaneous Controls and Checks

a. Vessel draft variation correction. Boat loading variances during the course of a survey will affect transducer height. Short-term variations in the draft due to fuel usage may be observed directly from scribe marks on the hull abeam of the transducer. Any such variation should be evidenced directly in subsequent bar checks, and only then may these draft variation corrections be applied to observed depths. The actual draft/index setting on the recorder/digitizer should *not* be changed to reflect a draft variation. These variations should be applied during the on-line or post-processing sequences. Likewise, a physically measured draft is not directly entered into a echo sounding/recording device but must be confirmed by an independent calibration. The actual draft should be determined by performing a standard bar check calibration near the upper water surface with the upper bar level set just below the transducer depth, i.e., 3 to 6 ft. A sequential trial-and-error calibration is performed as described previously. When no further adjustments are required either at the selected lower depth or at the upper depth, the final draft setting is considered to be the transducer draft. Data from this draft calibration observation should be compared with the water line mark readings to establish a record of draft variations, from which corrections can be directly applied to recorded depths based solely on hull waterline-mark elevations.

b. Sensitivity/gain control. Most echo sounders use a sensitivity control to vary the detection threshold at which a recorded acoustic signal is displayed. The shape and intensity of the returning pulse is partly a function of the bottom material. In unconsolidated sediments, slight variations in the sensitivity control can cause significant variation in the detection threshold, i.e., depth. Increased sensitivity can cause returns from vegetation to be recorded. Reflective characteristics of the check bar may also differ significantly from the bottom material. These constant variations can exceed 1 ft in some instances and can easily represent the major error component in depth measurement. The sensitivity/gain control may be varied during the initial bar check calibration to determine if there is any effect on the depth reading/display. If so, the sensitivity control should not be changed during the course of the survey; nor should automated settings be selected. To minimize errors due to this source, it is best practice not to change the sensitivity and gain controls during a survey or between successive surveys of the same project area.

c. Frequency stability. The stability of the mechanical frequency of older mechanical analog recording sounders can be a problem and must be continuously monitored. Many recorders display a “calibrate" line that records the frequency stability. This line should be stable to ±0.1 ft or ±0.2 percent. The machine frequency, or “speed of sound” control should never be changed except during an initial (before-survey) bar check. Echo sounders with erratic frequency stability should be replaced.

d. Draft display stability. The “draft” or “index” line on an older mechanical analog recorder must be stable to within ±0.1 ft during the course of a survey. Corrections must be made for lateral movements in the recording paper based on the movement in the index reference setting. Draft settings should never be altered except during initial calibration bar checks. Draft variations are not a problem on digital recording devices.

e. Display phase shifts. Calibrations of older mechanical analog recorders are valid only on the display phase on which they are performed. If use of a deeper display phase is required, the second phase must be calibrated separately from the first phase. Because some portable sounding recorders can have 2-ft or more phase shift errors, this check is critical in deep-draft projects in which switching between phases is common. If these phase errors are large, it is often easier to place a large index constant on the second (deeper) phase and perform all bar checks and surveys on this phase exclusively, eliminating any need to switch between phases.

f. Lead line calibration check on echo sounders. A hand lead line may be used to roughly check an echo sounder. This check should be done over a hard, flat bottom of depth at or near project grade. The echo sounder recorder velocity is then adjusted so that the displayed depth equals that observed with the lead line. Calibrating an echo sounder in this manner is only accurate at the lead line depth. *This method of calibration is acceptable only for non-navigation surveys*. However, it may have application in correlating dual frequency recorders in fluff areas.

9-13. Plotted Depth Options for Single Beam Surveys

Depth sounders are capable of recording depths at rates of 10 or more per second. However, positional updates are typically input every second. Thus, the processing software must interpolate and time-tag positions for the intermediate depths--Figure 9-20. Likewise, roll, pitch, heave and heading data comes in at varying times and must be time-tagged to each depth. This time-tagging is usually performed off-line. It is not feasible to plot all recorded "shot" depth data in plan view. Reduced sounding data are normally plotted on the final plan drawings at a density of between 4 and 8 soundings per inch at the scale of development--e.g., between 12 ft and 25 ft at 1 " = 100 ft. Higher densities (or all recorded depth data) may be plotted in profile form in section views.

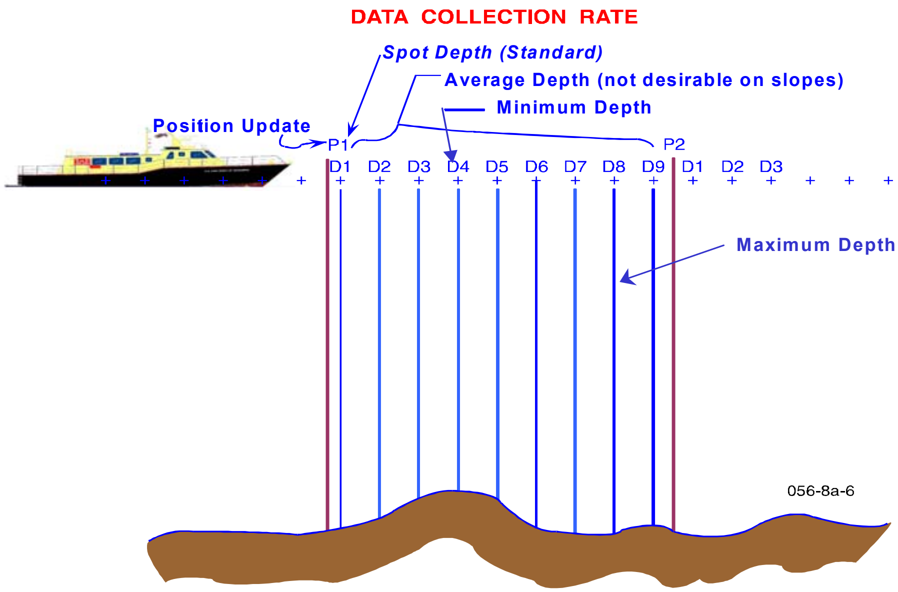


Figure 9-20. Tagging positions to intermediate depths

a. Depth filtering, thinning, and binning. Single beam profile data may be thinned using intelligent data thinning software routines. Placing data points at evenly spaced distances (single-beam binning) along the cross-section track may corrupt the topography. Intelligent software is available to filter and thin data while maintaining integrity of the profile--see Chapter 11, paragraph 11-12 (Multibeam Data Editing and Processing). When depth databases are thinned for plotting or other purposes, the random shot depth should be used. If databases are sorted to reduce the density of depths collected along a cross-section, then random depths along the section should be selected such that overplotting adjacent depths is avoided. Use of randomly thinned depths most correctly represents the original database and the accuracy of the individual observations. HYPACK sorting programs CROSS-SORT is designed to locate and plot the shot point depths in a selected region such that overplots are avoided.

b. Shoal biased minimum depths. Various depth data selection and thinning processes are employed to reduce depth data for plotting purposes. HYPACK sorting program "SORT" is designed to locate and plot only the minimum depths in a selected region such that overplots are avoided. Selection of minimum depths is termed "shoal biasing" in the Corps. Use of shoal biasing techniques is primarily intended for nautical charting purposes where the least recorded depth in a given area is desired. These minimum depth biasing techniques should not be used for dredging measurement and payment surveys--especially on after-dredging surveys where suspended sediment biasing can occur. Minimum depth biasing can also distort side slope depiction or bias shoaling along toes. Minimum depth selection should never be used when roll, pitch, and heave corrections are not observed and applied. Use of minimum depth biasing has led to numerous contract disputes and claims. Shoal biasing selected minimum depths may have application for project condition surveys when no quantity estimates are made from the data. Drawings should clearly note that original depth data was sorted and reduced by minimum depth selection methods.

c. Depth resolution. It is USACE policy to record and plot corrected depths to a resolution of 0.1 ft. Depths should be rounded using standard engineering practice.

9-14. Latency Tests

Latency is the time difference or lag between the time positioning data are received and the time the computed/processed position reaches the data logging module and is time-tagged. Latency typically results in a negative along-track displacement of the depth measurements--i.e., the time-tagged observed depth is acquired during the positioning system reading cycle whereas the output position is time-tagged when the computation cycle has been completed (see Figure 9-21). While surveying at slow speeds, this displacement will be small. At higher speeds, the displacement increases--i.e., it is proportionate to the speed. Position-depth latency distances of up to 40 ft have been observed--an intolerable systematic error that must be corrected and periodically calibrated. The impact of a latency error is illustrated in Figure 9-22 where a sawtooth contour results and dredge payment quantities become biased. Latency displacements are also a function of the type of positioning system used. For DGPS systems, the processing time for the position will vary with the number of observations used in the final GPS solution--thus causing small variations in the latency itself. Use of the T_0 pulse from the GPS receiver minimizes this error. If the time imbedded in the GPS message is used, then the correct synchronization between this time and the transducer or signal processing clock must be assured. The latency delay is computed by measuring the along-track displacement of soundings from the pair of coincident lines run at different speeds over a steep slope or other prominent topographic feature. Details on performing latency time bias tests are found in the Multibeam Systems chapter of this manual. Procedures for applying latency corrections (in real-time and/or post-processing corrections) are contained in hydrographic survey software manuals--typically under hardware setup sections where various positioning equipment offsets are entered. Latency bias calibration tests and application of correctors are absolutely mandatory for all USACE surveys.

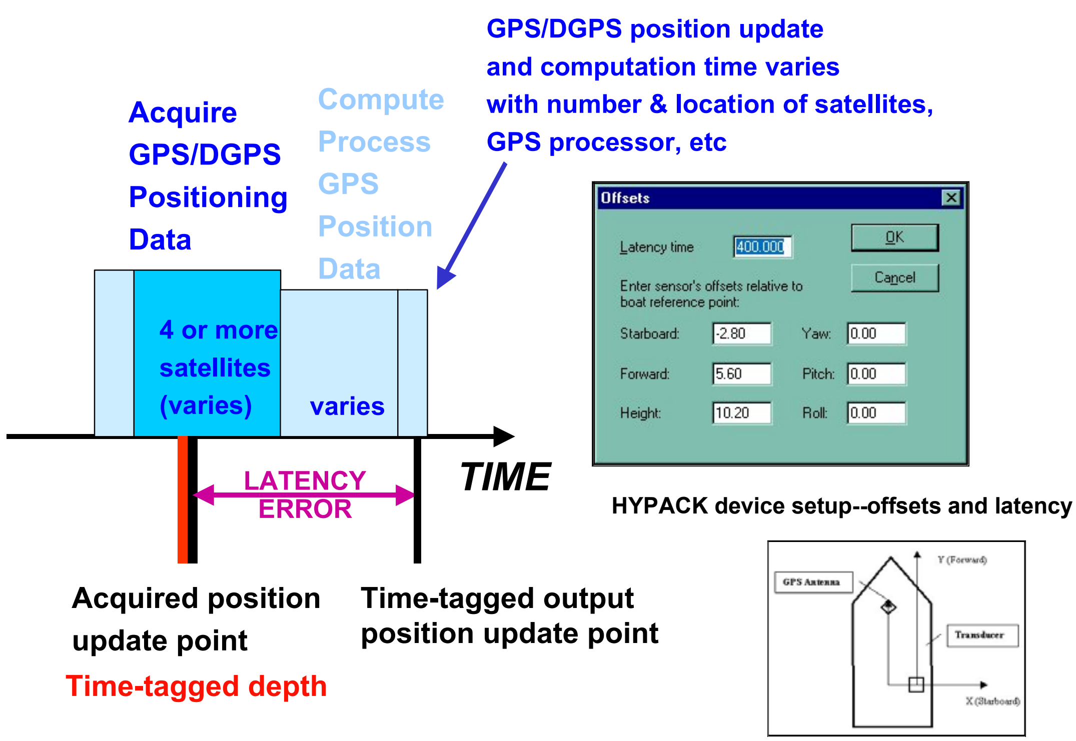
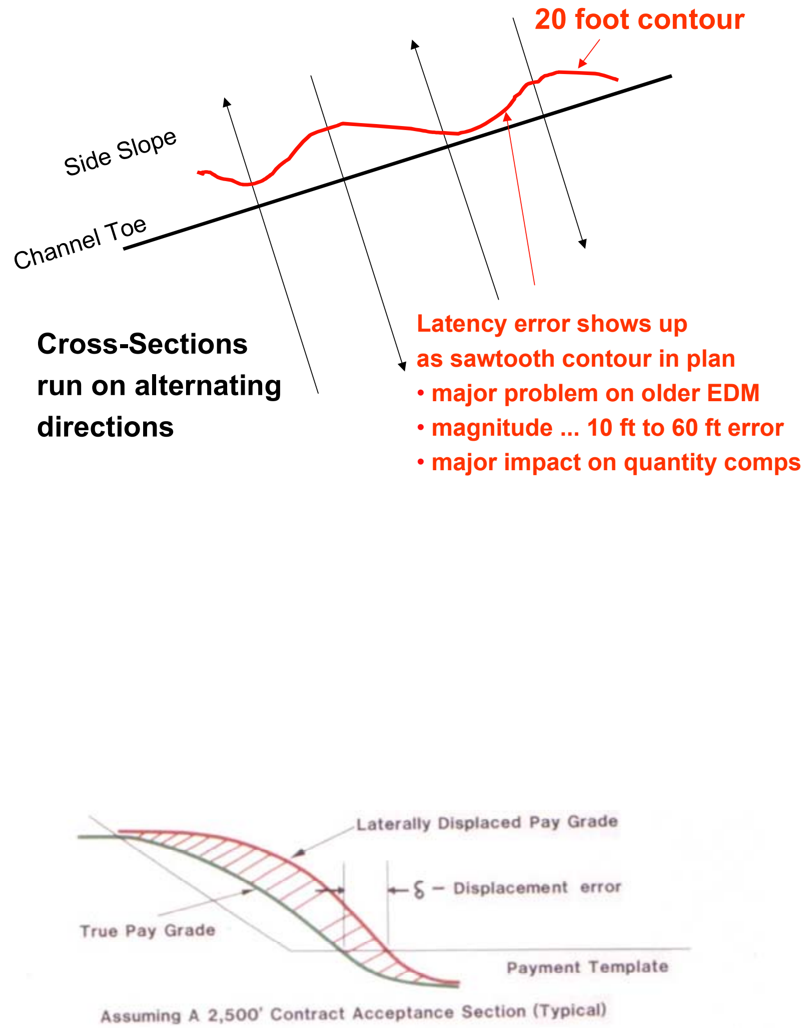


Figure 9-21. Positional latency correction



δ	Δ $ (10 $/cy)
1 ft	$18,500
5 ft	$93,000
10 ft	$185,000
20 ft	$370,000

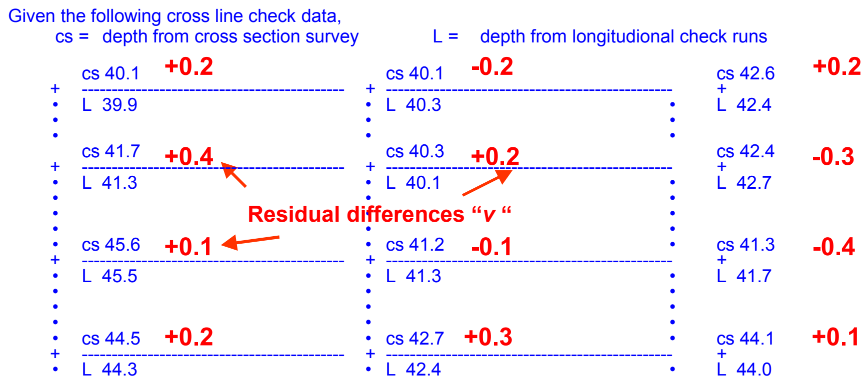
Figure 9-22. Effect of latency error in data contours as shown in plan view of channel (top). Potential impact of latency error on dredge payment shown in bottom view

9-15. Depth Quality Assurance Techniques for Single Beam Surveys

This section describes various procedures used to monitor quality assurance (QA) on a single beam hydrographic survey. These techniques are applicable to critical navigation and dredging payment surveys. The primary and most critical reason for these QA tests is to detect a systematic bias in the data--e.g., tide, velocity, squat, etc. QA tests generally rely on comparisons of depth measurements observed from independent surveys of the same area by the same survey vessel. The adequacy of these comparisons depends on the number of depth comparisons made and the independence of the comparative surveys; in many instances, the number of comparison points is not statistically valid and the surveys are not truly independent--see Chapter 4. From a rigid statistical sense the results of such comparisons are only an "estimate" of the true data accuracy. Therefore, comparative data derived from these surveys cannot be considered an absolute QA check.

a. Cross-line check method. To perform quality control checks on the internal consistency of dredging measurement and payment surveys, cross-line checks should be taken normal to the channel cross-sections. Preferably, these data are obtained at different tide/stage levels and after recalibration of depth sounding equipment. Elevations should be determined on survey lines and cross lines at each crossing by linear interpolation, using either manual or automated techniques. Differences should be tabulated and statistically analyzed. At least 100 check comparisons should be obtained--see minimum requirements in Chapter 4. The mean difference and standard deviations of crossing elevations should generally fall within the tolerances shown in Table 9-6. Exact linear interpolation for line intersections may not be necessary if the footprint size of the echo sounder is considered. The mean difference or bias between the two separate surveys is far more critical test than the standard deviation test result. A simplified example is shown in Figure 9-23. In this example, only 12 intersections are computed--a totally insufficient number of comparisons for any meaningful analysis--refer to paragraph 4-7 (Approximate Field Assessments of Depth Measurement Accuracy) in Chapter 4 for a discussion on the minimum number of cross-line checks that should be obtained. The mean difference and the standard error in this example are well within tolerances. The results of such an analysis will be noted on all plots, drawings, metadata files, maps, or charts as an indication of the data consistency obtained.

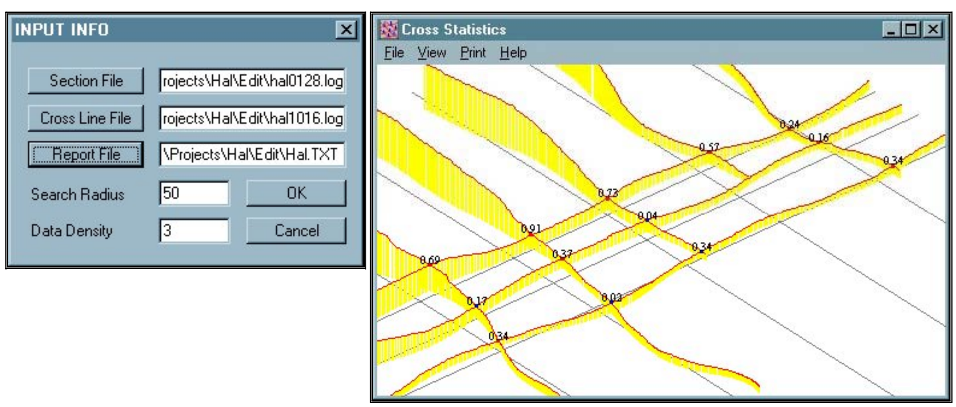
b. Automated computation of cross-line checks. Computer software to perform the cross-line check comparisons may be obtained from vendors. This software reads the cross-section profile data file and the longitudinal profile data file. It then computes the intersection and interpolates a depth from each input file. Each record of the output file lists the horizontal intersection, the interpolated depths, and the absolute difference in depths, along with the mean difference and standard deviation. If the output standard deviation is computed at the one-sigma level, then it must be multiplied by 1.96 to convert it to the 95% confidence level specified in Table 9-6 and Table 3-1. The example shown in Figure 9-24 is from HYPACK MAX Cross Check Statistics routines.



Mean of differences = sum (*v*) /n = +0.7 / 12 = + 0.058 ft << 0.2 ft allowed

Standard error (95%) = 1.96 * sqrt [sum |*v* ²| / (n-1)] = 1.96 * sqrt [(0.69) / 11] = +/- 0.50 ft
(+/- 2.0 ft allowed in > 40 ft project)

Figure 9-23. Sample cross line check computation



Cross Check Table	002_1022.PAT z1	z2	dif	003_1029.PAT z1	z2	dif	004_1032.PAT z1	z2	dif
007_1004.PAT	6.46	6.12	0.34	11.32	11.49	-0.17	24.37	23.68	0.69
008_1007.PAT	9.50	9.52	-0.02	9.33	8.96	0.37	13.78	12.87	0.91
009_1009.PAT	6.36	6.69	-0.34	11.72	11.76	-0.04	12.03	11.30	0.73
010_1011.PAT	n/a	n/a	n/a	n/a	n/a	n/a	11.53	10.96	0.57
011_1012.PAT	7.78	7.44	0.34	6.83	6.67	0.16	8.20	7.96	0.24

Figure 9-24. Cross line statistics routines (Coastal Oceanographics, Inc.)

c. External check line comparisons (Norfolk District). Another QA technique involves the establishment of external check sections. In order to verify accuracy of the vertical portion of the survey, check sections are set up on a large portion of projects. A track line is computed parallel with the channel and outside of it far enough that any activity in the channel will not affect the natural lay of the bottom covered by the track line. The line is computed so that it starts and stops on given station numbers, and an area is picked that is relatively devoid of any abrupt changes in elevation. Depending on the length of the survey there may be several lines, i.e. one in each tidal zone. These same lines are used each time the project is surveyed.

(1) How many times the check lines are run is largely a field decision made by field personnel that are on site. This decision is based on the weather, the length of time they have been surveying, the number of sections covered, and the performance of the depth recorder. At any suspicion that erroneous depths are being received, the calibration is checked and the check line re-run.

(2) Check lines are processed in the office just like any other line. These lines are not plotted on the map; instead they are run through a computer program that computes the average difference between each check line covering the same stations--see Figure 9-25. In this way it can be determined if a vertical shift has occurred. Such a shift would likely indicate problems in the local tidal model.

Cape Henry Channel -- External Checkline "A"
USAED Norfolk   Surveyboat Adams

Date of Section	Time	Average Depth	Residual	Residual Squared
06/26/92	947	37.83	-.01	.0001
06/26/92	951	37.85	.01	.0001
06/26/92	955	37.82	-.02	.0004
06/26/92	959	37.86	.02	.0004
	Totals	37.84	0.00	.0010

50% Error = (+/-) .0123146288346 = (+/-)0.6745 * Standard Deviation
Standard Deviation = (+/-) .0182574185835
90% Error = (+/-)1.6449 * Standard Deviation = (+/-) .030031627828

P&S Survey by Adams (RJW)

Date of Section	Time	Average Depth	Residual	Residual Squared
10/28/92	1622	37.95	0.00	0.0000
10/28/92	1627	37.95	0.00	0.0000
10/28/92	1631	37.92	-.03	.0009
10/28/92	1635	37.97	.02	.0004
	Totals	37.95	-.01	.0013

50% Error = (+/-) .0140408371664 = (+/-)0.6745 * Standard Deviation
Standard Deviation = (+/-) .0208166599947
90% Error = (+/-)1.6449 * Standard Deviation = (+/-) .0342413240252

Figure 9-25. External check line comparison (Norfolk District)

d. Averages of Extended Cross Sections (Norfolk District). Extended cross sections represent yet another quality control technique. They provide a means for comparing successive surveys of a given area. These comparisons help establish survey repeatability.

(1) The use of extended cross sections for comparing successive surveys requires that four conditions be satisfied. First, the number of extended cross sections needs to adequately represent the

survey. Second, each cross section must be extended beyond the area affected by dredging, since the comparisons could be made between surveys conducted before and after dredging. Third, the bottom outside of the dredging area must be relatively flat; otherwise it will be difficult to distinguish between the natural bottom and a survey discrepancy. Finally, the bottom must be relatively stable outside of the dredging area.

(2) The primary purpose of extended cross sections is to compare two given surveys by computing the average depth along the extended portion of each cross section. This is repeated for each successive survey of a given cross section. The algebraic difference between the average depth of each of the two surveys is computed. Then the average algebraic difference of all the cross sections is computed. The result of this analysis (Figure 9-26) will be a measure of how well two given surveys at a given cross section repeat each other and how well the two surveys of the entire group of cross sections compare overall.

Richmond Deepwater Terminal -- Average of Extended Cross-Sections
USAED Norfolk Surveyboat Adams

Average Depths are computed from 0 feet outside Toe to 100 feet outside Toe

Station No.	Avg. Depth (ft)	Avg. Depth (ft)	Col 1 - Col 2
5400.00	17.5	17.2	.3
5469.75	18.3	18.6	-.3
5500.00	18.4	18.3	.1
5600.00	18.0	18.1	-.1
5700.00	18.2	18.1	.1
5800.00	19.1	18.8	.3
5900.00	19.8	19.6	.2
6000.00	20.6	20.4	.2
6100.00	21.9	21.6	.3
6200.00	21.3	20.9	.4
6300.00	21.2	21.0	.2
Average	**19.5**	**19.3**	
Average Difference All Surveys =			**.2**

Figure 9-26. Extended cross-section comparison

9-16. Summary of Quality Control Criteria for Single Beam Echo Sounders

The following table contains critical QC and QA requirements for USACE single-beam surveys supporting dredging and navigation. This guidance has been developed from years of experience in numerous districts. It is intended to ensure Corps-wide consistency and quality in data used for water resource planning, design, construction, and operation. Requests for internal or external waivers from this guidance should be thoroughly justified and documented, especially if dredge measurement and payment surveys are involved. The table contains criteria for single-beam surveys in rock-cut projects. Since Table 3-1 requires 100% sweep coverage in such projects, use of a single beam system would not be practical. However, should a HQUSACE waiver from 100% coverage be obtained, then the criteria in Table 9-6 would be applicable.

Table 9-6. Quality Control and Quality Assurance Criteria for Single Beam Surveys

	PROJECT CLASSIFICATION		
	Navigation & Dredging Support Surveys		Other General Surveys & Studies
	Bottom Material Classification		(Recommended Standards)
	Hard *	Soft	
TRANSDUCER MOUNTING LOCATION:			
In-hull amidships below antenna	Required	Recommended	Preferred
Port-starboard (over side) mounts	if full HPR corr'n	if full HPR corr'n	Optional
Stern or bow mount	if full HPR corr'n	if full HPR corr'n	Optional
ACOUSTIC FREQUENCY (± 10%)	200 kHz	200 kHz	200 kHz
Beam angle @ - 3dB power points	3 deg	8 deg	8 deg
Low frequency fluff applications	24-28 kHz	24-28 kHz	24-28 kHz
VELOCITY CALIBRATION PROCEDURES:			
Perform at least	2/day	2/day	1/day
Bar check	Preferred	Preferred	Optional
Ross Ball check (w/ periodic bar cks)	Optional	Optional	Optional
Check with bar every	Month	Month	Month
Velocity casts (w/ periodic bar checks)	Optional	Optional	Optional
Check with bar every	Month	Month	Month
Lead line calibrations allowed	No	No	Optional
BAR/BALL CHECK CALIBRATION:			
Bar/ball cables marked at least every	5 ft	5 ft	5 ft
Independently measure cables	Quarterly	Annually	Annually
Correct line errors exceeding	0.05 ft	0.05 ft	0.05 ft
Location of calibration	At project site	Near project site	Vicinity
Number of comparisons within range	3 + (every 5 ft)	2	2
Record calibrations to nearest	0.1 ft	0.1 ft	0.1 ft
Data rejection tolerance between checks	0.2 ft	0.3 ft	0.5 ft
VELOCITY PROBE CALIBRATIONS			
Perform internal calibration	Weekly	Weekly	Monthly
Record velocity to nearest	1 fps	1 fps	1 fps
Record velocities at least every	5 ft	5 ft	5 ft
Reject tolerance between checks	5 fps	5 fps	5 fps
Location of calibration	At project site	Near project site	Vicinity
MOTION COMPENSATION REQUIREMENTS:			
Compensation reqd if roll-pitch exceeds	> 5 deg	> 10 deg	No limit
Compensation reqd if heave exceeds	> 0.2 ft	> 0.5 ft	No limit
Roll-Pitch beam steering position displacement reqd if corr'n > 1 m	Required	Recommended	Optional
Roll-Pitch beam slope-vertical corr'n reqd if error > 0.2 ft	Required	Recommended	Optional
Yaw position correction	Recommended	Optional	Not reqd
Pitch bias test	at installation	at installation	Not reqd
Transducer stabilization	Optional	Optional	Not reqd

Table 9-6. Quality Control and Quality Assurance Criteria for Single Beam Surveys (continued)

	PROJECT CLASSIFICATION		
	Navigation & Dredging Support Surveys Bottom Material Classification		Other General Surveys & Studies (Recommended Standards)
	Hard *	Soft	
MISCELLANEOUS CHECKS			
Squat test calibration performed	Annually	Annually	Annually
Check vessel draft variations	2/day	2/day	2/day
LATENCY TEST			
Perform every	3 mos	6 mos	Annually
Recommended vessel speed NTE	5 kts	10 kts	Unlimited
QA CROSS-LINE PERFORMANCE TEST			
Requirement	Required	Optional	Not reqd
Maximum allowable mean bias	< 0.1 ft	< 0.2 ft	N/A
Standard deviation (95%)	[per Table 3-1]		N/A
Minimum number of comparison points	[100 points--see Chapter 4, section 4-7]		
RECORDED DEPTH			
Depth recording density	50-100 millisec	250-1,000 millisec	as reqd
Dredge payment quantities	Full density shot	Full density shot	N/A
B/D or A/D plot	Selected shot	Selected shot	N/A
Project condition plot (thinned)	Shot	Shot or average	Optional
Record depth to nearest	0.1 ft	0.1 ft	0.1 ft
ARCHIVED ANALOG DEPTH RECORDS			
Contracted construction	[Hard-copy or write-once disc]		
Project condition surveys	Digital	Digital	Optional

* HQUSACE waiver required

9-17. Referenced Equipment Manufacturers

a. Odom Hydrographic Systems, Inc., 8178 GSRI Road, Building B, Baton Rouge, LA. http://www.odomhydrographic.com

b. Innerspace Technology, Inc., 36 Industrial Park, Waldwick, NJ. http://www.innerspacetechnology.com

c. Knudsen Engineering Limited, 10 Industrial Road, Perth, Ontario, Canada. http://knudsenengineering.com

d. Ross Laboratories, 3138 Fairview Ave. E., Seattle, WA 98102. http://www.rosslaboratories.com

e. Raytheon Marine Company, High Seas Products, 22 Cotton Road, Nashua, NH. http://www.raymarine.com

f. Coastal Oceanographics, Inc. (HYPACK MAX). 11-G Old Indian Trail, Middlefield, CT. http://www.coastalo.com

9-18. Mandatory Requirements

The criteria for navigation and dredging surveys in Table 9-6, along with supplemental explanatory material throughout the chapter, are considered mandatory. Allowable exceptions or deviations from the criteria in Table 9-6 may be contained in these sections.

Chapter 10
Multiple Transducer Channel Sweep Systems for Navigation Projects

10-1. General Scope

The Corps deploys a variety of multiple-transducer channel sweep systems for clearing shallow-and deep-draft navigation projects. These systems are designed to provide 100% coverage (see Figure 10-1) of a given project site and are particularly useful in searching for and supporting clearance of hazards to navigation. They also are used for performing dredge measurement and payment surveys since their full coverage capabilities provide more-accurate quantity computations. After-dredge surveys performed with channel sweep systems are used for certifying channel grade clearance. Some districts use sweep systems for routine project condition surveys because they are useful in locating channel obstructions or "strikes." Multiple transducer systems are mainly used on shallow draft and inland navigation projects. Their use on deep draft projects is declining due to increased reliance on multibeam technology. Since multiple transducer systems are similar in operation to single beam systems, most of the quality control and quality assurance procedures covered in the previous chapter are applicable to multiple transducer operations. Specific technical criteria for multiple transducer systems are found in Table 10-1 at the end of this chapter.

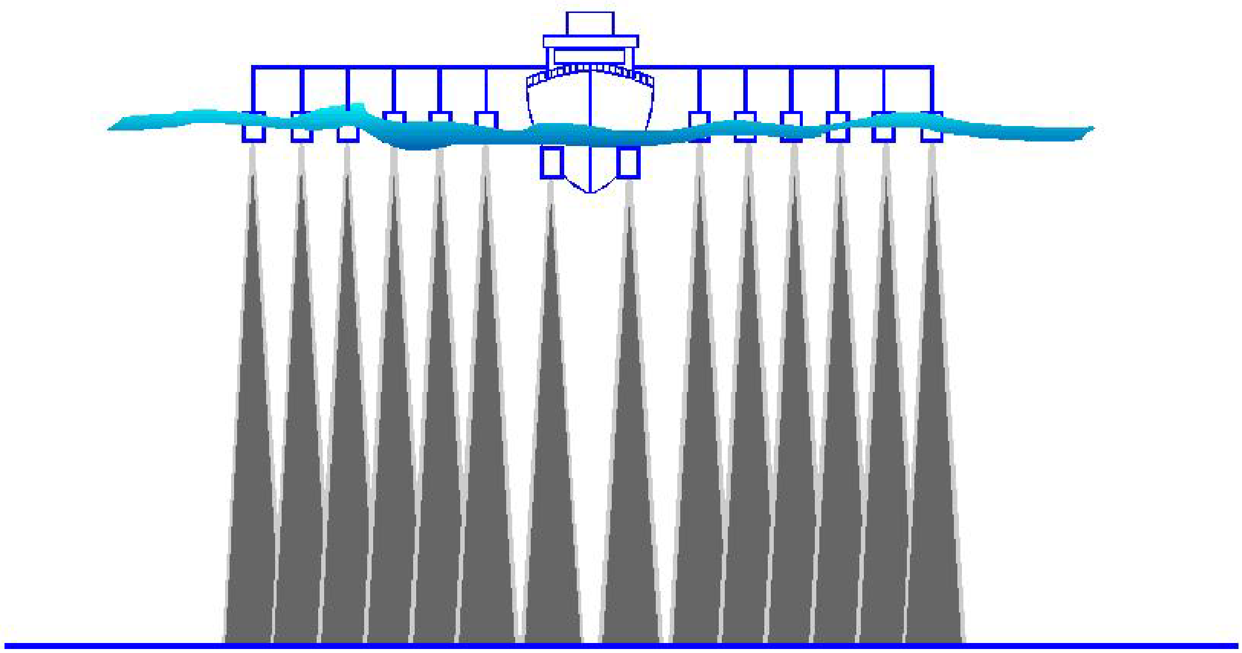


Figure 10-1. Generalized multiple transducer sweep array

10-2. Background

Multiple transducer systems were first deployed in the Corps during the early 1970s. The primary goal during that time was to replace the mechanical bar sweeps used by some districts for project clearance and acceptance. Most Corps districts contracted with Ross Laboratories to develop systems with transducers mounted on side-mounted booms. Other multiple transducer systems were developed by Raytheon, Innerspace Technology, and Odom. Currently (FY 01) eight districts are operating multiple transducer systems on both shallow- and deep-draft navigation projects: Detroit, St. Louis, St. Paul, New York, Savannah, Mobile, New England, and Portland.

10-3. Design of Channel Sweep Systems

Channel sweep systems are simply a series of standard single beam transducers vertically mounted on a boat, barge, or other stable platform. The transducers are typically mounted boom attachments to the vessel. The number of transducers in a sweep ranges from three up to 32. Bottom coverage is a function of transducer spacing, beam width, and channel depth. Due to high resultant motion at the far end of each boom (from vessel roll), boom-sweep systems are normally effective only on calm, restricted inland waterways. These systems are used to perform both payment and project condition surveys. Boom-mounted sweep vessels normally perform longitudinal run sweep surveys in order to identify shoals for dredging.

a. Sweep width. The sweep width is determined by the type of vessel deployed and project (channel) characteristics. Typically, sweep systems are designed to cover swaths ranging from 25 ft to over 120 ft. Optimizing sweep width with vessel maneuverability is often difficult--large sweeps using boom-mounted transducers being more difficult to control. Optimizing sweep width requires consideration of vessel characteristics and local conditions.

b. Transducer configuration. Sweep systems may use any number of transducers. Two or more transducers may be mounted permanently in the vessel hull. Additional transducers may be mounted on “over-the-side” outriggers or, more commonly, from hinged, retractable booms deployed to port and starboard. The more common systems deploy between 3 and 12 transducers on combinations of hull and retractable boom mounts. Figure 10-2 depicts a typical Ross boom sweep system operated by the St. Louis district. Similar boom-mounted Ross sweep systems are deployed by the St. Paul, New York, Mobile, and Savannah districts.

Figure 10-2. Typical Ross boom sweep system (St. Louis District)

(1) A typical installation for a boom system would include one or more transducers mounted in the hull and two or more transducers mounted on each boom. Often, a five-channel system is used (1 hull, 2 port, and 2 starboard). Transducers are 208 kHz at 8-deg beam angle. Each channel has its own

transmitter, receiver, and depth digitizer board. Both analog and digital depths are provided, and the multi-channel depth data is multiplexed via a single RS232 board.

(2) The port and starboard booms are retractable via hand winch. The stored position is vertical--usually against the side of the boat cabin. The individual struts mounting the transducers are designed with a breakaway feature should the strut strike a floating obstacle. The boom assemblies can be removed if necessary.

(3) Some portable multiple transducer systems were designed without boom arrays. Side transducers were temporarily mounted to the hull of the boat, as shown in Figure 10-3. With only three transducers, sweep coverage was reduced; however, higher vessel speeds could be attained without boom restrictions.

Figure 10-3. Typical three-channel hull mounted sweep (Jacksonville District)

c. Transducer beam width and spacing. Transducer spacing is determined by the nominal project depth, transducer beam angle, and desired side overlap between transducers. Transducer spacing typically ranges between 3 and 10 ft, depending on channel/project depth. Ideally, this spacing could be varied for given project depths; practically, however, the spacing is usually set for an optimum minimum depth in most projects. Transducer spacing can be computed by the following:

$$\text{Transducer Spacing} = 2 \cdot (d) \cdot \tan(b/2) \qquad \text{(Eq 10-1)}$$

where,

d = design project depth
b = transducer beam width

Transducer spacing (in feet) for 8 deg and 16 deg beam widths for various project depths (at 100% coverage--i.e., no overlap) are shown below.

	Depth (Feet)							
Beamwidth	10	15	20	25	30	40	50	75
8 deg	1.4	2.1	2.8	3.5	4.2	5.6	7.0	10.5
16 deg	2.8	4.2	5.6	7.0	8.4	11.2	14.1	21.1

From the above table, a five-transducer system operating in a 10-ft inland navigation project will cover about a 15-ft swath if a 16-deg beam width is used. Larger beam width transducers may be obtained to increase coverage. Full 100% coverage is not always required on shallow-draft inland projects; thus the spacing can be adjusted for 50% to 75% coverage. Spacing may also be reduced to provide overlapping coverage (i.e., > 100%) for critical strike detection.

d. Strike detection with sweep systems. The capability for strike detection using channel sweep systems is highly dependent on the operating characteristics of the transducers and the acoustic processing system, along with coverage patterns, floating plant maneuverability, and sweep overlap. Optimum transducer spacing and beam angle are essential for strike identification given a nominal project depth. Obtaining 100% coverage with an acoustic sweep system may not provide full assurance that all potential strikes have been recovered. Many objects can deflect acoustic energy such that they are below the detection threshold of the echo sounder. Some large rock fragments can exhibit "stealth-like" acoustic characteristics to vertically mounted transducers, and thus avoid acoustic detection. In such cases, it is best practice to run overlapping swath runs that will provide 200% (or more) bottom coverage.

e. Data collection methods. Both analog and digital data recording may be utilized on these systems. Figure 10-4 shows an analog representation from three transducers in an older Raytheon 719 CSS system operated by the Jacksonville district. Many digital display modeling techniques are now available to assist in interpretation of the large amount of recorded data, especially when 8, 16, 32 or more transducers are simultaneously operating. Vessel guidance, tracking, and data storage is performed using standard software packages containing modules for multiple transducer systems. Complete bottom coverage is assured by screen painting swath tracks similar to multibeam systems.

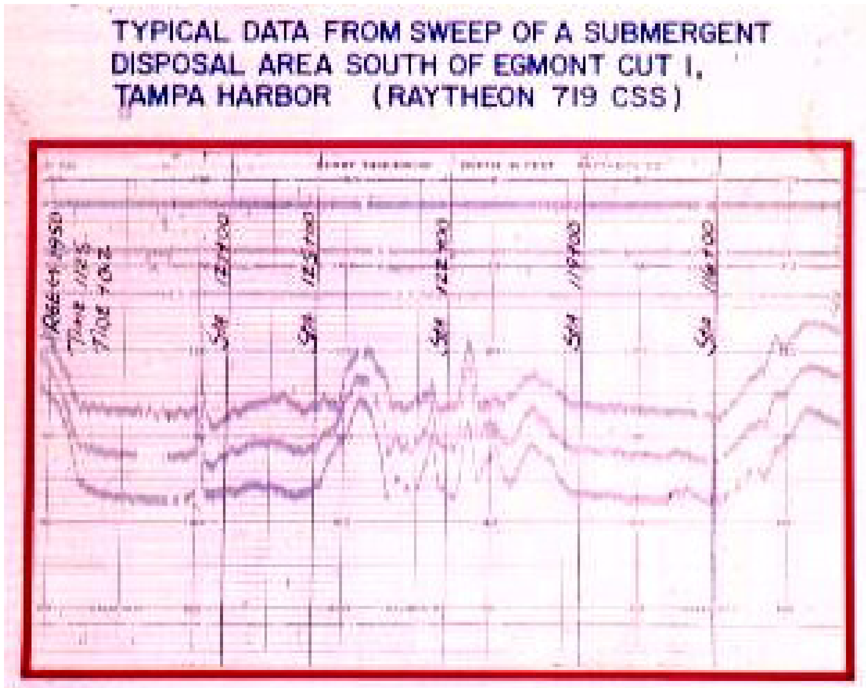


Figure 10-4. Raytheon 719 CSS multiple transducer analog record ca 1980 (Jacksonville District)

10-4. Philadelphia District Channel Sweep System

The Philadelphia District operated a ten-transducer boom-mounted Ross sweep system until 1999. It was used on deep-draft projects for clearance and dredge payment. It has recently been replaced with a multibeam system. Since this system is representative of most USACE sweep systems, a brief description of it follows.

a. Four of the 10 transducers are mounted directly to the hull of the catamaran-type survey vessel. Six transducers are boom mounted, three to port side and three to the starboard side boom. Transducers are calibrated with a bar check monthly. Daily, a Ross ball check is performed to monitor the hull-mounted transducers. A sound velocity profile is also observed to monitor velocity changes.

b. Vessel sweep speed is normally between 3 and 6 knots. Sweep data from all transducers is collected by time, not distance along the track line. Therefore, vessel speed must be controlled to avoid gaps. A fluxgate compass (or gyroscope) is interfaced with the data collection system to correct for yaw of the vessel and boom assembly--allowing for direct coordinate computation on each transducer. Any type of horizontal positioning system can be used--microwave and DGPS being the most common.

c. Sweep line spacings are designed for 20% side overlap. Cross-line checks may be run in order to monitor quality control of the sweep data. Comparisons can be made using either a single transducer or full terrain models.

d. Sweep data is edited though use of the system monitor aboard the vessel. Editing and review are made in plan or section format and the database corrected as required. Final plot scales and densities are selected depending on the nature of the project. In most instances, depth data must be selectively “thinned” for plan view plots at normal scales. Other options allow for selecting fixed cell (window) sizes for site plan plots or filtering out and plotting strikes above a preset grade.

e. Cell/window size can be automatically determined -- typically 5-ft or 10-ft square. Since one or more depths may have been recorded within a cell, different techniques are used in determining the final value displayed or in material quantity computations. Normally, either the least depth or average depth within a cell is used. This value is then shifted to the cell centroid for plotting purposes. This process for selecting, thinning, and shifting of data must be thoroughly understood by those evaluating the data relative to contract performance.

10-5. Detroit District 120-Ft Strike Detection System

An Odom Echoscan multiple transducer channel sweep system used by the Detroit District (Figure 10-5) is deployed from a 200-ton, 100-ft long by 30-ft beam by 7-ft draft, self-propelled barge containing 32 separate transducers spaced 3.75 ft O/C. The transducers are mounted along a catwalk that extends 10 feet beyond each end of the vessel. This provides for a 116.25 ft length or about a 120-foot swath at typical project depth. These systems are used for strike detection in rock cut channels. Obstructions may be caused by ice jams, propeller wash, or large vessels dragging anchors that lifts and loosens rock material within the channels. The district deploys two such systems--one in Detroit and another at Sault Ste. Marie, MI. They have replaced the manual sweep rafts previously used for strike detection. Each transducer has a large enough beam width to provide overlapping coverage in typical 25- to 30-ft project depths found in the Detroit, St. Clair and St. Marys channels. The operating frequency is 214 kHz with a pulse duration of 0.1 msec. The transducers are small ceramic discs 1.55 inches in diameter. The transducer beam width is 12 deg at -3dB and 17 deg at the -6 dB power points. Transducers are individually calibrated using standard bar check devices supplemented with velocity probe data and ball-check methods. A 32-foot calibration bar is employed in order to check every transducer Calibration is also performed in a lock chamber at the Soo Locks where 30-ft checks can be obtained. Each transducer has separate draft and sound velocity settings. This type of vessel usually works in conjunction with a crane barge (derrick boat) for removing loose rock and other debris within navigation projects.

(1) The vessels are propelled by two Schottell, 360-deg, hydraulically operated rudder propellers, one at each end of the vessel. They are driven by 240 HP engines. The vessels have no keel so all direction and movement is dependent on the rudder-propeller system. The vessels are controlled by the direction and amount of thrust from the rudder-propeller. The vessel is navigated to work sites as any 130-ft long vessel. The rudder is manually controlled and a handwheel from each rudder-propeller with arrows indicating thrust direction allows the boat operator to direct the engine's output. Throttles located in the center of the handwheel provide the thrust controls. Auxiliary power is obtained from two 30 kW generators operating at 3 phase and 480 volts.

(2) The vessels are operated sideways while sweeping. The boat operator controls the vessel's speed and direction with a single handwheel and throttle. The Schottell unit's actual direction and amount of thrust is controlled by a computer interfaced to a gyrocompass and autopilot. The computer maintains alignment of the vessel at 90 degrees to the direction of survey.

(3) The sweep vessels were originally positioned using Del Norte microwave range-range and range-azimuth modes. In the 1990s positioning was converted to differential GPS. Data acquisition was originally performed using Comstar Echo Scan software running on a HP 9000 computer. Processing originally required 16 hours for each 8 hours of survey data collected--requiring a 24-hour processing operation. Once PC-based HYPACK software was added in 1994, data processing time was reduced substantially. Since only "strikes" above grade are significant, processing and/or plotting of data below grade can be eliminated.

(4) Original staffing on the sweep vessel in 1986 was nine persons: 3 Wage Grade vessel operators and 6 GS survey technicians. With DGPS positioning and enhanced acquisition software, this staffing was reduced to 4 persons by 1995.

Figure 10-5. Detroit District Survey Vessel PAJ, a 120-ft, 32-channel sweep system

10-6. St. Paul District Channel Sweep Systems for Shallow-Draft Projects

St. Paul District operates two multi-transducer sweep survey systems on the Upper Mississippi River. Both are boom-mounted systems: one being a nine-transducer array and the other a five-transducer array. Both systems were designed and installed by Ross Laboratories Inc. The systems are primarily used on project condition and dredge payment surveys of shallow-draft projects in St. Paul District.

a. Nine-transducer system. The nine-transducer system has a 50-ft swath capability and the five-transducer system has a 25-ft swath capability. The nine-transducer system is boom mounted on a 36-ft Sea Ark vessel. It utilizes the USCG Radiobeacon DGPS for positioning. Its roll sensor and fluxgate compass are integrated into the HYSWEEP data collection software (Coastal Oceanographics). Although the boat is capable of a 50-ft swath, it is not trailerable and is extremely slow.

b. Five-transducer system. The five-transducer vessel is boom mounted on a 24-ft Sea Ark boat powered by twin 150-HP outboard engines (Figure 10-6). The survey system is a complete 12-volt system with DGPS, roll sensor, and fluxgate compass all integrated into HYSWEEP data collection software. The five transducers are interchangeable from 10-degree to 20-degree beam angles for shallower water. All surveys are accomplished longitudinally and usually at speeds of under seven knots. Sweep data is edited in HYSWEEP software and then e-mailed to the Fountain City Project Office for plotting and analysis.

c. Lock chamber calibration procedures. The electronics are calibrated monthly using an aluminum bar check inside a lock chamber with the gates closed. The lock floor monoliths are sounded by using a lead line or pole to make certain the monoliths have not heaved or sunk. The bar check is then used to calibrate the sounders with the depths at 5, 10, 15 and 20 feet. All transducers are then forced to read the same depths on the data collection computer. A predetermined survey line is set up in the lock chamber and both the 24-ft and 36-ft sweep boats run this line. The lines of each boat are analyzed for correct depths. If they all read the same the systems are ready for production. The Ross ball check is then calibrated at the same time for future daily or job specific use for project condition and /or payment surveys.

Figure 10-6. St. Paul District Five-Channel Ross Mini Sweep System

10-7. Mobile District Tuscaloosa Site Office Sweep Systems

The Mobile District Tuscaloosa Site Office operates four multiple-transducer automated sweep survey systems (Figure 10-7) utilizing depth sounding hardware manufactured by Ross Laboratories, and HYPACK data collection and post processing software from Coastal Oceanographics. The systems are used to provide support for dredging activities and project conditions along over 700 miles of the shallow draft 9-ft x 200-ft navigation channels of the Black Warrior–Tomigbee and Alabama River Systems. Brief descriptions of the systems follow.

a. General description. The Tuscaloosa Site Office Navigation Unit operates three (3) trailerable 24-ft sweep survey vessels and the 60-ft sweep survey vessel E.B. WALLACE. The three 24-ft small-boat systems have a total of five transducers with four being attached to spring-loaded strut and boom assemblies and one being mounted amidships through the hull. The small boat systems provide a 25 ft complete swath coverage of the bottom with no gaps at water depths of 17 ft while performing data collection survey operations. The E.B. WALLACE has a total of 12 transducers with 10 being mounted on spring loaded struts attached to two 30 ft hydraulically operated retractable booms and two being mounted amidships through the hull. The E.B. WALLACE provides a complete 70 ft wide swath of the river bottom with each pass of the vessel. All transducers are spaced at 5 ft intervals along the boom and operate at frequencies of 200 kHz with dual beam selectable angles of 10 and 22 deg. Each of the four vessel's electronic components is rack mounted and located in a climate controlled cabin area.

b. Survey procedures. The multi-transducer (sweep) survey systems generate accurate representations of the complete waterway bottom using depths received from multiple transducers configured for sweep survey application and electronic positioning. Data collection is performed for each assigned surveying effort by running sweep lines that are parallel to the navigation channel. This method is also known as “Mowing the lawn” or “painting the screen” and provides data coverage of the entire navigable water area or river bank to river bank survey.

c. Transducer calibration and quality control. Transducers are calibrated with daily “ball checks” using the Ross Labs lead ball check assembly. Traditional monthly bar checks are also made using steel angle iron and a calibrated chain to verify the transducer accuracy. Checks are also performed over fixed objects such as lock and dam miter sills to provide additional assurance of depth accuracy. Independent verification is also made by comparisons of hydrographic data produced with the sweep system with simultaneous collected data produced by A-E contract survey vessels.

d. Vessel positioning. Standard meter level DGPS Positioning is provided through Novatel 10 and 12 channel DGPS cards with Starlink Radio Beacon receivers providing differential correction signals from USCG broadcast sites. A KVH digital compass/roll sensor is incorporated into the data collection systems to provide heading and boom arm roll corrections.

e. Data processing. Sweep data in digital format is recorded and stored onto 3.5 inch diskette for editing and post-processing using Coastal Oceanographics HYPACK suite of software – presently the HYPACK MAX version. The data is processed into full color 30 x 42-inch plan drawings of each survey area. The finished plots consist of color filled depth contours with elevation labels. All data points collected during the sweep survey are used in the post-processing effort with various levels of data thinning being performed to achieve desired bottom mapping results.

f. Data distribution. End use of the processed data consists of not only hard copy plots but also digital dredging files and publicly available X-Y-Z data points. Contract rental dredges are given digital plans and detailed cut boxes that are displayed using government-furnished DREDGEPACK software from Coastal Oceanographics. Digital X-Y-Z data is also made available via the Tuscaloosa Homepage Internet site for FTP download by vendors desiring to produce electronic charting products. The available data set consists of edited ASCII X-Y-Z format sounding points from which the electronic chart vendor will utilize to produce contour maps. Such contouring will be incorporated into charts depicting the shoreline and other physical features of the river system. Vendors providing electronic charting systems will be responsible for providing the finished chart that will ultimately be displayed on a vessel by the end-user.

g. Equipment. The following is a list of equipment on the 24-ft Small-boat Systems and the 60-ft E.B. WALLACE:

- Ross Model 5001 Fine line survey recorder.
- Ross Model 4401 Precision Multi-track Transceiver.
- Ross Model 4801 Multi-channel Receiver/Digitizer.
  (5-channels) - Small-boat systems
  (12-channels) - E.B. WALLACE
- Ross Model 8501 Interface.
- Ross Model 1001 Converter.
- Ross Model 3101 Annotation Generator.
- Ross Model 9801 Mixer.
- Equipment rack of modular design and mounted on sliding tracks in a 19-inch cabinet housing all electronic component modules.
- Ross Transducer - 200 kHz, dual beam (10 and 22 degree beams).
- Ross one-man bar check and underwater housing.
- Associated hardware and KVH digital Compass/roll sensor.
- Novatel GPS card contained within data collection computer. (E.B. WALLACE and Small-Boat 6212 - 10 Channel Card, all others have 12-channel cards)
- Starlink Radio Beacon receiver
- Small-HP desktop printer
- Data collection computer (Located internally in equipment rack). Consists of 233 MHz Pentium with 128 MB of RAM, 4.3 Gig hard drive, 8 MB of Video Ram and CD-ROM dive.
- Flat screen monitor.

60- ft E.B. Wallace and three 24-ft sweep vessels

Figure 10-7. Mobile District (Tuscaloosa Site Office) sweep vessels

10-8. New York District Multiple Transducer and Multibeam Sweep System

Figure 10-8 shows a survey vessel operated by the New York District that is equipped with both a multiple transducer sweep system (Odom Miniscan) and a multibeam system (Odom Echoscan). These systems were developed by Odom Hydrographic Systems and allow simultaneous coverage of rock excavations in New York Harbor deep-draft channel deepening projects.

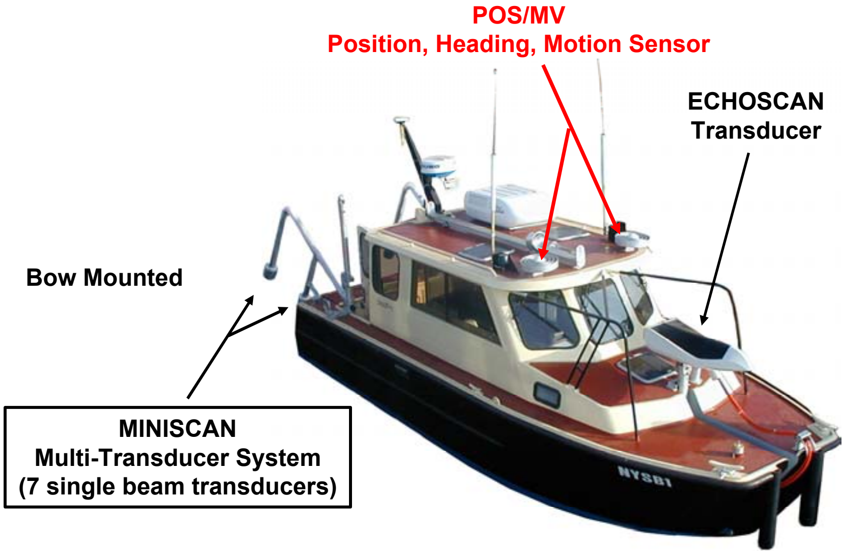


Figure 10-8. Dual Multiple Transducer and Multibeam Sweep System (New York District)

10-9. Multiple Transducer System Quality Control and Quality Assurance

Multiple transducer QC requirements are essentially identical to single beam QC covered in Chapter 9. Multiple transducer QA Performance Tests are identical with multibeam QA tests covered in Chapter 11. Table 10-1 below details QC and QA criteria for multiple transducer systems. The following paragraphs amplify some of the criteria in this table that were not described in this chapter or were previously covered under single beam systems in Chapter 9.

a. Velocity calibration. Multiple transducer system velocities are calibrated identically to single beam systems. Typically only one of the transducers is used to determine the velocity correction. All boom transducers are initially referenced to the hull transducer during installation. Maintaining and monitoring transducer draft and alignment throughout the booms is especially critical. Calibration of the multi-transducer system is performed similarly to that of single transducer systems, except during installation of the boom transducers. Index and/or draft errors of the boom transducers are individually stored in the hydrographic survey processing system as corrections. Removal of any one of the boom transducers for any reason (cleaning, etc.) constitutes a re-installation/boom calibration procedure. The bar check for the multi-transducer system is performed on the permanent hull transducer.

b. Boom calibration procedure after installation. The survey vessel must be in protected calm water for this procedure. The booms are lowered and leveled by the best possible means available. Roll motion must not be allowed at this time. A bar check using any of the accepted USACE methods is performed on the hull transducer. This will minimize the index and draft errors and establish the same speed of sound for all transducers. Next the bar is moved outward from the hull transducer (preferably by two steady small boats) to the nearest boom transducer on one side of the survey vessel. The hull transducer soundings are compared to the sounding values recorded at the hull transducer. Any discrepancy found is recorded as a combination of draft and index error. The opposite (negative) of this recorded value will be applied to all soundings from this particular transducer until the transducer is physically moved from the fixed position in the boom. All boom transducers are compared to the hull transducer by the same procedure. The area selected for the boom calibration should be where no changes in temperature or salinity could change the speed of sound during this important calibration. Clearly noticeable particles in the water column may also affect the speed of sound.

c. Periodic calibration of Ross Dolphin Sweep System (Philadelphia District Method). Periodic calibration of Ross Dolphin sweep systems is performed using basically the same criteria required for a single transducer system. Once a month, all transducers in the hull are calibrated, utilizing a standard bar lowered to the project depth directly under the vessel. Transducers in the port/starboard beams are calibrated on an annual basis. On a daily basis, a Ross ball check device, which is mounted as part of the referenced transducer pod, is utilized to obtain the speed of sound utilizing a 3½-deg transducer. The 3½-deg transducer is used to assure that the depth reference is as close to a true vertical distance as possible. A sound velocity profiler is also used daily to verify the ball check calibration procedure. Maintaining and monitoring the transducer draft is especially critical. Each transducer channel in the sweep is adjusted similar to the procedure used in the single transducer systems.

d. Lock chamber calibration. When a lock chamber with a clean, smooth floor is located in the district, multiple transducer sweep systems may be simultaneously calibrated. Calibration can be performed at varied surface elevations by drawing down the lock to desired intervals. The lock chamber affords a stable water surface that eliminates sea state effects on outer boom transducers. Individual transducer channels are calibrated and adjusted to read true depths.

e. Motion compensation requirements. Boom sweep systems are normally used on shallow draft inland projects where sea state conditions are typically calm. Thus, full X-Y-Z inertial motion sensors are rarely added to these sweep systems unless sea states cause excessive errors. Roll correction is especially needed to correct for motion at the outer transducers. Physical movement of the outer transducers will determine whether surveys should continue under adverse sea conditions. Small roll errors can significantly affect depth readings on long boom systems--e.g., a 1-deg roll on a 25-ft boom causes approximately a 0.4 ft error in the sounding. Excessive heave should not be a problem on inland navigation projects where sweep systems are deployed.

(1) Roll compensation. Roll should be compensated for and corrected in the processing software if the outer transducer on a boom experiences movement in excess that shown in Table 10-1. Smaller boat systems with short outriggers would be less subject to roll errors, so compensation would not be required. Beam steering position and slope corrections due to excessive roll and pitch are usually negligible for shallow-draft projects when wide beam transducers are used; thus the need for these corrections would be minimal.

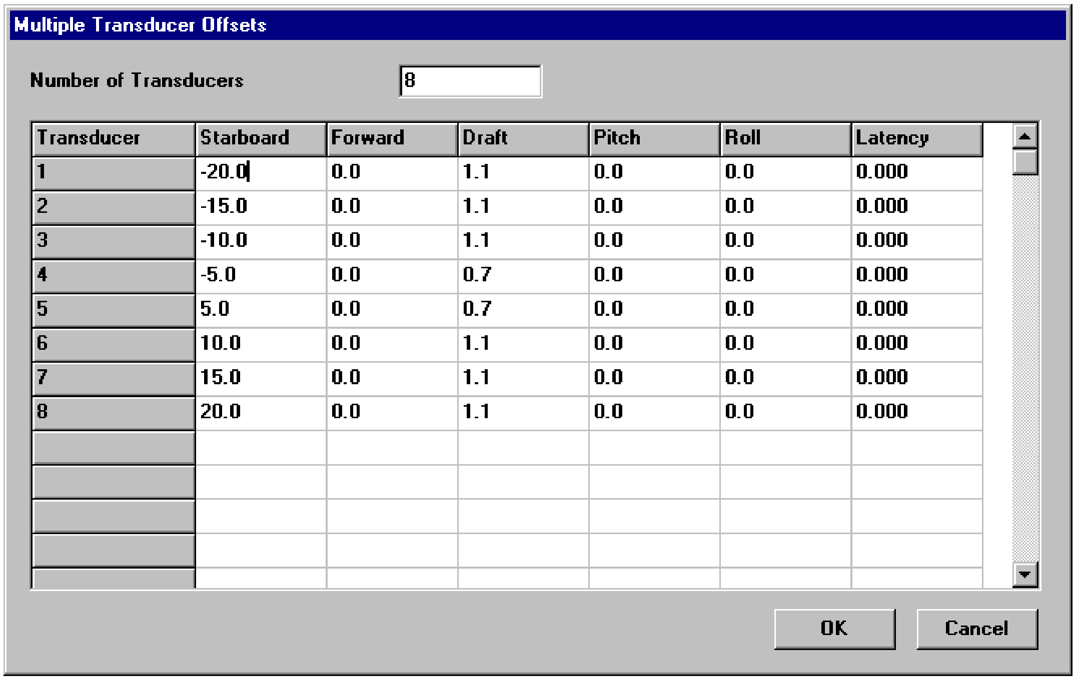
(2) Yaw correction. Boom alignment due to vessel yaw is controlled using a flux gate compass, a gyrocompass, or DGPS azimuth techniques. Software must correct each transducer offset relative to the positioning antenna in addition to correcting eccentricities due to yaw. This is done using similar techniques covered under the chapter on multibeam systems. Full yaw correction is critical.

(3) Heave correction. Only required in excessive sea states.

(4) Pitch bias. Usually negligible given slow sweep speeds.

(5) Latency. Latency between the positioning system and the multiple transducers is calibrated similar to single- or multibeam systems--see Chapters 9 and 11.

(6) Fixed offsets. Horizontal offsets of individual transducers are measured relative to the vessel center of mass--the point where a HPR unit should be located. Vertical offsets (draft) are relative to the water line and are determined from a bar check. Parameters for multiple transducer systems are entered in processing software in a variety of methods--Figure 10-9 depicts a typical HYPACK MAX/HYSWEEP offset table.


Multiple Transducer Offsets

Number of Transducers: 8

Transducer	Starboard	Forward	Draft	Pitch	Roll	Latency
1	-20.0	0.0	1.1	0.0	0.0	0.000
2	-15.0	0.0	1.1	0.0	0.0	0.000
3	-10.0	0.0	1.1	0.0	0.0	0.000
4	-5.0	0.0	0.7	0.0	0.0	0.000
5	5.0	0.0	0.7	0.0	0.0	0.000
6	10.0	0.0	1.1	0.0	0.0	0.000
7	15.0	0.0	1.1	0.0	0.0	0.000
8	20.0	0.0	1.1	0.0	0.0	0.000

OK Cancel

Figure 10-9. Multiple transducer offsets (Coastal Oceanographics, Inc.)

f. Squat tests. At slow sweep speeds vessel squat and settlement should be minimal; however this should be annually verified by a standard squat test as described in Chapter 9.

g. Vessel speed and shoal/strike detection hits. Vessel speed should be controlled such that objects or shoals above project grade receive at least three solid acoustic hits during a pass, or accumulate on overlapping passes. The depth update rate for each transducer channel must also be factored into the maximum speed determination. Data gaps can result if too high a velocity is maintained and individual channels do not update at a rapid enough level. Depths should be recorded at the maximum rate possible with the recording and processing system.

h. Quality assurance performance tests. QA tests with multiple transducer systems are performed similar to multibeam systems, i.e., comparisons between two independently collected full data sets over the same area. Follow the QA performance procedures described in Chapter 11.

i. Recorded depths. For dredge payment surveys, the maximum update rate shall be used in recording depths from each transducer channel. If depths are binned or gridded for plotting purposes, the shot depth nearest the bin centroid shall be used. Shoal biased (i.e., minimum) or average depths shall not be used to evaluate dredging progress. Data thinning shall be kept to a minimum for payment surveys. Likewise, bin sizes should be kept as small as possible. Refer to Chapter 11 (paragraph 11-12) for additional standards and guidance on intelligent data thinning and bin size restrictions.

j. Archived data. It is not practical to retain hard copy records of multiple transducer surveys. Original depth records from each transducer may be retained in digital format. Where contracted construction payment is involved, then a write-once type of media should be used.

Table 10-1. Quality Control and Quality Assurance Criteria for Multiple Transducer Surveys

	PROJECT CLASSIFICATION		
	Navigation & Dredging Support Surveys Bottom Material Classification		Other General Surveys & Studies (Recommended Standards)
	Hard	Soft	
ACOUSTIC FREQUENCY (± 10%)	200 kHz	200 kHz	200 kHz
Beam angle @ - 3dB power points	8 deg	8-25 deg	8-25 deg
Low frequency fluff applications	24-28 kHz	24-28 kHz	24-28 kHz
VELOCITY CALIBRATION PROCEDURES:			
Perform at least	2/day	2/day	1/day
Bar check	Preferred	Preferred	Optional
Ross Ball check (w/ periodic bar cks)	Optional	Optional	Optional
Check with bar every	Month	Month	Month
Velocity casts (w/ periodic bar checks)	Optional	Optional	Optional
Check with bar every	Month	Month	Month
Lead line calibrations allowed	No	No	Optional
BAR/BALL CHECK CALIBRATION:			
Bar/ball cables marked at least every	5 ft	5 ft	5 ft
Independently measure cables	Quarterly	Annually	Annually
Correct line errors exceeding	0.05 ft	0.05 ft	0.05 ft
Location of calibration	At project site	Near project site	Vicinity
Number of comparisons within range	3 + (every 5 ft)	2	2
Record calibrations to nearest	0.1 ft	0.1 ft	0.1 ft
Data rejection tolerance between checks	0.2 ft	0.3 ft	0.5 ft
VELOCITY PROBE CALIBRATIONS			
Perform internal calibration	Weekly	Weekly	Monthly
Record velocity to nearest	1 fps	1 fps	1 fps
Record velocities at least every	5 ft	5 ft	5 ft
Reject tolerance between checks	5 fps	5 fps	5 fps
Location of calibration	At project site	Near project site	Vicinity
MOTION COMPENSATION REQUIREMENTS:			
Compensation reqd if roll-pitch exceeds	> 1 deg	> 2 deg	No limit
Compensation reqd if heave exceeds	> 0.2 ft	> 0.5 ft	No limit
Roll-Pitch beam steering position displacement reqd if corr'n > 1 m	Required	Recommended	Optional
Roll-Pitch beam slope-vertical corr'n reqd if error > 0.2 ft	Required	Recommended	Optional
Yaw position correction	Required	Required	Not reqd
Pitch bias test	at installation	at installation	Not reqd

Table 10-1. Quality Control and Quality Assurance Criteria for Multiple Transducer Surveys (cont.)

	PROJECT CLASSIFICATION		
	Navigation & Dredging Support Surveys Bottom Material Classification		Other General Surveys & Studies (Recommended Standards)
	Hard	Soft	
MISCELLANEOUS CHECKS			
Squat test calibration performed	Annually	Annually	Annually
Check vessel draft variations	2/day	2/day	2/day
Boom/transducer alignments	annually	annually	annually
LATENCY TEST			
Perform every	3 mos	6 mos	Annually
Recommended vessel speed NTE	2-5 kts	5 kts	Unlimited
QA PERFORMANCE TEST			
Requirement	Required	Recommended	Not reqd
Maximum allowable bias	< 0.1 ft	< 0.2 ft	N/A
Standard deviation (95%)	[per Table 3-1]		N/A
RECORDED DEPTH			
Depth recording density	max possible	50-1,000 millisec	as reqd
Dredge payment quantities	Full density shot	Full density shot	N/A
B/D or A/D plot	Selected shot	Selected shot	N/A
Project condition plot (thinned/binned)	Centroid shot	Shot or minimum (bias)	Optional
Maximum bin size (quantities)	1 m	5 m	as reqd
Record depth to nearest	0.1 ft	0.1 ft	0.1 ft
ARCHIVED ANALOG DEPTH RECORDS			
Contracted construction	[Write-once disc]		
Project condition surveys	Digital	Digital	Optional

10-10. Mandatory Requirements

The criteria in Table 10-1 are considered mandatory, including applicable references to equivalent single beam systems in Chapter 9 and multibeam QA requirements in Chapter 11.

Chapter 11
Acoustic Multibeam Survey Systems for Deep-Draft Navigation Projects

11-1. General Scope and Applications

This chapter provides USACE policy and guidance for acquisition, calibration, quality control, and quality assurance of multibeam survey systems used on deep-draft navigation, flood control, and charting projects. Instructions for operating specific multibeam systems, or the acquisition, processing, and editing of data from these systems, are found in manufacturer's operating manuals and software processing manuals specific to the systems employed.

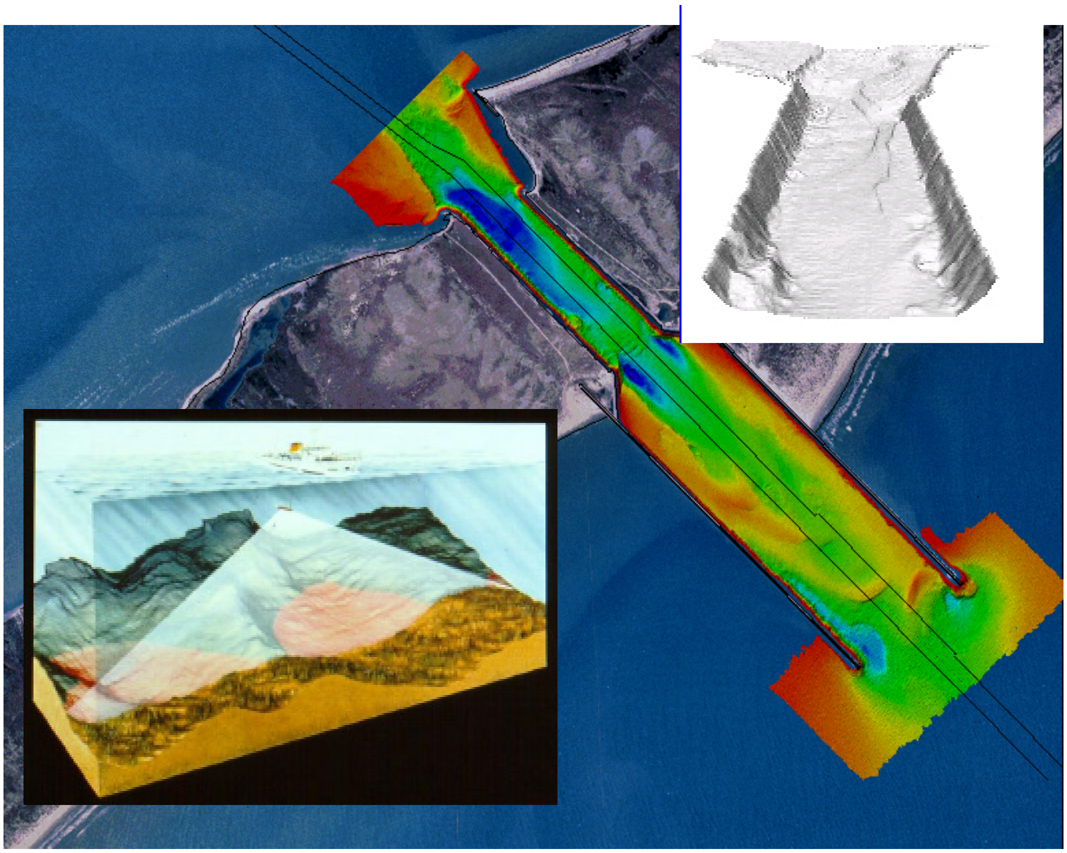


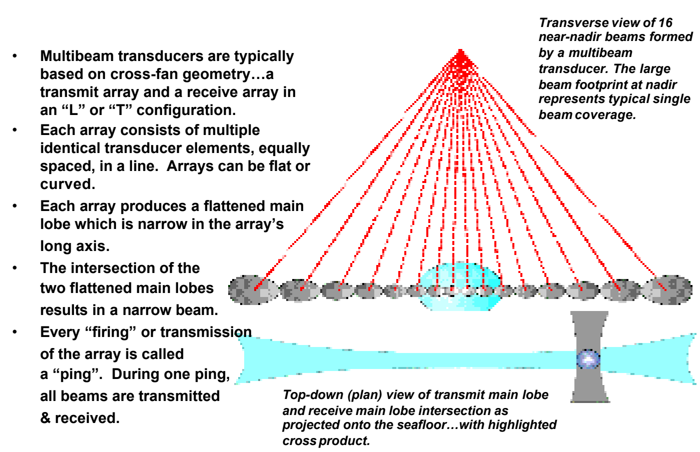
Figure 11-1. Full-coverage multibeam survey of coastal inlet navigation project (Galveston District)

11-2. Background

The US Navy developed multibeam swath survey technology in the early 1960s for deep-water bathymetric mapping. Only since the early 1990s has this technology been developed and marketed for shallow-water USACE applications, such as those illustrated in Figure 11-1. It is expected that the use of multibeam systems will significantly increase over the next few years, and will gradually supplant single beam transducer survey systems in deep-draft navigation projects. Multibeam systems, when coupled with digital side-scan imaging systems, have the potential to become a primary strike detection method in USACE. Multibeam systems have technically advanced since their introduction in the early 1990's to the point that they now have a direct application to most Corps navigation project survey activities. When properly deployed and operated, the accuracy, coverage, and strike detection capabilities of multibeam systems now exceeds that of traditional vertical single beam echo sounding methods.

11-3. Principles of Operation

Multibeam sonar systems employ beamforming or interferometric (phased array) acoustic detection techniques from which detailed terrain cross-section (swath) data can be developed many times per second. A single transducer, or pair of transducers, forms a fan array of narrow beams that result in acoustic travel-time measurements over a swath that varies with system-type and bottom depth--typically mapping an area 2 to 14 times the channel depth with each array pulse--see Figure 11-2. Generating many sweeps per second (e.g., the Reson Seabat 8101 generates 30 profiles per second at 7.4 times water depth), multibeam systems can obtain 100% bottom coverage, and can provide high resolution footprints when narrowly focused beams are formed--e.g., < 1 deg. Multibeam systems can also be configured for waters-edge to waters-edge coverage (i.e., over 180 degree swath), allowing side-looking, full-coverage underwater topographic mapping of constricted channels, lock chambers, revetments, breakwaters, and other underwater structures. Some systems collect acoustic backscatter information that can produce digital side-scan imagery simultaneously with the swath mapping data, an advantage in locating underwater rock, hazards, shoals, or other objects (strike detection). Multibeam acoustic frequencies and signal processing methods may be adjusted to match the survey requirements--dredging measurement and payment, strike detection, structure mapping, etc. Some systems can provide near real-time data collection, filtering, editing, quality assessment, and display; along with near real-time (i.e., on board) data processing, plotting, and volume computations; thus, final plan drawings, 3D terrain models, and dredged quantities can be completed in the field the same day the survey is performed.



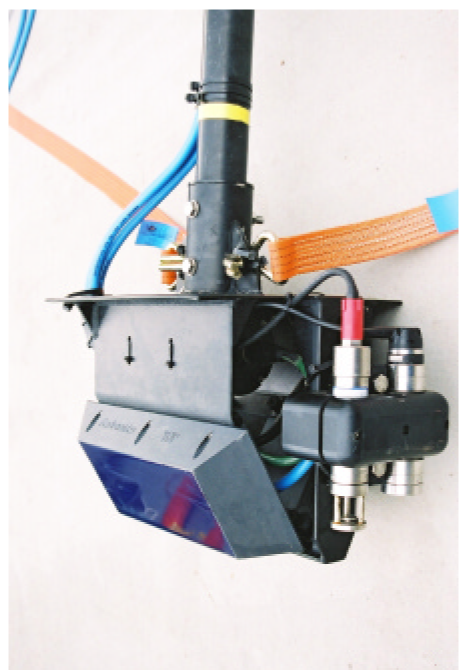


Figure 11-2. Multibeam geometry (NOAA) and typical transducer array configuration (GeoAcoustics, Inc.)

a. General. All multibeam swath systems use the same basic approach to depth measurement. A lateral swath of sea floor is illuminated acoustically and the returning echo signals are processed into vertical depths. Travel time estimates are converted into slant ranges, horizontal off-center distances, and then depth by applying beam angles and sound velocity profile data. The object is to convert two-way slope distance travel times to a vertical depth at points along the bottom. Slope distances are resolved using amplitude and/or phase detection methods. Amplitude detection relies on finding the time of beam bore site interception with the bottom, typically determined using a center-of-energy method, or matched filter method. Phase detection relies on finding the time of the zero phase crossing using two or more subsections of the receive array. Amplitude detection is typically used for the inner beams (e.g., 0 deg to 45-deg off-nadir) and phase detection is typically used for the outer beams (e.g., 45 deg out to 100-deg off-nadir). The changeover point between amplitude and phase detection varies by design; methods include absolute cutoff, real-time analysis of each beam, and combination amplitude and phase. Depth accuracy can change at bottom detection transition points.

b. Beam spacing. Swath systems are typically designed with between a 0.5 deg and 3.0 deg beam spacing. Due to the physics involved, a half-degree beam spacing is about the best that can be achieved and still have a portable electronically beam-formed system. To increase resolution, interferometric phased array techniques are employed. The accuracy of a wide-swath multibeam is determined by the ability of a multibeam system to resolve the actual beam angle in varying situations.

c. Signal parameters. Each individual bottom spot within the ensonifinied swath responds with an echo signal in which signal parameters (amplitude, frequency, phase) are all dependent. These parameters are dependent upon the characteristics of the bottom, namely (1) bottom reflectivity and (2) slope angle of incidence of the beam. The quality of the return signal is dependent upon the primary projector/receiver characteristics and the geometrical and reflective properites of the particular bottom spot. The hardware is a factor in the quality of the final data. In designs that rely totally on electronic beamforming, the transducer must be optimized for a particular application. A multibeam sonar's bottom detection thus provides three pieces of information: (1) the angle of the beam along which the acoustic pulse traveled, relative to the sonar head, (2) the round-trip travel time of the acoustic pulse, and (3) a signal intensity time series of the bottom return. These three pieces of information must be integrated with the other sensor data to determine the total sounding solution (i.e., X-Y-Z) relative to our Earth-fixed coordinate system. Most multibeam systems can also output the angle independent imagery--more commonly called pseudo side scan imagery.

d. Vessel roll, pitch, and yaw effects. Horizontal positioning accuracy is dependent upon the ability of the system to compensate for pointing errors caused by vessel roll, pitch, and yaw--Figure 11-3. Across-track location of each bottom point is critical. In wider swath systems, even a small degree of roll can cause large errors in the outer beams; thus, restrictions are typically placed on use of outer beam data. These errors are compounded due to beam spreading.

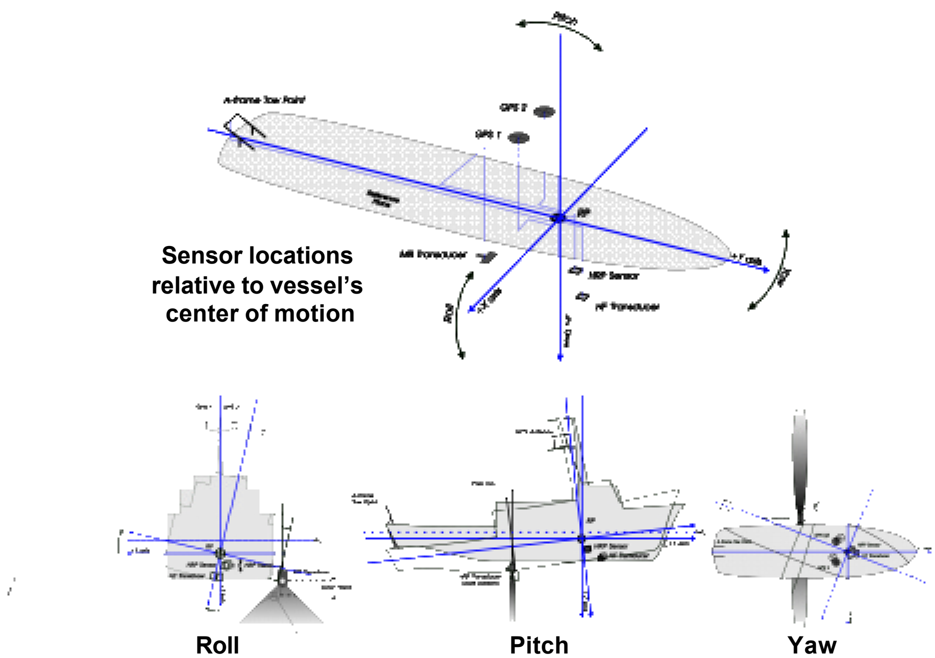


Figure 11-3. Multibeam offsets, roll, pitch, and yaw (NOAA)

e. Beam footprint size. Outer beam quality and accuracy is dependent upon footprint size. As with single beam echo sounders, the smaller the beam angle, the better the system is able to discern true depth and resolve small features. As the size of the footprint increases toward the outer beams due to beam spreading, the stability and accuracy of the data decreases, resulting in a degradation of data quality and accuracy in the outer portions of the beam array. For this reason, restrictions are typically placed on use of outer beam data; which limits the amount of single pass coverage in multibeam surveys.

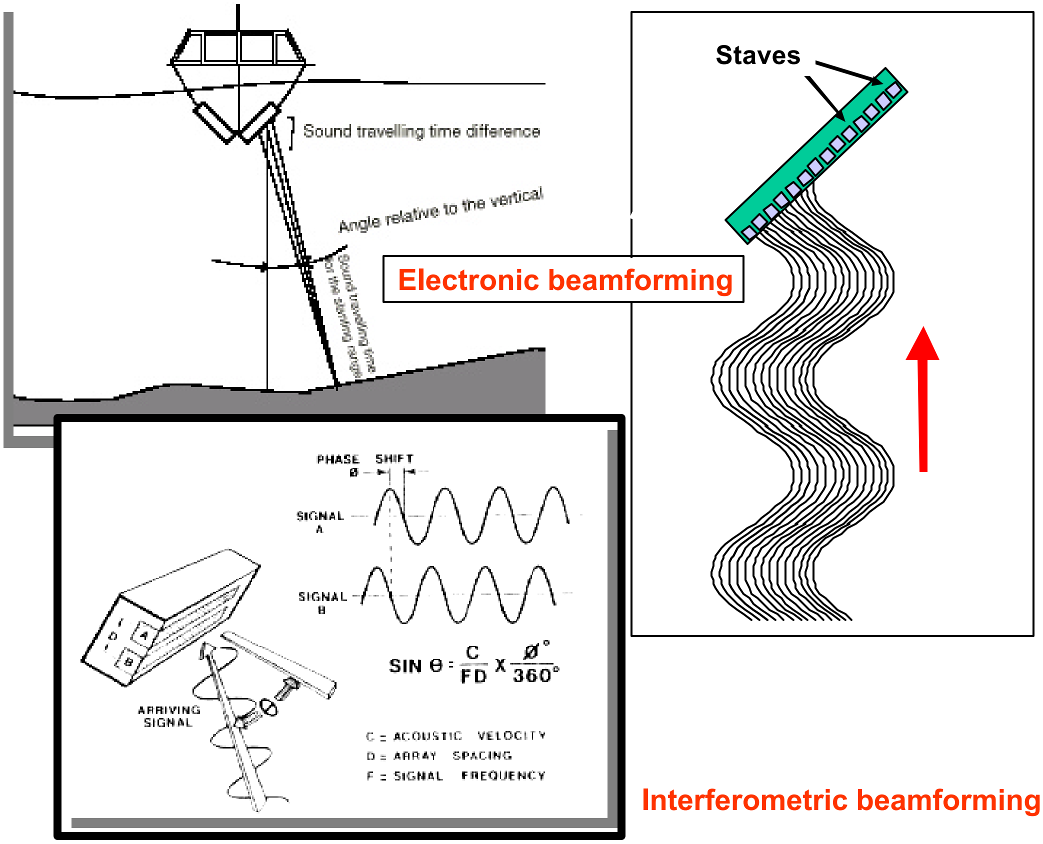


Figure 11-4. Beam forming methods in multibeam systems (Odom Hydrographic Systems and University of New Brunswick)

f. Beamforming methods. The following methods are used by various multibeam systems to determine slope distances and resultant depth from different directions in a beam array:

(1) Electronic beamforming. Electronic beamforming is generally based on electronic filter techniques to differentiate between individual echo contributions from different directions. Basically, each beam is formed by filtering out unwanted components. Depth is resolved based on center-of-energy or phase estimates. Electronic beamforming multibeam systems estimate the slant range to each echo event point based on the strength of the signal relative to a threshold. Electronic beamforming provides a stable and robust range and bearing estimate for each individual channel, primarily in the inner beams. A disadvantage is that the resolution is limited by the geometric properties of the transducer array and the multiplexing rate of the electronics. Also, the transducer design dictates the resolution of the system. Because it would be impossible for the electronics box to contain a separate bank of filters for each channel, the electronics must be time-shared. Therefore, a multiplexer is required and it must sample each channel individually. All other channels are ignored during this sampling time. This results in a spatially truncated profile or "blocky" data set. All electronic beamformers also incur some degree of overlap between adjacent beams and inherent side lobe interference. Due to the mechanical design of an electronic beamforming transducer, it is almost impossible to avoid beam overlap at some point. Side lobe interference--something inherent in all electronic beamformers--causes unwanted returns that cannot always be removed in the filters. Side lobe interference also causes problems in the bottom detection process (especially where sharp bottom features are present) and false targets may be generated in the side

scan imagery. Electronic beamforming can be applied to either the transmit or receive cycles. To steer a beam downward, multiple staves (elements) are sequenced with a slight delay--see Figure 11-4. Each stave fires in sequence. The sum of the signals from each stave would then produce a wavelet in the desired direction. To steer a beam normal to the face (straight out), all staves would fire at the same time. In the case of a transmit beam formed system, each beam must be formed one at a time. The process of transmit beam steerage is slow since each beam must be formed in sequence. A better solution (and the one used by all current electronic beamforming multibeams) is to apply this "phasing" principle to the receive signals. A fanbeam is projected across the swath and the received signals are processed (usually one iteration for each beam). Filters must be used to remove unwanted components from adjacent channels.

(2) Physical beamforming. The physically beamformed echo sounders use a common fanbeam projector and an array of polymer receive elements physically pointed in the desired direction. Depth is determined based on the amplitude of the return signal (the center-of-energy detection method). Beam parameters are determined by the physical shape of polymer receive elements. Odom Hydrographic System's ECHOSCAN uses a piezoelectric non-ceramic material, known as PVDF, that can be physically cut and shaped to produce the desired beam pattern that provides high sensitivity to weak signals, eliminates side lobe interference, and forms elliptical (pencil beam) patterns. Because it is not a "wide swath" multibeam, the ECHOSCAN can effectively apply the center-of-energy method of bottom detection and is not as prone to "ray bending". To offset the limited swath of 90 deg, the motion sensor is contained inside the transducer housing to allow tilting of the transducer to look up at structures or out to water's edge. The hydrodynamic shape to the transducer also allows for faster survey speeds. Also co-located are the side scan elements (traditional high-resolution, analog receive elements) to receive imagery simultaneously derived from the common 200 kHz projector. Advantages of physical beamforming include (1) very high signal-to-noise ratio, (2) negligable side lobe interference, (3) low percentage of "bad" data points, and (4) less expense. The only limitation to the physical beamforming approach is the compromise between swath width and transducer size.

(3) Interferometry (Phased Array). Beam direction is determined by measuring differences in signal arrival times on an array of receive elements (phase differentiation). Interferometers provide range and bearing estimates to bottom depth points by detecting propagation delays from individual bottom spots to different transducer subsections. The bottom spot direction is determined by differencing the acoustic arrival times (i.e., phasing). In Figure 11-4 the same signal arrives at element A slightly later than it does at B. This is interpreted by the electronics as a phase difference in the signal. The phase difference is then converted to an angle or receive vector relative to perpendicular (boresight). Interferometry differs from the standard beam former in that the beams are created by a signal processor from data stored in the receive buffer. In interferometric systems, discrete beams are not physically formed--phase information from all directions are received and processed simultaneously. The term "beam" actually does not apply here in a physical sense. Consolidation into beams is more of a mathematical operation executed after the data is received and buffered. Interferometric techniques can provide extremely high resolutions and a large number of beams. There are distinct advantages to an interferometric multibeam system that cannot be achieved by other methods. Outer beam detection is more robust and stable and tends to be less noisy than in electronic beamforming methods. The beam angles are easily steered to compensate for vessel motion and can be adjusted to provide "equal footprint" ensonification to compensate for beam spreading. Depth resolution is limited only by the processing power of the electronics. The disadvantages of a purely interferometric multibeam echo sounder include: (1) phase tracking circuitry can become unstable and cause high data variations, and (2) resolution depends on the internal detection rate (i.e., sophistication of the processing system).

(4) Combined electronic beamforming and interferometric (phased array) method. The FANSWEEP Models 15 and 20 use a combination of electronic and interferometric techniques to process

multibeam data. This provides equal footprint spacing across the full array rather than variable footprint size from fixed beam width arrays. (See Figure 11-5). To accomplish this, the beam spacing angle must be variable from 1.5 deg at nadir to 0.12 deg on the outermost beams. The processing system must have full control of the beam spacing and direction--in real-time.

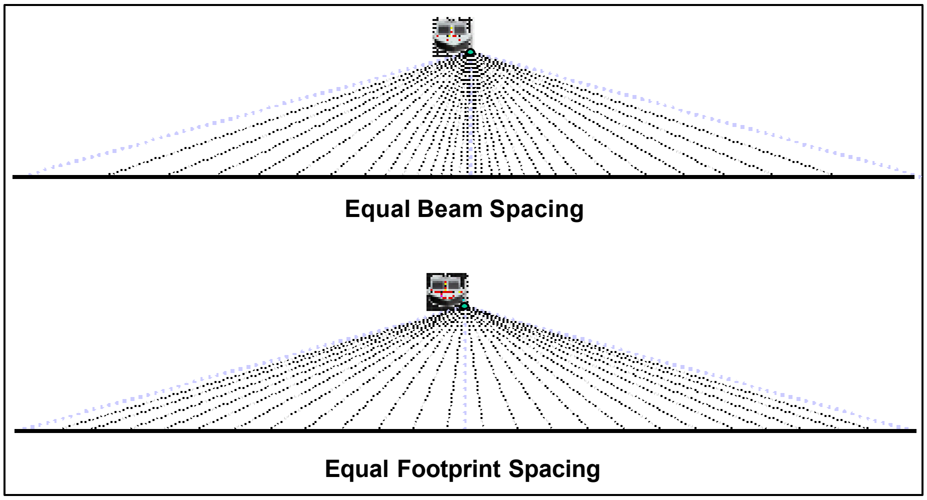


Figure 11-5. Equal footprint spacing using electronic and interferometric beamforming (Odom Hydrographic Systems)

Figure 11-6 depicts the design and configuration of the FANSWEEP 15/20 multibeam system mounted over-the-side on the 27 foot survey vessel. In this combined system, electronic beamforming techniques form four (4) transmit beams and each transmit beam is at a slightly different frequency with the lower frequencies in the two outermost patterns to compensate for the longer ray paths. It configures 26 rows of elements into two groups for transmit beamforming, then into 10 groups for interferometric reception. The combination also allows for highly focused beams in the along-track direction. Individual beams in the across-plane follow an adaptive scheme which also allows for equal footprint ensonification over terrain that is not flat. All received raw echo samples are stored into an internal amplitude/phase memory. No beams are involved during the receive portion of the cycle; instead, all of the information is buffered simultaneously as it is received. This includes both phase and amplitude information. Independent, simultanous software processes emulate both the classical beamformer and the interferometer algorithms providing two independent depth estimates which are then resolved into 4096 bathymetry and side scan points across the swath. Based on the initial amplitude and phase estimates, a secondary correlation filter re-iterates the buffer to consolidate the points into groups of three or more (total of 1,440 at 12 times water depth). Data are grouped into the desired number of beams (bottom points). The number of beams (up to 1440) and the swath width (up to 12 times the water depth), and coverage restrictions to a small sector (port or starboard), are all operator selectable.

A Combined Electronic Beamforming and Interferometric (Phased) Multibeam

- Square transducer array arranged in a "V"-shape aligned symmetrical to the ship's centerline
- Combined transmit/receive arrays including all necessary hydroacoustically active elements for transmission beamforming
- Each array consists of 26 rows of individual elements grouped into 2 sections for transmission and 10 sections for reception
- Each section provides identical, highly focussed beams in the for/aft direction
- Individual beams in the across plane follow an adaptive scheme

Over-The-Side Mount
M/V ECHOTRAC
(27-ft vessel)

Figure 11-6. FANSWEEP 20 combined electronic beamforming and interferometric multibeam (Odom Hydrographic Systems)

g. Other corrections. The half round-trip travel time, i.e. each beam's slant range, is traced from the earth-fixed launch angle through the refracting water column, yielding the corrected along track, cross track, and depth relative to the sonar head. The along track and cross track distance for each beam are rotated with vessel attitude (roll, pitch, and heading) into geographical coordinates using offsets of the GPS navigation center and the sonar head.

h. Multibeam sidescan imagery. Multibeam imagery is generally not as good as towed side scan imagery. The high aspect of a hull mounted transducer results in high grazing angles. High grazing angles result in small shadows. The amplitude imagery (one of the sonar's data "triplets") is of limited hydrographic value. Each pixel represents the amplitude intensity of just one beam. The larger the beam footprint, the coarser the amplitude imagery. Each pixel is colored, or shaded, according to the beam's intensity. Off-nadir beam amplitude imagery degrades quickly because of the poor intensity of the returned acoustic energy and is subject to "false target generation" in side lobe interference situations. Amplitude imagery is also called "backscatter intensity" and could be exploited for bottom classification. Angle independent imagery, or time series imagery, provides an image very similar to towed, low resolution, side scan sonar. The resolution is much higher and the data rates are much higher. Multibeam data acquisition that includes the angle independent imagery results in very large data files.

11-4. USACE Multibeam Policies, Procedures, and Applications

Multibeam systems are primarily deployed on deep-draft navigation projects where full-bottom coverage is required. Survey lines are run longitudinal with the channel alignment. The coverage of each swath is dependent on the depth and beam width. A typical 40-x 400-ft project can be covered with 3 to 5 lines, depending on beam angle. Vessel speeds are typically slow in order to ensure multiple hits on potential hazards or shoals, or when collecting side scan imagery. At an update rate of 30 profiles/sec, some 2,000 to 3,000 depths/elevations per second are generated; resulting in a large database for the subsequent processing and other engineering applications. The tradeoffs to wide-swath, high-density data are increased editing and post processing time and the requirement for more sophisticated computer hardware.

a. Dredging measurement and payment surveys. Multibeam swath survey systems that provide complete bottom coverage are recommended for use in dredging measurement and payment surveys, i.e., plans and specifications surveys, pre-dredge surveys, post-dredge surveys, and final acceptance/clearance surveys. Multibeam systems are an effective quality control process on dredging projects requiring 100% bottom coverage to assess and certify project clearance. The full digital terrain model (DTM) generated from a multibeam survey provides a more accurate and equitable (to the government and contractor) payment quantity than that obtained from traditional single-beam cross-sections. Use of multibeam systems on dredging measurement, payment, and clearance work requires far more extensive quality control and assurance calibration and attention to bottom type with respect to frequency as this may impact significantly upon volume computations. Multibeam systems are not recommended for payment or clearance use on shallow-draft projects.

b. Project condition surveys and coastal engineering surveys. Multibeam survey systems may optionally be used for project condition surveys of channels, revetments, and other underwater structures where complete bottom coverage is desired to delineate the feature or structure. Multibeam sensors can be configured to detail pipelines, bulkheads, floodwalls, lock walls, revetments, breakwater riprap, and other similar underwater structures. Systems can be configured (or the transducer rotated) to provide up to 190-deg coverage, which would provide "water's-edge to waters-edge" coverage to both port and starboard. In some narrow projects, a single swath pass may provide full coverage.

c. Shoal or strike detection. Multibeam survey systems represent an effective mechanism for detection of shoals, rocks, wrecks, debris, or other navigation hazards lying above grade in a navigation channel. The side-looking aspects of both the multibeam signal and the digital backscatter sonar imagery signal may be used for such investigation purposes. In order to enhance the probability of detection, and depending on documented system performance characteristics, 200% bottom coverage may be specified in order to ensure objects are ensonified from two aspects--and to confirm at least three multiple hits on these objects. Performance demonstration tests on simulated objects should be periodically performed to assure data detection quality and assess the need for overlapping coverage.

d. Emergency operations. Multibeam systems recording both topographic data and digital side scan imagery are recommended for locating underwater objects and marking objects for clearing after natural disasters.

e. Other channel sweeping methods. Multiple-transducer, boom-mounted, channel sweep systems are generally preferred for use over multibeam survey systems in shallow-draft (<15 to 20 feet), sand/silt-bottomed navigation channels. Multi-transducer systems will also provide 100% bottom coverage on navigation channels, as will mechanical, or manual, channel sweeping techniques, and towed side scan sonar devices. Mechanical bar sweeps remain an effective dredging quality control technique when rock is encountered.

f. Volume computations. Measurement and payment surveys performed using either multibeam or multiple transducer boom systems should compute pay quantities using the densely populated digital terrain models (DTM) generated by swath survey data. Data sets should be thinned only when multiple or duplicate points within a specified bin size exist; the representative depth selected within a fixed bin should not be biased or overly smoothed. The bin (or DEM post) size should generally not exceed either the estimated positional accuracy or the acoustic beam footprint size. The algorithms used for data thinning routines must be thoroughly tested to verify that thinned and/or binned volume quantities do not differ from raw data set quantities. In effect, data thinning should be kept to an absolute minimum. Actual dredged quantities should be computed from the binned DEM relative to the applicable payment template using standard CADD software routines. (For sparse data sets, such as traditional single-beam cross-section surveys, dredged volumes may be computed using traditional average end area routines or from triangulated irregular network (TIN) models).

g. Dredging contract specifications. Measurement and payment provisions in dredging contract specifications should clearly stipulate the type of survey system, acoustic frequency, navigation guidance system and software, data acquisition parameters (horizontal and vertical control, density, etc.), data processing and binning techniques, and mathematical volume computational method/software that will be employed by the government. In order to ensure consistency when performing measurement and payment surveys, commercially available software should be employed for data collection, data processing, data quality control, and volume computations.

h. Training requirements. Multibeam system operators require considerable expertise in both surveying and on CADD workstations. Prior to using multibeam systems on USACE surveys, system operators should have completed specialized training. Presently, the Corps PROSPECT course on Hydrographic Surveying Techniques is not considered sufficient for multibeam training. Comprehensive training courses are available from: (1) the University of New Brunswick, (2) Coastal Oceanographics, Inc., (3) Triton Elics International, (4) Odom Hydrographic Systems, Inc., (5) University of New Hampshire-NOAA Joint Hydrographic Center, or (6) The Hydrographic Society of America seminars. Multibeam manufacturers may also offer specialized training sessions. In addition, the operator should have completed a manufacturer or Corps PROSPECT course associated with the differential GPS system, inertial compensating system, and CADD processing/editing system employed. For contracted multibeam survey services, the Architect-Engineer (A-E) contract solicitations should require that proposals identify the experience and training of system operators in Block 7 of the SF 255.

i. Plant utilization and justification. Multibeam surveys may be obtained using hired-labor forces or through A-E service contracts. Commands considering procurement of multibeam systems should internally determine that such a system represents an effective and efficient utilization of floating plant, given the $200 K to $500 K investment for a complete system. Some factors that should be evaluated include: (1) proposed multibeam vessel, (2) system configuration (hardware and software), (3) estimated annual utilization (time and location), (4) FTE allocations, (4) system operator qualifications, (5) field data processing, editing, and plotting, and turnaround capabilities, (6) estimated daily plant and survey crew rental rate, and (7) comparative analyses between hired-labor and contract costs.

j. Calibration and quality control. Field calibration of multibeam acoustic refractions and vessel motion is significantly more critical and complicated than that required for standard single beam systems. Recommended calibration requirements, procedures, and allowable tolerances are described in later sections of this chapter. Accuracy performance tests are essential in order to demonstrate data quality. These quality control calibrations and quality assurance performance tests must be processed and adjusted on board the survey vessel prior to and during the survey--after-the-fact checks in the district office are of little value. This implies that near real-time field-finish data collection, processing, and editing must be established in the field in order to ensure the most cost-effective utilization of this technology.

k. Multibeam installation on Corps floating plant. Multibeam systems are mounted on a variety of vessels, ranging from 22-ft up to 65-ft vessels. Multibeam systems are normally more cost-effectively utilized on small, mobile (trailerable) survey vessels up to 26 feet in length, with the transducer assembly externally mounted over the side (bow, port, or starboard). This allows the system to be rapidly deployed on remote projects. Permanent placement on large, non-trailerable, 30- to 65-ft survey vessels is generally recommended in areas where such a vessel is permanently deployed on a major navigation project. Following are examples of multibeam installations aboard a 65-ft and 23-ft vessel, taken from representative Corps districts.

(1) 65-Foot Survey Vessel Adams II, Norfolk District. In 1998, the Norfolk District installed a RESON "HydroBat 200 Multi-beam Sonar Integrated Hydrographic Survey System" (SeaBat 8101 with Option 037) on their 65-ft survey boat. Option 037 is the titanium sonar head in lieu of the standard aluminum sonar head. Figure 11-7 shows the location of the transducer. The SeaBat 6042 data acquisition system is interfaced with an Ashtech Z-12 DGPS positioning system, a gyro heading sensor (Anschütz –Standard 20), motion sensor (TSS–DMS–05), and the SeaBat 8101 sonar processor. Project defined real-time navigation capability is provided by HYPACK software. Calibration, playback, editing, and binning are handled with HYPACK/HYSWEEP software. Additionally, velocity profile information is collected with an AML (SV-Plus) velocity profiler and manually input in HYPACK file format.

Figure 11-7. RESON SeaBat 8101 installation on Survey Vessel Adams II (Norfolk District)

(2) 23-Foot Survey Boat, Buffalo District. In 1998, the Buffalo District installed a multibeam sonar system for use on its navigation projects on Lake Ontario and Lake Erie. Following is a brief description from Buffalo District reports as to why a multibeam system was purchased, the equipment installed, and the rationale behind the installation particulars.

(a) The Buffalo District decided that a multibeam was needed for several reasons. The first of which was to provide for better surveys of the District's channels. The multibeam would provide 100% coverage of the channel resulting in a more accurate description of the bottom of the project. For dredging purposes, a more complete volume computation could be obtained using a full-model method of computation--i.e., TIN--rather than the approximate "average end area" method. The multibeam system will provide information between the normal cross-sections--a TIN volume computation method takes into account the whole area; thus providing a better 'picture' of what the channel looks like. The second reason the District needed a multibeam system was to survey the various breakwaters within the Buffalo District to check for needed repairs. The multibeam would be able to show areas where the stone was falling away and needed to be replaced.

(b) The components of the multibeam system installed were 1) Reson SeaBat 8101 with 210 deg array coverage and with sonar display, 2) TSS POS/MV Model 320 motion sensor, and 3) Triton-Elics Isis computer and data logging software. Also on the Triton-Elics computer is HYPACK software used for navigation purposes. The TSS POS/MV was chosen because is provides the motion data [heave, pitch, roll], heading, and position all in one processor, with a small inertial block, making it easier to install on a small boat. An Innerspace Model 449 dual-frequency (vertical beam) depth sounder was already being used and would be part of the new system for quality control purposes. In addition, an Innerspace velocity profiler that was already being used within the Buffalo District was also part of the installation. A major concern is how to get the data from the boat to the office. Since the office personnel already had computers with PCMCIA slots, it was decided that the data would be put on a PCMCIA card and sent to the office. Since the computers in the District Office have a Windows NT operating system, software from SystemSoft (called 'Card Wizard'), a "hot swap" of PCMCIA cards is possible without shutting down the computer.

(c) The Buffalo District installed the system on a 23-foot SeaArk launch. This meant space was limited within the cabin and weight distribution was a major concern. As with most smaller survey vessels, the launch operator sits on the starboard side and the equipment operator sits on the port side of the boat, at the back of the cabin. Without changing that balance, the processors for all new and existing equipment would be rack-mounted on the starboard side, behind the launch operator. This will allow the equipment operator to have them within easy reach. The only equipment in front of the operator are two monitors, one for the computer doing the data recording and a second monitor for the operator to see what the launch operator sees. This is achieved with a video splitter. Because the computer doing the data recording has a virtual screen, this allows the navigation display to be sent to a flat panel screen for the launch operator, negating the need for a second computer for navigation. Next choice was where to install the sonar head. Since the multibeam has coverage of 210 degrees, if the sonar head were mounted through the hull, it would have to be mounted deep enough for the outer beams to get past the outer edges of the hull. This was not practical since the boat is transported by trailer. The other option, which was eventually chosen, was to mount it over the side. It was mounted on the port side to aid in proper weight distribution. It is attached to a pipe that can be rotated to bring the sonar out of the water for putting the boat on a trailer. The next decision was how deep to have the sonar in the water. Because of the typical hazards that are in the Buffalo District, i.e., submerged pilings, and allowing for the ability to survey in rougher sea conditions, it was mounted deep enough to ensure that the sonar head was shallow enough to remain out of danger of obstacles and deep enough to remain in the water during rough seas (heave, pitch and roll). The effect of this is that the sonar head is in the water deep enough to get only approximately

95 degrees from nadir on the starboard side, not the full 105 degrees. This only presents a problem for doing the above-mentioned breakwater surveys. To get the best coverage, the boat will always survey with the port side of the boat towards the breakwater.

(3) 45-Foot Survey Launch Vollert, Galveston District. Figure 11-8 depicts the installation of an Odom multibeam system aboard the Vollert. The Vollert is a 45-foot length vessel with twin diesels, a 12-foot beam, and 3-foot draft. This vessel is normally used to conduct extensive hydrographic surveys in the Houston, Galveston, Texas City, and Freeport areas. The multibeam transducer shown is side-mounted on temporary rigs near the mid section of the vessel.

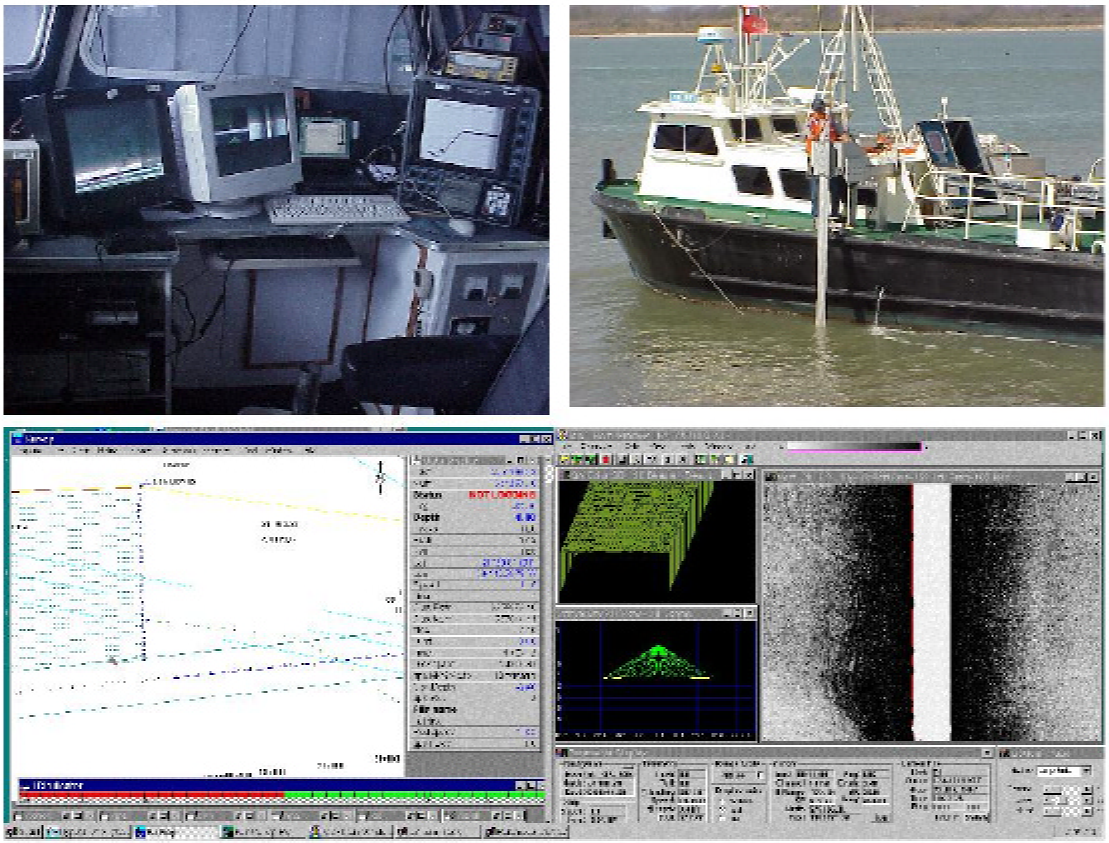


Figure 11-8. Surveyboat Vollert Odom Multibeam installation and typical real-time display (Galveston District)

l. Data collection hardware/software. Navigation, data collection, and data processing software employed with multibeam systems should have real-time guidance, display, and quality assurance assessment capabilities. The software should also be capable of applying all calibrations and corrections in the field such that data can be collected, edited, and processed in near real-time in order to support dredging contract administration. Software should also be capable of performing near real-time statistical quality assurance assessments between comparative accuracy performance test models. Strike detection systems may require more high-end PC-based or CADD workstations in order to adequately display and replay 3D imagery in real-time. CADD data thinning or binning routines should be rigorously tested to ensure data integrity is not adversely modified. This may be accomplished by comparing quantities between raw and thinned data sets. Figure 11-9 shows the instrumentation and equipment requirements for a typical multibeam system.

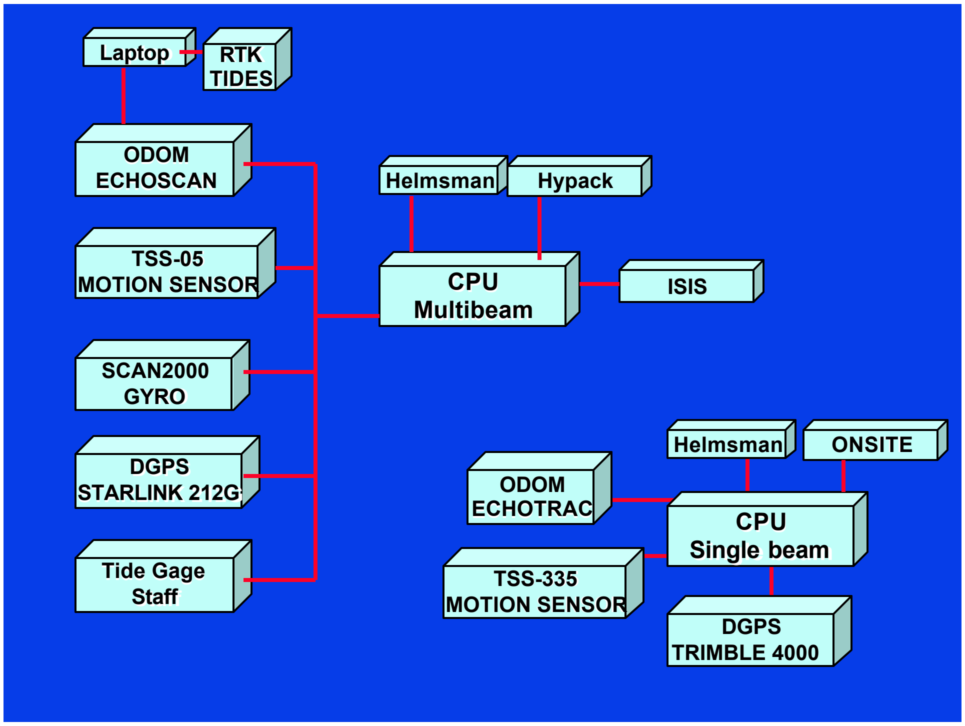


Figure 11-9. Multibeam system configuration (Surveyboat Vollert, Galveston District)

A number of multibeam data acquisition software packages are used by Corps districts. The more common packages include HYPACK/HYSWEEP MAX (Coastal Oceanographics), Bathy Pro Real Time (Triton Elics), and 6042 Version 7 (Reson, Inc.). Data acquisition packages must support all navigation peripheral devices, such as those shown in Figure 11-9. They must also provide the QC and QA calibration and testing requirements indicated in Table 11-2 at the end of this chapter. Other software packages (e.g., Caris) are tailored to post-processing of multibeam data. Both data acquisition and processing packages must be capable of editing and processing data to meet engineering and construction purposes, as opposed to nautical charting functions. If the software packages do not meet these criteria, then multibeam data may have to be processed using standard engineering CADD packages such as AutoCAD or MicroStation.

m. Vessel positioning requirements. In general, code-phase, meter-level US Coast Guard differential GPS radio beacons will provide sufficient accuracy for most project surveying applications. It also ensures Corps projects are referenced relative to the National Spatial Reference System (NSRS). Where required, translations from NAD 83 to NAD 27 should be performed real-time by the hydrographic data acquisition software. In offshore coastal areas where traditional tidal modeling is deficient, carrier-phase kinematic DGPS (i.e., RTK) may be needed to enhance vertical accuracy of measured depths. When the multibeam is deployed horizontally to map underwater structures, RTK carrier-phase DGPS may be needed to maintain decimeter-level horizontal accuracy.

11-5. Quality Control and Quality Assurance Procedures for Multibeam Systems

a. General. The following sections in this chapter provide recommended technical guidance for performing system alignments, quality control calibrations, and quality assurance tests of multibeam sonar systems used on Corps dredging and navigation projects.

b. Background. Field alignment and calibration requirements for multibeam systems are similar to those required for single beam systems described in Chapter 9. However, some calibration and quality control procedures for multibeam systems are more critical and demanding than those required for single beam echo sounders. Periodic, precise calibration and verification testing is absolutely essential in order to assure multibeam derived elevations meet the prescribed accuracy tolerances for the project--especially near the outer beams of the array where refractive ray bending and vessel alignment and motion variations can significantly degrade the data quality. With improved resolution and increased beam coverage, there is a greater need for accurate sensors to ensure that the recorded sounding is reduced to its correct position on the sea floor. This is accomplished by interfacing the multibeam system with position and attitude sensors, such as: (1) a high accuracy differential GPS system (including heading and attitude RTK systems), (2) inertial motion reference units (MRU) to monitor changes in position, velocity, acceleration, heave, pitch, and roll, and/or (3) a gyrocompass. In addition, the time synchronization for all these components is critical. For this reason, the system accuracy is comprised not only of the multibeam sonar accuracy but also the various components that make up the total system.

(1) The various components that make up a multibeam system must be periodically aligned, calibrated, tested, and monitored in order to ensure overall data quality. Quality control calibration tests are performed to measure alignment and timing biases in the transducer head, inertial measurement unit, gyrocompass, GPS antenna, etc. These calibrations attempt to minimize errors due to time latencies, roll, heave, pitch, and heading for the integrated suite of equipment.

(2) Quality assurance performance tests are periodically performed to compare independently surveyed multibeam swaths and/or single beam runs made over the same area. A performance test will provide a statistical estimate of the data accuracy (or "repeatability" if the comparative surveys are not truly independent). The test results should be checked against the prescribed statistical accuracy criteria in Table 3-1.

c. QC and QA requirements. Procedures for performing these calibration and quality assurance tests are outlined in the following sections of this chapter and are more fully detailed in the manuals provided with the individual sensors making up a multibeam survey system. These include acoustic refraction measurements (i.e., velocity casts and bar checks), system latency calibrations (time variances between positioning, depth, and motion sensors), vessel motion and heading sensor calibration (roll, pitch, yaw, and heave sensors), and various other vessel alignment and coordinate/datum corrections. A summary of recommended measurement and calibration requirements is contained in Table 11-2 at the end of this chapter. Some of these calibration requirements are critical--failure to perform adequate calibration may render a survey invalid. Since many of the alignment and offset parameters are interrelated, failures at one level of test may require recalibration and/or retesting prior levels. Some calibrations are performed during initial equipment installation on the vessel; however, others must be performed on a more frequent basis--especially when dredging measurement and payment surveys are involved. It should be strongly emphasized that the software and procedures for calibrating, processing, editing, and thinning multibeam data are still being refined and will undergo modifications as new systems are acquired and performance is validated. Likewise, the overall accuracy and object detection performance capabilities of multibeam systems are still being assessed.

11-6. Initial Installation Alignment and Static Offset Measurements

Alignment and offset parameters must be measured for the various sensors making up the multibeam system, e.g., MRU and gyroscope alignment/offsets, transducer mounting angles/offsets, DGPS antenna offsets, static and dynamic drafts, vessel settlement/squat, and estimated latencies. These measurements are made upon initial installation or upon replacement, removal, and reinstallation of a sensor. Alignment and offset corrections are typically entered in the software system setup modules--e.g., HYPACK Device Setup.

a. Static offsets of the sensors. These are the distances between the various sensors and a designated reference point on the vessel. This entails physical measurement on the vessel platform--locating the relative X-Y-Z coordinates of the multibeam transducer, GPS antenna(s), gyrocompass, MRU sensor, POS/MV system, etc. These measurements should be performed with the vessel stabilized on a trailer or on blocks where more exact, stable measurements can be made. A total station and/or tape are used to obtain the measurements. The sensors should be measured from a reference point in the vessel. This point is typically the center of gravity or the intersection of the pitch and roll axis. The center of gravity will change with varying load conditions of the vessel and thus must be chosen to represent the typical conditions while surveying. On large stable vessels, the center of gravity will slightly change vertically along an axis that contains the center of buoyancy. On smaller vessels, the center of gravity and the center of buoyancy may not be exactly aligned due to eccentric loading. This condition is to be avoided as it also contributes to the instability of the vessel itself. This information can be obtained from the blueprints of the vessel. This reference point (now the coordinate system origin) should be a place which is easily accessible and from where measurements to the sensors will be made. The coordinate system should be aligned with the x-axis along the vessel keel, the y-axis abeam the keel, and the vertical (z-axis) positive up. The offsets of the sensors are measured from the reference point to the center of the sensor. The center of the sensor can be found in the manufacturer's schematic for the sensor, or can be accurately measured with a survey tape. It is common for the acoustic and physical centers to be in different places (e.g., Simrad EM 3000). The magnitude and direction of the measurement should be verified and recorded.

b. MRU Sensor. If possible, the inertial MRU sensor should be placed on the centerline of the vessel as close as possible to the center of gravity or the intersection of the roll and pitch axes of the vessel. (Some MRU devices allow heave high pass filtering at a remote location). If possible, use the same mount angles as used for the transducer. The x-axis of the MRU should match the x-axis of the transducer. Azimuthal misalignment of the MRU will result in the depth measurements being in error proportional to the water depth. Misalignment of the MRU sensor in yaw causes a roll error when pitching, and a pitch error while rolling. (If the transducer and MRU are collocated (e.g., Odom Echoscan), many alignment corrections become far less critical).

c. Multibeam transducer. The multibeam transducer should ideally be installed as near as possible to the centerline of the vessel and level about the roll axis. However, in practice, the transducer is usually offset from the keel by varying amounts, and may be forward or aft of the center of gravity (e.g., side mounts, bow mounts, twin hull mounts, etc.). The transducer should also be precisely aligned with the azimuth of the vessel. The depth of the transducer head below the waterline of the vessel must also be determined. As in single beam systems, standard bar checks are performed to measure static draft variations, which may include a constant index error that would not be detected if only a physical measurement were made. Likewise, squat/settlement tests are performed to calibrate dynamic vessel variations. Longer-term fuel loading variations must also be monitored.

(1) Most multibeam transducers used on smaller (e.g., less than 30 foot) USACE vessels are mounted over-the-side on a shaft and boom device. Most Corps 65-foot vessels have permanent hull-mounted transducers. Other larger vessels have retractable transducers. Some smaller survey vessels are outfitted with retractable bow-mounted transducers. With the over-the-side type of mount, it is imperative that the azimuthal alignment between the transducer and keel be as accurate as possible. This can be accomplished with the vessel on a trailer or blocks on land and using standard surveying and leveling techniques. Since this boom-mounted technique allows for raising the transducer at the end of each day of operations and lowering it at the start of the next day's survey, this type of mount should be periodically checked for correct alignment. The frequency with which it is checked will depend on what type of surveying is performed and under what conditions. Hull mounted transducers are generally fixed in place and will not need to be checked as frequently.

(2) The angle of the transducer mount must be determined and recorded, unless the MRU is collocated. Since most vessels underway will be lower in the stern, the transducer will generally need to be rotated aft to compensate for this angle. The patch test will also check for the transducer angle. The resulting beam should then project normal to the sea floor while conducting surveying operations.

d. *Gyroscope*. The electronic gyroscope should be aligned with the x-axis of the vessel using an electronic total station and geodetic control points. This can be done with the vessel on a trailer or secured tightly against a pier where there is minimal wave action. The gyro should be warmed up and, if necessary, the proper corrections for latitude applied. Locate two points on the centerline of the vessel and position a target on each of them. Observe the two targets with the total station and synchronize the readings with the gyro readings. Several readings will be needed for redundancy. Compute the vessel's azimuth and compare with the gyro readings. Compute the mean and standard deviation of the readings. If the offset is more than 1deg at the 95% confidence level, realign the gyro with the centerline and repeat the observations. If less than 1deg, apply the correction to the gyro output. This procedure can also be performed using three GPS receivers instead of the total station. The processing may take longer than with the total station.

e. *MRU sensor time delay*. Time delay in the attitude sensor will result in roll errors, which greatly affect reduced elevations at the outer beams. In addition, horizontal accelerations in cornering can also affect the MRU measurements, which will also result in errors in the depth measurements. Basically, the principle to detect roll errors is to observe, from the bathymetric data, short period changes in the across track slope of the sea floor when surveying flat and smooth areas. Coastal Oceanographics' HYPACK MAX and TEI's Isis/Bathy Pro programs can be used to check the time delay. HYPACK MAX will process the timing in post-time while the TEI Isis/Bathy Pro displays a real-time confidence check. The Canadian Hydrographic Service and University of New Brunswick have developed UNIX based software to assess time delay in multibeam data.

f. *Positioning time delay (Latency)*. Time delay in the positioning is the time lag between the time positioning data are received and the time the computed position reaches the logging module. This results in a negative along-track displacement of the depth measurements. While surveying at slow speeds, this displacement will be small. In general, the processing time for the position will vary with the number of observations used in the final GPS solution. If the time imbedded in the GPS message will be used, then you must ensure the correct synchronization between this time and the transducer or signal processing clock. A Patch Test (described below) is performed to determine a constant latency correction. If RTK DGPS positioning is employed, then the system should be checked for latency (or lack of a latency correction).

11-7. Vessel Squat/Settlement and Draft Variations

a. *Squat/Settlement measurement*. The combined squat and settlement of the vessel should be measured at several speeds and a look-up table produced for correcting the transducer draft. (Refer to procedures outlined in Chapter 9). This measurement is essential since a MRU will not measure the long-term change in elevation. A MRU heave sensor will record the sudden change in elevation but the measured heave will drift back to zero. The settlement can be measured with a transit on shore and a 2-meter level rod or stadia board on the vessel positioned over the MRU sensor (i.e., the point where the heave data are low pass filtered). The vessel should make several passes at various speeds in front of the shore station and the rod elevation recorded. The elevation difference at each speed is noted and used as the draft correction while surveying. Be sure the correct sign is applied when entering the correction in the software.

b. *Squat/Settlement measurement using RTK DGPS*. An alternate method for determining squat/settlement makes use of carrier-phase differential GPS elevation difference measurement.

(1) Position the DGPS antenna near the center of the vessel and measure the vertical and horizontal distance from the antenna to the vessel's reference point with steel tape.

(2) Use data from a nearby tide gauge to provide a datum from which to measure the elevation. The gauge should be in the survey area and if the area is large, two gauges should be used.

(3) Run the same survey line at different speeds. Also, run the line under different loading conditions.

(4) Record the GPS positions, heave, pitch, roll, vessel speed and water levels at common times. The sampling rate should be at the highest for GPS and MRU sensors (10 Hz and 100 Hz, respectively) while the water levels can be recorded at approximately 5-10 minute intervals.

(5) Record the antenna height while stationary.

(6) All data should be synchronized and interpolated if necessary.

(7) Use the GPS antenna offsets and attitude data to compute the roll and heave, and correct the antenna elevations. Subtract water level data and heave data from GPS antenna elevation.

(8) With these corrections for motion and water levels, compute the average speed in the water and the average antenna elevation with respect to the ellipsoid. Produce a look up table for the transducer draft correction.

c. *RTK DGPS squat/settlement determination*. If precise carrier phase GPS is being used as an absolute elevation reference for the multibeam transducer, then there is no requirement to enter in a squat/settlement correction. Likewise, tide/stage data and dynamic draft corrections may also be eliminated. However, if RTK DGPS is used only to determine the tide/stage level, then squat and draft measurements must be input to the processor.

d. *Short term draft measurements*. Changes in vessel draft due to fuel or loading changes should be monitored throughout the day, and depth corrections applied if trim variations are significant. These procedures are identical to those described for single beam surveys (Chapter 9). Heave corrections output from RTK and/or MRU systems must be monitored to ensure long-term sea swells or vessel turns do not bias the data.

11-8. Patch Test (Residual Bias Calibration)

Patch tests are periodically performed to quantify any residual biases in the initial alignment measurements described previously. This test (actually a series of reciprocal lines run at varying speeds, depths, and bottom terrain--see Figure 11-10) must be performed carefully to ensure that subsequent survey data collected is accurate and reliable. The Patch test determines (and provides correctors for) the following residual biases:

- pitch offset
- roll offset
- positioning time delay (latency)
- azimuthal (yaw) offset

The determined offsets and delays will be used to correct the initial misalignments and calibrate the system. Each of these bias tests is described below.

a. Data acquisition. Survey quality code or (preferably) carrier phase DGPS positioning must be used when conducting the Patch tests--especially in shallow draft projects. The weather should be calm to ensure good bottom detection and minimal vessel motions. Since most of the lines to be run will be reciprocal lines, it is important to have capable vessel steering and handling. The lines should be run in water depths comparable to the typical project depths encountered. The order the lines are run is not important although it is recommended that at least two (2) sets of reciprocal lines be run for redundancy. In practice, multiple runs should be made to average (and assess the long-term repeatability) of the computed bias parameters. Although the outer beams of multibeam sonar are subject to a smaller grazing angle, these beams should provide good data provided the appropriate corrections are applied from the patch test. Vessel speed should be regulated such that 50% forward overlap is obtained. The maximum speed may be calculated by the following equation:

$$v = S \cdot d \cdot \tan (b/2) \qquad \text{(Eq 11-1)}$$

where:

v = maximum velocity (m/s)
S = sounder sampling rate per second (1/t)
d = depth
b = fore-and-aft beam width angle

b. Positioning time delay test and pitch bias test. Two pairs of reciprocal lines are run at different speeds to check for biases in both positioning time delay (latency) and pitch bias. Latency is determined from runs made over the same line in the same direction, but at differing speeds. (Both these biases may exist simultaneously and must be discerned and separated during the test data processing). These lines should be run in an area with a smooth, steep slope--10° to 20°, if possible. The slope should ideally be at least 200 m long in order to obtain good samples. A channel side slope may have to suffice if no other relief is available. At least two pairs of reciprocal lines should be run both up and down slope, at velocities differing by at least 5 knots to best assess the time delay. The greater the difference in velocity, the more accurate the test. Pitch is determined from the runs made over the same lines at the same speed in opposite directions.

c. Roll bias test. In an area of flat topography, run at least one pair of reciprocal lines approximately 200 m in length to test for roll biases. Roll bias will best show up in deep water. Depending on the type of multibeam system, these lines should be run at a speed to ensure significant forward overlap of the beam's footprint. The beam width can be found in the manufacturer's specifications.

d. Azimuthal (Yaw) offset test. At least two adjacent parallel pairs of reciprocal lines shall be run normal to a prominent bathymetric feature such as a shoal or channel side slope, in shallow water. Do not use a feature with sharp edges such as wrecks since there is more ambiguity in the interpretation. The adjacent lines have an overlap of about 15% and the feature should be wide enough to ensure adequate sampling. This width is generally greater than three swath widths. These lines should be run at a speed to ensure significant overlap of the beam forward footprint--use the same equation as that for roll bias.

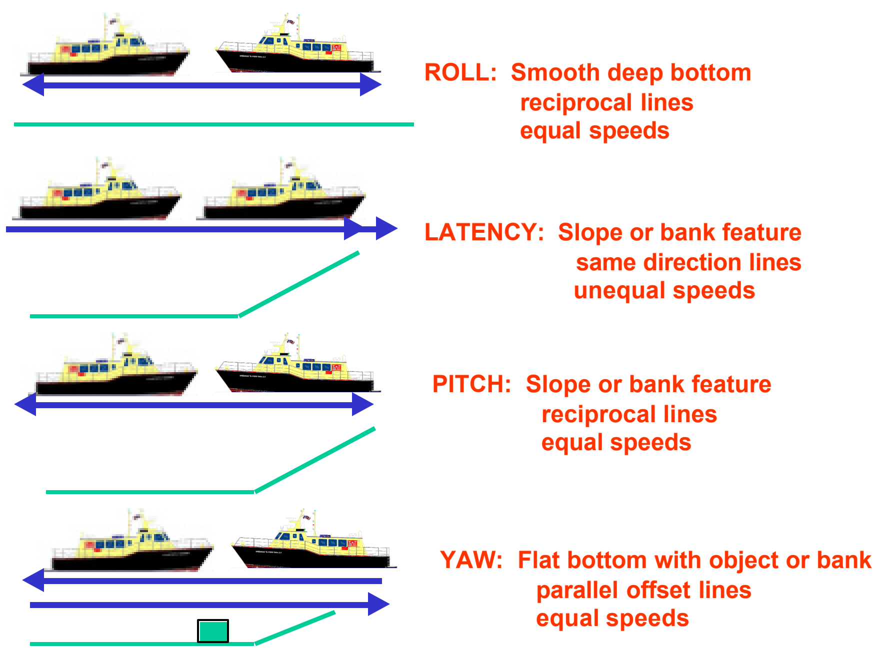


Figure 11-10. Summary of patch test runs

e. Patch Test Data Processing and Adjustment. Commercial patch test routines automatically calculate system latencies, roll, pitch, and yaw biases in multibeam data. The adjustment procedure outlined below uses the entire data set collected from the patch test lines without thinning (i.e., gridding or binning). Visualization of the bathymetric data is important. In addition, the position and attitude data should be checked for errors, especially noting the time-tag errors. Cleaning of the bathymetry is not necessary since individual soundings will not be adjusted but rather clusters of data points will be analyzed. The procedures to process the patch test data should follow the sequence recommended below. Note that this differs from the sequence recommended by Coastal Oceanographics: roll-latency-pitch-yaw. Since a single run Patch Test may contain internal inaccuracies due to positioning, inadequate depth, poor feature recognition, etc, it is recommended that the test be performed over different conditions and times in order to arrive at an average, longer term, correction. Future software packages are expected to fully automate the sequential process described below, using imagery enhancing and model fitting technology. Such a process would be far more accurate than the current sequential process.

(1) Positioning time delay (latency) bias. This delay is computed by measuring the along-track displacement of soundings from the pair of coincident lines run at different speeds over the steep slope or other prominent topographic feature. Lines run in the same direction should be used to avoid the effect of pitch offset errors. The equation to compute time delay is:

$$TD = d_a / (v_h - v_l) \qquad \text{(Eq 11-2)}$$

where:

- TD = time delay in seconds
- d_a = along-track displacement (ft)
- v_h = higher vessel speed (ft/sec)
- v_l = lower vessel speed (ft/sec)

The survey lines are processed, plotted, and compared while assuring that no corrections are made for positioning time delay, pitch error, roll error, and gyro. The time delay is then averaged by getting several measurements of the displacement in the along-track direction. This process is performed iteratively until the profiles and contours match or achieve a minimum difference.

(2) Pitch offset bias. The pitch offset bias is determined from the two pairs of reciprocal lines run over a slope at two different speeds. The important characteristic of pitch offset is that the along-track displacement caused by pitch offset is proportional to water depth. Thus, the deeper the water the larger the offset. The pitch offset (in degrees) can be computed using the following equation:

$$a = tan^{-1} [(d_a / 2) / (depth)]$$

where:

- a = pitch offset (bias angle)
- d_a = along-track displacement
- $depth$ = water depth

The lines are processed while only applying the positioning time delay correction and the static offsets of the sensors. The pitch offset is then averaged by taking several measurements of the displacement in the along-track direction. This process is performed iteratively until the profiles and contours match or reach a minimum difference. It should be noted that unless kinematic GPS (i.e., RTK DGPS) positioning is employed, determining d_a to a reasonable level of accuracy is difficult in shallow water.

(3) Azimuthal (Yaw) offset bias. Parallel lines run normal to a bathymetric feature will be used for the measurement of the azimuthal offset. One pair of adjacent lines run in opposite directions is processed at a time to remove any potential roll offset. The azimuthal offset (in degrees) can be obtained from the following equation:

$$y = sin^{-1} [(d_a /2) / X_I] \qquad \text{(Eq 11-3)}$$

where:

- y = azimuthal offset (deg)
- d_a = along-track displacement (ft)
- X = relative across track distance for beam i (ft)

The survey lines are processed with only the positioning time delay, pitch offset corrections, and static sensor offsets. The azimuthal offset is averaged by several measurements of the displacement d_a over the feature and knowing the across-track distance *X* at the location of the measurements. This process is performed iteratively until the profiles and contours match or achieve a minimum difference.

(4) Roll offset bias. Roll bias is computed using the pairs of reciprocal lines run over a flat, deep area. Generally, this offset is the most critical in deeper water and should be carefully measured. For small angles of less than three (3) deg, the roll offset can be estimated by the following equation:

$$r = tan^{-1} [(d_z / d_a) / 2] \quad \text{(Eq 11-4)}$$

where:

r = roll offset (deg)
d_z = depth difference (ft)
d_a = across-track distance (ft)

The survey lines are processed while applying the positioning time delay, pitch offset, gyro offset corrections, and static sensor offsets. The roll offset is averaged by several measurements of the across track displacement d_a along the test swaths. This process is performed iteratively until the profiles and contours match or achieve a minimum difference.

Table 11-1. Summary of Patch Test Procedures and Computations

	Latency Delay	Pitch Offset	Azimuth/Yaw Offset	Roll Offset
LINES REQUIRED	Two (2) on same heading over slope or shoal; different speeds	Two (2) pairs on reciprocal headings at 2 speeds	Two (2) pairs over bathymetric feature at equal speed	Two reciprocal lines over flat area; equal speed
PRIOR CORRECTIONS APPLIED	None--other than static offsets	Positioning time delay	Position time delay and pitch	Position time delay, pitch, & gyro
COMPUTATION METHOD	Average of displacements in along track direction	Average of displacements in along track direction	Average of displace in across track direction	Average of displacements in across track direction
VISUAL METHOD	Match profiles and contours	Match profiles and contours	Match profiles and contours	Match profiles and contours

(5) Automated Patch Test. Figure 11-11 depicts screen displays of automated Patch Test bias computations. The results are input directly into the real-time processing system.

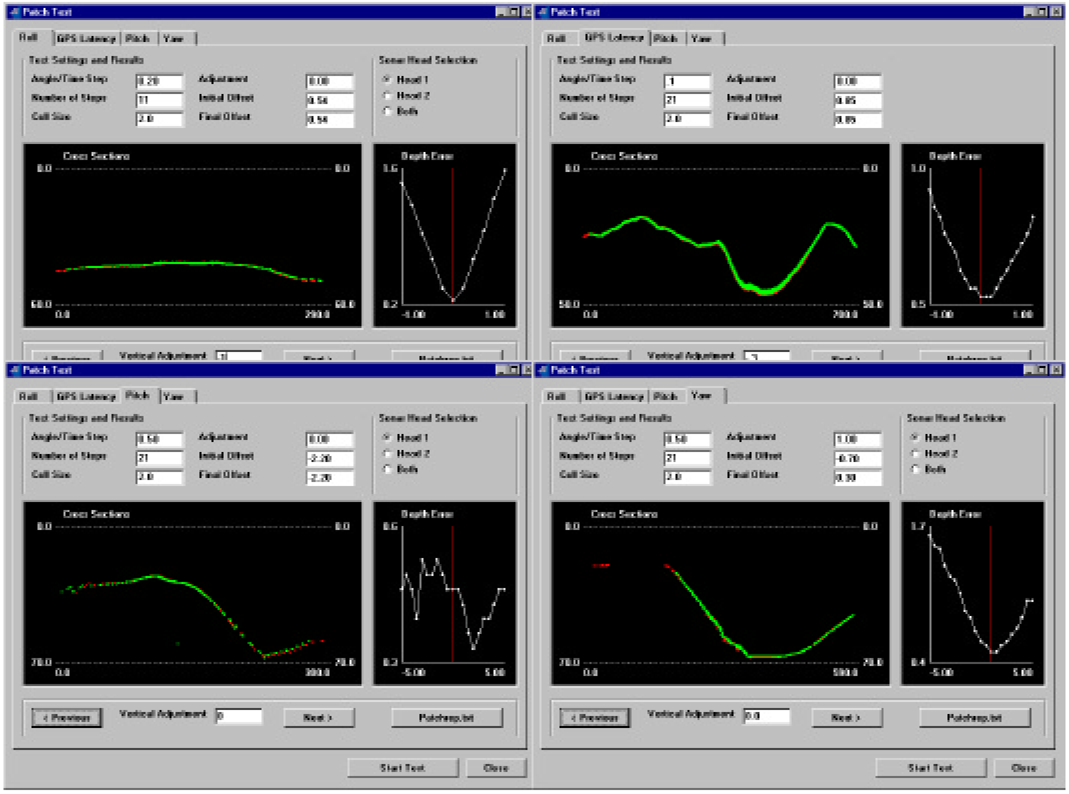


Figure 11-11. Automated Patch Test parameter computations--roll, latency, pitch, and yaw. (Coastal Oceanographics, Inc.)

11-9. Velocity Measurements

As in single beam systems, the velocity of sound in the water column must be accurately known so the correct depth can be measured. However, in multibeam systems, velocity measurements are more critical due to the effects of refraction ("ray bending") in the outer beams. Since sound velocity in the water column can vary spatially and temporally, improper or inadequate determination of sound velocity corrections can render multibeam data unusable. Velocity calibrations should be performed periodically during the day, and no less than twice per day, and at more frequent intervals or locations if physical changes in the water column (e.g., temperature, salinity) are affecting data quality. Some multibeam systems (e.g., GeoAcoustics, Inc. GeoSwath System) incorporate continuous near-surface velocity meters in the transducer head—see Figure 11-2). The quality of velocity data may be subsequently assessed through use of the "Performance Test" which compares overlapping survey data models. Beam angles should be reduced below the maximum limits specified in Table 11-2 if velocity data and/or performance tests indicate uncertainty in outer beam depth measurements. Velocity profile data is entered into the system such as under the HYPACK MAX Sound Velocity Program section.

11-10. Vessel Draft and Index Measurements (Bar Checks)

As in single beam systems, a bar check represents the "reference standard" by which multibeam echo soundings are calibrated. Upon initial installation, and periodically thereafter, a traditional bar check should be performed to calibrate the multibeam draft and index corrections and verify velocity corrections (from velocity meter casts) are accurate. The frequency of this calibration is a function of the results, the stability of the system, and the nature of the survey. If periodic bar checks verify the draft/index corrections are holding constant, then less frequent checks are needed--perhaps every few months. Multibeam bar checks are performed similarly to single beam bar checks. The check bar may likewise be coated with foamed material to more nearly simulate actual bottom conditions (reflectivity).

a. Nadir beam bar checks. Bar checks are performed under the center beams to quantify any draft or index errors in the system. As stated above, these need only be done on an infrequent basis, depending on the long-term stability of the results. This calibration is identical to that performed for single beam transducers (Chapter 9). Figure 11-12 depicts a typical bar check over a portion of the multibeam array. See also reference 11-14 c.

b. Outer beam bar/plate checks. The New York District has developed a quality assurance procedure whereby a small bar or single-line plate can be lowered from either side of the boat to perform a "blunder" or "confidence" check on the recorded multibeam data. Such a check can be quickly performed before or during each survey. Any portion of the multibeam array that is picked up can be used. Although not intended to definitively calibrate draft/index values like a bar check, this check will reveal gross biases. If biases exist between the plate/bar depth and the multibeam depth, then the standard QC and QA tests should be performed to determine the cause of the bias. It is recommended that this type of "blunder" check should be performed before each survey.

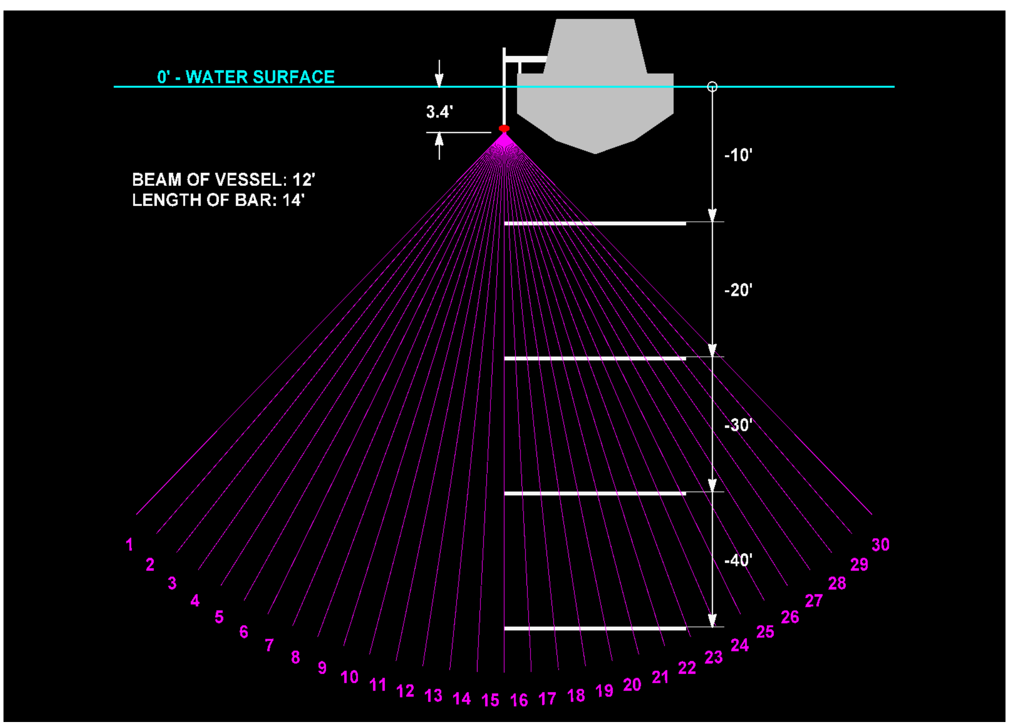


Figure 11-12. Standard bar check of a multibeam system (Galveston District)

11-11. Beam Width Restrictions on Multibeam Systems

The coverage of multibeam systems is a function of swath width and water depth. Most systems provide coverage of two to approximately seven times the water depth. The number of individual beams (and footprint size) within the swath array varies with the manufacturer. As outlined in previous paragraphs, the outer beams on each side of the swath are subject to more corrections and may not be useful for most dredging and navigation applications. The maximum angular extent of coverage must be verified, and accordingly restricted, by conducting some form of independent performance test. Thus, the recommended maximum beam limits in Table 11-2 are contingent upon some type of quality performance check to verify the adequacy of the entire array. Depending on various factors, primarily velocity and bottom reflectivity variations, it may be necessary to restrict beam widths to less than the recommended limits shown in Table 11-2. (There are known cases where multibeam arrays had to be restricted to ± 22.5 deg due to poor data quality outside these limits).

11-12. Quality Assurance Performance Test (Overlapping Models)

A performance test is used to evaluate the quality and confidence of multibeam data being collected. This test typically compares overlapping data sets from two different multibeam surveys--performed either by the same vessel or by different vessels. This test may also be performed by comparing multibeam data with that collected by another single beam or multiple transducer echo sounder--obtained by either the same vessel or different vessels. Other comparison test methods are also used, such as matching multibeam bathymetry of a flooded Corps lock chamber against topographic data measured in the same lock chamber during a dewatered state. Object detection capabilities may also be verified by sweeping over simulated objects of known size; placed either in open water or in controlled lock chambers.

a. Purpose. The purpose of a performance test is to obtain an estimate of the accuracy (or repeatability) of a multibeam system throughout its entire swath. These accuracy estimates can then be compared with the minimum standards in Table 3-1. This test also partially checks the parameters and biases that were measured and computed during the previously described QC calibrations (velocity profile calibrations, Patch Test bias parameters, etc). If performed over different tidal phases, it may also detect poor tidal modeling in the survey area.

b. Frequency of performance tests. Tests should be conducted before a critical dredging measurement and payment survey project; however, they are not needed prior to individual surveys in that project. For non-navigation surveys, performance tests may be conducted weekly, monthly, quarterly, or less frequently, depending on the long-term stability of the results, known variations in different project areas, etc. Performance tests should also be conducted upon equipment installation or modification. Performance test data reduction, processing, and statistical analysis should be performed in near real-time--i.e. on board the survey boat.

c. Undetected biases. Performance tests conducted by the same vessel, the same multibeam system, and over a short tidal time period, are not truly independent but are only an assessment indicator--a constant bias in the system could go undetected. A more truly independent performance test is obtained when comparison surveys are run at different tidal phases, using different multibeam and single beam systems, by different vessels, in different locations, and differing sea state conditions. However, this type of ideal test is not practical in actual Corps practice--typically, a performance test is done at the beginning of the day before the pre/post dredge survey is run. In this case, the test more properly indicates a level of "repeatability" in the data--see Chapter 4. Some of the biases that may not be detected when the same vessel and multibeam system is used in a performance test include:

(1) Squat/settlement bias. A constant error in the squat/settlement correction for the vessel will be undetected since the same vessel speed is run for all tests. Running different speeds might detect this error; however, it is probably small for most vessels. Use of RTK DGPS eliminates this potential bias.

(2) Draft errors due to undetected loading variations.

(3) Tide/stage modeling errors. When the comparison test is performed at the same time (tidal phase), errors in the tidal model will not be detected. However, performing the test at the same time will indicate the multibeam system is outputting quality data, independent of any tidal modeling errors. Performing the comparison tests at both the same and different tidal phases is strongly recommended, in that the independent quality of the multibeam system can be checked separately from any biases in the tidal model. As was discussed in Chapter 4, errors in the tidal model can represent the major portion of an error budget for an individual depth measurement, and can easily mask the errors in the multibeam system. If performance test biases are small (< 0.05 ft) when run at the same tide phase, and large when tested over different times/phases, then a tidal modeling problem is indicated. No amount of multibeam QC calibration or QA testing will rectify this modeling error--the only practical solutions are to correct the tidal model or utilize RTK direct elevation solutions (which also require appropriate geoidal and tidal modeling corrections).

(4) Bottom reflectivity. A constant depth error due to signal processing biases may be detected by comparing different portions of the array, multibeam systems, frequencies, etc. Variations can also occur in the outer beams due to differences in amplitude and phase detection processing. In addition, any index variations due to reflectivity differences between the bar check and actual bottom will not be detected.

Given the above, obtaining an absolute performance confidence test on a multibeam system is not a simple task. However, since use of the same vessel (and survey system) is recommended for all USACE measurement and payment surveys on a project, the performance test will yield a good estimate of the data repeatability and confidence, and indirectly the accuracy of any pay yardage derived from a survey. This presumes any undetected biases are constant (and hopefully small) for both pre and post dredge surveys.

d. Reference and Check Surface development. The procedure described below compares a "check line" multibeam dataset with a "reference surface" dataset complied from narrowly spaced multibeam data using only near-center beam data. The "reference surface" derived from independent vertical single beam data could also have been used, provided a reasonably dense single beam model is obtained. Failure of the performance test survey to meet the recommended tolerances in Table 3-1 and Table 11-2 requires corrective action--i.e., remeasurement, recalibration, patch testing, etc.

(1) Reference surface (Figure 11-13). This is essentially a small survey run over an extremely flat area (less than 1 ft gradient) in water depths of not more than 100 ft. A flat bottom area minimizes the effect of positional errors on the test. It represents the "baseline" area. Four or five parallel lines are run with at least 150% bottom overlap--i.e., 25% sidelap. The line spacing must be close enough to ensure that the inner beams overlap enough to give redundant data. The beams outside a 45-60 deg swath width should be removed prior to editing. After these lines are run, four or five parallel lines are run perpendicular to the previously run lines with the same swath and overlap. The speed over the ground should be the same on both sets of lines. A velocity cast should be made in this area and the corrections applied. All the edited data in the Reference Surface are then binned at 1 ft x 1 ft cell sizes. The data in each cell are then thinned using the average depth of all the depths in a cell.

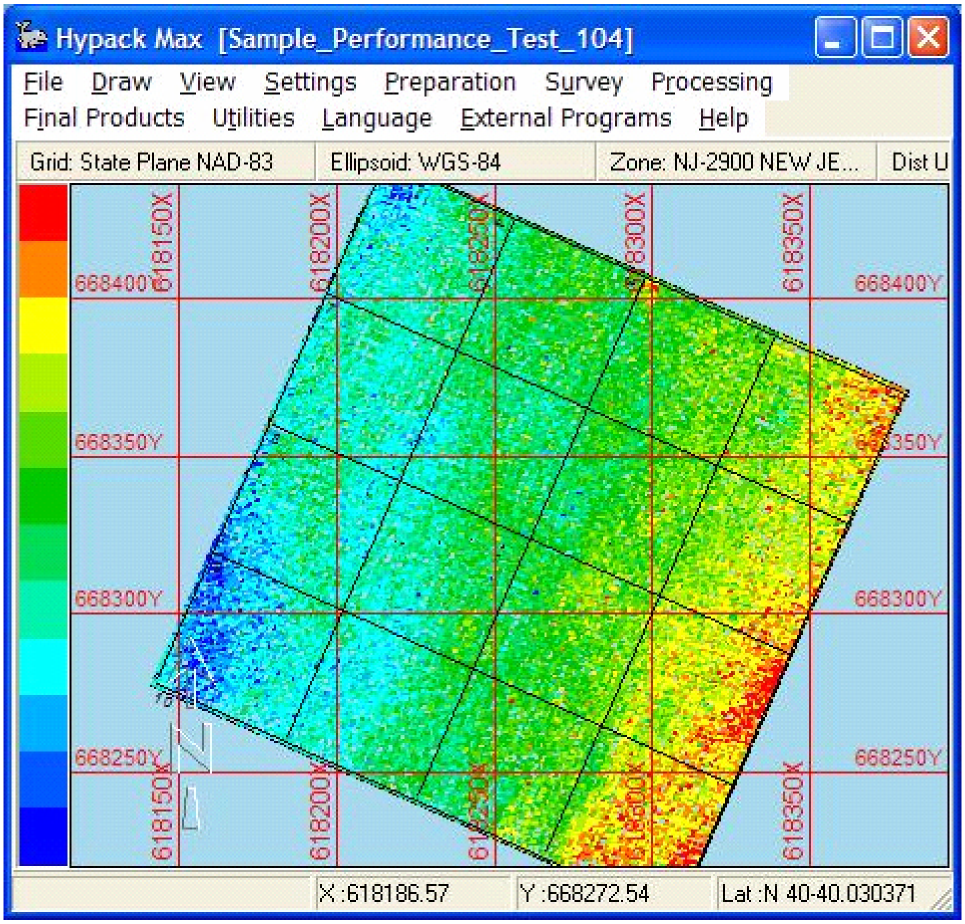


Figure 11-13. Color-coded Reference Surface binned into 1 ft x 1 ft cells. Five multibeam lines were run in each direction and combined to make up the Reference Surface (Coastal Oceanographics, Inc.)

(2) Check lines. Multibeam "Check Lines" will be run such that the full beam array can be tested against the Reference Surface. At least two perpendicular multibeam swath lines should be run inside the reference surface. The vessel speed is the same as for the reference surface. Ideally, a more independent test is obtained when the Check Lines are additionally surveyed at a different time and tidal phase from that of the Reference Surface survey; however, this is not always feasible in practice. (Another alternative is to run single beam Check Lines--either from the same vessel or another vessel-- to compare with the multibeam Reference Surface). The beam width of the Check Lines is not restricted so that the data quality in the outer parts of the array can be assessed. A difference surface between the Reference Surface and the Check Line surface can also be created and statistics computed to assess overall performance. From these differences, the corrections to the system can be checked against the criteria recommended in Table 3-1 (and Table 11-2). Software vendors have developed programs that will automatically perform these statistical assessments.

e. Data processing and analysis. Performance test data processing and analysis should include assessment of the following statistical parameters:

- *Outliers*. Depth differences between the Check Line surface and Reference Surface are computed at each beam point along the Check Line array. They can be visually displayed in a histogram as shown in Figure 11-14. Maximum outliers should not exceed the values recommended in Table 11-2. Presence of excessive outliers in the outermost portions of the array indicates calibration/velocity problems, and requires correction and/or restricted beam widths.

- *Mean difference or bias*. The difference, or bias, between the Reference and Check surfaces should not exceed the maximum allowable bias value in Table 11-2 (and mandated in Table 3-1). This is the most critical quality assurance check on the data in that a bias error will adversely skew depths and related quantity computations. Excessive surface bias errors require immediate assessment and correction. They could indicate problems with the multibeam data (e.g., MRU alignment) or vertical tide/stage corrections (see paragraph c above). The confidence of the computed bias can be estimated by computing the standard error of the mean, as demonstrated in chapter 4. Given thousands of comparative data points on multibeam surveys, the standard error of the mean should be small; typically well less than 0.05 ft, and well within the relatively liberal 0.1 ft and 0.2 ft allowable tolerances in Table 11-2 (Table 3-1) which factor in assumed uncertainties in the tidal model. The example test in Figure 11-15 shows biases computed at various beam angle widths. This type of plot should be used to determine the maximum beam width that should reliably be used.

- *Standard deviation*. The standard deviation of the differences between the Reference and Check surfaces should not exceed the limit shown in Table 11-2--i.e. the prescribed performance accuracy standard for depths given in Table 3-1. Some software programs typically output one-sigma standard deviations. These must be converted to the 95% confidence level--i.e., multiply by 1.96. The existence of excessive outliers and biases will increase the overall standard deviation. Restriction of the beam array angle may reduce this error if most of the excessive outliers are in the outermost portion of the array. Results from this test may be used as an indicator of overall accuracy performance. In order to assess resultant accuracy as a function of swath width, it may be necessary to isolate sections of the beam swath, as is shown in Figure 11-15.

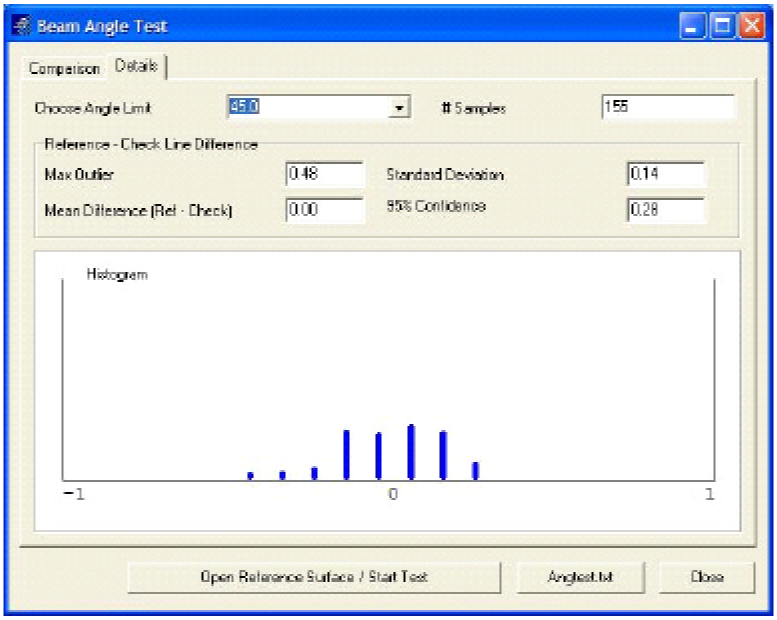


Figure 11-14. Statistical results of a Performance Test with Check Line beam angle width of ± 45 deg. Histogram shows dispersions and outliers (- 0.48 ft maximum). No bias was present and the 95% confidence was ± 0.28 ft. (Coastal Oceanographics, Inc.)

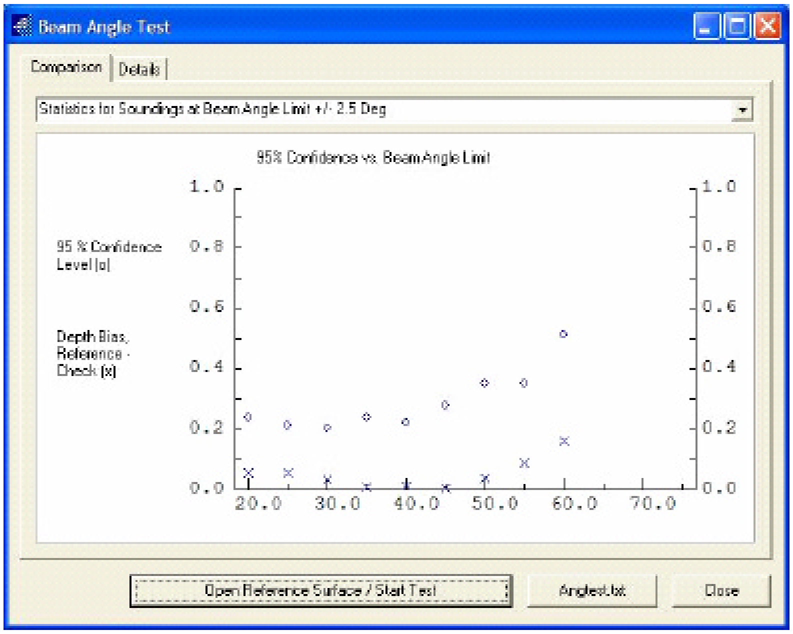


Figure 11-15. Plot of statistical bias and confidence results at various beam angles widths. Note that bias and confidence degrades beyond ± 45 deg, indicating data should not be used outside a full 90 deg swath width. (Coastal Oceanographics, Inc.)

f. Sample performance test calibration--Philadelphia District (Surveyboat Shuman). The performance test was done over a very flat anchorage area with depth variation of less than 2 ft over a 200 x 200-ft test area. A reference surface was created by running two sets of four parallel lines, line sets perpendicular to each other with spacing equal to the approximate water depth (45 ft). After editing and application of tide and sound velocity corrections, the reference survey was gridded into 2 x 2-ft cells. The average of each cell (approximately 17 points per cell) is saved to an XYZ file. The results from comparison of the reference surface with two check lines (one in each direction) are shown in the following tables.

Statistical Quantity	Shuman Result	Maximum Allowed
Maximum Outlier	0.40 ft	1.0 ft OK
Mean Difference (Reference surface – Check line)	+ 0.10 ft	< 0.2 ft OK
Depth Standard Deviation (1-σ)	± 0.07 ft	-------
at 95% Confidence (per Table 3-1)	± 0.15 ft	NTE ± 2.0 ft OK

Results of the comparison of the multibeam check lines to the reference surface can also be tabulated as shown below. This report is generated by the Beam Angle Test section of HYSWEEP multibeam processing program MB Max.

± Beam Angle Limit	Max Outlier	Mean Diff	Std Dev	95% Confidence
20	0.37	0.11	0.08	0.16
25	0.37	0.11	0.08	0.16
30	0.37	0.11	0.08	0.15
35	0.40	0.11	0.08	0.15
40	0.40	0.10	0.08	0.15
45	0.40	0.10	0.07	0.15
50	0.40	0.10	0.07	0.15
55	0.45	0.10	0.07	0.15
60	0.88	0.10	0.08	0.15
65	0.88	0.10	0.08	0.16
70	0.88	0.10	0.08	0.16
75	0.88	0.11	0.08	0.16

The results of the above sample Performance Test indicate the multibeam system is providing reliable data out to a ± 75 deg beam width. However, the relatively large constant biases of + 0.1 ft between the two surveys might be questioned and further evaluated as to the cause. If this test had been performed for a payment survey on a rock cut project, then these large biases would have exceeded the 0.1 ft allowable tolerance in Table 11-2.

g. Real-time quality assurance tests. This simply involves operator assessment of data quality as it is being collected, making visual observations of cross-track swaths (i.e., noting convex, concave, or skewed returns in flat, smooth bottoms), data quality flags/alarms from the DGPS or MRU systems, or noting comparisons between adjacent overlapping swaths or between independent single beams. Real-time software must have features that allow some form(s) of real-time quality assurance assessment, and performing immediate corrective actions.

11-13. Multibeam Data Processing--Editing, Filtering, Thinning, and Binning

Multibeam data is processed and edited on a variety of commercial platforms and software packages--e.g., HYPACK MAX Sweep Editor. Data processing software has now progressed to the point that multibeam data may be filtered, edited, thinned, and binned in real-time; thus eliminating much of the post-processing editing work previously associated with large multibeam datasets. It is important that data filtering, thinning, and binning processes do not adversely corrupt or erroneously warp the reduced model, potentially biasing dredged volume computations. Automated filtering for data spikes must be closely monitored. Data thinning routines must be intelligent in order to maintain the integrity of the topography. Averaging data into matrixed bins must also ensure that the basic topography is not compromised. If bin sizes are too large, data may be overly smoothed. Topographic data corruption can also occur if shoal biasing is used to form bins (or cells) in a digital terrain model (DTM) or digital elevation model (DEM)--any such biasing processes should be used with caution. Many of these procedures, and related intelligent data thinning software routines, are being continually updated as new algorithms and performance test techniques become validated.

a. Editing and filtering data. Multibeam data typically contains many noise spikes that must be edited out of the database. Filtering and editing can be done in real-time, in post-processing, or in combination. Manual editing could be performed by viewing each cross-section and editing out spikes from individual beams. At 40 cross-sections/sec, this is not practical. More commonly, the entire dataset is viewed in 3D form and data spikes are edited out manually in the 3D model. This is likewise a labor-intensive process. Spike or data anomaly filtering can also be performed during data acquisition or during post-processing. Such "intelligent" filtering is usually based on setting up maximum data quality or magnitude changes. During this process, data can also be automatically thinned and binned. Final 3D model review and editing is still recommended. Given the increasing densities of collected multibeam data, coupled with requirements for small bin sizes, smart use of automated filtering and editing has become a practical way to process these large datasets.

b. Thinning and binning multibeam datasets. In theory, there is no need to reduce the size of the collected multibeam dataset. The entire "raw" database could be used for project or dredging condition assessment, volume computations, etc. However, these large datasets are thinned for a number of reasons, such as: (1) plotting in plan view without sounding overlap, (2) dredge volume computations, (3) channel clearance strike plots, (4) controlling channel depth reports, (5) 3D visualization models, or (6) simply to reduce the data down to a manageable size. There are a number of methods for reducing (or thinning) the size of large, edited multibeam datasets. For basic terrain visualization requirements (i.e. non-navigation uses), various thinning routines have been developed that can reduce datasets by 95% or more; typically selecting representative depths based on gradient changes over large areas. In current USACE practice, multibeam datasets are typically thinned into a fixed matrix or grid cell. The size of the cell is selected based on terrain irregularity, dredge volume computation requirements, or to prevent overplotting adjacent depths.

11-14. Depth Selection Options

Once raw data points are collected within their given positional cell, the multiple depths within each cell may be thinned to a single representative depth for that cell. Binning or gridding routines (e.g., HYPACK MAPPER) provide options to thin multiple depths within a cell. Although designed for reducing the size of multibeam data, these binning routines may also be used for single beam data as well. Various representative depth outputs are possible with binned data:

- Minimum depth within the cell (e.g., "shoal biasing")
- Maximum depth within the cell
- Average (or mean) of all depths recorded within the cell
- Median of all depths recorded within the cell
- Shot depth closest to the cell center

Each of the above depth selection options has advantages and disadvantages. On dredge measurement and payment surveys where multiple passes are made, a small (e.g., 5 ft x 5 ft) cell could contain, say, 5 to 50 data points, from which a single representative (i.e. "thinned") depth must be selected. One of these points could be a noise "spike" that passed the processing filter described above. The average of 50 depths within the cell may not be representative if the cell is too large and shoaler depths within the cell are obscured by the average. Likewise, the shot depth nearest the cell center (centroid) may not be representative. Therefore, selecting a bin size and representative thinned depth for a given project is a complex task and should be based on experience with specific project applications. Recommended maximum bin sizes and depth selection options are given in Table 11-2 for this purpose. In addition, for most surveys, the X-Y coordinate origin of the grid matrix must be specified so that different processors will obtain the same results from a given dataset.

a. Shot Depth. For most applications, the "shot depth" closest to the cell center is used to best represent the terrain. This is because some of the other options can significantly bias the terrain representation if the cell sizes are too large, resulting in a false depiction of the true bottom condition (and dredged quantities). Statistically, a shot depth selection represents the best option for depicting datasets in that no inherent biases are produced in thinning the data. (Use of an unthinned raw dataset is, in effect, nearly unbiased; however, the size of the raw dataset may be too large for efficient quantity computations). The position of the shot depth is typically shifted to the X-Y coordinates of the center of the cell.

b. Average (mean) depth. The "average depth" option can overly smooth the data if cell sizes are too large; however, this may be desirable in some instances. If cell sizes are kept relatively small, then the average depth can be a good representation of the bottom condition; and will represent a consistent, equitable payment method in dredging surveys. "Average" depths within a small, fixed bin size are recommended for computing dredged quantities--see Table 11-2. If bin sizes are set too large, then averaged depths may not be desirable on excavated slopes. (Visual interpolation of analog depth records on single beam surveys, in effect, averages the depths nearest the fix event mark. If single beam averaged depths are recorded, the system software must tag a position with the center of the depth series--requiring some form of on-line position interpolation).

c. Median depth. The median depth of all depths in a cell will generally be nearly equal to the average depth when a large number of depths fall within the cell. When only one or two depths are contained within a cell, the median depth is identical to the average depth. The median depth may be superior to the average depth if noise spikes have not been adequately filtered out. For example, in a cell containing three depths (6 ft, 7, ft, and 17 ft), the median depth would be 7 ft but the average depth (10 ft) is biased due to the 17 ft spike.

d. Shoal-biased or minimum depth. The minimum depth recorded within a given area has often been used for strike detection, dredge clearance, and controlling channel depth purposes. NOAA uses these minimum recorded or "shoal-biased" depths on nautical charts as a form of safety factor. Shoal-biased depths for Corps construction applications should be used with caution unless multiple "confirmed hits" are recorded within a bin, and/or between adjacent bins over a given area. Use of minimum shoal-biased depths can adversely skew dredge quantity computations and erroneously portray clearance depth data. Raw shoal biasing can also skew minimum clearance computations on Channel Condition Surveys or on tabular Channel Condition Reports. Shoals above project grade must be assessed based on multiple hits over successive passes--the least depth recorded in a bin is not necessarily the absolute elevation over an object. This is due to the relatively high variance in acoustic depth data--see discussion on data accuracy and confidence levels of assessing multiple hits in Chapter 4. Automated software has been developed to perform this "multiple hit" analysis within each bin, and output bins containing depths with "confirmed" hits above a specified grade.

e. Maximum depth. There are few USACE applications for processing maximum depths in a project.

11-15. Plotting Representative Depths in Plan

When individual depths are plotted on a traditional plan drawing at some fixed scale (e.g., 1 in = 200 ft), the method by which a particular depth is selected from a dense multibeam dataset is a difficult process. This was not a problem with older lead line or single beam survey methods--data were recorded at 25 ft or 50 ft intervals and could be easily plotted on a 1 in = 100 ft or 1 in = 200 ft drawing scale (without any need for thinning or binning). With multibeam data points being collected at 1 ft sq or smaller densities, it is impossible to portray the data at any reasonable or realistic two-dimensional hard copy drawing scale. The entire raw or binned dataset of individual depths, or equivalent three-dimensional terrain models, can be easily viewed on computer displays. However, as long as traditional hard copy drawings of plotted depths are required, then standardized procedures must be developed for plotting representative depths from the large multibeam database.

a. Selecting representative depths. Selecting a representative depth to depict on a plan drawing entails selecting a plot cell size that is large enough to prevent overlapping plots but small enough to represent the condition and still be readable at the plot scale. For example, at a scale of 1 in = 200 ft, a minimum cell size would be roughly 40 x 40 ft square to 50 x 50 ft square in order to avoid overlapping depth plots. Such a large cell size could contain hundreds of multibeam data points; thus the single representative depth that is selected for the plot may not be representative of the overall cell and may represent less than 1% of the total data points that were collected. For this reason, plan drawings of representative depths should not be used for dredge clearance or volume computations--far smaller bin sizes are needed for such purposes. Plan drawings used in contract plans and specifications, dredging as-built surveys, disseminated project condition surveys, etc., should clearly indicate the depth selection option used, and whether or not this is a biased selection.

b. Contour or color-coded plots. As an alternative to traditional 2D plan view plots of individual depths, contour or color-coded point 2D plots or 3D models may be used to better depict project conditions. This allows use of the entire edited (or binned) dataset. Any of the above depth selection options may be used, depending on the purpose of the survey. Thus, even at a 1 in = 200 ft plan scale, nearly all data points can be adequately represented by point color or contour plot.

11-16. Recommended Bin Sizes and Depth Selection for USACE Navigation Surveys

The following paragraphs contain guidance on maximum bin size and depth selection for all types of navigation surveys as defined in Chapter 3, to include: dredging measurement & payment surveys, dredge clearance/acceptance surveys, plans and specifications surveys, project condition surveys, and other related navigation surveys. This guidance is based on over five years of collective multibeam data processing experience by the Districts within the North Atlantic Division, and some other USACE Districts. These recommended standards may be included, either directly or by reference to this manual, in dredging contract specifications. The intent of this guidance is to provide a consistent standard throughout USACE for processing multibeam data and computing dredge payment. These same criteria may also be applied, with some modification, to multiple transducer boom sweep systems and single-beam systems. The recommended bin and depth selection standards in the following subparagraphs are summarized in Table 11-2 at the end of this chapter, under the section "Recommended Depth Selection and Data Processing/Thinning Bin Matrix Limits" at the end of the table.

[Note that "selected representative shot, average, or minimum depths" referred to in the following sections are derived from the entire <u>edited</u> multibeam dataset. This implies that extraneous noise spikes have been filtered or manually edited out of the raw dataset before binning is performed.]

a. Recommended Maximum Bin Size. For a "hard" bottom material classification (as defined in Chapter 3), a 3 ft x 3 ft cell size is specified. For a "soft" bottom material classification, a 5 ft x 5 ft cell size is specified. Evenly spaced 3 ft or 5 ft grid matrices shall be generated over the full dataset relative to a fixed origin point to ensure that different individuals (or software) processing the same edited dataset will obtain identical results--e.g., dredged quantities.

b. Depth Selection Method for Dredging Volume Computations. The "average depth" of all depths within each 3 x 3 ft or 5 x 5 ft cell should be used as the representative depth for the cell. The horizontal location of the representative average depth is the cell center or centroid. The representative average depths are used to generate rectangular digital terrain models (DTM) or trapezoidal triangulated irregular network (TIN) models from which dredge volume computations are computed in CADD routines using all the bins in the edited dataset matrix. If optional average end area volume (AEA) computations are performed in soft material by generating simulated cross sections through the full DTM or TIN model, cross sectional spacing shall be kept small so that AEA approximation errors are minimized. For example, a 5-ft cross-section spacing is far more accurate than a 100-ft spacing, and will better approximate the volume derived from a full TIN model computed using CADD differencing routines.

c. Plotting Selected Depths on Dredging and Navigation Surveys. For generalized plan drawing portrayals of a project condition, plans & specifications, or dredging progress survey, a "shot" depth taken from randomly selected bins provides the most unbiased representation of the pre- or post-dredged bottom condition. Shot depths are randomly selected from the edited 3 x 3 ft or 5 x 5 ft bins. As outlined in Section 11-15 above, only a small percentage of the depths in the dataset matrix can be shown on typical plan drawing scales used in USACE (e.g.,, 1 in = 100 ft). Plan drawing CADD note block layers/levels should clearly state that the generalized plotted depths are not representative of the full dataset, and that the plotted depths shown should not be used for channel clearance or volume computations; and also noting that the original binned dataset should be (or was) used for such purposes.

d. Contour or Color-coded Plots of Dredging and Navigation Surveys. Use all “shot” depths in the edited dataset matrix to generate contour or color-coded plots.

e. Navigation Surveys--Strike Detection or Minimum Channel Clearance. For strike detection or dredge clearance/acceptance purposes, multiple "hits" on strikes or shoals above a specified grade are required. Typically, the specified grade is the “Required Grade” although an overdepth grade or supergrade could also be used. Multiple confirmation sweep passes are always recommended for channel clearance surveys in that strikes above grade detected from different sweep aspects helps to minimize the possibility of noise spikes creating false strikes on a single pass. The representative "shoalest depths" are used to generate "strike plots" depicting project areas remaining above grade, and the possible need for additional excavation.

(1) Confirmed hits. The multiple "hits" may be obtained on a single sweep pass or from multiple sweep passes over a suspected shoal/strike area. A recommended USACE standard of three (3) hits is specified to represent a “confirmed” hit. The “hits” above grade are determined by assessing “minimum” edited depths recorded in a cell, or from a series of adjacent cells. Three confirmed hits within either 3 x 3 ft or 5 x 5 ft cell sizes are used; however, adjacent cells may need to be assessed if only sporadic hits occur in a single bin.

(2) Strike Plots--plotting minimum hits above grade in plan. If many shoals/strikes exist in bins over a small area, then the processing software will have to select the most representative (e.g., highest/shoalest) confirmed strike to plot for this area--to avoid overplotting depths at the plot scale. If contour or color-coded depth plots are generated, then all the minimum confirmed hits can be easily represented in plan or 3D format.

f. Reports of channel conditions (EP 1130-2-520--ENG Forms 4020-R and 4021-R). Tabular reports of controlling minimum depths in a channel reach are, in effect, large bins encompassing a wide breadth of the channel over its entire length. Reducing hundreds of thousands of recorded multibeam depths in this "bin" down to a single representative "minimum controlling" depth requires some type of standardized process. For example, in a 400 ft x 5,000 ft channel reach, the minimum depth shown for each channel quarter represents a 100 ft x 5,000 ft bin, or a 500,000 sf area. A "shoal biased" depth selection option is typically selected to represent the minimum depth over such a large reach. Unless the dataset is evaluated based on a "confirmed hit" type of analysis, a single anomalous and unrepresentative noise spike could end up being the falsely reported controlling depth for the entire channel reach. Reported controlling minimum depths should be truncated to the nearest whole foot, as shown in EP 1130-2-520. Channel Condition Reports are intended to report a minimum (safe) clearance depth based on the latest survey (Post dredge, Project Condition, etc.). If an additional clearance "safety factor" is desired, then the representative depth could be rounded up to the nearest whole foot using the NOAA 0.7 ft truncation rule.

(1) Standards for Reports of Channel Conditions. For assessing minimum clearances over an entire project reach (e.g., Channel Condition Reports), "minimum confirmed" depths above grade should be used. Tabular reports of channel conditions should be generated similarly to Strike or Clearance detection above. Depths are binned from the edited dataset using either 3 x 3 ft (hard material) or 5 x 5 ft (soft material) cell sizes. The "shoalest depth" of all depths in the cell is used as the representative depth for the cell; provided that there are a minimum of three (3) confirmed hits above project grade in the cell; or in an area between adjacent cells when the cells themselves are sparsely populated. The controlling minimum depth within a channel reach is then selected by analyzing all the cells in the given reach and selecting the individual cell with the minimum "confirmed" depth above grade. Automated software has been developed to perform this analysis over a channel reach.

(2) Plotting or tabulating only selected "minimum confirmed" depths (or worse, "unconfirmed" minimum recorded depths) on a Project Condition Survey that accompanies a tabular Channel Condition Report is a biased representation of the true project condition. Survey plots depicting only minimum (shoal-biased) depths should never be used for dredging plans and specifications since significant constant biases may be present. Plan drawings (or CADD files) of Project Condition Surveys should clearly note the depth selection option used.

g. *Other General Surveys and Studies*. There is no specified maximum bin size or depth selection method for other types of non-navigation surveys that are defined in Chapter 3. Bin sizes may be varied depending on the type of bottom or purpose of the project (e.g., beach sand transport studies, hydraulic studies). In smooth, flat areas, bin sizes may be expanded to any level that will adequately depict the terrain. Bin sizes as small as 1 ft sq may be used for applications where maximum detail is required--e.g., underwater structure surveys. Instead of binning, more efficient data thinning methods may be used to generate a TIN model for 3D analysis. Any of the representative depth selection options may be used, although the "shot" depth is recommended for most applications to avoid biasing the data.

11-17. Contract Specifications for Multibeam Measurement and Payment

The following contract clauses are recommended when multibeam systems are used on dredge payment or acceptance surveys. This version was developed by the North Atlantic Division Multibeam User's Group (Reference 11-18f).

> Measurement and Payment. The total amount of material removed and to be paid for under the contract, will be measured by the cubic yard in place. Measurement of the number of cubic yards in place will be made by computing the volume between the bottom surface shown by soundings of the last survey made before dredging and the bottom surface shown by the soundings of surveys made as soon as practicable after the work specified in each acceptance section has been completed. The volume for measurement will include the material within the limits described in the Paragraph entitled: "OVERDEPTH AND SIDE SLOPES', less any deductions that may be required for misplaced material described in the Paragraph entitled: "DISPOSAL OF EXCAVATED MATERIAL" of this section. The volume of material removed will be generated by using either the Average End Area Method or by the TIN (Triangulated Irregular Network) computation, as outlined in the Hydrographic Surveying Manual EM 1110-2-1003, dated 1 January 2002, and subsequent changes/revisions issued by HQUSACE. All depths obtained from single beam surveys will be utilized for volume computation purposes. If multiple vertical transducer sweep systems or multibeam survey technology is used, a 5-foot by 5-foot matrix using the average depth of all depths recorded in a cell will be generated from the edited multibeam data to perform the TIN volume computations, following the procedures outlined in EM 1110-2-1003. Any corresponding plotted plan view sounding sheets depicting representative depths over a dredging project will be generated using a cell size that is plot-scale dependent, utilizing a

randomly selected sounding that is closest to cell center (shot depth) shifted to the center of the cell from the edited multi-beam data, as described in EM 1110-2-1003. If the material to be dredged in the contract is categorized to be hard bottom, the matrix used for the volume computations will be reduced to a 3 foot by 3-foot matrix and an average of the soundings in the cell will be used. Shoal or strike plots depicting material above the required dredging grade will be generated using confirmed minimum depths in accordance with the data processing procedures outlined in EM 1110-2-1003. All raw survey data and edited/processed binned data used for volume computations shall be available to the Contractor upon request.

Hydrographic Survey Equipment. Hydrographic surveys will be conducted to meet USACE minimum accuracy standards defined in Table 3-1 of EM 1110-2-1003 (Hydrographic Surveying). Surveys will be performed by single vertical beam transducer, or multiple vertical beam transducer sweep, or multibeam sweep methods. When vertical single beam or multiple sweep beam transducers are employed, an acoustic frequency of [200 kHz (± 20%)] *[*or insert alternate frequency*]* will be used. When utilizing multibeam technology, the operating acoustic frequency will range from [180 kHz to 250 kHz] *[*or insert alternate frequency*]*. All depth measurement devices will be calibrated following the procedures outlined in EM 1110-2-1003.

11-18. Multibeam Technical References

The following publications provide additional technical information on the use and calibration of multibeam systems.

a. Field Procedures for the Calibration of Shallow Water Multibeam Echo-Sounding Systems, André Godin, Canadian Hydrographic Service, Ottawa, Ontario, February 1996.

b. HYPACK MAX User's Manual and Annual HYPACK Conference Training Notes, Coastal Oceanographics, Inc., Middlefield, CT., www.coastalo.com, (latest edition).

c. Multibeam Surveying Workshop Proceedings, U.S. Army Corps of Engineers and NOAA Surveying, Mapping, and Remote Sensing Conference, St. Louis, MO, 19 Aug 1997.

d. Trimble HYDROpro Navigation Software Manual, Trimble Navigation Limited, Sunnyvale, CA, http://www.trimble.com

e. American Congress on Surveying and Mapping (ACSM), ACSM-ASPS-MAPS-MARLS 2000 Workshop Program, Hydrographic Surveying, Little Rock, AR, 21 March 2000 (Shallow Water Multibeam Systems for NOAA Hydrographic Surveys).

f. US Army Corps of Engineers, North Atlantic Division Multibeam User's Group Conference Reports, 2002 (New York District) and 2003 (Philadelphia District).

g. GeoAcoustics, Inc. GeoSwath Product Information Bulletin, November 2002, Cypress TX.

11-19. Mandatory Requirements

All calibration, QC, and QA criteria summarized in Table 11-2 are recommended unless otherwise indicated as being mandatory. These updated criteria supersede QC, QA, and procedural criteria in other chapters of this manual.

11-20. Summary or Multibeam QC and QA Criteria

Table 11-2 below summarizes criteria for conducting multibeam surveys. The measurement, alignment, calibration, quality assurance, and data processing criteria are based on procedures currently followed by a variety of government and commercial sources; and especially from actual USACE experience on dredging projects (Reference 11-18f). For some criteria, references are provided to their applicable sections in this chapter. Since some of the criteria in Table 11-2 duplicate single-beam criteria, explanations for these items are referenced to sections in Chapter 9.

a. Frequency of tests and checks. QC and QA checks, calibrations, and other tests are recommended at beginning of all critical dredging projects, and on all surveys where high quality assurance is required (e.g., a project clearance survey in dispute). Depending on documented stability of a system, and user experience and confidence, the frequency of calibrations and performance tests may be locally modified from the indicated intervals.

b. Calibration, QC, and QA documentation. Project or contract files must contain documentary evidence that all calibration and performance tests were performed. This would include a written log (or equivalent digital record) of sensor offset and alignment measurements, patch test calibration results, sound velocity measurements, bar checks, squat calibrations, tide/stage observations, performance test results, etc. Original records of such calibrations should be retained in a permanent, bound surveyor's field book aboard the boat.

c. Other Surveys and Studies. Specific criteria for multibeam surveys outside navigation projects are not listed in Table 11-2. It is recommended that the general QC and QA procedures for dredging surveys be followed. For general underwater topographic surveys, many of these requirements can be significantly relaxed based on user experience with a particular system. This would include unlimited beam width restrictions and far less frequent calibrations. However, for detailed underwater structural investigations, more demanding criteria than that shown in Table 11-2 might be warranted.

Table 11-2. Recommended Minimum Quality Control and Quality Assurance Criteria for Multibeam Surveys

Criteria		PROJECT CLASSIFICATION Navigation & Dredging Surveys Bottom Material Classification Hard	Soft	Section Reference and Notes
QUALITY ASSURANCE PERFORMANCE TEST				Mandatory Calibration (Table 3-1) Reference Section 11-12
Perform Calibration		1/project	1/project	Test should be performed at the beginning of each new project (e.g., a pre or post dredge survey), and periodically during a longer-term project, such as a Project Condition Survey. The time interval needed between QA Performance Tests will depend on the consistency of test results.
Perform comparison with different vessel multibeam and/ or single beam		Periodically	Periodically	
Location of test		at project site	at project site	
Perform tests over same and different tidal phases		Recommended	Recommended	Tests should be conducted over same and different tidal phases to check for tidal model biases. Reference 11-12c (3).
Maximum outliers between data set comparison points		1 ft	1 ft	
Maximum bin size for comparison data sets		1 ft sq	1 ft sq	Use averaged depth in bin for Reference Surface
Maximum allowable mean bias between data sets		< 0.1 ft	< 0.2 ft	The maximum mean bias computed between two data sets should not exceed the indicated tolerances (repeated from Table 3-1). Reference 11-12e.
Resultant Elevation/Depth Accuracy	Depth (d)			
	(d<15 ft)	± 0.5 ft	± 0.5 ft	Standard Deviation (at 95%)--computed from Performance Test results (repeated from Table 3-1). Reference 11-12e and Chapter 4.
	(15>d<40 ft)	± 1.0 ft	± 1.0 ft	
	(d>40 ft)	± 1.0 ft	± 2.0 ft	
POSITION QUALITY ASSURANCE CHECK		1/day	1/project	Mandatory Calibration (Table 3-1) Check different DGPS beacons, known point, etc. Reference Chapter 7, Table 7-1

Table 11-2. Recommended Minimum Quality Control and Quality Assurance Criteria for Multibeam Surveys (Continued)

Criteria	PROJECT CLASSIFICATION Navigation & Dredging Surveys Bottom Material Classification Hard	Soft	Section Reference and Notes
SOUND VELOCITY CALIBRATION			Mandatory Calibration (Table 3-1) Reference Section 11-9 and Chapter 9, Section 9-10
Perform velocity probe calibration	> 2/day	2/day	Velocity casts should be taken at the indicated intervals. They shall be taken directly in the work area and at a density such that the water column is adequately modeled. More frequent calibrations may be needed in conditions where temperature or salinity are variable, or where Performance Test data indicates large variances are present.
Location of calibration	In project site	In project site	
Record velocity to nearest	1 fps	1 fps	
Record velocities in water column every	5 ft	5 ft	
Perform internal (distilled water) probe calibration	Weekly	Monthly	Reference Section 9-10.
BAR or BALL CHECK ON CENTER (NADIR) BEAM	Quarterly	Quarterly	Mandatory Calibration A QC Bar Check should be made as near to the nadir beam as possible. This periodic check shall be used to verify/calibrate any index or draft error in the system. Reference procedures outlined in Sections 9-7, 9-8, and 9-9.
SQUAT TEST CALIBRATION PERFORMED	Annually	Annually	Mandatory Calibration Reference procedures in Sections 9-11 and 11-7.
PLATE CHECK ON OUTER BEAMS	Daily	Daily	Perform before each survey as QA "blunder" check Reference Section 11-10b.
RECORD SHORT TERM VESSEL DRAFT VARIATIONS	2/day	2/day	Reference procedure in Sections 11-7d and 9-12

Table 11-2. Recommended Minimum Quality Control and Quality Assurance Criteria for Multibeam Surveys (Continued)

Criteria	PROJECT CLASSIFICATION Navigation & Dredging Surveys Bottom Material Classification Hard	 Soft	Section Reference and Notes
OBJECT DETECTION CONFIDENCE CHECK (for specialized search surveys)	Daily	Daily	Reference procedures in Chapter 12 Similar to side scan confidence check Verify hits on multiple passes over object
MAXIMUM BEAM ANGLE	90-deg	90-deg Meas & Pay Surveys 120-deg Proj Cond Surveys	Reference Section 11-11 Beam/swath width should generally not exceed the indicated values, unless independent QA performance test results indicate depth accuracies can be achieved with wider arrays. The beam angle may be further reduced for critical object detection-due to footprint expansion and poorer return from outer beams--or should QA performance test results indicate poor correlation in the outermost portion of the array.
BEAM OVERLAP	50%	10%	Reference Sec. 6-7 (Density of Data & Line Spacing) In navigation projects, a 50% side overlap (i.e., 200% bottom coverage) is strongly recommended when sweeping for rock shards or other hazardous objects remaining above project grade. Two or more overlapping passes on different aspects of the beam are recommended in shoal areas--to confirm hits above grade.
MAXIMUM SURVEY SPEED	2-5 kts	5-10 kts	Recommended maximum velocities are prescribed to ensure data integrity and minimize latency errors. Further limitations may be required for multibeam or side-scan systems to ensure 100% or greater forward (along-track) coverage or object detection.

Table 11-2. Recommended Minimum Quality Control and Quality Assurance Criteria for Multibeam Surveys (Continued)

Criteria		PROJECT CLASSIFICATION Navigation & Dredging Surveys Bottom Material Classification Hard	 Soft	Section Reference and Notes
INSTRUMENT ALIGNMENT/OFFSET MEASUREMENTS				Reference procedures in Section 11-6
Measure Antenna-Transducer-Inertial system relative coordinates to nearest		0.05 ft	0.05 ft	Alignment measurements are performed on installation or change of equipment.
PATCH TEST BIAS CALIBRATIONS				Reference procedures in Section 11-8
Perform test		periodically	periodically	The time interval required between Patch tests is dependent on Quality Assurance Performance Test results -- usually when mandatory QA Performance Tests indicate data is not meeting standards . No specific interval is mandated.
Patch Test Bias Resolution				Based on user experience, patch test bias corrections may be averaged over a long series of Patch Tests, rather than using the results from a single test. See Section 11-8e.
	Roll	0.1 deg	0.1 deg	
	Pitch	1 deg	1 deg	
	Yaw	1 deg	1 deg	
	Latency	0.1 sec	0.1 sec	
HEAVE CORRECTIONS (MRU)				
Measure heave to accuracy of		0.2 ft	0.2 ft	or 5% of heave amplitude, whichever is less
MRU/RTK update rate at least		20 Hz	20 Hz	

Table 11-2. Recommended Minimum Quality Control and Quality Assurance Criteria for Multibeam Surveys (Continued)

Criteria		PROJECT CLASSIFICATION Navigation & Dredging Surveys Bottom Material Classification Hard	Soft	Section Reference and Notes
MISCELLANEOUS CRITERIA				[Refer also to applicable single-beam criteria in Section 9-12]
MINIMUM PROJECT DEPTH (Dredging Surveys)		> 15 ft	> 15 ft	Reference Section 11-4a. Multibeam systems are recommended for dredge measurement, payment, and acceptance purposes in project depths greater than those shown.
ACOUSTIC FREQUENCY (+ 20%)	Nominal	200 kHz	200 kHz	Reference Section 9-3d (200 kHz standard frequency)
	Project Option	[< 20 KHz to > 500 KHz]		The nominal 200 kHz frequency is recommended for most USACE navigation projects; however, different frequency systems may optionally be used if needed for better beam definition on objects (e.g., 450 KHz) or to penetrate suspended sediments in a particular project area (e.g., 24 KHz). The same frequency should be consistently used for a specific project and specified in dredging contracts. See Section 9-3d.
ARCHIVED DIGITAL AND/OR ANALOG DEPTH RECORDS				
Contracted construction		[Write-once disc]		Reference Section 9-4d. Entire raw data file should be retained similarly to single-beam requirements. Retention of side scan data also recommended.
Project condition surveys		Digital	Digital	

Table 11-2. Recommended Minimum Quality Control and Quality Assurance Criteria for Multibeam Surveys (Continued)

Criteria	PROJECT CLASSIFICATION Navigation & Dredging Surveys Bottom Material Classification Hard	 Soft	Section Reference and Notes
RECOMMENDED DEPTH SELECTION AND DATA PROCESSING/THINNING BIN MATRIX LIMITS			*[Reference Sections 11-13 through 11-16]*
Dredging Measurement & Payment Surveys and Project Condition Surveys (including those used for contract Plans & Specifications)			
Bin/Cell size--Recommended maximum	3 ft sq	5 ft sq	The X-Y coordinate origin of the matrix must be specified. Reference Section 11-16a.
Depth Selection--Method used to select representative depth from multiple depths in a cell for use in volume computations	Average of all depths in 3x3 cell	Average of all depths in 5x5 cell	Average depth is truncated to nearest 0.1 ft and located at the cell centroid X-Y coordinate. Reference Sections 11-16b.
Volume computation method	Full DTM/TIN binned matrix	Full DTM/TIN binned matrix AEA optional	Volumes should be computed using the selected representative depths from the entire 3 x 3 or 5x 5 ft sq dataset matrix. AEA cross section spacing should be kept as small as possible. Reference Sections 11-16b.
Depth Plot (Plan)--Method used to select depths from cell matrix for a generalized hard copy display of individual depths/elevations	Randomly selected 3x3 ft cells containing representative shot depth	Randomly selected 5x5 ft cells containing representative shot depth	Density of plotted data dependent on output drawing scale. Plotted depths are generalized representations of the full multibeam dataset and should not be used for quantity computations. Shot depth may be shifted to center of 3x3 or 5x5 ft cell. Reference Section 11-16c.
Contour or Color-Coded Plot-- Method used to select depths from a cell matrix for generating contours or DTM color-coded plots	Use all 3x3 cells containing representative shot depth	Use all 5x5 cells containing representative shot depth	Full edited database used. Reference Section 11-16d.

Table 11-2. Recommended Minimum Quality Control and Quality Assurance Criteria for Multibeam Surveys (Concluded)

Criteria	PROJECT CLASSIFICATION Navigation & Dredging Surveys Bottom Material Classification Hard	 Soft	Section Reference and Notes
RECOMMENDED DEPTH SELECTION AND DATA PROCESSING/THINNING BIN MATRIX LIMITS (Continued)			*[Reference Sections 11-13 through 11-16]*
Dredge Clearance & Acceptance Surveys (Shoal/Strike detection) and Minimum Channel Clearance Condition Reports			*Surveys using "minimum" or "shoal biased" depths shall NOT be used for Plans & Specs or volume computations.*
Depth Selection--Method used to select representative "shoalest" depth from multiple depths in a cell	Shoalest of 3 confirmed depth hits above project grade in 3x3 cell	Shoalest of 3 confirmed depth hits above project grade in 5x5 cell	Individual cells must be assessed to determine multiple hits above grade. Reference Section 11-16e.
Number of confirmed "hits" above grade required per cell	3 hits	3 hits	Based on a single pass or multiple passes. Hits on multiple passes provide better confidence. Reference Section 11-16e(1).
Depth Plot (Plan)--Method used to select plotted depths from cell matrix for a generalized hard copy display of the shoalest individual depths above grade	Selected 3x3 ft cells containing representative shoalest confirmed depth	Selected 5x5 ft cells containing representative shoalest confirmed depth	Density of selected cells that can be plotted dependent on output drawing scale. Reference Section 11-16e(2).
Contour or Color-Coded Plot-- Method used to select depths from cell matrix for generating contours or DTM color plots	Use all 3x3 cells containing representative shoalest depth	Use all 5x5 cells containing representative shoalest depth	Full edited database matrix used. Reference Section 11-16e(2).
Tabular Report of Channel Conditions (ENG Form 4020/4021) Method used to select minimum controlling depth for channel reach	Least recorded depth in 3x3 ft cells containing representative shoalest confirmed depth	Least recorded depth in 5x5 ft cells containing representative shoalest confirmed depth	Select least controlling depth from all the cells contained over a given channel reach. Selected controlling depth should be shown on plan of condition survey if submitted. Reference Section 11-16f.
Record minimum controlling depth to nearest	1 ft	1 ft	Reference EP 1130-2-520 (Chapter 2)

Chapter 12
Navigation Project Clearance and Object Detection --Mechanical Bar Sweeps and Side Scan Sonar

12-1. General Scope

A number of tools are available to confirm if a project is clear to a prescribed grade. Acoustic techniques include vertical and multibeam systems covered in previous chapters. This chapter covers the use of mechanical bar sweeping and side scan sonar techniques to detect small objects or shoals lying above project grade.

12-2. Channel Clearance Bar Sweeps

Clearing channels or determining the elevations of underwater obstructions is done by bar sweeps. Channel sweeps are often performed using sweep rafts or sweep barges. In other applications, channels may be routinely monitored and/or swept clear by bar sweeps to ensure safe navigation to a certain depth. A bar sweep has particular application in blasted or cut rock dredging construction where hull clearance verification is especially critical. In many cases, a bar sweep represents a more reliable clearance verification than that obtained by acoustic methods. A heavy bar is suspended vertically below the barge and is maintained at the project or clear depth required.

a. Channel clearance sweep requirements. The Sault Ste. Marie (Soo) Area Office (Detroit District) began deploying sweep rafts in the St. Mary's River (MI) around 1930. The purpose was to certify clear grades in the approach channels around the Soo Locks. Channel depths swept vary from 27 to 30 feet. The original channel was designed based on a design draft of 25.5 feet. Channels in hard rock areas are cut to 28.0 feet with very little overdredging below that level due to the hard material. Commercial ore carriers will typically load close to the 28.0 foot level. The channels that produce the most dangerous grounding hazards to commercial vessels are those constructed in native bedrock. The next most dangerous channels are those cut through glacial deposits containing boulders. Commercial vessel groundings in other channels constructed in soft material have not proven significant. Vessel loadings are driving the need to clear the channels free of navigation hazards. Vessels typically load to 0.3-foot clearances above the swept clear grade reported by the Corps. Groundings (holings) on commercial vessels have occurred on the west approach to the Soo Locks due to loading too close to the cleared grade.

b. Detroit District sweep rafts. The Detroit District operated four sweep rafts on the Detroit River, St. Claire River, and St. Mary's River. They were wooden rafts or barges 120- to 130-ft-long, with a 15-foot beam and 4-foot draft. The sweep system dragged six, in-line, 21-ft-long by 2.5-inch diameter solid steel bars; each bar weighing approximately 600 lb. This resulted in a clearing swath of some 120-ft (see Figure 12-1). The bars were suspended by a 3/8-inch diameter cable wound on manually operated reels designed to raise and lower the bars by 0.1-ft increments. The bars are suspended along the center of the sweep raft with a 1-ft overlap between adjacent bars.

(1) Three observers were required to monitor the sweep bars--each person responsible for two bars. Concurrent river stage observations are required to continually adjust the depth of the bar. Sweeping is done at a slow speed (slightly greater than drift velocity) in order to keep the bar(s) suspended vertically at the proper depth. Strikes are detected by manual feel of vibration in the cables suspending the bar. When the bar "strikes" a hazard, the position is fixed and the height above grade determined. Individuals monitoring the suspended cables are able to determine the relative hardness and softness of a struck object by feel and sound in the wires. The raft is towed, pushed and maneuvered by a 45-foot harbor tug. The tug requires a two-person crew. The tug was traditionally powered by a 170 HP engine using low power to avoid dragging the head anchor. Control of the sweeping is done using a headwire anchor about 600 feet upstream, as shown in Figure 12-1. The tug drops the anchor, connects to

the tow line, and the sweep pulled downstream to the sweep area while letting out cable. Sweeping is performed with the tug attached to the fixed-length tow line, the sweep and tug held by the anchor to prevent them from going downstream, and pulling the sweep back and forth on the cable. The length of the cable payed out represents the radius of the sweep. Sweeping begins at one side of the channel. The bars are wheeled down and set at depth, corrected for river stage. After each swept arc, an additional 100 ft of cable is payed out downstream and the next arc swept. This provides a 20-foot overlap between successive sweep arcs. Upon completion of sweeping, the cable is picked up onto the drum of the hoist and the anchor brought back aboard.

(2) Horizontal positioning was accomplished using sextant resection from fixed targets along the river bank, and later electronic positioning. For sextant positioning, an "arc chart" of the channel was prepared consisting of two families of constant sextant angle circles. Positions of the beginning and end of the swept arc are determined by sextant resection. When a strike was detected, the resected position from two observed sextant angles could be quickly plotted aboard the sweep raft.

(3) Locations of any snagged obstructions (i.e., strikes above grade) are precisely positioned, and the pinnacle or obstruction elevation is measured by sweeping at successively higher elevations until it is cleared. It is estimated the accuracy of mechanical sweep raft measured elevations is $\pm$ 0.2 feet. A "strike plot" is prepared showing all contacts encountered. Sweep rafts often work in conjunction with a derrick boat or crane barge to remove strikes. A derrick boat clears the strike either by dragging a bar over the area or by blind pattern digging with a clam shell bucket.

(4) The total crew required for a sweep operation was nine persons:

- (1) Party Chief
- (1) Sweep Foreman
- (2) Tug boat operators
- (3) Bar sweep tenders -- "Chairpersons"
- (1) Gage reader (ashore)
- (1) relief

(5) In the mid to late1980s, the Detroit District began using 32-transducer (130-ft) multiple transducer systems to sweep the Detroit River and St. Mary's River. Other districts also once deployed similar bar sweep systems. They too have gone to more efficient multiple transducer and multibeam acoustic methods. Although labor-intensive and slow relative to current acoustic methods, these bar sweep systems provided reliable, certifiable channel clearance verification in rock cut areas.

c. Wire sweeps. Wire sweeping methods were commonly performed by the US Coast & Geodetic Survey for sweeping wide areas, usually in deeper (non-maintained) approaches to navigation projects. Wire sweeps were rarely performed by USACE since they were not considered as reliable as the bar sweep methods described above. The US Lake Survey District last performed wire sweeps at Cleveland Harbor, Lake Erie, in the early 1980s.

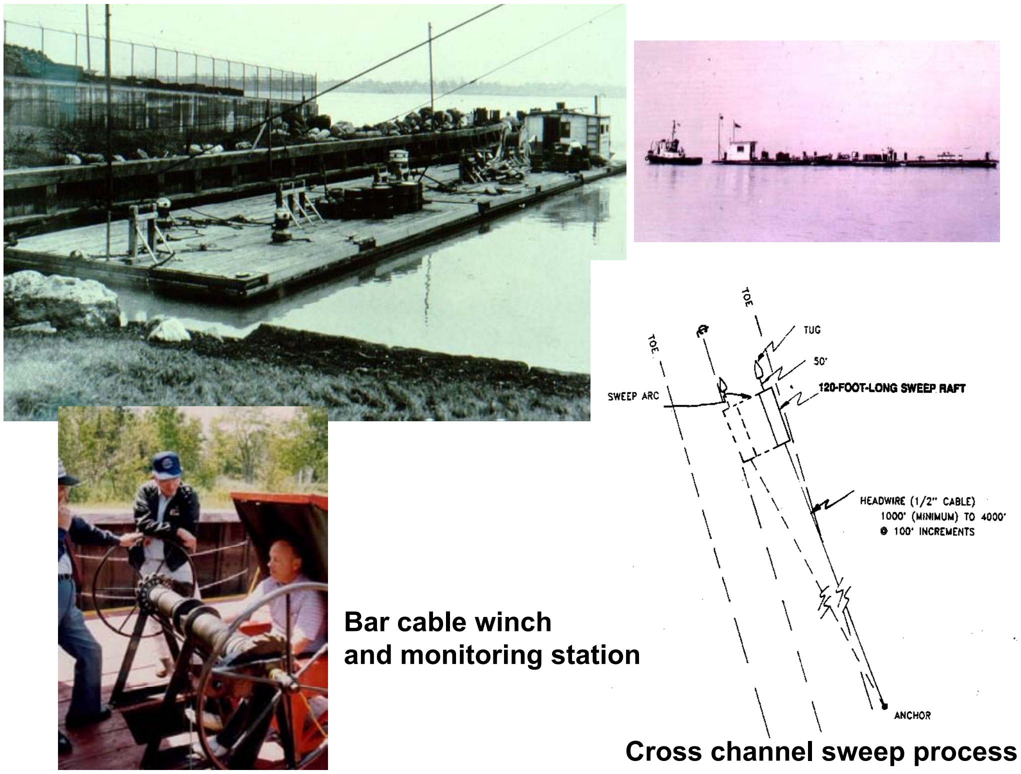


Figure 12-1. 130-Ft Sweep Raft (Detroit District--Soo Area Office)

12-3. Side Scan Sonar

Side scan sonar offers a high-resolution tool that provides a general depictive map on both sides of a survey vessel's path--Figure 12-2. Side scan sonar will not provide absolute elevations of objects; it will, however, provide relative elevations off the surrounding sea floor from which an approximate top elevation may be estimated. Side scan is a practical method for obtaining detailed acoustical pictures of the sea floor called sonographs, usually printed on a paper medium in analog form. Newer systems provide digital side scan records which can be permanently recorded. Digital side scan systems, when coupled with multibeam survey systems, have application in performing precise strike detection surveys or final acceptance surveys in critical navigation channels.

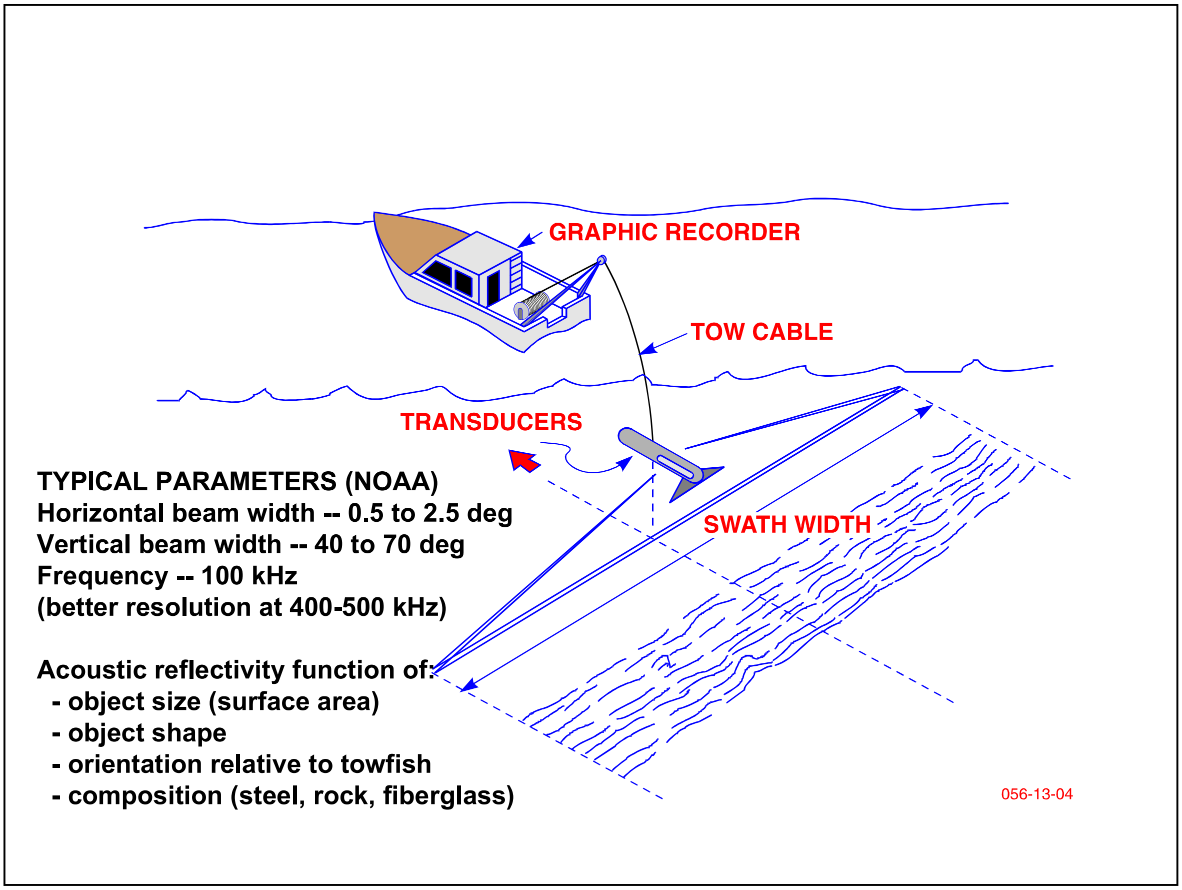


Figure 12-2. Side scan sonar

a. Operating principles. A side scan sonar consists of a recording device, an underwater sensor, and a cable to connect the two. In basic operation, the side scan sonar recorder charges capacitors in the towfish through the tow cable. On command from the recorder this stored power is dumped to the transducers, which emit the acoustic pulse that propagates out through the water. Then over a very short period of time, the returning echoes from the sea floor are received by the transducers, amplified on a time varied gain curve, and transmitted up the tow cable to the recorder. The recorder further processes the signals, digitizes them, calculates the proper position for them in the final record, pixel by pixel, and then prints these echoes on electro-sensitive or thermal paper one scan or line, at a time. The horizontal beam width of side scan sonar is typically between 0.5 and 2.5 degrees. The vertical beam width is between 40 and 70 degrees.

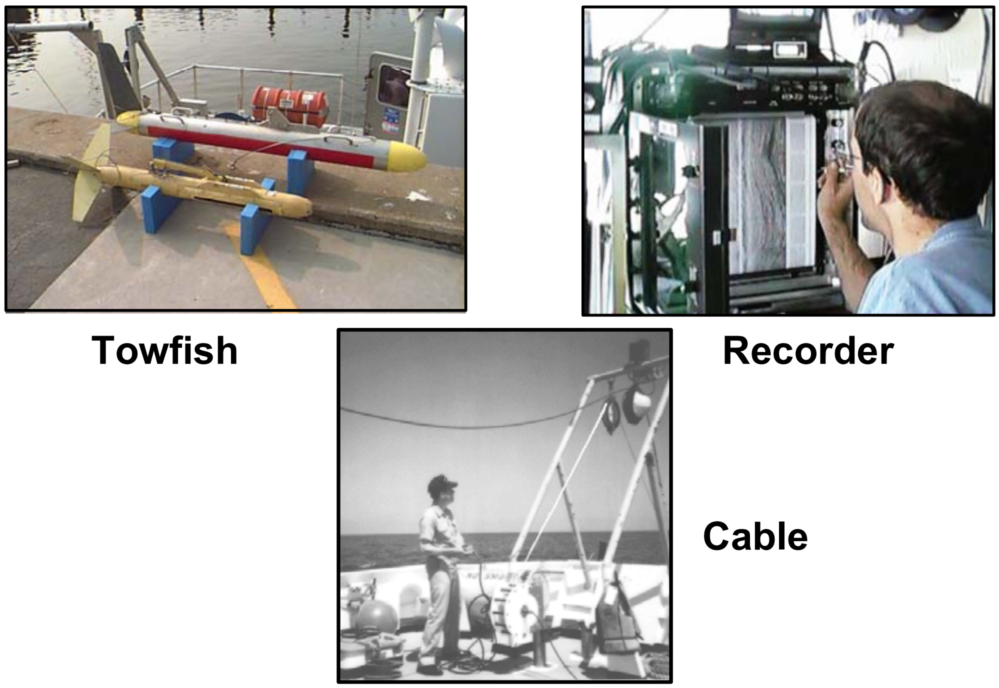


Figure 12-3. Basic components of a side scan sonar (NOAA)

Recording can be analog on a moving paper medium (Figure 12-3), or it can be digital. Digital data collection will permit the application of slant range corrections in order to produce approximate planimetric images, which may be assembled into mosaics to depict large areas of sea floor. Such a system is depicted in Figure 12-4. Digital side scan data files can also be merged with concurrently recorded swath data from a multibeam system.

Figure 12-4. Digital side scan display system (Sea Systems Corporation)

b. Tow height and speed. The quality of the sonar data is often a function of the height of the towfish above the bottom, or bottom targets during a survey or target imaging. In general, with standard sonar configurations, surveys are performed with the towfish positioned a distance above the bottom approximately equivalent to between 8 percent and 20 percent of the range setting of the sonar. If the transducer array is towed high off the seafloor, shadowing will be lessened and target recognition may be reduced. If towed too low, the reflectivity at outer edges will be reduced limiting the effective range of the system. So when the towfish is towed at less than 8 percent above the bottom, the swath width that is considered achieved is reduced. NOAA's "Rule of Thumb": Below 8%, the achieved range = 12.5 x towfish height (m). The towing speed is adjusted such that 3 acoustical hits (pings) are received on an object.

c. Object imagery. The accuracy or ability of the system to detect a given size object is dependent on a number of factors, including the material type, size, and shape of the object, refraction, noise, biological interference, boat wakes, surface reflections, and towfish stability. On a homogeneous bottom type, shadow zones or lighter areas (or darker areas for digital reverse image display) on the sonar record are typically a function of the amount of ensonification an area receives. A shadow zone in front (towards the towfish) of a strong reflector indicates a depression in the sea floor. A shadow zone behind (away from the towfish) of a strong reflector indicates a rise in the sea floor.

d. Object height computation. Approximate heights of an object can be estimated from these shadows--see Figure 12-5. Acoustic reflectivity is a function of the size of the object (surface area presented), the shape of the object, its orientation relative to the towfish, and its composition. Steel or rock are good reflectors. Fiberglass, soft pine, plastics, and rubber are poor reflectors. Usually 200% scanning coverage is required with a side scan range scale set at 100 meters. Confidence checks should be conducted daily to ensure the specified size object is being detected.

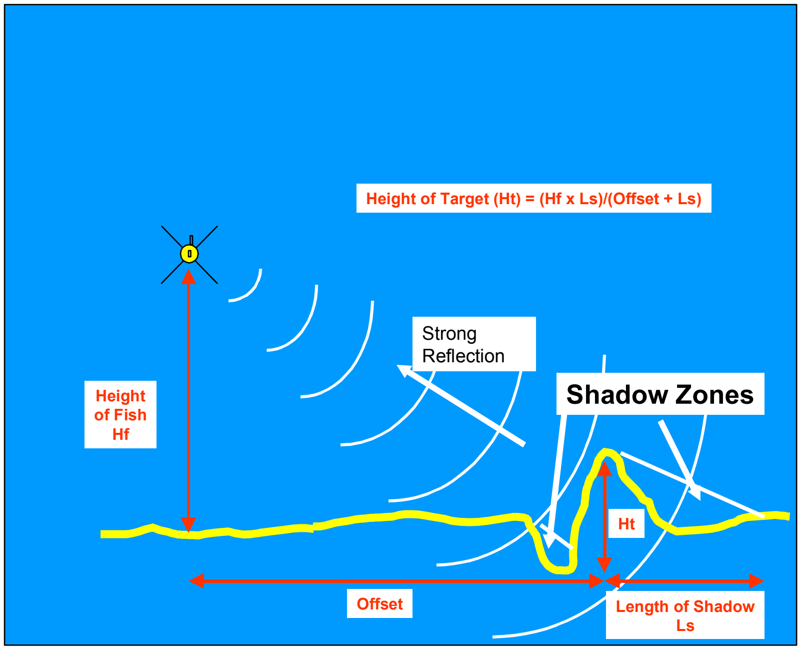


Figure 12-5. Side scan height and contact height computations (NOAA)

e. Object position determination. In order to accurately determine the position of a side scan sonar contact, we need to first determine the position of the vessel, and then translate that position to the towfish. In NOAA, the transducer location is used as the origin for a local coordinate system that is established aboard the vessel. Directions fore and aft are called laybacks, while distances measured from port to starboard (beam to beam) are called offsets. By convention, layback is positive in a direction aft of the transducer, while offsets are positive to starboard (the right). The position of the transducer is computed from the GPS antenna by geometrically combining the antenna's offset and layback coupled with a course-made-good heading of the vessel. Once the position of the towfish is known, the computation for the position of the contact is easy. The contact offset is scaled from the sonar record. In Figure 12-6, the contact has an offset of about 38 meters on a 75-meter range scale--offset is positive to starboard, negative to port. Given the offset from the fish and the vessel's heading, the position of the contact can be computed.

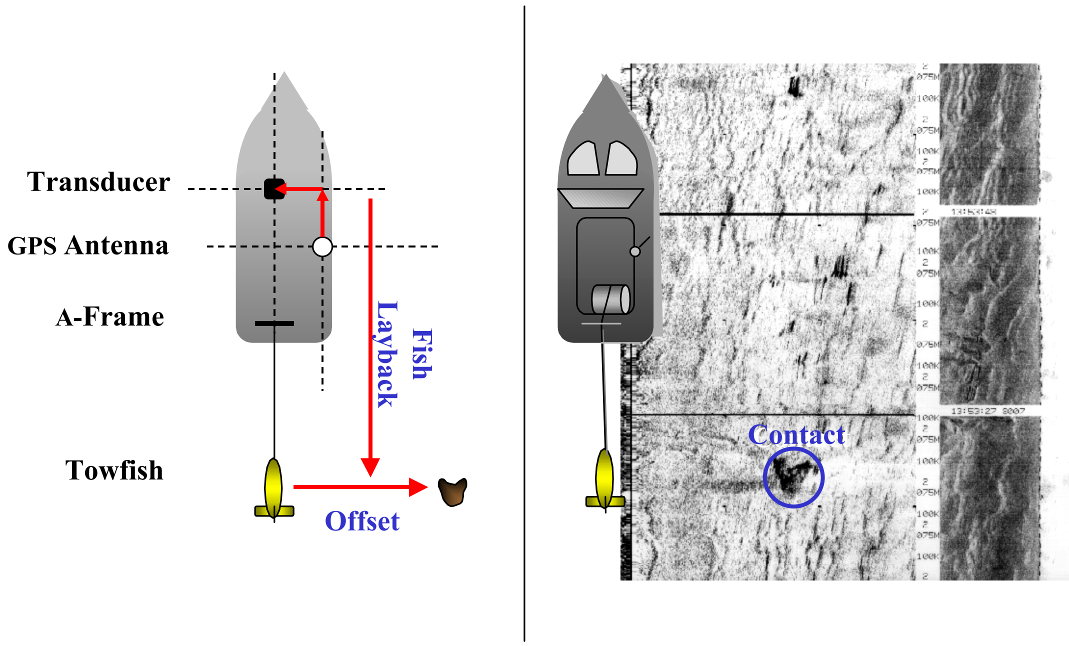


Figure 12-6. Contact position computation (NOAA)

f. Side scan sonar records. In general, there are two types of sonar records. Slant range corrected records show distances as if the bottom were flat as if taken by an aerial photograph. By knowing the fish height above the bottom, the slant range from the fish to the bottom can be rectified. In addition, the recorder paper speed will be adjusted based on the speed of the survey vessel. Therefore, on the paper, 100 meters in the along-track direction will equal 100 meters in the across-track direction. Uncorrected records show the fish height as the first return. True horizontal distances cannot be scaled directly from the sonar record. The image in Figure 12-7 shows small sand waves throughout. These waves rise off the bottom about a meter. A rock is shown with a black mark, signifying a strong return. The white behind the rock is an acoustic shadow. The position of the rock can be determined by scaling the offset (across track distance) off the record. In this case, the rock is about 15 meters to starboard of the towfish track. The shadow height is then scaled in order to determine the height of the object off the bottom. The horizontal black marks across the record are made at a predetermined time interval. This enables the operator to correlate the record with position and depth data. Figure 12-8 depicts computer-generated side scan imagery enhancements that will provide significant detail of bottom objects or sediments.

g. Accuracy. Movement of the fish can cause a degradation of the side scan record. In particular, on a short tow in shallow water, the surface waves affecting the ship can have a coupling effect with the towfish. As it pitches fore and aft, the towfish experiences a similar dampened motion. The rapid accelerations and decelerations of the towfish degrade the sonar record.

- Roll - The rhythmic movement of a ship or tow body along its longitudinal axis.

- Yaw - An instability characterized by the side to side movement of a ship or towed body about its vertical axis

- Heave - The rise and fall of a surface vessel or towfish in a rhythmic movement

- Pitch - An instability in the towfish expressed by the alternate rise and fall of the nose and tail about a horizontal axis.

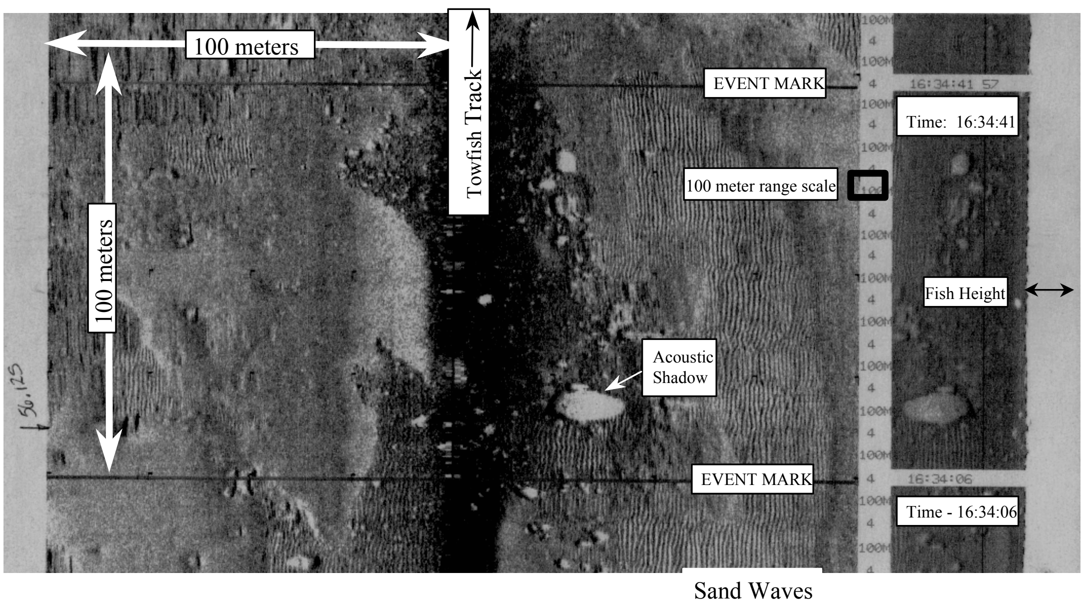


Figure 12-7. Side scan sonar record (NOAA)

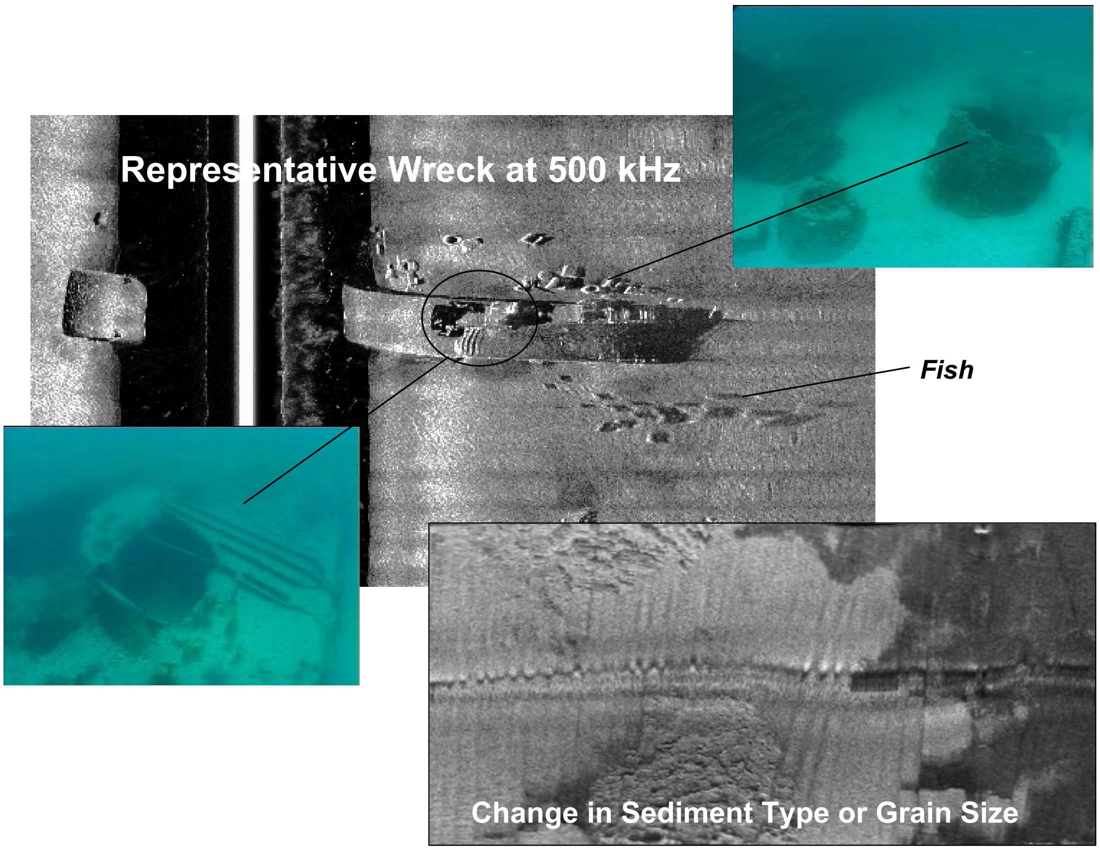
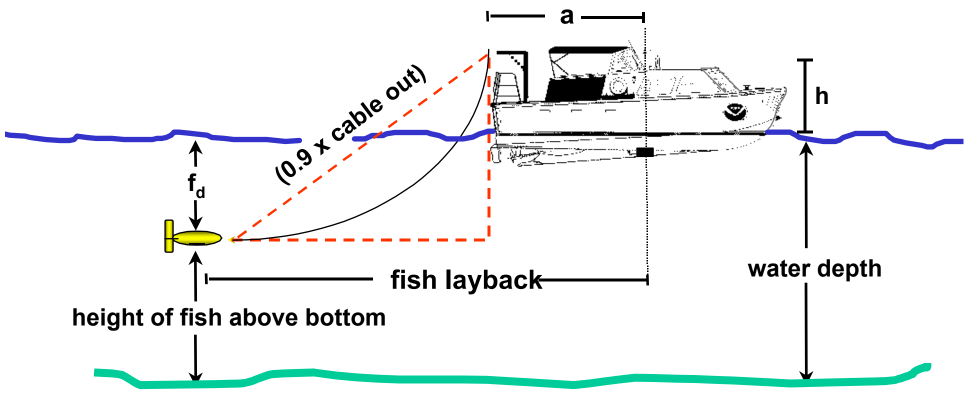


Figure 12-8. Enhanced side scan imagery depicting detailed underwater features (Sea Systems Corporation and OIC GeoDas)

12-4. Side Scan Sonar Survey Specifications (NOAA)

The following paragraphs under this section contain excerpts from side scan specifications developed by NOAA for both internal survey forces and contracted forces. Although they were developed for nautical charting applications, these specifications and standards are directly applicable to side scan survey operations performed by Corps in-house or contract crews on USACE navigation and dredging projects. Bracketed areas relate to project-specific information.

a. General Requirements. Side scan sonar shall be used to locate obstructions and a shallow water multibeam sonar system shall be used to determine the least depth over the obstructions. Side scan sonar data shall be collected over the channel areas indicated on the drawing at [___________], which is identical to that required for multibeam coverage. The Contractor shall acquire digital side scan sonar data using a towed system. The side scan sonar system shall be operated with a maximum range scale of 100 meters and with a towfish height above the bottom of 8% to 20% of the range scale in use--see Figure 12-9. The side scan sonar data shall be horizontally referenced to [NAD 27] [NAD 83].



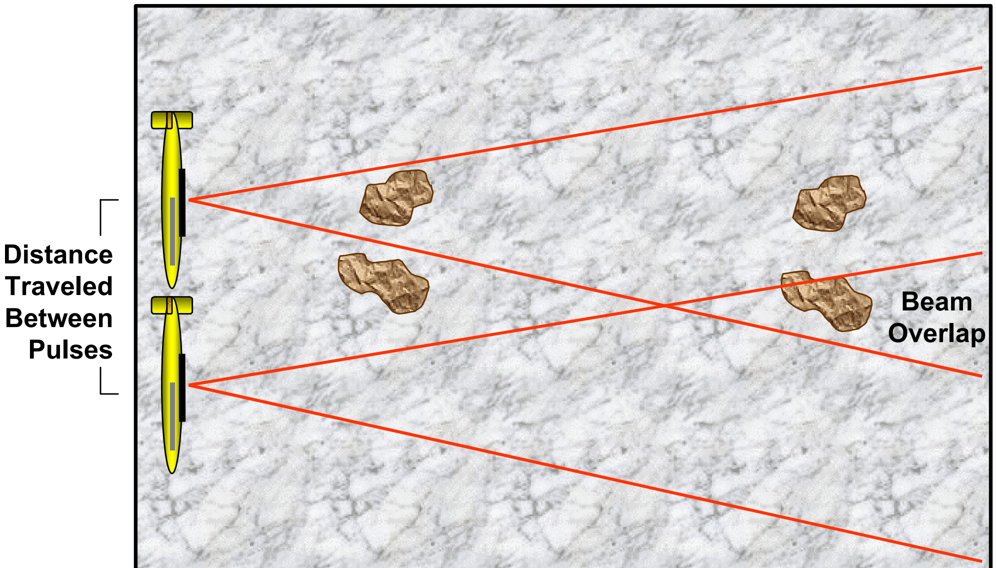
$$\text{fish layback} = a + \text{sqrt}\left[(0.9 \times \text{cable out})^2 - (h + f_d)^2 \right]$$

where a = layback of A-frame from echo sounder transducer
h = height of cable block on A-frame above waterline
f_d = depth of side scan sonar fish = water depth - height of fish above bottom

Figure 12-9. Height and position determination of towfish (NOAA)

b. Accuracy. The side scan sonar system shall be operated in such a manner that it is capable of detecting an object that measures [0.5] [1.0] meter cube from shadow length measurements.

c. Towing Speed. Since the sonar is pulsing at a fixed rate based on its range scale, the speed that the towfish is being towed will have an affect on the ability to resolve items. In general, the slower the fish is towed the more definition is obtained. The side scan sonar shall be towed at a speed such that a detected object in the channel would receive a minimum of three pings per pass. The required towing speed may be computed as shown in Figure 12-10.



Maximum speed (meters/second) = Target size (meters) x prr/3 (second^{-1})
where: prr = pulse repetition rate = reciprocal of pulse period
knots = meters/second x 1.9
For example:
For a 100-meter range scale with 7.5 pulses/sec
Maximum vessel speed = 4.8 knots
For a 150-meter range scale with 5 pulses/sec
Maximum vessel speed = 3.2 knots

Figure 12-10. Determining towing speed for side scan sonar (NOAA)

d. Coverage. The scanning coverage shall be 200%. "Scanning coverage" is the concept used to describe the extent to which the bottom has been covered by side scan sonar swaths, that is, the band of sea bottom which is ensonified and recorded on the side scan sonar record along a single vessel track line. Trackline spacing shall be reduced from the maximum if the quality of the side scan sonar records deteriorate, i.e., record does not show features in the outer edges of the swath. For hydrographic purposes, scanning coverage of an area is expressed as multiples of 100%, and is cumulative. One-hundred percent coverage causes an area to be ensonified once, with a small overlapping area between adjacent swaths that is ensonified twice. For example, if a region of the bottom is ensonified twice, coverage of that region is said to be 200%. Approved 200% coverage techniques are as follows:

(1) Technique 1. Conduct a single survey wherein the vessel track lines are separated by one-half the distance required for 100% coverage.

(2) Technique 2. Conduct two separate 100% coverages wherein the vessel track lines during the second coverage split the distance between the track lines of the first coverage. Final track line spacing using this technique is essentially the same as Technique 1. The advantage of this method is that areas are viewed at different parts of the range scale for each run. (The ability to distinguish targets directly under the fish and at short ranges is difficult. This method ensures an area is covered other than directly under the fish.) The disadvantage is that an obstruction with a narrow east/west aspect could be undetected.

(3) Technique 3. Conduct two separate 100% coverages in orthogonal directions. This method allows contacts to be ensonified from two different aspects. Also, depending on weather conditions, a vessel course can be selected to obtain the best return from the sonar. The disadvantage is that some areas have only been ensonified with the fish directly overhead.

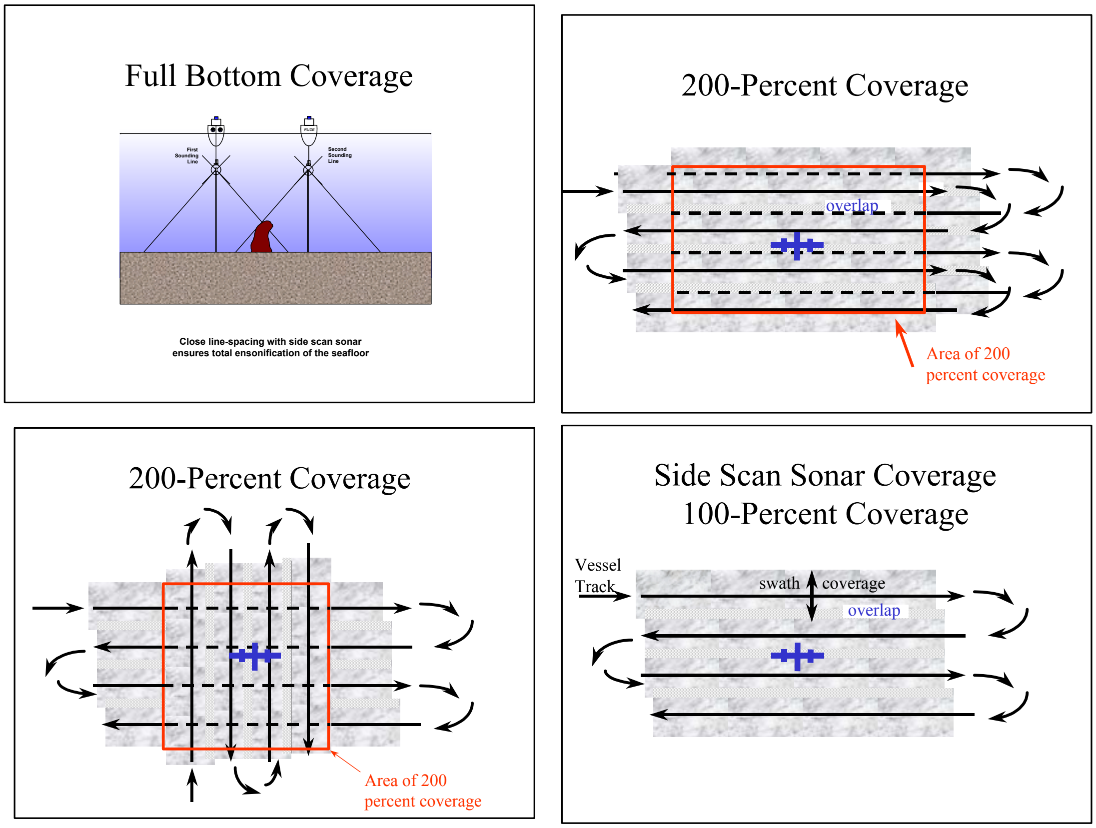


Figure 12-11. Side scan coverage (NOAA)

Figure 12-11 shows a plan view of a side scan sonar search area. The object in the middle is a cartographic symbol signifying the submerged wreck that is being searched for. The dark lines with arrows represent the vessel trackline. On the 100% coverage sketch, the search was conducted by running east-west lines. The side scan sonar ensonifies an area to the north and south of the vessel trackline. The line spacing may be computed as follows:

Image-correcting:
Recommended Line Spacing = (2 x RS) - 40 meters

Non-correcting:
Recommended Line Spacing = (2 x RS) - 40 meters - (0.05 x RS)

where RS = range scale (i.e., 100 or 150 m) *e. Quality Control.*

(1) Confidence Checks. Confidence checks of the side scan sonar system shall be conducted at least once daily. These checks should be accomplished at the outer limits of the range scales being used based on a target near or on the bottom. Each sonar channel (i.e. port and starboard channels) shall be checked to verify proper system tuning and operation. Confidence checks can be made on any discrete object, offshore structure, or bottom feature that is convenient or incidental to the survey area. Targets can include wrecks, offshore structures, navigation buoy moorings, distinct trawl scours or sand ripples. Confidence checks can be made during the course of survey operations by noting the check feature on the sonargram. If a convenient or incidental target is not available, a known target may be placed on or near the bottom and used for confidence checks. Confidence checks shall be an integral part of the daily side scan sonar operation and shall be annotated in the side scan sonar data records.

(2) Significant Contacts. Contacts with computed target heights (based on side scan sonar shadow lengths) of at least [0.5] [1.0] meter should be considered "significant." Other contacts without shadows may also be considered "significant" if the sonargram signature (e.g., size, shape, or pattern qualities) is notable.

(3) Correlate with Multibeam Data. The Contractor shall examine the multibeam data and correlate anomalous features or soundings with the side scan sonar data. The contractor shall examine and correlate targets between successive side scan sonar coverages (i.e., compare the first 100% with the second 100% sonar coverage). Anomalous features or targets which appear consistently and correlate in each type of data record provide increased confidence that acquisition systems are working correctly and help to confirm the existence of these features or targets. The Contractor shall cross reference and remark on each target correlation in the Remarks column of the Side Scan Sonar Contact List.

(4) Identification of Potential Field Examinations. The Contractor shall use the sonar contact list, in conjunction with an analysis of multibeam least depths, to identify hydrographic features which may require further examination. The contractor shall make recommendations for additional field examinations that are deemed necessary to establish survey completion.

f. Side Scan Sonar Contact List and Coverage Plot. The contractor shall produce a separate sonar coverage plot for each 100% side scan coverage. This provides a graphic means for documenting that the effective scanning swath from each search track sufficiently overlaps the effective scanning swath from adjacent tracks.

(1) Contact List. The Sonar Contact List is compiled manually using a form or as the output of an automated listing device. An acceptable method is described below. The column entries required on the Sonar Contact List are the specific elements of information which the Hydrographer needs to prepare the preliminary Sonar Contact Plot. The various column entries are described below, along with a brief discussion of how each is to be derived.

Column 1. Search Track Number - identifies the particular search track from which the contact was observed.

Column 2. Contact Number - uniquely identifies the contact. An example of a contact number is a number based on the date/time the contact was observed, followed by a letter indicating the port or starboard (P or S) channel; i.e., if a port-side contact is observed on day 181 at 150125, the contact number will be 181/150125P. Using signed (+ or -) contact range in column 4 eliminates the need for the P or S indicator.

Column 3. Towfish Layback - the approximate distance in meters from the positioning system antenna to the towfish. Unless computed by an automated system, the towfish may be assumed to be directly astern of the towing vessel and on the search track.

Column 4. Contact Range - the horizontal distance from the towfish track to the contact, expressed in meters. All ranges scaled from the sonargram are slant ranges for standard sonars, true ranges for image-correcting sonars. True ranges are obtained from slant-range information by geometric corrections using the Pythagorean Theorem.

Column 5. Contact Position - the preliminary position as determined by reconstruction of the vessel position, towfish layback, towfish position, port or starboard channel, and contact range at the time the contact was observed. The Contact Position shall be stated as a latitude/longitude.

Column 6. Estimate of contact height computed from range and shadow length.

Column 7. Remarks - used to denote first impressions of the contact's identity (wreck, rock, etc.), or to make any comments deemed appropriate. If after examining the records and correlating targets from overlapping coverage the Hydrographer determines that a contact does not warrant further investigation, it shall be noted as such. A brief statement of the reasons must be made. This determination should not be made until all numbered contacts are plotted on a preliminary Sonar Contact Plot. Any abbreviations should be defined on the list.

Column 8. Comparison with shallow water multibeam data - used to note the corresponding shallow water multibeam data (day/time, line number, etc.), the results of comparing the side scan sonar data with the multibeam data (e.g., contact did not appear in the multibeam data, SWMB least depth = x.x - SSS least depth = y.y), and the type of multibeam coverage (i.e., center beams or reconnaissance beams).

Column 9. Contact is depicted on a drawing [file] - yes/no.

Once added to the list, a contact should never be removed. If after further processing a contact is deemed not significant by the hydrographer, it shall be labeled as such in column 7. The contact list, and any subsequent field examination lists and records developed from the contact list, shall be included with the data submission in both hard copy and digital forms.

(2) Contact Plot. The Contact Plot will show the position of all significant contacts entered on the Sonar Contact List. Only "significant" contacts, along with the views from adjacent lines, need to be plotted on the Sonar Contact Plot. In some areas, "significant" contacts may be clustered (e.g., debris, boulder fields). Such an area may lend itself to being depicted as a single feature with least depth(s). Only the most significant contact(s) in the group needs least depth(s) and position(s) determined.

g. Sonargrams. If sonargrams are recorded, annotation of the sonargram while on-line is mandatory during all side scan sonar operations. All annotations shall be made in the margins of the sonargram so that no portion of the trace is unduly obscured. Time references shall be made in Coordinated Universal Time (UTC). Additional annotations will be added during contractor processing. Note: If sonar data is supplied in digital format only, the digital data needs to be similarly annotated.

(1) Header Annotations. Header annotations are required to identify the sonar work and for ease of later reference. Header annotations are:

1) Registry number
2) Item number (AWOIS, if applicable)
3) Day of year and calendar date
4) Towing vessel
5) Tow Point

Header annotations shall be made:

1) at the beginning of a new paper roll,

2) at the beginning of each day's work (for 24-hour operations, these annotations shall be made at the beginning of the first complete track of the new day),

3) when there is a change in the towing configuration during a day's operation.

(2) System-Status Annotations. System-status annotations are required to describe the recorder settings and the towing situation. System-status annotations are:

1) mode of tuning (manual or auto)
2) range-scale setting
3) paper-speed setting
4) left and right channel recorder settings
5) operator's initials
6) length of tow-cable deployed (tow point to towfish)
7) depressor in use (yes or no)
8) weather and sea conditions

System-status annotations shall be made:

1) prior to obtaining the first position of the day,

2) prior to obtaining the first position on a new paper roll,

3) at any time the recorder has been switched off and then back on,

4) while on-line, approximately every hour, regardless of any changes made.

(3) First Position/Last Position Annotations. The following annotations shall be made at the first position on each search track:

1) Line begins (LB) or Line Resumes (LR)
2) tow-vessel heading (degrees true or magnetic)
3) towing speed (engine rpm, and pitch if applicable)
4) index number and time (at event mark)

The following annotations shall be made at the last position on each search track:

1) Line turns (LTRA, LTLA), Line breaks (LBKS), or Line ends (LE)

2) index number and time (at event mark)

(4) Special Annotations. The occurrence of any of the following events shall be annotated on the sonargram margin at, or as soon after as possible, the time the event occurs:

1) new index number (at event mark)
2) change in operator (new initials)
3) change in range-scale setting
4) change in paper-speed setting
5) confidence checks
6) individual changes to recorder channel settings
7) change in tow-cable length (tow point to towfish)
8) change in towing speed (engine rpm and pitch) or vessel heading
9) change in tow point
10) significant contact observed (flag using an arrow)
11) surface phenomenon observed (wakes, passing vessels, etc.)
12) passes by buoys or other known features within sonar range
13) interference (state source if known)
14) time corresponding to the index marker.

The Hydrographer shall make any other annotations necessary to note any occurrence that may later serve to reconstruct the operation. Too much information is always better than not enough.

(5) Annotation Methods. Header and system-status annotations may be made using any of the following methods:

1) freehand on the sonargram,
2) by use of a stamp,
3) by use of an automatic annotator, if available.

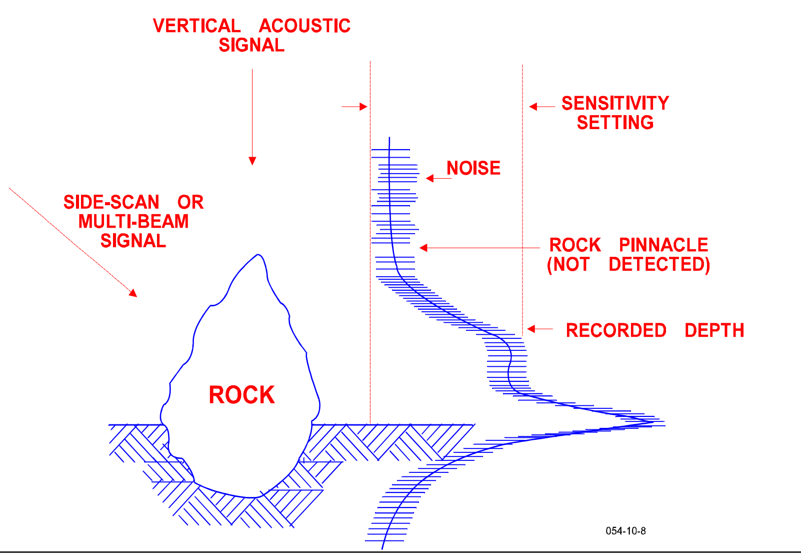
The method is left to the Hydrographer's discretion, but should be used consistently throughout the operation.

h. Side Scan Sonar Data Format and Media. [The Government] will review the side scan data on an Aspen workstation running the Unix version of CARIS SIPS (version 4.2.7, by Universal Systems LTD). Therefore, all side scan data shall be submitted on 4 mm or 8 mm tape, such that, the data can be loaded directly onto the workstation and viewed using CARIS SIPS. The contractor shall include a file listing of each tape, describe the archiving method used, and shall work with the Government to ensure no compatibility problems exist after data submission.

i. Final report of contacts. If a final survey report is required then side scan sonar operations should be included. Identify the manufacturer, model, and serial number of all side scan sonar equipment used. State the vertical beam width used and depression angle, if adjustable. State the frequency used (for example, 100 or 500 kHz). Briefly describe the operations. Include range scales, depths of water, standard line spacing, and point of deployment (bow, stern, or beam). Describe the methods and frequency of confidence checks. The percentage of area coverage (normally 100 or 200) obtained by the swaths should be noted. Where necessary, factors affecting data quality, such as towfish stability, signal interference, degraded returns due to thermoclines, and clutter, should be addressed. A discussion of side scan sonar work devoted exclusively to item investigation is not necessary in this section if the information is included in the Item Investigation Report, or an equivalent form, filed with the survey data. Methods and standards used to examine sonar records should be noted and a brief description of processing procedures should be provided. Two examples of topics include the methods for establishing proof of coverage and the criteria for selecting contacts.

12-5. Channel Obstructions

Once an obstruction is detected from routine hydrographic surveys or other reports, a special survey is performed to determine its precise horizontal and vertical extent. The horizontal detection and mapping can be done by a variety of methods, but perhaps the best technique to help identify an obstruction is side scan sonar coupled with multibeam acoustic swath survey systems. Reciprocal headings past the target can provide average coordinates within 20 ft to 30 ft of the true obstruction location using DGPS code phase positioning. Divers can easily find targets at this accuracy provided a buoy can be deployed this close. Side scan can also locate the diver over the target by observing the trace of the air bubble reflections in the side scan record. The safety of the divers must be ensured with this procedure. Following a positive location, divers usually move the buoy sinker to the target for more precise horizontal positioning by a survey vessel. The new location of the marker buoy may be plumbed over the survey vessel bow and marked with an event from the navigation system. The improved horizontal coordinate is obtained from the vessel heading, magnetic declination, and distance to the bow from the antenna. In the vertical, the pinnacle elevation is most accurately determined by a bar sweep. Further elevations can be obtained by other high-resolution sensing equipment or physical inspection by diver. Targeted obstructions or objects can be removed or cleared by dredging, blasting, or recovery. Stealth-like objects, such as rock shards remaining after blasting, may be difficult to detect with standard, vertically-mounted, single-beam survey echo sounders. The return energy is buried within the noise level and sensitivity adjustments are not capable of distinguishing the object from the noise--see Figure 12-12. Very little of the pinnacled object is capable of reflecting sonic energy back to the transducer. However, there is a greater degree of side reflection if a side scan or multibeam system is used.



- Insufficient Energy Is Returned From Small Pinnacle
- Side-looking Sonar Or Multibeam Will View More Surface Area

Figure 12-12. Acoustic return from a stealth-like object

Multibeam and side scan imagery can be used to enhance the detection of underwater objects. This is illustrated in Figure 12-13 where an object is detected by both the multibeam array and the side scan imagery. The side scan imagery can also be overlayed onto the bathymetric data set, as illustrated in Figure 12-14.

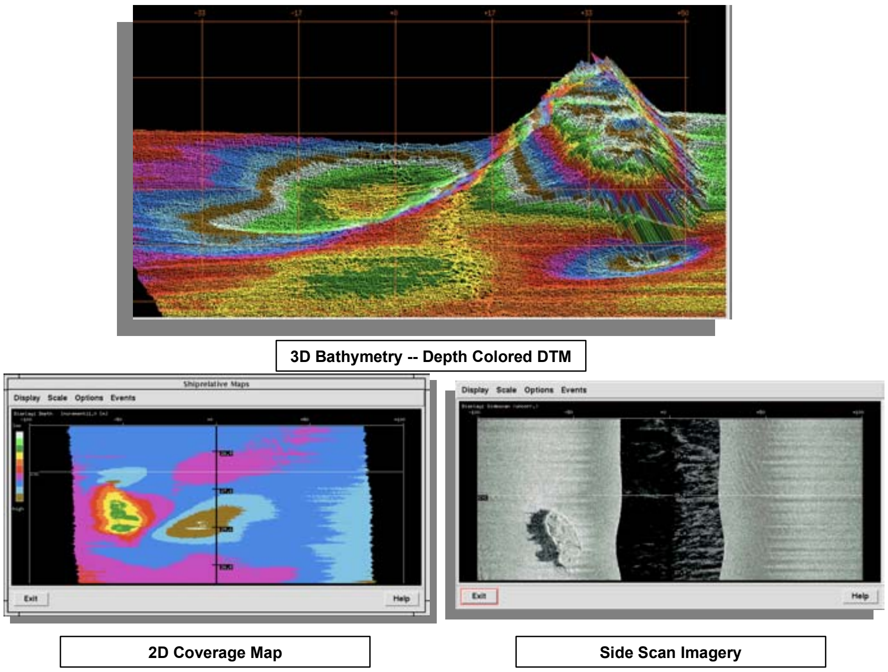


Figure 12-13. Combined Odom Echoscan multibeam and side scan imagery (Odom Hydrographic Systems)

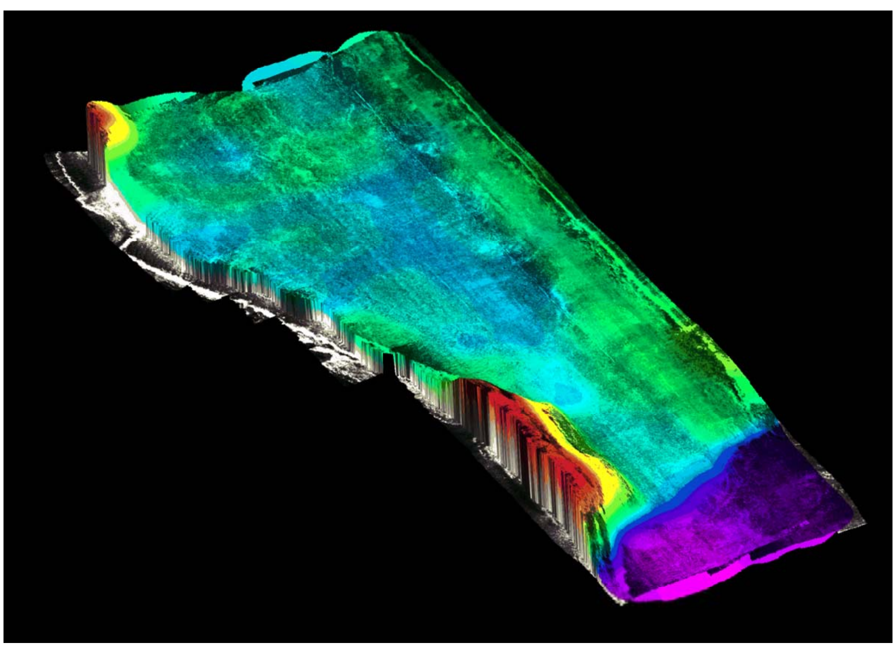


Figure 12-14. 3-D multibeam bathymetry with side scan imagery overlay (Odom Hydrographic Systems)

12-6. Magnetometer Surveys

Detection of ferromagnetic objects near the sea floor is possible through the measurement of magnetic anomalies with a magnetometer. Typical applications include detection of sunken ships, pipelines, communication cables, and other items that could hinder navigation or use of the sea floor.

a. Magnetometers are relatively simple to operate. The sensor head is towed behind the survey vessel at a distance of several boat lengths. If operations are conducted in shallow water, a buoy may be attached to the fish to prevent sinkage and to keep it at a consistent depth. Output on shipboard is real time in the form of a single line scribed on a strip chart. A variation in the line's position is an indication of the nearby presence of ferrous objects.

b. Magnetometers may be operated in towed pairs, termed gradiometers, which will measure the rate of change of magnetic lines, permitting approximate positioning of magnetic features on the bottom. Tow cables should be long enough to place the survey ship at sufficient distance so it will not affect readings.

12-7. Quality Control and Quality Assurance Criteria

Table 12-1. Quality Control and Quality Assurance Criteria for Side Scan Surveys

	PROJECT CLASSIFICATION		
	Navigation & Dredging Support Surveys		Other General Surveys & Studies
	Bottom Material Classification		
	Hard	Soft	(Recommended)
RECOMMENDED COVERAGE	200%	100%	100%
REQUIRED ACOUSTIC HITS	3 minimum	3	3
QA PERFORMANCE TEST	1/day	1/day	1/day

12-8. Mandatory Requirements

The criteria in Table 12-1 are considered mandatory.

Chapter 13
Airborne LIDAR Hydrographic Surveying

13-1. Introduction: Summary of Technology

This chapter provides an overview on airborne hydrographic survey methods currently employed by the Mobile District.

a. The Scanning Hydrographic Operational Airborne LIDAR Survey (SHOALS) system was developed by USACE and has demonstrated the ability to achieve orders of magnitude increase in survey speed while collecting densely spaced high resolution data. The term LIDAR stands for LIght Detection And Ranging. The USACE accepted the SHOALS system in March 1994 following field testing which indicated that the system met or exceeded all design specifications. Since then, SHOALS has surveyed a wide range of Corps projects from navigation and shore protection, to coastal structure evaluation, and emergency response operations. SHOALS has also performed several missions for the National Oceanic and Atmospheric Administration (NOAA), as well as the US Navy with projects varying from coral-reef damage assessment to nautical charting of international waters.

Figure 13-1. SHOALS field data collection and processing system

b. SHOALS is a fully operational bathymetric survey system capable of surveying a variety of project types. SHOALS operates from the Joint Airborne LIDAR Bathymetry Technical Center of Expertise (JALBTCX), which is headquartered at US Army Engineer District (USAED), Mobile. The

JALBTCX mission is to operate the SHOALS system and to develop new products and applications. Additional goals for the JALBTCX include expansion of mapping and charting capabilities and the fusion of LIDAR bathymetry with auxiliary sensors such as multi-spectral imaging systems and Synthetic Aperture Radar (SAR).

13-2. Operating Principle

SHOALS consists of an airborne data collection system and a ground-based data processing system (Figure 13-1). The system operates by emitting laser pulses 400 times per second while being scanned in a 180 deg arc pattern across the flight path of the airborne platform (Figure 13-2), which can be a helicopter or fixed-wing aircraft. Each laser pulse travels from the airborne transmitter to the water where some light energy is reflected and detected by onboard optical sensors. The remaining light passes through the water column, reflects from the sea bottom, and returns to the optical sensors as illustrated in Figure 13-2 (Guenther, Thomas, and LaRocque, 1996). The time difference between the water-surface and sea-bottom returns indicates the water depth. Operating from an airborne platform at an altitude of 300 to 500 m and a speed of up to 70 m/s allows the ability to provide depth measurements on a 4 to 8 m horizontal grid and covering up to 35 km^2 per hour. Sounding densities can be adjusted by flying higher or lower, at different speeds, or by selecting different scan widths.

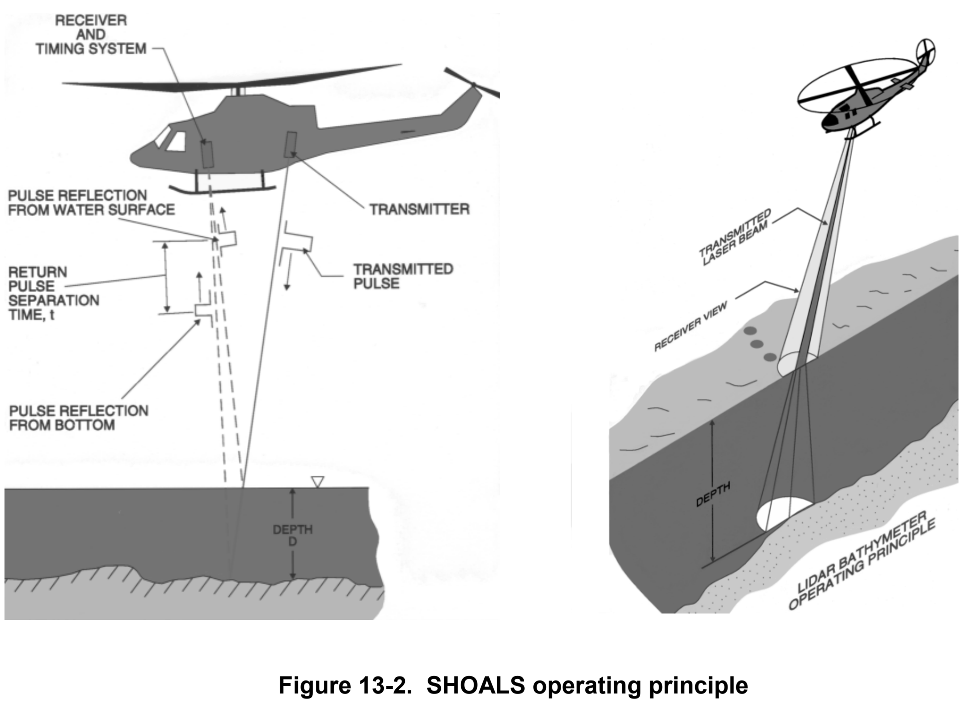


Figure 13-2. SHOALS operating principle

13-3. Typical Survey Products

SHOALS produces high density measurements that can be used for creating three dimensional digital elevation models from which navigation and shore protection projects can be monitored and managed. This is a unique product that allows the USACE engineers the ability to manage sediment on a regional scale rather than on a project by project basis. Typical products include: a) metadata file for compliance with the FGDC requirements, b) plan view engineering drawings of the entire survey area consisting of contour maps with elevation points for data review at a customer specified scale, c) information and references pertaining to the SHOALS system, d) digital corrected survey data files on CD-ROM composed of ASCII XYZ files containing all the data for the entire survey area and corrected to a designated local vertical and horizontal datum, and e) geo-referenced color video of the surveyed sites.

13-4. System Characteristics, Performance Specifications, and Accuracy

a. Accuracy and data quality meet or exceed all USACE and International Hydrographic Organization (IHO) Order 1 standards. Through independent testing both the National Oceanographic Service (NOS) (Riley, 1995) and US Navy have verified that SHOALS meets the IHO accuracy standards for nautical charting; the IHO being the organization that sets these standards. Canada, Sweden, Australia and private industry have similar airborne LIDAR systems that are being used for nautical charting surveys. In addition, the USACE has conducted extensive field tests to determine that SHOALS meets its accuracy requirements for navigation surveys, which are more stringent than the charting standards set forth by IHO (Lillycrop et al., 1994). The performance characteristics and accuracy specifications are shown in
Table 13-1.

b. In response to USACE increased needs to map beaches, dunes, and above-water structures, SHOALS was enhanced with the capability to utilize kinematic GPS (KGPS). Since the need to use water surface as a vertical reference is eliminated, KGPS allows more extensive measurements of beaches and dunes. With the ability to collect both hydrographic and above water survey data, SHOALS can simultaneously conduct complete navigation and shore protection project surveys. Data acquired by SHOALS is being used to generate channel condition reports, beach profiles, cross sections, and contours, perform volumetric analysis, and create complete 3-D digital elevation models of Federal projects and their adjacent regions.

Table 13-1. SHOALS Specifications and Standards

	PROJECT CLASSIFICATION		
	Navigation & Dredging Support Surveys Bottom Material Classification		Other General Surveys & Studies
SURVEY PARAMETER	Hard	Soft	
DEPTH MEASUREMENT SPACING	3 m	4 m	8 m
FLIGHTLINE OVERLAP	25%	25%	20%
CROSS LINE CHECKS	2 per flightline	2 per flightline	2 per flightline
MAXIMUM DEPTH	40 meters or 2 to 3 times Secchi depth		
VERTICAL ACCURACY	$\pm$ 15 cm (1-sigma)		
HORIZONTAL ACCURACY	$\pm$ 3 meters (1-sigma)		
SOUNDING DENSITY	4 to 8 meter grid … variable		
OPERATING ALTITUDE	300 TO 500 meters … variable		
SCAN SWATH WIDTH	150 to 250 meters … variable		
OPERATING SPEED	up to 135 knots (approximately 70 m/s)		
PLATFORM	Helicopter or Fixed-wing aircraft		

13-5. System Constraint

This technology is capable of rapidly collecting dense survey data over large areas. However, the main constraint of any LIDAR bathymeter is water clarity. In clear waters SHOALS is effective to about 60 meter depths. In less clear waters SHOALS is successful to depths of 2 to 3 times the visible depth, as measured by a simple device called a Secchi disk. LIDAR bathymetry systems should not be considered for areas with chronic high turbidity. There are locations where airborne LIDAR bathymeters cannot operate at certain times and/or conditions due to water clarity. However, this can many times be mitigated with proper planning and operations in a particular region when water clarity is optimal. To assure the highest possible data quality, certain quality control criteria have been established for SHOALS surveys and are presented in Table 13-3.

13-6. SHOALS System

SHOALS is comprised of two sub-systems: the airborne and ground-based data processing sub-systems. The airborne sub-system operates from a Bell 212 helicopter or DeHaviland Twin Otter fixed-wing aircraft (or equivalent) and performs the task of primary data acquisition. The ground-based data processing extracts an accurate water depth or elevation from each laser sounding and matches it with a horizontal position.

13-7. Platforms

SHOALS was originally developed to be installed and operated on a Bell 212 Helicopter. The helicopter platform provides a high degree of maneuverability and flight speeds while surveying coastal projects. SHOALS was later modified to fit into a Twin Otter DHC-6 fixed-wing or similar type of aircraft. Although giving up some of the inherent maneuverability of a helicopter, a fixed-wing provides a greater travel range to and from projects and allows more time in the air collecting data. On large, remote projects, a fixed-wing aircraft provides the ability to fly farther, high, and faster, thus, covering larger areas over a shorter period of time while maintaining the high data resolution.

13-8. Airborne System

The airborne sub-system is divided into three components (Lillycrop and Banic, 1993): Transceiver (TRS), Airborne Positioning and Auxiliary Sensors (APASS), and Acquisition, Control and Display (ACDS).

a. The Transceiver (TRS) consists of the laser, scanner, and receiver. The function of the TRS is to transmit laser pulses in a defined scan pattern and receive backscattered energy from these pulses to produce laser depth soundings and aircraft altitude information. The laser is a 400 Hz, Nd:YAG operating at a wavelength of 1064 nm (infrared) and frequency doubled to 532 nm (green). The laser backscatter energy (surface and bottom energy) is collected by a 20-cm catdioptric Cassegrain telescope and split into two green channels, two infrared (IR) channels, and a red channel at the water Raman wavelength (645 nm) (Guenther, Thomas, and LaRocque, 1996). Outputs from the two green channels, the main IR channels, and the Raman channel are digitized and time tagged along with various other system outputs and recorded on a high density, 8-mm magnetic tapes for post-flight data processing and depth calculation. One green channel senses light returning from depths greater than about 7-m and the other green channel senses heights above the water to a maximum of 12-m. The infrared and raman channels are used to detect the water surface. The fifth channel (infrared) is used to perform real-time discrimination between water and land. TRS also includes a real-time depth algorithm which provides and displays approximate depths to the airborne operator, which permits a first line of quality control and allows the operator to make in-flight decisions concerning mission activities such as the need to alter flight parameters to optimize coverage, refly a line, or move to a different area.

b. The Aircraft Positioning and Auxiliary Sensors (APASS) functions are to collect information from the Global Positioning System (GPS), inertial reference system, and to provide a video image of the area being scanned. Horizontal positioning for the SHOALS system is provided by the Global Positioning System and the inertial navigation system (Litton LTN-90), which provides aircraft attitude, including roll, pitch, heading, and vertical acceleration. Included as an auxiliary sensor is a video camera to record digitally annotated imagery of the area being scanned by the laser. A video frame at the time of any sounding can be viewed to help with the interpretation of any anomalies.

(1) Differential GPS (DGPS). For each depth sounding, SHOALS typically obtains horizontal position of the aircraft from differential GPS (DGPS) while vertical position is directly correlated with measured water-surface locations. Measurements consist of GPS horizontal corrections down loaded from the US Coast Guard Beacon System or the Omni Star satellite system. During DGPS survey operations SHOALS uses the water surface as a reference plane, therefore, in order to reduce the data to a common vertical datum such as NGVD, MLLW, etc., it is necessary to obtain tidal or water level heights during the time of the survey. In response to USACE needs to map not just the nearshore, but also beaches, dunes, and above-water structures, SHOALS was modified to extract topographic elevations in conjunction with water depths. In DGPS mode elevation measurements are vertically referenced to the water surface and land measurements can only be collected if half of the survey swath is over the water or within 50m of the waterline.

(2) Kinematic GPS (KGPS). A further enhancement to the SHOALS system is the implementation of KGPS. This permits the precise 3-D positioning of the aircraft with respect to the ellipsoid to be determined to within several centimeters while the vertical distance from the aircraft to the sea bottom is measured simultaneously. This capability permits depths to be determined without wave and water level corrections. In fact, the use KGPS provides the capability to collect topographic survey data without the presence of a water surface.

(3) Aircraft Motion Compensation. To ensure a consistent survey swath and to correct for various other sources of error, compensation for aircraft motion is required. This information is provided by the system's Inertial Reference System (IRS) which is a Litton LTN-90. The main function of the IRS is to measure the attitude angles of the LIDAR sensor and to provide vertical acceleration data. The IRS generates digital outputs of altitude, heading, position, angular rates and linear accelerations, ground speed and track, horizontal and vertical velocity components, drift angle, flight path angle, and magnetic heading. This information is used in the determination of the horizontal coordinates of the laser footprint on the water's surface relative to the aircraft and in conjunction with the scanner angles enabling the onboard computers to continually adjust the scan pattern to compensate for the motion of the aircraft. The vertical acceleration data is utilized by the wave correction algorithm to isolate the motion of the aircraft in correcting for surface waves.

(4) Video. A down-looking video camera is used to provide an audio/visual record of the scanned area and is stored on 8-mm video tape. The main function of the video is to provide a record of the area surveyed and to assist hydrographers while processing and mapping the data. When anomalous data are identified, the hydrographer can review video of the area to obtain information about the anomaly in question. The audio track may also contain verbal notations from the operator that may also be used to provide some indication of the data characteristics. Each video frame contains digital annotations providing a continual display of the time, latitude, longitude, altitude, and the pitch, roll, and heading of the aircraft as shown in Figure 13-3. Each frame also contains a cross hair that tracks the nadir of the

aircraft. The cross hair is calibrated to 30-m across in both the horizontal and vertical. The cross hair provides the ability to obtain rough position and measurements of structures, navigation aids, and objects in the water.

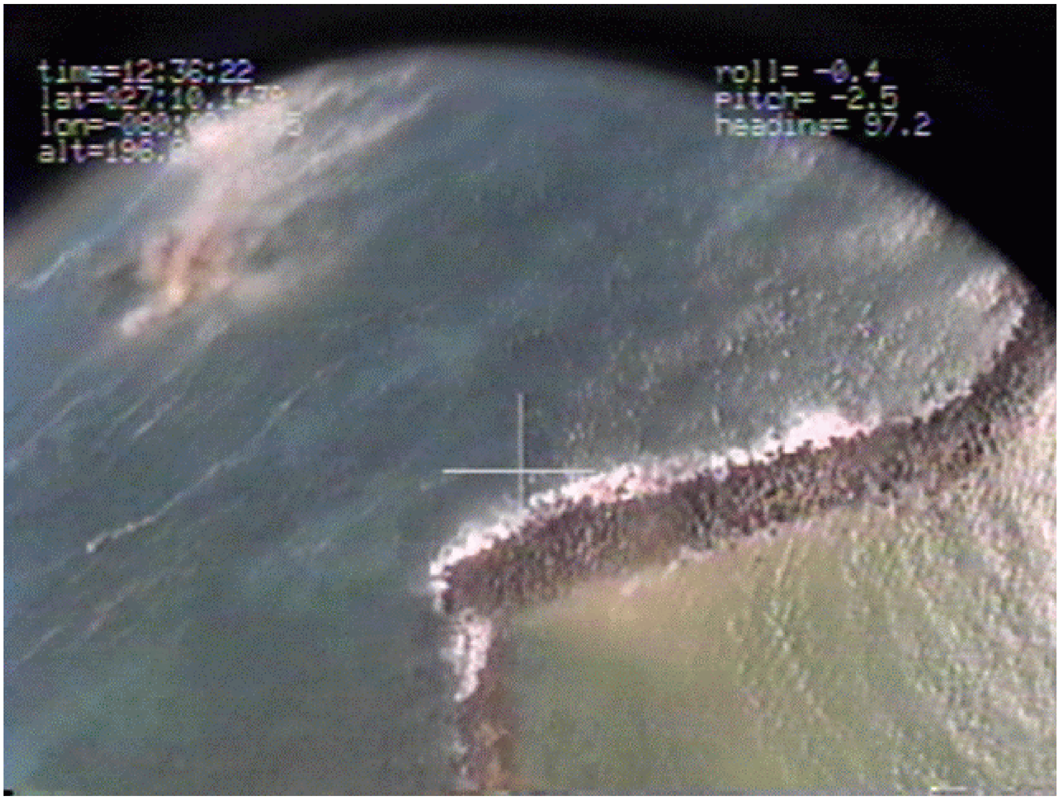


Figure 13-3. Digital annotations

c. Central to the SHOALS airborne system is the ACDS, which provides an operator interface to monitor and control the airborne system. The ACDS provides five functions: data collection, operator interface, pilot guidance, airborne depth processing, and system integrity. The data collection function acquires data from all sub-system components and manages data as it flows through the system and is recorded onto magnetic tape at a rate of over 300 Kb per second. The operator interface allows human interaction between the operator and the system with access to all elements of the airborne system. The pilot guidance function provides a navigation system that guides the pilot from the airport to the survey site and along each survey line. The airborne depth processing function calculates and displays preliminary water depth in real time, at 200 soundings per second, to provide the operator a tool for quality checking data during a survey mission. The last and perhaps most important function is system integrity. Through this function, the entire airborne system is constantly interrogated and monitored.

13-9. Data Processing Sub-system

Preliminary data processing occurs on-site in the mobile field facility shown in Figure 13-1. This 40-foot, air conditioned, tractor trailer facility travels from site to site with the airborne system. It contains all of the data processing and mapping systems including space for mission planning, meetings, storage of spare parts, tools, and supporting survey equipment. The Airborne Sub-system acquires a tremendous volume of raw data during a single mission. The Data Processing Sub-system (DPS) is the hardware and software that provides the capability to post-process this enormous data set. Its main functions are to: 1) import airborne data recorded on high density data tape ; 2) calculate depth and position (XYZ) values for each sounding; 3) perform quality control checks on initial depths and horizontal positions of soundings; 4) provide display and edit capabilities; and 5) output final XYZ positions for each sounding. The DPS software is organized into three operational functions: 1) Data Stripping (DS); 2) Automated Processing (AU); 3) Manual Processing (MP).

a. The interface between the airborne system and DPS is via the high density 8-mm tape containing the raw data acquired during the airborne mission. All of the airborne data are collected at varying rates and recorded in an asynchronous format producing a massive amount of data. Therefore, the primary task of the Data Strip (DS) is to read and unload the raw data from the data tape. As data are being unloaded they are parsed according to data type and rate of collection. This requires some extrapolations/interpolations so that the information can be synchronized into a complete 400 Hz data set. Following this step the data are initially interrogated for quality, and a preliminary quality assessment value is assigned to the various data.

b. The AU function provides a fully automated capability to post-process data prepared by DS and compute depth and horizontal positions to within the accuracies presented in Section 2. The first step is to accurately identify the surface and bottom returns utilizing the pre-recorded airborne sensor data. Depths are then determined by computing the differences between the arrival times of the surface and bottom returns and applying corrections for depth errors and biases associated with light propagation and various inherent system characteristics (Guenther and Thomas, 1984a and Guenther and Thomas, 1984b). AU utilizes sophisticated modeling algorithms to predict and apply corrections associated with these errors (Guenther, 1985).

(1) Wave Correction. Horizontal positioning for each sounding is established through the GPS and IRS data collected during airborne acquisition combined with various other system parameters. This information combined with the optical properties of the water makes it possible to transform the coordinates of the transceiver to an X-Y bottom position. The database is then updated with corrected XYZ coordinates and the final output is in ASCII format. Additional processing is performed to remove the errors introduced by surface waves and swells from each sounding and producing depths that are relative to a common mean water surface. Both the aircraft and water surface exhibit random vertical fluctuations that, if not removed, would contribute directly to the depth error. Determining a mean water surface and isolating the aircraft's vertical fluctuations allows for an accurate estimation of the aircraft height above the mean water level. Applying corrections for tide then produces a depth reference to a known water level datum such as mean low water.

(2) Tide and Water Level Adjustments. SHOALS surveys are based on measuring water depth. In doing so, an average water surface must be determined as a reference for each depth measurement. Topographic measurements using SHOALS also must rely on the determination of an average water surface to determine the height above the water's surface. While collecting survey data, the airborne system measures the slant range or distance between the platform and the water surface for each laser sounding. The average water surface is then determined by calculating a running average of the slant ranges over a specified time interval. When conducting surveys using DGPS it is necessary to collect tidal or water level information at the time of the survey. Data can be obtained from an instrument as simple as a tidal staff or as sophisticated as a self-recording tidal or water level gage. It is required, however, that the tidal/water level station be referenced to a known vertical datum. The water level information recorded at the time of the survey is then used to correct the depth measurements to the desired vertical datum such as NGVD, MLW, or MLLW.

c. Manual Processing. The Manual Processing (MP) is used for quality control of the results from the AU and allows evaluation and editing of anomalous data. This function provides the ability to color-code geographic displays of outputs for selected areas of the survey such as real-time and post-processed data for both hydrographic and topographic data along with various other data information and system parameters. Zoom features allow for viewing the data at different scales and to the level of individual soundings as illustrated in Figure 13-4. When selecting individual soundings, raw data and various associated output parameters can be viewed. A typical manual processing display showing individual LIDAR waveforms is presented in Figure 13-4. After making edits, data are returned to AU where they are re-processed and updated. As mentioned above, a video image of the survey area is also available for visual scrutiny and aid in the interpretation of anomalies. When the hydrographer has addressed all the identified anomalies and is confident that the data are ready, the final adjusted X,Y,Z data file is created. The final data set is imported into a CAD package for mapping and charting.

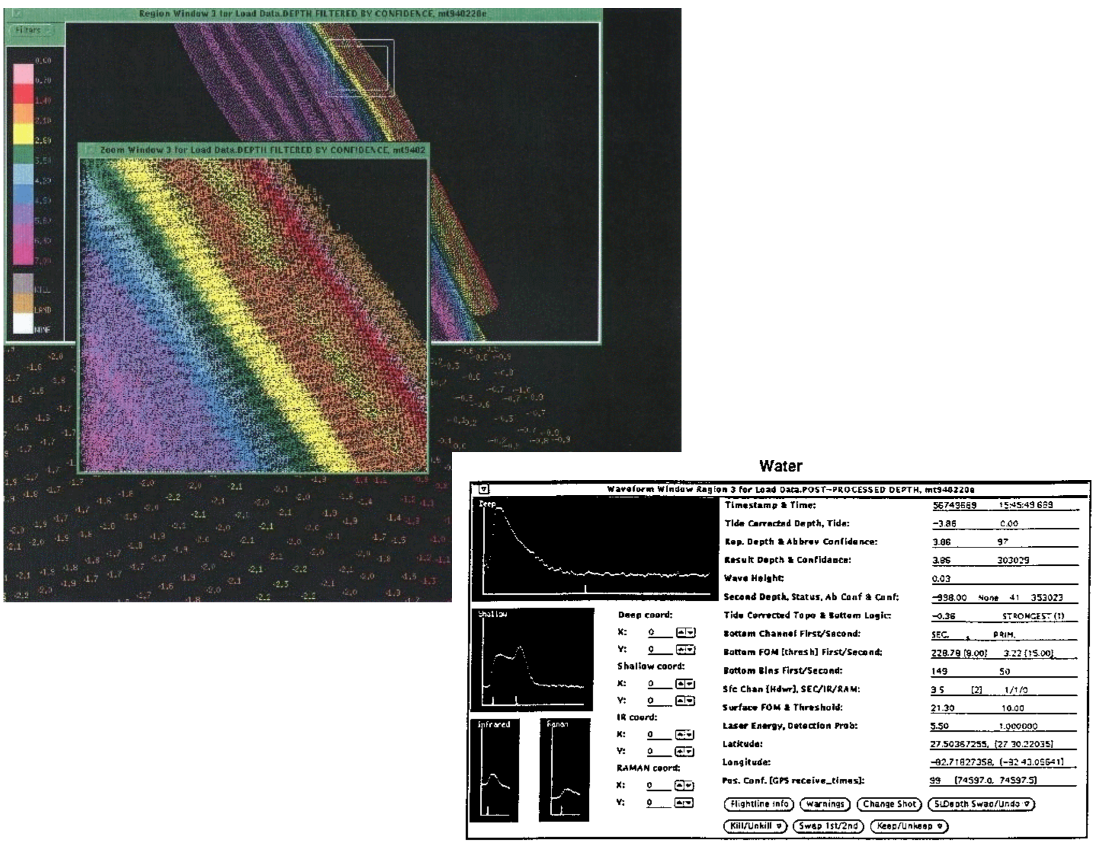


Figure 13-4. Zoom options

13-10. Product Generation

Final products vary greatly depending on the scope of each survey and how the data are to be used. A CAD program is used to produce final products that have included a variety of engineering drawings of navigation projects, plots of navigation structures, and shoreline and depth contours as well as other products. Three-dimensional color plots can also be produced for use in study reports and other publications. Examples of some of these products are shown in the following section and can also been seen at http://shoals.sam.usace.army.mil. For nautical charting, depths are plotted on smooth and field sheets, which represent a subset of the most, shoal depths as well as potential navigation hazards such as rocks or sunken vessels. Each LIDAR survey mission is unique, therefore the capability for producing final products must be versatile. In additional to the products mentioned above, SHOALS has the capability to calculate volumes between successive data sets, which is often required to quantify sediment that has eroded or deposited since the last survey. All of the final output products as well as the ASCII X,Y,Z file are written to CD ROM for distribution to the customer.

13-11. Data Preparation

After the raw LIDAR data have been processed by the DPS, the resulting ASCII X-Y-Z file is output. This file contains a information about each data point collected, such as geographic coordinates, time stamp, and the calculated depth for each data point.

a. Datums. At this time the vertical datum has already been defined by the DPS. However, the depths are in meters and it is at this point that they are converted to feet if required by the customer. The horizontal input format for the each data set is geographical latitude/longitude coordinates, but typically transformed from geographical coordinates to a State Plane Coordinate System--on NAD 1927 or NAD 1983 or to the Universal Transverse Mercator (UTM) system.

b. After the data are input into the mapping system and transformed to the proper coordinate system, a process of comparing each data set to expected values is conducted. These expected values are based on existing charts, maps and other information available to the project engineer. The data are also compared to each other to make sure that each falls within the system requirements. If any of these comparisons do not yield satisfactory results, the problem area is isolated and further evaluations made to correct the problem. In the event that the problem cannot be corrected, these data are deactivated and not used in mapping.

c. When the comparisons fall within the expected limits and any problem areas addressed, the data set is cleaned to remove anomalies. These points are typically returns from trees, buildings, fish, boats, or floating or suspended matter in the water. Any point that is not considered a natural part of the terrain is deactivated from the data set or Digital Terrain Model (DTM). This DTM is to be used to create the Triangulated Irregular Network (TIN).

13-12. Mapping

Once the data preparation process is complete the data are ready for mapping. The standard SHOALS mapping package includes E-sized sheets of a color contour map, plan and profiles of any existing structures and cross sections of those structures.

a. Contour maps. The maps consist of color contours usually at a two foot or one meter interval (project dependent). Overlaid on the color contours are depths to provide the engineer with greater detail about the project. A review of this map provides the greatest comprehensive management information for the engineer. An entire project can be easily reviewed and problem areas immediately identified, such as shoal channels, jetty scour, structure failure, and many other critical evaluations necessary to provide effective project management.

b. Structure plan and profiles. The plan and profiles are created for any existing structures within the project limits. If the alignments for these structures are not furnished by the client, the apparent centerline is determined based on the contours. Once the centerline is determined, a typical plan and profile sheet with stationing and centerline information (coordinates) is created for each structure, with scale and units being project dependent. Such information is useful in performing structure condition evaluations. The profiles along the crest of the structure indicate areas where there is a loss in elevation or possible breaching.

c. Cross-sections. The cross sections are created for the same alignments as the profiles. The scale and units for these sheets are also project dependent. These cross sections can be used to identify areas within a structure, such as a jetty, where there may a deterioration of the structure side slope caused by slumping or armor stone displacement.

d. Point reduction. For some applications, a high density data set may not be required. The current method of reduction is spatial binning and thinning. A bin size is chosen based on the scale of the project or changes in elevation. The data are then placed in the selected bin. The data within each bin are analyzed and the shoalest point within the bin is written to a file. While this method works well in areas of consistent grade, in areas where elevation vary significantly (i.e. structures, dunes, channel sides) it is to reduce the bin size.

e. Final Products. Once the sheets for the color contours, plan and profiles, and cross sections are created digitally they are plotted or printed for review. The printed sheets are proofed and corrections are made for the final printing and plotting. With the final plots in hand the project booklet is created. The project booklet contains a metadata file that describes the data and format for the project, the plots, a history and reference section, and the digital data for the project.

13-13. Applications: Navigation and Structures

Since becoming operational, SHOALS has performed a wide variety of missions (over 230 project surveys as of 6/98) including many navigation projects at tidal inlets, where the USACE is typically concerned with channel depths, disposal areas, navigation structure condition, and project impacts to adjacent shorelines (Lillycrop, Irish, and Parson, 1997). Using SHOALS these types of surveys are completed in a few hours, resulting in high-resolution coverage of an entire inlet system as well as associated structures and adjacent beaches. The survey provides information to perform regional sediment management, quantify channel dredging requirements, indicate condition of the associated jetties both above and below the water including the structure toe, and the entire beach and nearshore areas adjacent to the inlet. Figure 13-5 presents the result of a SHOALS survey conducted at Ft. Pierce Inlet on the east of Florida. Ft. Pierce was among the first missions completed with KGPS during the winter of 1997. Analyses of the data show exceptional coverage of the upland beach and dune system along with the nearshore bathymetry. This high-resolution survey quantifies several of the inlet's features such as reef and rock outcrops, the rock-blasted channel, navigation jetties, shoal features, and beach and nearshore morphology.

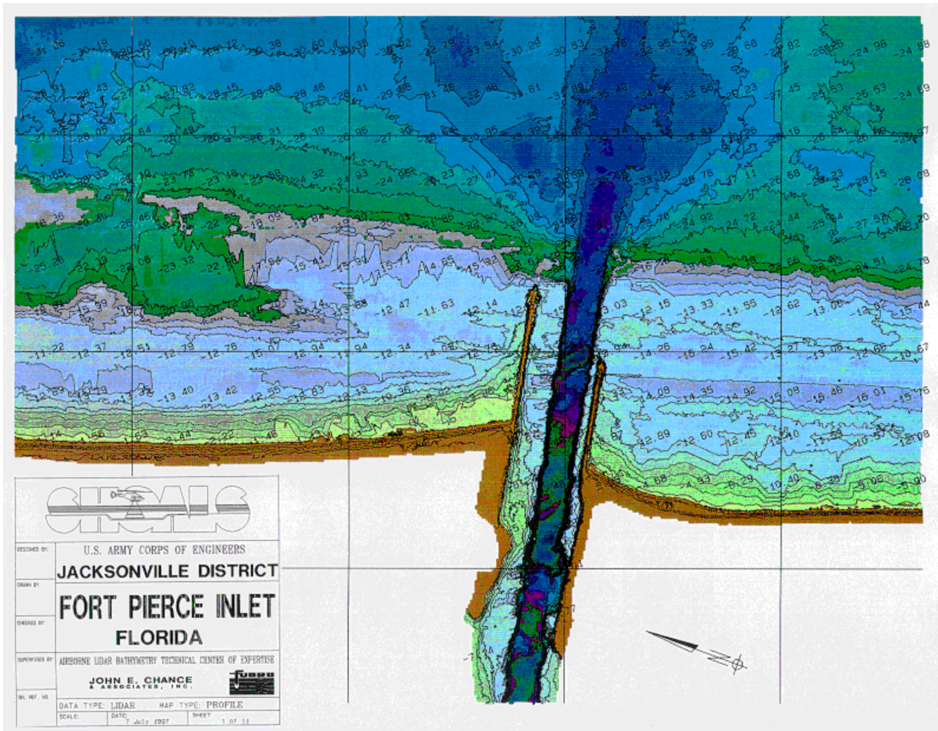


Figure 13-5. Fort Pierce, FL

13-14. Applications: Nautical Charting

Four SHOALS surveys were conducted for the NOAA National Ocean Service and one for the US Navy explicitly for creation of nautical charts and identification of navigation hazards. These included Miami Harbor and Port Everglades, Florida, and Elwood and Gaviota, California, and SHOALS' first international mission off the Yucatan Peninsula, Mexico. The Mexico project, completed for the US Navy, was the largest single survey mission for SHOALS (Figure 13-6). Over 56 days of data collection, SHOALS completed 800 km^2 totaling over 100 million depth measurements. In preparation for this mission, SHOALS auxiliary sensor capabilities were augmented to include a geo-referenced video for establishing positions of above-water features such as piers, lighthouses, and navigation aids as well as some underwater features in clear water. During the Mexico mission, SHOALS bathymetry and video located and mapped two previously uncharted shipwrecks.

Figure 13-6. Yucatan Peninsula, Mexico

13-15. Applications: Beach and Shoreline Surveying

a. Beach and nearshore survey data are required during the life cycle of coastal projects. For example, surveys of beaches are required in order to develop shoreline change maps to determine the effects a navigation project has on the surrounding area. Beach surveys are also used for planning, design, and construction and to monitor projects. Conventional beach surveys typically consist of a series of shore- normal profile lines extending from the beach into the nearshore at widely spaced intervals. Many times the results are sparse data sets that may not adequately represent the dynamic three dimensional environment and provide only gross shoreline change, missing smaller scale features such as scalloped beach faces, variations in nearshore shoals, or small reef and rock outcrops.

b. As previously discussed, SHOALS was modified in response to USACE's increased need to map beaches, dunes, and nearshore areas. Airborne LIDAR provides the capability to collect comprehensive hydrographic and topographic elevation data. Using specialized data processing techniques, above-water elevations from the SHOALS LIDAR signal can be computed. This produces not only depths but also elevations of the subaerial beach and other associated features above the water's surface. With the ability to collect both hydrographic and topographic survey data, SHOALS can simultaneously conduct complete beach and structure surveys above and below the waterline providing the most accurate data for calculating design volumes or post-storm erosion assessments. The data can be used to generate beach profiles, cross sections, contours, and is very accurate in performing volumetric calculations.

c. Figure 13-7 shows a 3-D plot from a SHOALS beach survey collected at Presque Isle on Lake Erie near Erie, Pennsylvania. Visible in the plot are detailed nearshore features that were missed using conventional beach survey methods. The survey was also able to completely capture the detached breakwaters placed to stabilize the shoreline. This high resolution data set provides detailed information of the structure and surrounding bathymetry extending onto the dry beach. Of additional interest is the geologic fault that was previously unknown. Features such as this may have an effect on the behavior of the immediate area, but it was not detected using conventional profiling methods. If desired, profiles can be cut through the LIDAR data at previously established profile locations for comparisons with historical data sets.

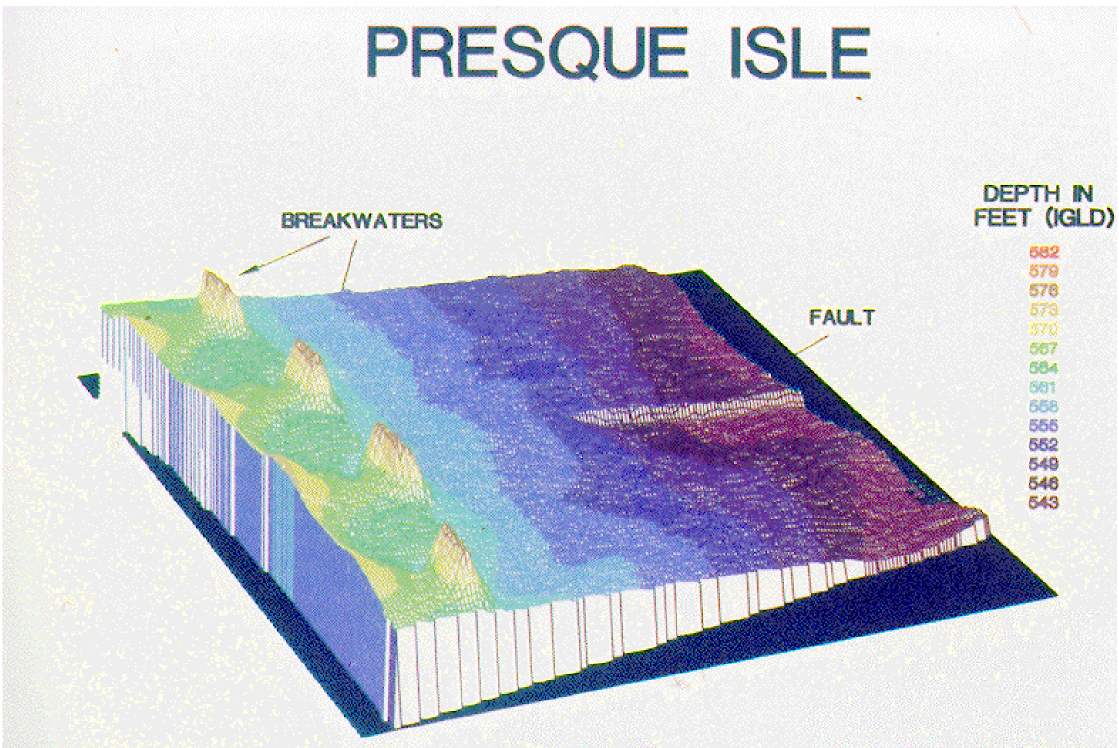


Figure 13-7. Presque Isle, Ohio

13-16. Applications: Emergency Response

a. Since SHOALS is rapidly deployable and quickly collects both bathymetry and elevations above the water, it is an ideal tool for emergency damage assessment. In 1997, SHOALS performed an emergency response survey to quickly assess coral reef damage at Maryland Shoal in the Florida Keys resulting from the grounding of a cargo vessel. The mission was completed in less than an hour and successfully quantified the damage to the reef system.

b. In October 1995, following Hurricane Opal, SHOALS surveyed two projects along Florida's panhandle: East Pass and Panama City Beach (Irish et al., 1996). East Pass is jettied on both sides and provides the only direct access from the Gulf of Mexico into Choctawhatchee Bay through a maintained navigation channel. On the east side of the pass is a sand spit, known as Norriego Point. The East Pass survey was completed (Figure 13-8) within an hour and included over 300,000 soundings within the 3 km^2 area. Elevation measurements ranged from the dry beach and above-water structures to 10-m depths and detailed the entire inlet system including Norriego Point, the two jetties, the inlet throat, and the ebb shoal. Within six hours of the survey, hard-copy maps were generated, dredging requirements inside the navigation channel were calculated, and jetty damages assessed.

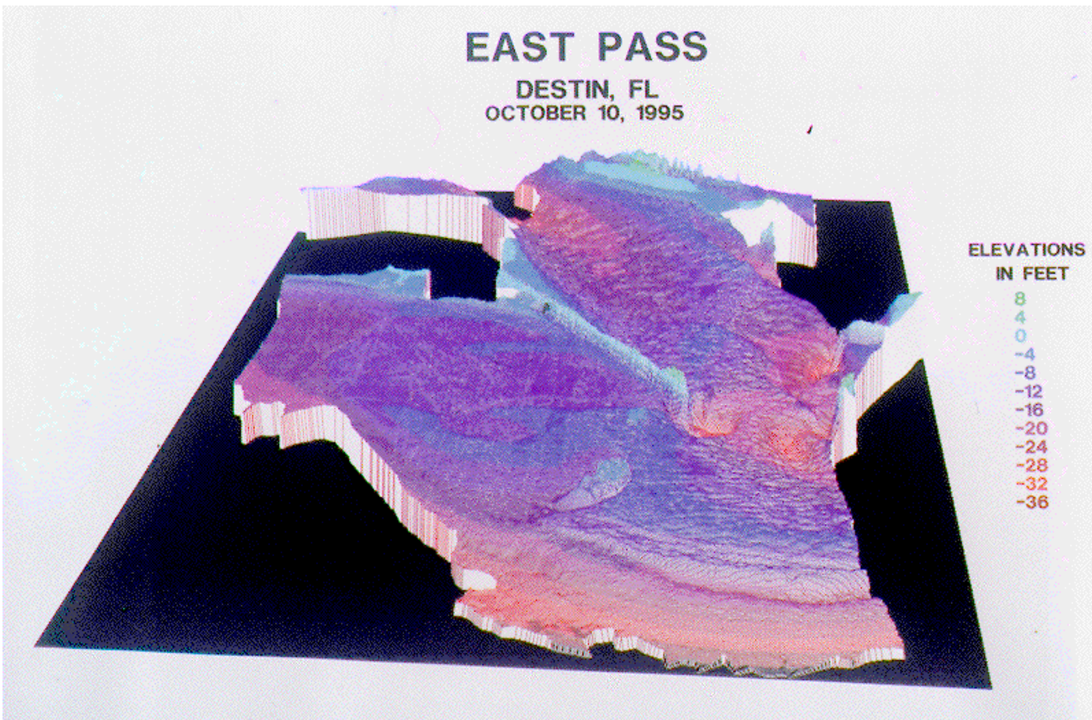


Figure 13-8. East Pass, Florida

13-17. Applications: Shallow Water

An additional benefit of remotely collecting bathymetric data is the ability to collect data in shallow and environmentally-sensitive waters that are typically inaccessible using conventional survey techniques. Additionally, environmentally-sensitive areas, like those with sea grass beds, may restrict boat usage making data collection with conventional techniques impossible. SHOALS is capable of collecting high-resolution shallow water bathymetry without disturbing the environment. In 1994 and in 1997, SHOALS performed surveys in the shallow areas of Florida Bay (Parson, et al., 1996). Florida Bay is the focus of an inter-agency program involving a modeling effort to define internal water circulation exchanges with surrounding waters. Models such as these require detailed resolution of the Bay's morphologic features which are characterized by extensive shallow-water networks of mud banks, cuts, and basins. Prior to the SHOALS mission, this shallow-water depth information did not exist. The area surveyed exhibited numerous channel cuts transecting shallow mudbanks that are believed to influence water flow between the Atlantic Ocean and Florida Bay. These channels range from 0.5 to 3 meters deep. SHOALS surveyed the 6 km^2 area in a few hours. The survey data clearly revealed these channel features and quantified their dimensions for use in the modeling effort.

13-18. Applications: Confined Disposal Facilities

Disposal sites consist of both upland (confined) sites and subaqueous (open-water) sites. To obtain maximum long-term usage of a site, an accurate account must be obtained of the changes in storage capacity resulting from gains or losses and consolidation of disposal material (Poindexter-Rollings, 1990). Obtaining comprehensive surveys of confined upland disposal facilities is not easily met using conventional topographic surveying methods. With the ability of SHOALS to collect high-resolution topographic survey data over large areas, monitoring confined dredge disposal facilities can be easily accomplished. The survey represented in Figure 13-9 is from an upland disposal facility near Mobile, Alabama. This survey was performed exclusively as a topographic survey and was collected using KGPS positioning. Apparent on this survey is the disposal dike surrounding the containment area and the detailed interior features formed by spur dikes and cross dikes. These structures are placed within the interior containment area to increase the water retention time, allowing for maximum settling of sediment from the dredged material. The high resolution of this survey will allow for accurate volume calculations when compared to future LIDAR surveys of the same density.

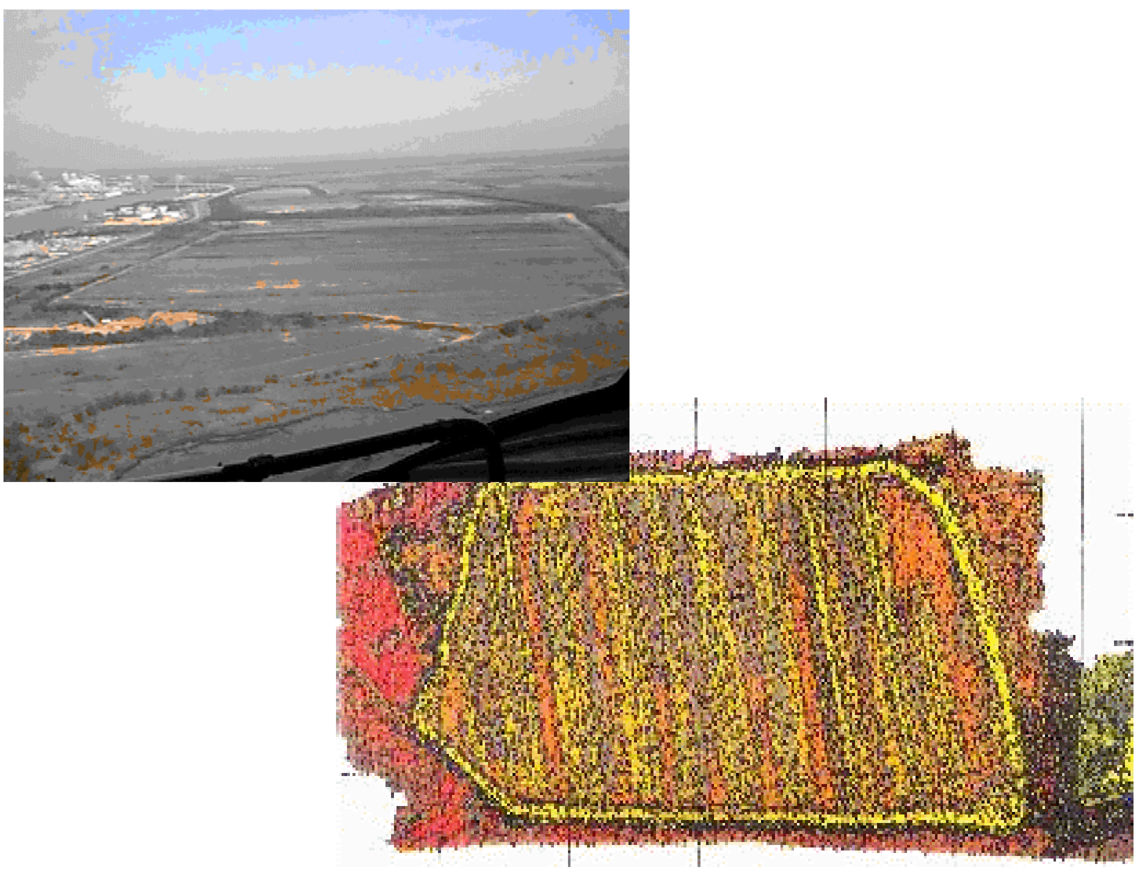


Figure 13-9. Confined disposal area, Mobile, AL

13-19. Applications: Hazard Detection

It is important to provide information concerning the condition of a navigation harbor, however, the ability to detect smaller objects that could compromise safe navigation is also a desirable feature. Objects such as coral heads, rock outcrops, displaced armor stone, sunken boats, storm debris, etc. can be hazardous to navigation. To accomplish the detection of such features, the standard SHOALS data processing and depth extraction techniques were modified to extract shoal depths by a feature that identifies the depth based on the first LIDAR pulse return signal. Typically for Corps surveys, depth determination is based on the pulse with the greatest signal to noise ratio. On projects where the primary mission is to locate and identify potential hazards to navigation, all depth are identified using this first pulse method. After the LIDAR data is processed, it is checked for outliers, where abrupt shoal depths were evident in the data. The individual waveforms for the outliers are checked using the manual processing capability to determine if the data represents a true hazard. If it is determined that a potential hazard exists, the area will be revisited to survey the site in greater detail. An example of locating and mapping a navigation hazard can be seen in Figure 13-10.

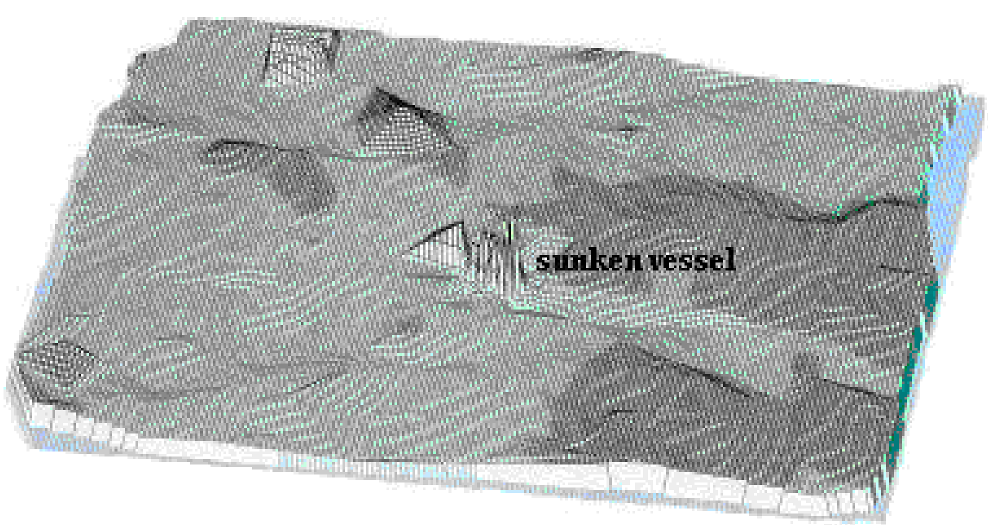


Figure 13-10. Hazard detection

13-20. Obtaining SHOALS Surveys

SHOALS is a government owned and contractor operated system. This approach was selected for two main reasons: first to achieve a long term goal of facilitating private sector interest, and secondly, to optimize operational flexibility necessary to implement an national and international survey program

(Lillycrop, Parson, and Irish, 1996). The USACE provides the overall management of the system through the JALBTCX, including operation, maintenance, and system evolution required to pursue the long-term goals. John E. Chance & Associates, Inc. (CHANCE) of Lafayette, Louisiana was selected through a competitive bid process to operate and maintain SHOALS. SHOALS surveys are administered and conducted through the USAED, Mobile and the JALBTCX through a Task Order Contract that Mobile District has procured with private industry to operate and conduct SHOALS surveys. To initiate SHOALS services from a Federal agency, interested parties should contact the JALBTCX. The first step is to provided a Statement of Work (SOW) which includes a map or chart of the project area defining the boundaries of the survey and specific survey requirements. Survey requirements should address special survey coverages and /or features, desired data density, required datums, and deliverable products. The SOW should also contain information pertaining to vertical and horizontal control data such as locations of nearby survey benchmarks and tide/water level gages. Upon review of the SOW the JALBTCX will respond with a proposal outlining survey operations and cost. When both parties have agreed to the cost and terms of the survey the funds are provided to the JALBTCX through a Military Interdepartmental Purchase Request (MIPR) or other interagency purchase request. Parties interested in obtaining SHOALS surveys should contact the JALBTCX at (334)690-3467.

13-21. References

Guenther, G.C. 1985
Airborne Laser Hydrography, System Design and Performance Factors, National Ocean Service, Rockville, MD, 385 pp.

Guenther, G.C., Thomas, R.W.L, and LaRocque, P.E. 1996
"Design considerations for achieving high accuracy with the SHOALS bathymetric LIDAR system," *SPIE Selected Papers, Laser Remote Sensing of Natural Waters: From Theory to Practice,* edited by Victor I. Feigles and Yurij I. Kopilevich, St. Petersburg, Russia, volume 2964, pp 54-71.

Irish, J.L., Thomas, E.J., Parson, L.E., and Lillycrop, W.J. 1996
"Monitoring Storm Response With High Density LIDAR Bathymetry: The Effects of Hurricane Opal on Florida's Panhandle," *Proceedings, 2nd International Airborne Remote Sensing Conference and Exhibition*, Environmental Research Institute of Michigan, June 24-27, San Francisco, CA, pp. III723-732.

Lillycrop, W.J., and Banic, J.R. 1993
"Advancements in the US Army Corps of Engineers Hydrographic Survey Capabilities: The SHOALS System," *Marine Geodesy,* Volume 15.

Lillycrop, W.J., Irish, J.L., and Parson, L.E. 1997
"SHOALS system - three years of operation with LIDAR bathymetry experiences; capability and technology advancements," *Sea Technology,* vol. 38, no. 6, pp 17-25.

Lillycrop, W.J., Parson, L.E., and Irish, J.L. 1996
"Development and Operation of the SHOALS airborne LIDAR hydrographic survey system," *Laser Remote Sensing of Natural Waters: From Theory to Practice, Selected Papers*, The International Society for Optical Engineering, Vol. 2964, pp. 26-37.

Lillycrop, W.J., Parson, L.E., Estep, L.L., LaRocque, P.E., Guenther, G.C., Reed, M.D., and Truitt, C.L. 1994

"Field test results of the US Army Corps of Engineers airborne LIDAR hydrographic survey system," *US Army Corps of Engineers 1994 Training Symposium, Survey and Mapping, Remote Sensing and GIS,* Army Topographic Engineering Center, Alexandria, Virginia, pp. SM-2A, 1-6.

Parson, L.E., Lillycrop, W.J., Klein, C.J., Ives, R.C., and Orlando, S.P. 1996
"Use of LIDAR Technology for Collecting Shallow Bathymetry of Florida Bay," *Journal of Coastal Research*, Vol. 13, No. 4.

Poindexter-Rollings, M.E. 1990
"Methodology for analysis of subaqueous sediment mounds," Technical Report D-90-2, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Riley, J.L. 1995
"Evaluating SHOALS bathymetry using NOAA hydrographic survey data", *Proceedings 24th Joint Meeting of UNIR Sea Bottom Surveys Panel,* November 13-17, Tokyo, Japan.

Note that references to HQUSACE publications are listed in Appendix A.

13-22. Mandatory Requirements

There are no mandatory requirements in this chapter.

Chapter 14
Dredging Support Surveys

14-1. General Scope

This chapter provides an overview on hydrographic surveys performed in support of the Corps dredging program. Types of dredging templates and surveys are defined. This chapter also provides background information concerning dredging contract clauses that deal with measurement and payment surveys. For detailed guidance on dredging procurement policies and practices, refer to the appropriate regulations applicable to dredging--e.g., FAR, DFARS, EFARS, and ER 1130-2-520, "Navigation and Dredging Operations and Maintenance Policies."

14-2. Background

The US Army Corps of Engineers performs hundreds of surveys annually that are used to monitor dredging in over 25,000 miles of navigable waterways, which includes deep and shallow draft channels and harbors. During Fiscal Year 1999, the Corps dredged 373 million cubic yards of material. Approximately 88% of this work was done by contract dredging, involving over 250 contracts. The Corps-owned Minimum Dredge Fleet performed the remainder of the work. A variety of hydrographic surveys are conducted in support of these dredging operations--both for Corps-owned dredging equipment and contracted dredging operations. Dredging measurement and payment surveys are usually performed by Corps survey crews; however, they may be conducted by independent Architect-Engineer survey firms or the dredging contractor's survey crews. Most dredging contractors also maintain an independent survey capability to monitor dredge performance and progress, and to check the official Corps measurement and payment surveys. Dredging support surveys typically require high degrees of accuracy since they are used to estimate annual dredging budget and quantity requirements, determine dredging contractor payment, and to certify final acceptance and clearance of a project to its authorized navigation depth. In many instances, the adequacy and accuracy of these hydrographic surveys are reviewed and challenged by contractors with resultant disputes involving: the amount of material removed for payment; unexcavated shoal material remaining above the required dredging grade; or the adequacy of acoustic and density measurements of unconsolidated materials in the channel bottom. In order to minimize these disputes and construction contract claims, the accuracy standards, procedural technical specifications, and other quality control policies covered in previous chapters of this manual must be rigorously followed. All dredging surveys require the utmost in accuracy standards, quality control, and timeliness, as explained below.

14-3. Types of Dredging Support Surveys

The following paragraphs describe some of the surveys used to monitor dredging operations in river and harbor navigation projects. Figure 14-1 depicts a section view of the typical dredging templates and surveys.

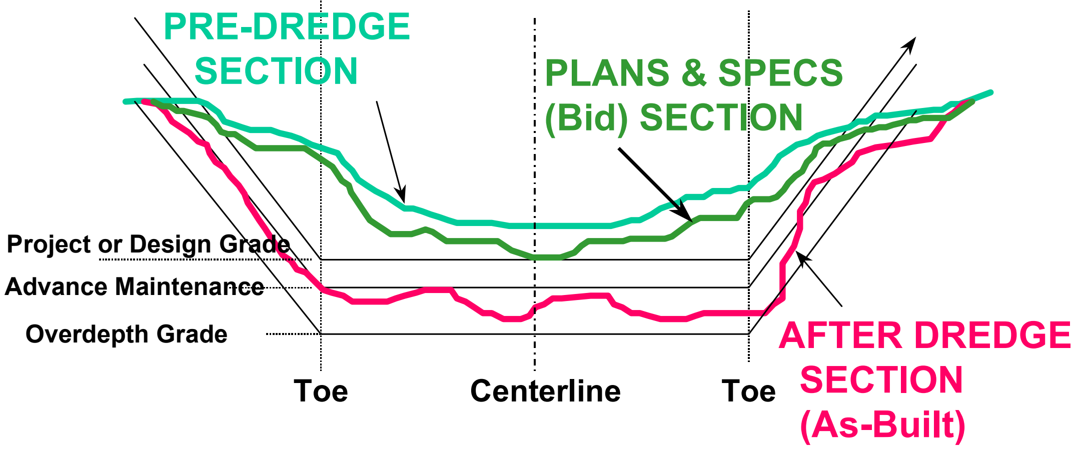


Figure 14-1. Typical dredging templates and payment surveys

a. Project condition or plans & specifications surveys. Hydrographic surveys are performed over Corps projects on at least an annual basis. On rapidly shoaling projects, more frequent surveys may be performed--e.g., daily surveys are performed on Southwest Pass at the mouth of the Mississippi River where almost continuous dredging is performed. These "Project Condition Surveys" are used to assess needs for maintenance dredging, and may be used as the basis for the estimated quantities in dredging contract documents from which bids are made. The hydrographic survey drawings and estimated quantities shown in the contract documents (generally termed Plans & Specifications Surveys) shall have been made as close to the solicitation advertisement date as possible--typically within 120 days or less, depending on estimated shoaling rates.

b. Pre dredge surveys. Once a dredging contract is awarded and dredging plant and equipment is on site, surveys are performed over the contract area as close to the start of dredging as possible; generally within 14 days prior to commencement of work in the reach (i.e., Acceptance Section) to be dredged. These Pre Dredge surveys are often referred to as "Before-Dredging" surveys, or "BDs." Plots of Pre Dredge surveys and related quantities requiring excavation are required within two (2) days of completion of the surveys. The quantities from the Pre Dredge surveys are compared with the quantities that were estimated in the contract solicitation documents--i.e., the Plans & Specifications surveys.

c. After dredge, final clearance, and acceptance surveys. After-Dredging (AD) surveys are performed as soon as possible after dredging in a reach or acceptance section is completed; generally within five (5) days or less. Final survey plots and quantity computations are required within two (2) days of the survey in order to release the dredge to other work. See ER 1130-2-520, "Navigation and Dredging Operations and Maintenance Policies." Normally the After-Dredging survey suffices for assessing contract performance, and the project, or an individual acceptance section, is contractually "accepted" based on this survey. In many cases, the After Dredge survey reveals not all material has been removed and subsequent dredging and surveys must be performed before final clearance/acceptance is verified. Often, repeated full-coverage channel sweep surveys must be performed to locate and remove material or man-made objects above grade. Channel sweep surveys may be made with multi-transducer boom sweeps, multibeam (swath) transducers, or bar-sweeps (sweep rafts). In many instances, the accuracy of these surveys are challenged by contractors who are understandably anxious to have the project accepted as "clear to grade" so they can move their dredge plant to another project and receive final payment. Typically, disputes over remaining material above the required depth involve the positional and depth measurement accuracy capabilities of the survey. These disputes often involve shoal material or objects that are well less than the accuracy tolerances of most echo sounding equipment--i.e., 0.2 ft to 0.5 ft. Other disputes involve remaining shoal material 5 to 10 feet inside the channel toes--also near the tolerances of dredging or hydrographic survey positioning. In many cases, repeated surveys of these shoal areas yield different results, or may not agree with those performed by the dredging contractor's survey crew. In accordance with the contract, the Corps Contracting Officer can unilaterally direct the contractor to remain on site removing any shoal areas that were indicated on the After-Dredging survey(s)--or "alleged shoals" from a contractor's standpoint. Payment for this disputed extra work may be difficult to resolve, and often is decided years later by the Engineer Board of Contract Appeals or in other claims or appeals processes.

d. As-Built drawings. These various after dredge surveys are used to form the "as-built" survey drawing for the project, which is furnished to navigation interests. This project clearance information is used by the US National Oceanic and Atmospheric Administration (NOAA) to update their nautical charts of the area, the US Coast Guard (USCG) for notice to navigation interests, and many private and public interests, such as local ports and harbors and pilots associations.

e. Contractor access to government records. In accordance with standard practice, dredge contractors are provided full and open access to all survey data obtained by the Corps, for all surveys listed above. This includes analog records (e.g., echosounder traces), digital data (e.g., digitized depth data, GPS correctors), and all other recorded information used to correct hydrographic survey data (e.g., bar check records, velocity measurements, tide corrections) or to perform volume computations (CADD generated data files). In addition, dredge contractor representatives are normally on board the survey vessel to observe all surveys performed for payment or acceptance. This provides the contractor with the opportunity to assess the technical adequacy and accuracy of surveys performed by the Corps; and hopefully resolve any alleged or real deficiencies before dredging progresses.

14-4. Variation in Estimated Quantities

Dredging contracts involving payment based on hydrographic surveys contain a "Variation in Estimated Quantities" (VEQ) clause that is invoked when significant disparities between these surveys occurs. This clause provides for a modification of the unit price originally bid due to a significant change (usually ± 15%) between the estimated and actual quantities. A contract modification is prepared which adjusts the quantity and cost in the contract documents due to the variation in work. Negotiation of a revised unit price for the work is often difficult and contentious, especially when the Pre Dredge survey indicates less material than that estimated in the contract bid documents. Thus, both the contract Plans & Specifications survey and the Pre Dredge survey must be timely and accurate, especially in areas subject to rapid shoaling. When the VEQ clause is used, the government estimates the quantity of units of work to be performed, and the solicitation and contract provide a unit price for the work.

14-5. Dredge Contracting and Production Measurement Methods

There are two general methods for contracting dredging work: (1) Unit Price contracts, and (2) Firm Fixed Price (FFP) contracts. Unit price contracts are preferred by the Corps and are far more predominant than fixed price contracts. All types of these dredging contracts require detailed hydrographic surveys to monitor construction progress, performance, payment, acceptance, and/or project clearance. A short description of these contracts follows since hydrographic survey support and accuracy requirements will vary somewhat with the type of contract payment method.

a. Unit price--in-place volume measure. A majority of dredging contracts in the Corps are awarded with payment based on in-place volume measure. These contracts determine payment based on the amount of material removed from a navigation channel (or placed, as in beach renourishment projects). This measurement is performed by comparing before and after dredging hydrographic surveys, and deducting any material that has been unexcavated or over-excavated, as indicated by the "non-pay" areas in Figure 14-2. Normally for beach renourishment projects, payment is based on before and after beach placement profiles, not from quantity excavated. Payment is made based on the unit price bid by the contractor--typically cubic yard (CY) or cubic meter. Use of in-place volume measurement requires that the Corps has the capability to "perform payment surveys in a timely and accurate manner" and can "assure that the surveys specified in the contract are sufficient to verify that the contract requirements are met."

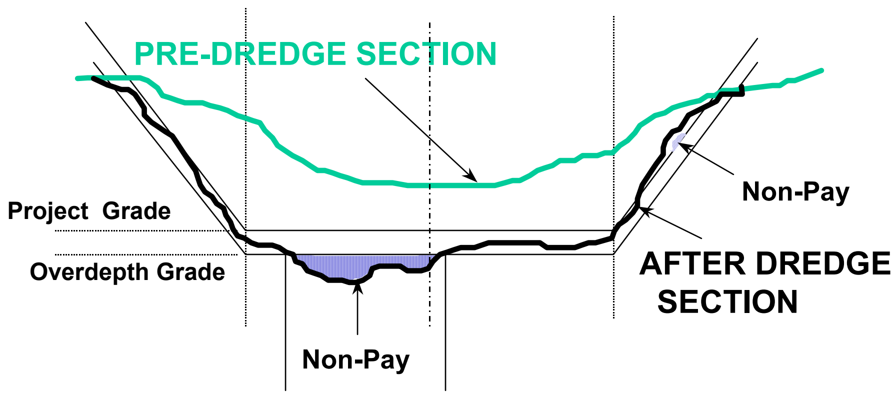


Figure 14-2. Typical Pre/Post Dredge Section

b. Unit price--area measure. Area measure contracts are used in channels where depths of cut are relatively small and constant, and the area of dredge cut is the determining price factor, not depth of the "face" cut. The bid unit area (in square yards) is a channel section between fixed stations--thus the term "Station Dredging" for this method of dredging--see Figure 14-3. Final hydrographic surveys are performed to ensure clearance to grade and acceptance of work--quantities may be computed however payment is made for the fixed section of work completed and accepted. These contracts are typically used in smaller navigation canals.

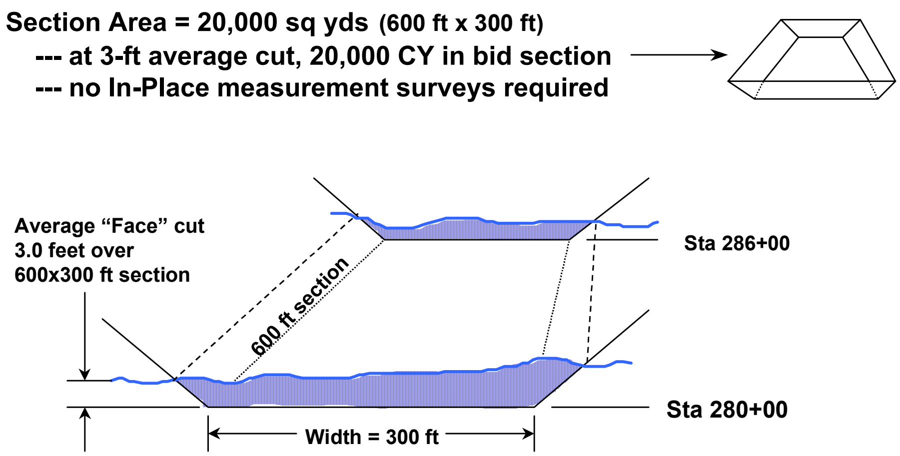


Figure 14-3: Station Dredging

c. Unit price--time measure. This type of dredging is performed when the quantities of material cannot be accurately estimated by in-place volume survey methods, such as in active or erratic shoaling areas, or where rapidly fluctuating river stages exist, or where "accurate and timely surveys are difficult to accomplish" (from ER 1130-2-520). Dredging plant and equipment is leased at an hourly or daily rate bid by the contractor. On these types of contracts, hydrographic survey accuracy requirements are not as demanding as in-place payment methods--usually due to high shoaling rates encountered. However, daily survey support is required to monitor channel dimensions and overall contract compliance. These contracts are common on the lower Mississippi River.

d. Unit price--scow or bin measure. Payment based on scow or bin measure, and/or related production/density flow meters, require final after-dredging hydrographic surveys to certify clearance and contract acceptance. In addition, hydrographic surveys are needed to determine the amount of any excess dredging; for a payment reduction. Related hydrographic surveying and electronic positioning is usually required for monitoring the placement of dredged material in open water.

e. Firm Fixed price--lump sum contracts. This method is used on maintenance work where the rate of shoaling is small or predictable over the length of the contract. In this method the dredge contractor bids a lump sum price for the job based on the contract plan and specification surveys. No pre-dredge survey need be performed; however, after-dredge clearance and acceptance surveys are required to ensure the contractor has removed all material from the required prism.

14-6. Dredged Material Payment Prisms

Hydrographic surveys supporting dredging operations, and related dredge volume and payment computations, are performed with respect to a variety of payment prisms. Survey data must be collected at sufficient accuracy and density so it can be evaluated relative to these prisms. Failure to collect survey data with sufficient coverage makes accurate pay quantity computation difficult, and can result in payment disputes. The following parameters are used to define the various payment reference surfaces found on navigation projects. Refer back to Figure 14-1 for a graphical depiction of the following prisms.

a. Authorized project dimensions. A channel's "required depth" or "project depth" and width are specified in the Congressional authorizing legislation for each project. This legislation may also detail the dimensions of channel entrances, bends (wideners), sidings, anchorages, and turning basins. The required project depth (authorized project depth) is based on the draft of the loaded design vessel plus, squat, sinkage in fresh water, effect of wind and wave action, under-keel safety and efficiency clearance, etc.--see ER 1110-2-1404, "Hydraulic Design of Deep-Draft Navigation Projects." Project width of a channel is a function of traffic, winds, currents, curvature, vessel maneuverability, bank conditions, etc. See Figure 14-4. In some instances, over-width dredging may be performed for advance maintenance purposes--EM 1110-2-1202, "Environmental Engineering for Deep-Draft Navigation Projects."

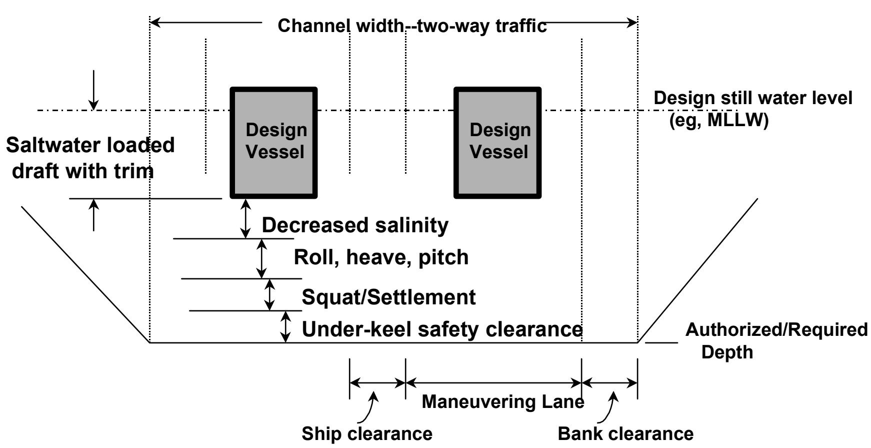


Figure 14-4: Typical Deep-Draft Navigation Channel Dimension and Clearance Parameters

b. Allowable overdepth. Dredging below the required project depth prism is permitted (and paid) to allow for inaccuracies in the dredging process. This is called the "overdepth allowance." A maximum two-foot overdepth is typically allowed for coastal, Great Lakes, and inland waterway projects. Payment is made for material excavated above both the required depth and the allowable overdepth grade. In some cases, no overdepth allowance is paid--termed "zero tolerance" dredging. In such cases, surveys must assure that the contractor has dredged below the required depth to ensure all material has been removed .

*c. Required overdepth***.** On newly constructed channels where hard material exists (e.g., rock, dense clays), a required depth prism, a required overdepth prism, and an allowable overdepth prism will be specified in the dredging contract.

d. Advance maintenance dredging. In areas where fast shoaling occurs, an additional advance maintenance dredging depth may be allowed--see Figure 14-1. Overdepth dredging below this prism may also be allowed. Advance maintenance dredging is not usually allowed for removal of rock, or to provide navigation channel dimensions for vessels that exceed the design limitations of a project.

e. Channel side slopes and box cut allowances. Side slope grades are designed based on the geophysical properties of the material on the channel banks. Side slope grades typically vary between from 1 on 1 (45 deg) up to 5 on 1 (11 deg). Advance maintenance and overdepth payment prisms are extended up the side slopes parallel to the authorized project depth prism, and payment may be allowed for material removed within these sections. In some instances, allowance may be made for material excavated below the payment prism based on the potential for undisturbed material to slough downward to the channel toe. This is commonly referred to as a "box cut allowance"--see Figure 14-5.

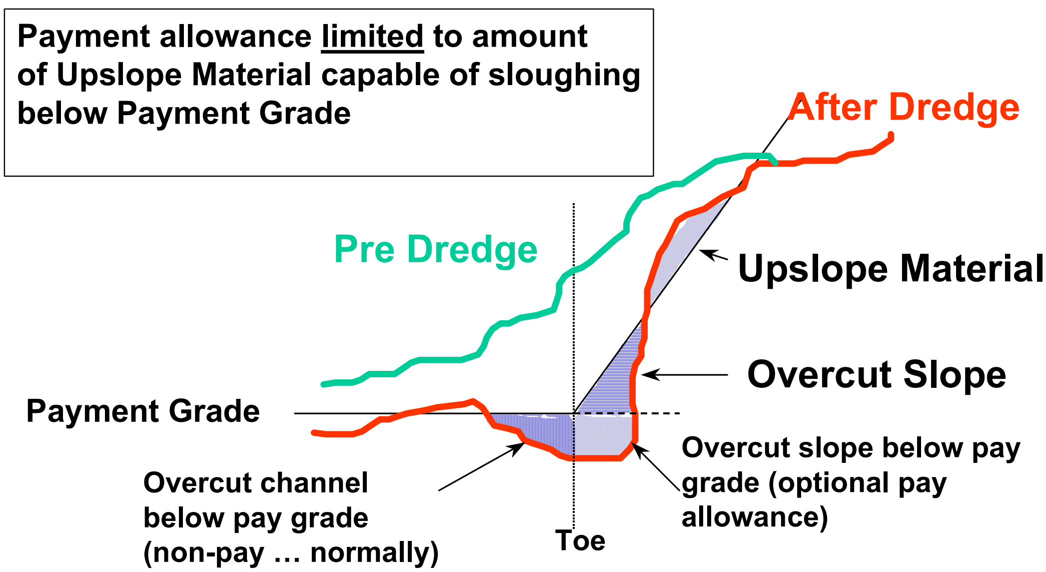


Figure 14-5: Box Cut Payment Method

f. Corps-Wide variations. Dredging payment prisms are not fully standardized among the Corps districts or their subordinate area offices. A number of local restrictions are placed on allowable payment within a dredged section. Volume computations use the "Standard Payment Method" or the "Contour Method" and variations within these methods, as described in the chapter on dredge volume computations. Some Corps offices make no pay allowance for side slope dredging and/or box cut excavation, or may place other limits on pay allowances. These variations require like variations in the analysis of hydrographic survey data and the method by which final payment quantities are computed.

g. Volume computation techniques. The "Average End Area" (AEA) method is used by most Corps offices to compute payment volumes for contract dredging work. Although this method is well known to be only an approximation, and contains biases, its use is widely accepted within the Corps and the dredging industry. Of late, some districts are beginning to compute volumes obtained directly from digital elevation models in a CADD environment--e.g., triangulated irregular network (TIN) surface volumes. However, these more advanced methods have been rarely used in contract payment given Corps and industry reluctance to deviate from the "traditional" average end area approximation. With the advances in electronic technology, survey methods and practices will gradually migrate away from the AEA method.

14-7. Other Factors Impacting Measurement and Payment Surveys

A number of factors will determine the ultimate accuracy requirements for a particular hydrographic survey supporting a dredging operation. These include:

a. Type of excavated material. The type of excavated material (including its disposal) will impact required survey accuracies. Areas with hard material, such as rock, may require blasting which could result in numerous rock fragments remaining above project grade by small amounts (e.g., 0.1 ft to 0.5 ft). Accurate acoustic or mechanical sweep surveys will be performed to locate these fragments and excavate or drag them clear.

b. Unit price. The bid unit price may impact accuracy requirements in a number of ways. High unit price material obviously requires more accurate surveys and/or volume computations. The unit price will also determine whether it is cost-effective for the contractor to dredge close to the required depth or to dredge significant amounts of overdepth material. When economics dictate that overdepth dredging is not economical, dredging close to the required depth can result in many remaining areas left above grade, and resultant disputes.

c. Dredge equipment. The type of dredging equipment used may impact the accuracy requirements for a hydrographic survey. In the Corps, removal of loose materials is normally accomplished by suction dredging (dustpan dredges, hopper dredges, hydraulic pipeline suction dredges, or sidecasters). Since these types of dredging operations are not as precisely controlled (in depth and location), survey accuracy and density of coverage may be reduced. For removal of hard, compacted material (e.g., rock), mechanical dredging is performed, using clamshell, dipper, or ladder dredges. This is typical of new work. A cutterhead dredge (combined suction and mechanical) is employed for either soft or hard material. Survey accuracy requirements are generally higher for mechanical or cutterhead dredge equipment since these operations can fairly precisely control the location and depth of cut. See also EM 1110-2-5025, "Dredging and Dredged Material Disposal."

d. Physical site conditions. Interference with marine traffic and navigation congestion in the waterway, height obstructions such as bridges, towers or high rise buildings, and other natural phenomena must be considered for complete survey accuracy.

14-8. Measurement, Payment, Performance, and Acceptance Surveys

The following excerpts are taken from clauses contained in most dredging contracts involving payment based on hydrographic surveys. These contract requirements have significance to the survey measurement process, both procedurally and technically, and the interpretation of the adequacy of Corps survey data. Although the government, as the contracting agent, developed these clauses to protect the government's interests, they also provide mechanisms for the contractor to challenge the government's interpretations and assessments, and obtain relief if necessary. Contract clauses are continually changing; therefore, the abbreviated excerpts below may not be current. The full contract clause may be obtained in the applicable procurement regulation.

a. Survey errors. Contract acceptance clauses provide for a contractor to challenge the accuracy of any payment survey based on a "obvious error" in that survey. "Obvious error" provides extremely wide latitude for alleged survey deficiencies in that no specific magnitude of the error is defined; thus, this clause is frequently invoked by dredging contractors. However, by implication, any allegations of "obvious error" must relate to recognized survey standards and practices--i.e., conformance or non-conformance with the criteria in this engineer manual. See also "Board of Contract Appeals: Decision in the Appeals of Cottrell Engineering Corporation," (1997). The contractor has the burden of documenting the alleged survey deficiency, based on observed non-conformance with standard practice or inconsistencies in the data relative to independent measurements. Government-performed surveys, and assessments or evaluations thereof, must always be "above board" and performed in a manner that both represents the government's interests and is equitable to the contractor for the actual work performed under the contract.

> "Surveys for Acceptance: ... the [Plans & Specifications hydrographic survey] drawings are believed to accurately represent conditions existing at the time indicated but the depth shown thereon will be updated as required by [Pre Dredge] soundings taken prior to commencement of dredging. Determination of quantities removed to be paid for in the areas specified, after having once been made, will not be reopened, <u>except on evidence of collusion, fraud, or obvious error</u> ... The time for redredging to remove shoals and for [second] [third] and subsequent [hydrographic] surveys shall be the responsibility of the contractor."

> "… Final Examination and Acceptance: As soon as practicable after completion of the entire work or any section thereof ... such work will be thoroughly examined at the cost and expense of the Government by sounding or sweeping, or both, as determined by the Contracting Officer. Should any shoals, lumps, or other lack of contract depth be disclosed by this examination the Contractor will be required to remove same by dragging the bottom or by dredging at the contract rate for dredging, but if the bottom is soft and the shoal areas are small and form no material obstruction to navigation, <u>the removal of such shoal may be waived by the discretion of the Contracting Officer</u>. The Contractor will be notified when soundings and/or sweepings are to be made, and will be permitted to accompany the survey party. When the area is found to be in a satisfactory condition, it will be accepted finally. Should more than two sounding or sweeping operations by the Government over an area be necessary by reason of work for removal of shoals disclosed by a prior sounding or sweeping, <u>the cost of such third and any subsequent sounding or sweeping operations will be charged against the Contractor</u>. The rate for each day in which the Government [survey] plant is engaged in such sounding or sweeping operations and/or is en route to or from the site, or is held, for the Contractor's convenience at or near the site for these operations, shall be [$800.00]*, except on Saturday, Sunday and holidays when the rate shall be [$1,000.00]…"

b. Remaining shoals. The above excerpt from a typical acceptance clause provides latitude to the government in assessing the significance of remaining shoals. This assessment will evaluate the magnitude of the shoal relative to the achievable survey tolerances, achievable dredging tolerances, and/or navigation impacts. Obviously, the positional and depth measurement accuracy tolerances of a survey must be thoroughly considered before a contractor is directed to undertake additional work at his time and expense--see Figure 14-6. Note also that the contractor is liable for the costs of repeated survey effort.

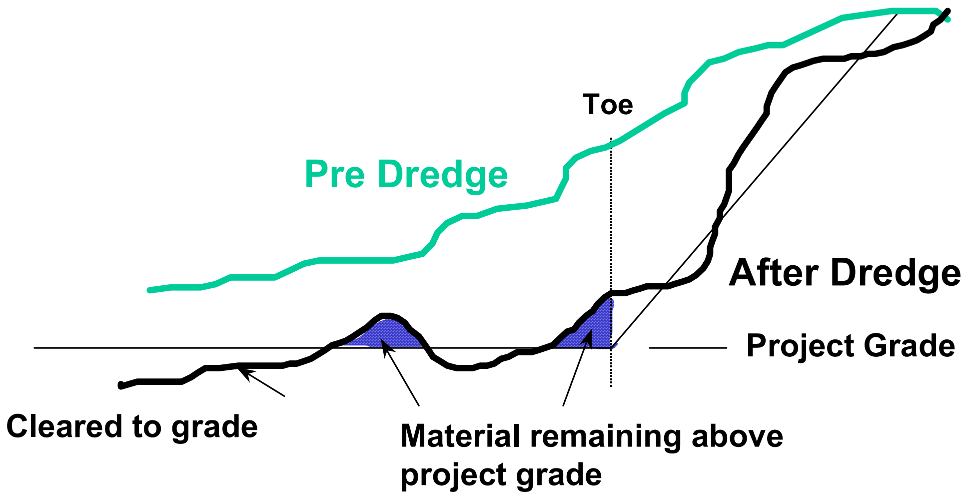


Figure 14-6. Channel clearance along toes

The Contracting Officer has authority to unilaterally direct a contractor to continue dredging any disputed shoal material under the Disputes clause, which reads in part:

> " …This contract is subject to the Contract Disputes Act of 1978 ... The Contractor shall proceed diligently with performance of this contract, pending final resolution of any request for relief, claim, appeal, or action arising under the contract, and comply with any decision of the Contracting Officer. …"

The Disputes clause allows the contractor to recover costs for the additional work if it can be later proven (by the contractor) that the Contracting Officer's directive to proceed with the work was based on erroneous or unreliable hydrographic survey data. Thus, it is imperative that the Contracting Officer be provided with high quality and technically defendable survey information when such unilateral directives must be made. This is especially critical in that the cost of litigated disputes (i.e., interest, attorney fees, etc.) may far exceed the cost of the actual work in dispute.

> " …Inspection of Construction: ... the Government shall accept, as promptly as practicable after completion and inspection, all work required by the contract ... Acceptance shall be final and conclusive except for latent defects, fraud, gross mistakes amounting to fraud, or the Government's rights under warranty or guarantee …"

The above part of the Inspection clause requires the Corps to perform final (After-Dredging) acceptance surveys as expeditiously as practicable, and to release the contractor's dredge from the work. This clause also is applicable in cases where fraudulent work may have been performed. In the past, numerous cases exist where dredging was performed only on the even 100-ft stations/sections surveyed by the Corps (usually by manual tagline/leadline techniques), and no material was excavated between the sections. Often this fraudulent work was not discovered until long after the work was accepted. Such incidents are rare today given full-bottom sweep capabilities of modern survey equipment.

c. Survey certification. In most districts, a dredging contractor's representative is requested and/or required to be aboard the government vessel requested and/or required to be aboard the government vessel performing payment surveys. The intent of this requirement is to resolve any problems with the survey while still on site. The representative may be asked to certify the survey. The following is an example of clauses used by the Jacksonville District to fulfill these requirements.

General
The Contracting Officer shall be notified, in writing, three (3) weeks in advance of the need for pre-dredging and after-dredging surveys. Surveys will be performed in accordance with paragraph "Quantity Surveys" of SECTION 00800; SECTION 01450: CONTRACTOR QUALITY CONTROL; Engineering Manual (EM) 1110-1-2909 dated 1 July 1998 "Geospatial Data and Systems"; and, Engineering Manual (EM) 1110-2-1003 dated 31 October 1994 entitled "HYDROGRAPHIC SURVEYING." A copy of the EM's will be available for review by prospective bidders during the bid period or can be viewed or downloaded at http:www.usace.army.mil/inet/usace-docs/eng-manuals. A copy of the EM's will be provided to the Contractor at the pre-work conference.

Contractor Representative
All in-place measurement surveys and final acceptance sweep surveys will be performed with a representative of the Contractor on board the Government platform during the full execution of the survey. No in-place measurement or final acceptance survey will be performed without a representative of the Contractor on board the survey vessel. The Contractor's representative shall be fully knowledgeable in offshore construction subsurface surveying procedures, techniques, equipment, and horizontal and vertical calibration methods, and state-of-the-art horizontal and vertical accuracy limitations. The Contractor's representative shall observe and review, in progress, the adequacy and accuracy of the survey for in-place payment purposes, and for the potential existence of collusion, fraud, or obvious error in the data.

Survey Certification
Immediately upon completion of any survey, the Contractor's representative shall, based on his onsite review of the survey execution, determine that the survey contains no evidence of collusion, fraud, or obvious error, and that subsequent horizontal and vertical corrections are accurately annotated on the subsurface record.

The Contractor' authorized representative shall bring aboard the survey vessel a blank copy of the Certification Statement and shall attest to an acceptable survey by signing the Certification Statement before leaving the vessel. Sample copy of the Certification Statement is appended to the end of this section.

In the event the Contractor's authorized representative observes (and quantifies) specific documentary evidence of either fraud, collision, or obvious error, the survey will be immediately rerun. Resurveys will totally supersede any previously run survey and will be run over the full reach of any particular Acceptance Section or transit or pipeline route..

If acceptability is not acquired after performing one resurvey of an Acceptance Section, a meeting shall be held between the Contractor and the Contracting Officer's Representative to expeditiously resolve the issue causing rejection of the survey. Contractor equipment and personnel standby time to resolve acceptability of the survey shall be at the Contractor's expense.

In no case shall a previously unacceptable survey be later judged acceptable by the Contractor; unless such a reassessment/reevaluation is performed within 24 hours after the original survey, and prior to initiating any resurvey action based upon identifiable collusion, fraud, or obvious error.

Should the Contractor or his authorized representative refuse to certify to the acceptability of a survey for contract payment without identifiable collusion, fraud, or obvious error, then the following actions will follow:

a. Preconstruction (pre-dredging) Survey. Excavation shall not commence until representatives of the Contractor and Contracting Officer have met and resolved the basis for refusal of certification. Should the Contractor commence excavation prior to obtaining an acceptable survey, he shall be liable for any excavation performed. If a resurvey is performed, and accepted, prior excavation will not be measured, estimated, or paid for.

b. Postconstruction (after-dredging) Survey. The 3-week survey window allowed under paragraph "Measurement" above, will be indefinitely extended until a final survey is accepted. Any material accretion which might occur due to such a time extension will neither be measured, estimated, or paid for.

c. Contractor equipment and personnel standby time to resolve his refusal to certify to the acceptability of a survey when there is no identifiable collusion, fraud, or obvious error shall be at the Contractor's expense and resultant delays shall not be the basis for time extensions of the contract.

CERTIFICATION STATEMENT
CONTRACT: ____DACW______________________
ACCEPTANCE SECTION/SURVEY:
____
REFERENCED SOURCE DOCUMENT:
____

I have fully observed the performance of the subject survey and have determined, based on my review of the referenced source document record, that the data contains no evidence of collusion, fraud, or obvious error. The recorded data, including calibration corrections thereto, have been obtained in accordance with the systematic/procedural methods and techniques described under SECTION 02325: DREDGING of the contract specifications, that all known and unknown systematic and random errors have been minimized consistent with: (1) The relative precision levels of the equipment utilized; and, (2) Absolute accuracies expected (or likely) given current (state-of-the-art) horizontal and vertical measurement limitations associated with offshore survey systems, procedures, and related variables; and, as such, the observed/recorded data are fully and finally acceptable for determining and measuring contract performance and payment.

AUTHORIZED REPRESENTATIVE: ______________________________
/s/ ____________________________
TITLE: __________________________
DATE: __________________________

CF:
Contractor Representative
Area Office

14-9. Measurement and Payment Surveys Performed by Other than Corps Hired-Labor

On most projects, quantity survey measurements are performed by Corps hired-labor (in-house) survey forces. However, over the past 15 years, there has been an increasing trend to contract out these payment surveys. This is primarily due to decreased government manpower allocations. Often there are insufficient Corps survey personnel to cover surveying requirements for many on-going construction and dredging contracts. Many contracts (e.g., beach renourishment and revetment construction) require full-time survey capability throughout the construction season; thus, it is more efficient to contract this effort.

a. When necessary, either independent A-E contractors or dredge contractor survey forces may be used in lieu of Corps surveyors. Corps policy regarding contracting measurement and payment surveys is prescribed in EP 1130-2-520. Basically, surveys may be performed using (1) USACE hired-labor forces, (2) Architect-Engineer (A-E) service contractor forces selected using Brook's A-E Act (PL 92-582) qualification-based selection procedures, or (3) Dredge contractor forces, provided a qualified government representative is on board the contractor's vessel during the surveying operation.

b. Corps policy clearly outlines a preference for performing surveys with Corps forces. This policy is justified in that payment and project clearance/acceptance is based on these surveys, and any disputes (between the Corps and construction contractor) over survey adequacy or accuracy become difficult to resolve unless the contract agent is fully responsible for the survey data. Reduced manpower is making this ideal situation less common; thus, more reliance is being made on A-E firms and construction contractors to perform payment surveys.

c. The use of construction/dredging contractors performing their own payment surveys represents a special case, given the need for quality assurance oversight that must be performed by the Corps when such surveys are performed. Corps policy (in EP 1130-2-520) outlines steps that must be taken when a district elects to use dredge contractor forces for hydrographic payment/acceptance surveys. Basically, districts must provide a rationale and justification for proposing to use dredge contractor's surveys forces and document their unsuccessful efforts to obtain contracts with qualified independent A-E hydrographic survey firms. Districts may require a contractor's surveyor be a licensed land surveyor or hold hydrographer certification from the American Congress on Surveying and Mapping. Certain minimum equipment specifications may also be required in the dredging contract.

d. Most dredge contractors normally have survey forces on the project to perform progress payment surveys, and these same forces can be used for payment and acceptance surveys as well. In some instances, dredge contractors will subcontract their hydrographic survey work. Although Corps policy requires surveying and mapping services to be procured using Brooks A-E Act methods, dredging contractors cannot be directed to follow these procedures when selecting subcontractors for this work.

e. Overall, the majority of districts still conduct payment and contract acceptance surveys with their own in-house forces. With declining manpower allocations, there is a definite trend towards contracting an increasing amount of these services. These trends are most noticeable in Alaska and California, and in some districts in the Southeast and Gulf Coasts.

14-10. Unconsolidated Sediments (Fluff) on Dredging Projects

One of the most difficult issues in evaluating hydrographic survey data occurs when low-density suspended sediments obscure the echo sounding return. This phenomena, commonly know as fluff, occurs in the natural low-flow environments and may also occur during dredging operations due to the agitation of the bottom material. It is most pronounced in southeastern U.S. navigation projects. Multiple layers of fluff can occur, with these layers ranging from 1 to 15 feet above the bottom. Assessment of dredging progress, clearance above required depth, and the equitable payment grade can be extremely difficult--even when dual frequency sounders are used, or when correlation is made with non-acoustic devices (lead lines, sounding poles, nuclear density probes, etc.). As a result, contract payment techniques based on in-place volume measure can often be difficult and may require negotiated settlement. In some instances, after dredge surveys have shown more material in a channel than before dredging surveys. Certification of the clear navigable depth may also be tenuous where the firm channel bottom cannot be clearly determined. Procedures for performing and evaluating surveys in unconsolidated sediments are described in a later chapter in this manual.

14-11. Ocean Disposal Positional Monitoring

Platforms used for transporting excavated material to offshore disposal sites are usually continuously monitored for position and draft changes. Hopper dredges working in environmentally sensitive channels are also monitored throughout the work period. Various automated systems have been developed to position barges and dump scows en route and over submergent disposal areas. Standard Positioning Service (SPS) DGPS positional accuracy is usually adequate. The following clauses are representative of those used for disposal area positional monitoring and hopper dredge monitoring.

Electronic Tracking System (ETS) for Dredging and Ocean Disposal Vessels

The Contractor shall furnish an Electronic Tracking System (ETS) for surveillance of the movement and disposition of dredged material during excavation, ocean transit and beach disposal. This ETS shall be established, operated and maintained by the Contractor to continuously track in real-time the horizontal location and draft condition of the disposal vessel for the entire dredging cycle, including dredging area and disposal area. The ETS shall be capable of displaying and recording in real-time the disposal vessel's draft and location in an acceptable coordinate system which can be related to, or is directly based on the appropriate state plane coordinate system every 500 feet (at least) during loading cycle and during travel to disposal area, and every minute (at least) or every 200 feet of travel, whichever is smaller, while approaching within 1000 feet and within limits of disposal area.

ETS Standards

The Contractor shall provide an automated (computer) system and components to perform in accordance with EM 1110-1-2909. A copy of the EM will be made available at the District Office for review by prospective bidders during the bid period or can be downloaded at http://www.usace.army.mil/inet/usace-docs/eng-manuals. A copy will be provided to the Contractor at the Pre-Construction Conference. Horizontal location shall have an accuracy equal to +/- 10 feet (horizontal repeatability). Vertical (draft) data shall have an accuracy of +/- 0.5 foot. Horizontal location and vertical data shall be collected in sets and each data set shall be referenced in real-time to date and local time (to nearest minute), and shall be referenced to the same state plane coordinate system used for the survey(s) shown in the contract plans. The ETS shall be calibrated as required, in the presence of the COR at the work location before disposal operations have started, and at 30-day intervals while work is in progress. The Contracting Officer shall have access to the ETS in order to observe its operation. Disposal operations will not commence until the ETS to be used by the Contractor is certified by the COR to be operational and within acceptable accuracy. It is the Contractor's responsibility to select a system that will operate properly at the work location. The complete system shall be subject to the Contracting Officer's approval.

Data Requirements and Submissions

All data shall be collected and stored on 3-1/2 inch disks or CD-ROM in ASCII format using IBM-compatible MS-DOS 5.0 or later version. Data shall include date, time, trip ID number, vessel name and name of vessel's captain, location and draft of disposal vessel every 500 feet (at least) during loading cycle and during travel to disposal area, and every minute (at least) or every 200 feet of travel, whichever is smaller, while approaching within 1000 feet and within limits of disposal area. Data collected while the disposal vessel is in the vicinity of the disposal area shall also be plotted in chart form, in 200-foot intervals, to show the track and draft of the disposal vessel approaching, traversing, and leaving the disposal area. More than one disposal area trip may be stored on a single disk or CD ROM as long as trip data is indexed and clearly identifiable. The completed, original disk or CD-ROM shall be furnished to the COR within 24 hours. Plotted charts shall be organized and maintained at a central work location for inspection on a daily basis by the COR. Plotted charts shall be organized as directed, bound and submitted weekly to COR for permanent file record.

ETS

The ETS for each disposal vessel shall be in operation for all dredging and disposal activities and shall record the full round trip for each loading and disposal cycle. The Contracting Officer shall be notified immediately in the event of ETS failure and all dredging operations for the vessel shall cease until the ETS is fully operational. Any delays resulting from ETS failure shall be at the Contractor's expense.

Recording Charts for Hopper Dredge(s)

All hopper dredge(s) shall be equipped with recording devices for each drag head that capture real time, drag head elevation, slurry density, and at least two of the following: Pump(s) slurry velocity measured at the output side, pump(s) vacuum, and/or pump(s) RPM. The Contractor shall record continuous real time positioning of the dredge, by plot or electronic means, during the entire dredging cycle including dredging area and disposal area. Dredge location accuracy shall meet the requirements of the latest version of EM 1110-2-1003.

The recording system shall be capable of capturing data at variable intervals but with a frequency of not less than every 60 seconds. All data shall be time correlated to a 24 hour clock and the recording system shall include a method of daily evaluation of the data collected. Data shall be furnished to the Contracting Officer's Representative for each day's operation on a daily basis. A written plan of the method the Contractor intends to use in order to satisfy these requirements shall be included with the Contractor's Quality Control Plan.

14-12. Mandatory Requirements

There is no mandatory guidance in this chapter.

Chapter 15
Dredge Measurement and Payment Volume Computations

15-1. General Scope

A primary use of hydrographic surveys supporting river and harbor construction is to determine the quantity of material that is excavated or placed. These material quantity estimates are used for design/bidding purposes and contracted construction payment. This chapter deals with the computation of dredged quantities (either excavated or placed) as determined from in-place hydrographic surveys. Other methods of estimating dredged quantities (scow/bin load measurements, production flow rates, station/face cut dredging, etc.) are not covered. This chapter prescribes Corps-wide standards for performing dredge quantity computations.

15-2. Dredge Volume Computation Techniques--Background

Dredge volume computation procedures in the Corps have generally followed those used in railroad and roadway construction--the Average End Area (AEA) method. Cross-sections of a channel are taken at a constant interval and the quantity is computed based on the volume between the cross-sections. The major assumption is that the cross-sectional area is relatively constant between two successive cross-sections. If not, then this method becomes an approximation (or estimate) of the true volume. Decreasing cross-sectional spacing to improve the AEA computation accuracy had economic limits due to increased field survey costs. Thus, cross-sectional spacing for most dredging work ranged from 100- to 500-feet throughout the Corps. Alternate computational methods have been used to compute volumes of sparse cross-sectional data. These include the prismoidal correction to the AEA method and the Triangulated Irregular Network (TIN) method.

a. Since the 1970's, multiple-transducer sweep systems and multibeam systems have provided a dense, full bottom coverage of a channel, allowing for more accurate quantity take-offs than that using only sparse 100- to 500-ft sections. In effect, these full-coverage systems provide cross-sections at 1- to 5-foot spacing, or data densities ranging from 1 to 5 sq ft. Quantities can be computed using the AEA method at the denser sectional spacing, or using vertical projection methods of the individual elements.

b. In general, all commonly used volume computation methods reduce down to that of determining the area bounded by a finite group of data points and projecting this area over some length to obtain a prismoidal volume. These projections may be done either horizontally or vertically, as shown in Figure 15-1. The methods used in the Corps are:

- Average End Area -- used for sparse cross-section data
- Triangulated Irregular Network-- used for sparse cross-section data
- Bin -- used for dense multibeam coverage data

For most USACE construction and dredging work, the horizontally-projected average end area (AEA) method has been considered the standard volume computation method when sparse cross-section data is available (i.e, 100- to 500-ft spaced cross-sections). An alternate method is to develop vertical prismoidal elements between the sparse cross-sectional data, and compute the volume of each prismoidal element--a vertical projection. See Figure 15-1. Development of the triangular prisms between two cross-sections is termed a Triangulated Irregular Network, or "TIN." TINs have application when data are sparse, such as is typical in widely spaced cross-sections, and where cross-line data is available. When full-coverage data is available from multiple transducer or multibeam systems, it can be gridded or binned at a dense grid spacing, and volumes computed from the vertical projection of each grid cell to a reference surface.

c. In Figure 15-1, the AEA volume is a function of the horizontally projected areas of each cross-section--A_1 and A_2 -- projected along the distance (L) between the two sections. An approximate volume results from this AEA computation. When TIN prismoidal elements are generated for data points between the two cross-sections, the volume of each prismoidal element can be computed given the X-Y-Z coordinates of the three vertices--i.e., observed depths converted to elevation differences above (below) the reference channel surface/prism. The resultant volume computation is somewhat more accurate than the AEA method. If full-coverage binned data are available, then the volume of each grid cell can be computed given the cell area on the reference surface (A_b) and the elevation (h_b) of the depth above (or below) that reference surface. Given the higher-density coverage, this is the most accurate volume. AEA or TIN volume computation methods may also be used to compute quantities when densely gridded data is available; however, this adds an extra step to the process.

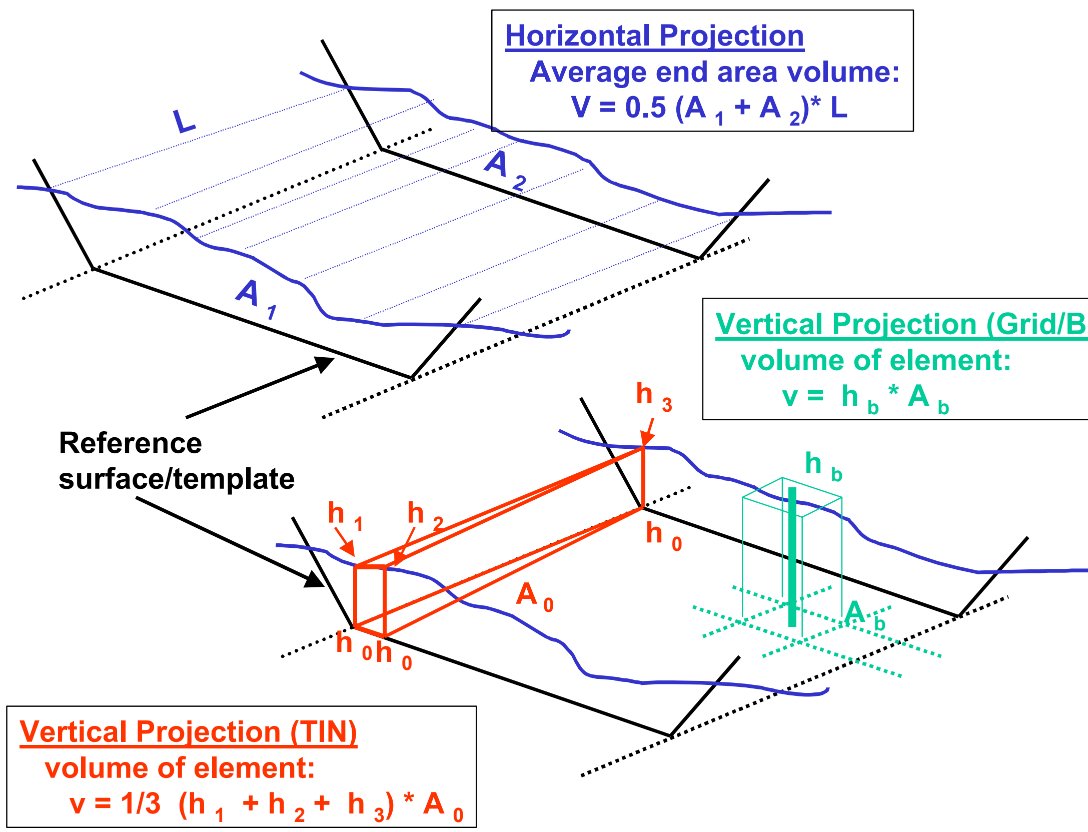


Figure 15-1. Generalized depiction of Average End Area, TIN, and binned volume computation methods

15-3. Average-End-Area Volume Computations

Traditionally, earthwork or dredging quantities for purposes of design estimates and construction payment have been obtained from cross-sectional surveys of the project area. These surveys are normally run perpendicular to the general project alignment at a predetermined constant spacing. The elevation data are plotted in section view along with the design/required depth and/or allowable overdepth templates. One or more reference or payment templates may be involved on a dredging project (e.g., zero tolerance, null ranges, etc.). Given sectional plots of both preconstruction and postconstruction (as-built) grades (or, in some cases, intermediate partial construction grades), the amount of excavated (cut) or placed (fill) area can be determined at each cross section. Figure 15-2 shows the typical templates used to compute relative cut/fill quantities. The sectional area can be determined by use of any number of manual or automated methods. The average areas of two successive cross-sections are computed, and these averages are then projected along the project alignment (linear or curved) by a distance equal to the sectional spacing, resulting in an approximate estimate of the volume of material cut or filled during construction. This approximate estimating technique is known as the trapezoidal or average-end-area method and is universally used (and accepted) in highway, railroad, and marine construction for design estimating and payment purposes.

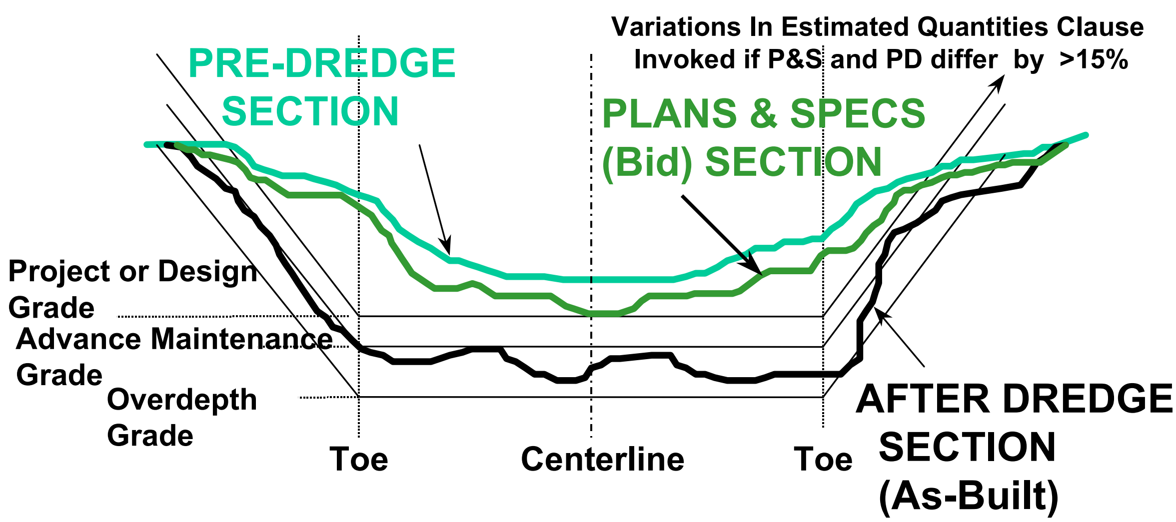


Figure 15-2. Typical reference templates from which payment quantities are computed using AEA methods

a. Average End Area computation formulas. Given two successive cross sections of areas A_1 and A_2 and distance L apart (Fig 15-1), the equation for an average end area volume between two cross sections is:

$$V = (L/2) \cdot (A_1 + A_2) \qquad \text{(Eq 15-1)}$$

Cross-sectional areas are measured in square feet, and the resultant volume is converted to cubic yards by dividing the measure area by 27 cubic feet/cubic yard (*cf/cy*).

$$V = (L/54) \cdot (A_1 + A_2) \tag{Eq 15-2}$$

where A_1 and A_2 are expressed in square feet.

In cases in which even 100-ft cross sections are run, the formula simplifies to

$$V = (1.852) \cdot (A_1 + A_2) \tag{Eq 15-3}$$

The results of Equations 15-1 through 15-3 are exact *only* when the end areas are exactly equal (i.e., $A_1 = A_2$). As one end area approaches zero, the trapezoidal element becomes a pyramid, and the error in using the average-end-area volume formula approaches 50 percent. This commonly occurs in dredging projects where large area variations are found between successive cross-sections.

b. Prismoidal correction to AEA. Various types of prismoidal correction formulas have been developed over the years to compensate for this inherent inaccuracy in average-end-area volumes. More often, however, a higher accuracy is achieved by decreasing the cross-sectional spacing in attempts to define the terrain more precisely (e.g., cross-sectional areas become more nearly equal). This increased field survey densification increases costs, which may not be proportionate to the increase in accuracy obtained, primarily because, in this procedure, survey alignments are restricted to obtaining cross sections over rigid orientation alignments, and these rigid alignments may not be the most practical or efficient method of densifying ground coverage. In fact, for most typical marine construction dredging projects, obtaining cross sections of channels is often the least efficient survey alignment, due to many factors associated with the offshore survey process. When survey alignments are run parallel (i.e., longitudinal) to the project/channel alignment, cross-sections may be easily developed from the DTM (possibly a TIN) database. This is done by passing sectional spaced planes through the database and interpolating depths at the intersecting section planes. From these simulated cross sections, volumes can be computed by use of the average-end-area method. If prismoidal (or Simpson's) formulas or corrections are used in lieu of standard average-end-area methods, the construction specifications should identify that fact. Use of prismoidal corrections is rarely done in practice.

c. Box cut allowance. A limited number of districts provide an allowance for material left above the pay prism grade on side slopes when sufficient non-pay excavation has been performed at the base of the slope to allow for sloughing. Such box cut quantities must be computed separately due to limitations in payment, which shall not exceed the excessive excavated yardage at the base of the slope. This allowance is illustrated in Figure 15-3. Box cut payment allowances are not uniformly applied throughout the Corps--e.g., payment for over-excavation inside the channel. Automated computation of box cut allowances adds significant complexity to the quantity take-off process. Since traditional box cut computation methods were derived from manual cross-section planimeter area techniques, automated terrain model analysis cannot be effectively performed; thus, AEA sections need to be generated even though full terrain model data is available. Often box cut quantities are negligible relative to the overall volume. More significantly, AEA box cut quantity computations have been shown to have significant biases (up to 50%) due to zero allowances on many successive cross-sections--see paragraph 15-3a above. For these, and other reasons, Corps-wide use of a box cut allowance is no longer recommended except in unique circumstances. The following contract clause is typical of those used for box cut allowances:

> Side Slopes. Side slopes may be formed by box cutting or dredging along the side slope. Material actually removed, within the limits approved by the Contracting

Officer, to provide for final side slopes not flatter than shown on the contract drawings, but not in excess of the amount originally lying above this limiting side slope, will be estimated and paid for in accordance with the provisions contained in paragraphs, "Measurement" and "Payment" above. Such amount will be estimated and paid for whether dredged in original position or by box cut dredging whereby a space is dredged below the allowable side slope plane on the bottom of the slope for upslope material capable of falling into the cut. End slopes and transition slopes will not be estimated and paid for under this contract. In such cases, a 0 horizontal on 1 vertical will be used with no upslope allowance provision applied outside the required prism.

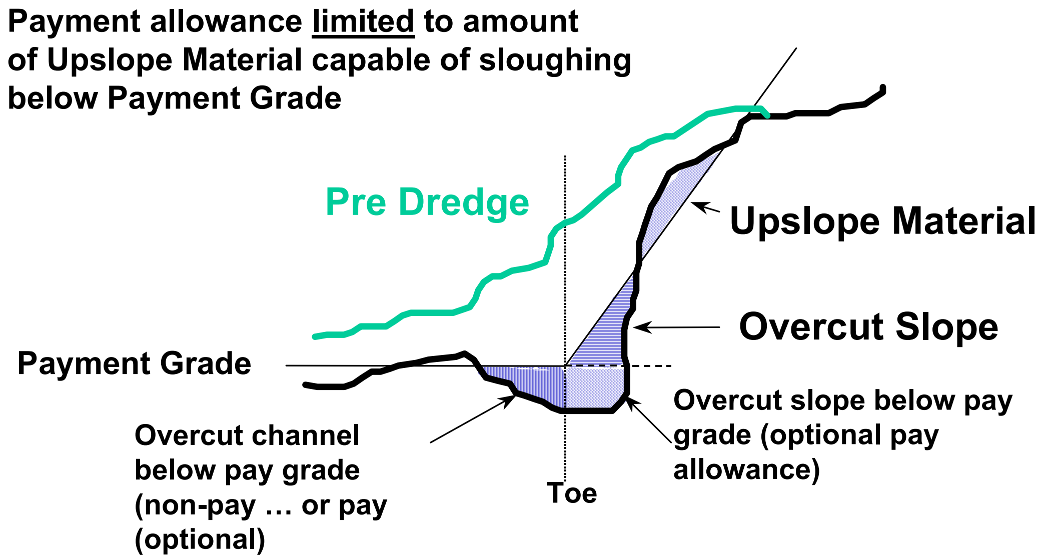


Figure 15-3. Box cut payment allowance

d. Cross-sectional area computations. Over the years, Corps districts have used a number of methods to compute the area of a cross-section that is used in the AEA volume computation. Some of the more prevalent methods of computing cross-sectional areas for dredging are listed below. Details on most of these methods can be obtained in any engineering/surveying handbook.

(1) Direct formula. Various formulas have been developed for computing areas directly from cross-section notes. All generally presume that a slope stake elevation (i.e., grade-side slope intercept point) has been determined along with uniform spacings off the centerline of the channel. Thus, these methods are not useful for dredging work.

(2) Area by coordinates. This is the most common and easiest hand computation method when cross-section notes and/or plots are available. A variation of this method is called the double meridian distance (DMD) method. The cut (or fill) section is treated as a closed traverse, and the area is computed using the offsets (departures) and the depths (latitudes). Offset and depth at the slope-grade intersect (slope

stake point) must be interpolated or scaled on the cross-section plot since these values are not measured in the field. Likewise, a depth must be scaled at each channel toe. Automating this method requires the same interpolations at the toes and slope stake points. A cross-multiplication system is the simplest method of computing the (double) area of the section. As the density of points along a given cross section increases, this manual computation process can become time-consuming. When automated, the greater density approaches a truer representation of the bottom. An example of this computation is shown in Figure 15-4. In this example, pre- and post-dredge end areas are computed separately and relative to the (-) 40.0 foot payment prism. These end areas are combined for use in the AEA volume computation with adjacent cross-sectional areas. Alternatively, the payment end area (4,225 sq ft) could have been directly computed. It is usually desirable to compute available pay quantities as soon as the pre-dredge survey is completed (to compare with the bid quantity estimates); thus, the (usually) small amount of material remaining on the after-dredge survey is easily computed and deducted from the pre-dredge quantity.

(3) Planimeter (mechanical). A polar planimeter was once commonly used by many districts to measure areas directly from the section drawings. Although not as precise as a direct computation, it is typically accurate to about 1 or 2 percent of the computed end area. Normally, the end area was planimetered two or three times and the average taken as the final end area. The disadvantage is that large-scale sectional plots of the survey data and payment templates are required. Section drawings were retained with bid, pre-dredge, and post-dredge cross-sections plotted, the pay area in the cross-section in Figure 15-4 would be planimetered.

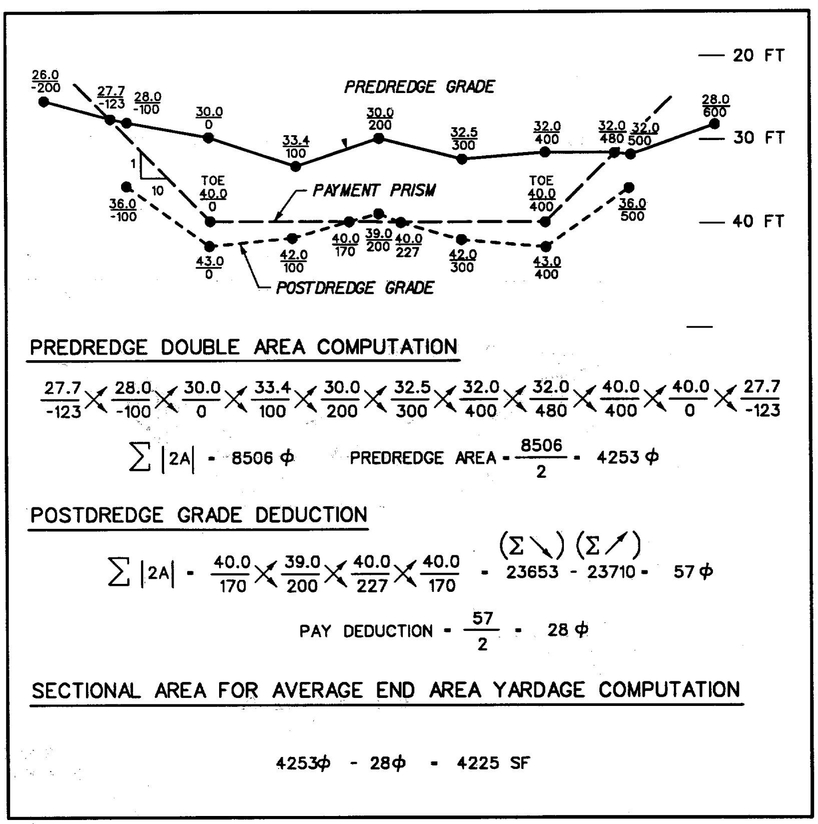


Figure 15-4. Typical predredge and postdredge quantity take-off by coordinate method

(4) Planimeter (digitizer). Sectional grades may be digitized on a tablet for direct computer area computation (Figure 15-5). An analog echo sounder tape can be directly digitized. More commonly, a final section drawing is used containing both the predredge and postdredge surveys. Occasionally, prebid surveys and intermediate partial payment surveys are plotted in section on this sheet for comparative purposes. In all cases, pay template data must be plotted in section for input as part of the area computation.

Figure 15-5. Automated quantity take-offs from digitizing tablet (ca 1976 Jacksonville District)

(5) Automated methods (numerical integration). Quantities may be directly computed on any automated computing device from digitized and/or field-automated hydrographic survey data. No sectional plot is necessary. The end area may be computed by a number of methods, such as coordinate/ DMD areas, summing trapezoidal elements, or numerical integration--see Figure 15-6. The first two methods require interpolation routines to determine toes and slope stake points, but the third method (numerical integration) does not. Numerical integration simply breaks up the cross-section at a fixed interval (e.g., 0.1 or 1 foot) and interpolates depths within this interval; summing up the small area increments across the channel to obtain the total sectional area. Most automated computation systems use this method to compute end areas--e.g., HYPACK MAX. In addition, upslope box cut payment allowances can be simply and directly computed using numerical integration methods.

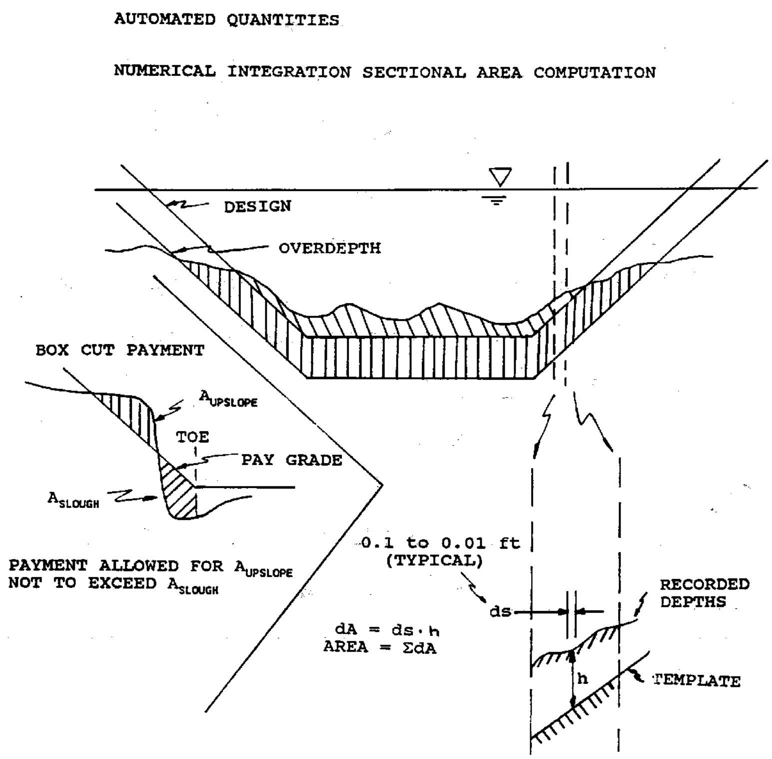


Figure 15-6. Automated quantity take-offs using numerical integration methods

15-4. Triangulation-Based Volume Computations (Triangulated Irregular Networks)

The Triangulated Irregular Network (TIN) volume technique is based on comparison of two terrain models. In the case of dredged material volumes, one model represents the actual bottom terrain as surveyed, and the other model usually represents a design surface (e.g., required depth and overdepth), although two surveyed surfaces can also be compared. TIN routines offer great flexibility in the collection of survey data, since the terrain coordinates need not be in any particular pattern or alignment. TIN programs also enable visual terrain models of the surveyed topography and of design, or hypothetical, terrain surfaces--see Figure 15-7. The TIN model volume is also more accurate than an AEA volume computed from the same data base. TIN routines for volume determination and terrain visualization are commonly available in commercial site design and some survey software packages. For dredged material volume applications, TIN routines are particularly well-suited to cases in which the channel is not a simple straight layout, such as in turning basins, settling basins, widener sections, curved channels, etc.

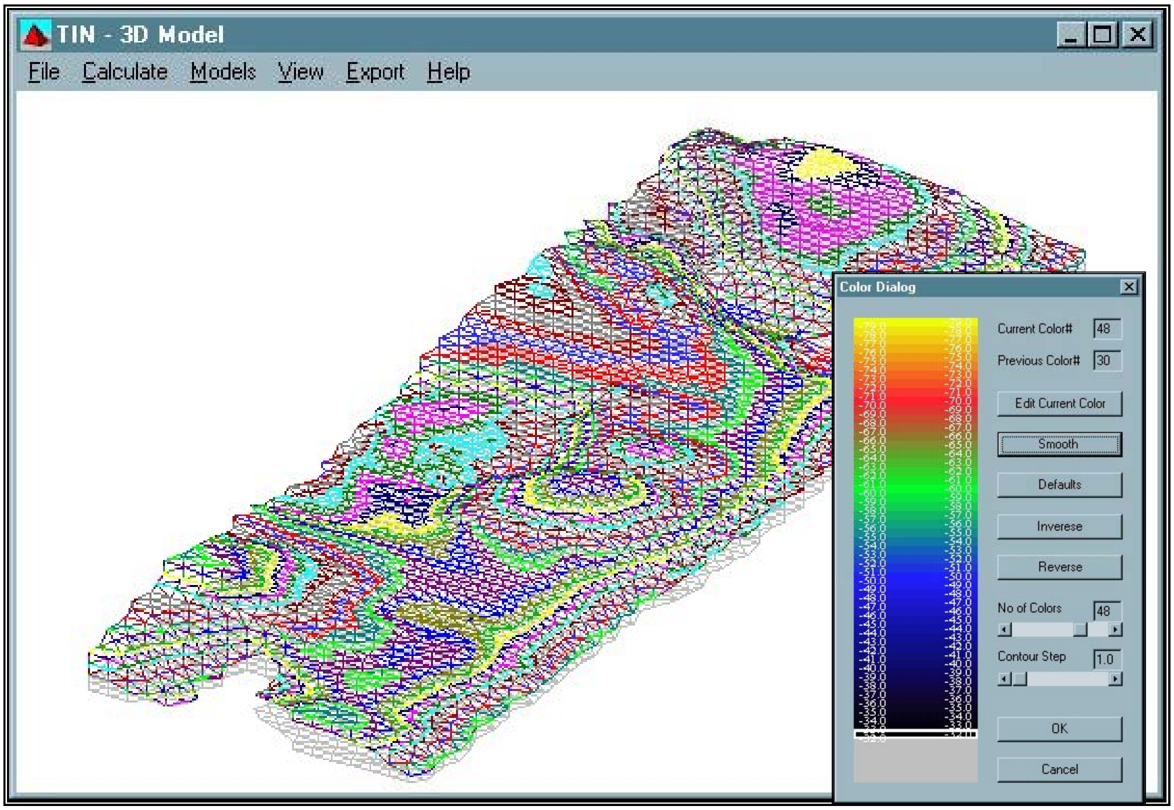


Figure 15-7. Color-coded three-dimensional TIN surface model (Coastal Oceanographics, Inc.)

a. General concept of TINs. A TIN is actually a set of triangles which represents the terrain surface. Consider a set of survey coordinates marked on a map. These coordinates are "triangulated": a set of triangles is specified such that their vertices are these spatial points, no triangle contains coordinates other than its vertices, and the triangles cover the area of interest exactly and without overlapping each other. Any such set of triangles defines a TIN. The maximum area a TIN can cover is the "convex hull" of all coordinates. That convex hull is the polygon which contains all coordinates, whose vertices are the coordinates, and which is convex; that is, any straight line segment connecting two points in the interior of the polygon is entirely contained by the polygon. The convex hull of all coordinates is also the convex polygon of smallest area containing all coordinates. A TIN may fail to cover its maximum area while still covering all available coordinates; some triangles along the boundary may be missing.

b. Delaunay Principle for generating TINs. Any particular set of survey coordinates may be triangulated in many different ways, each yielding a different TIN. The Delaunay Principle, which is common in many TIN routines, is preferred for dredged material volumes. This procedure computes a unique TIN for a given set of coordinates and helps avoid long narrow triangles where possible. The Delaunay Principle requires that the circle circumscribed around any triangle in the TIN contain no points (soundings) in its interior. An exception to the uniqueness of the Delaunay TIN described above occurs when a circle circumscribed around a triangle in a Delaunay TIN contains on its circumference, but not in its interior, one or more sites in addition to the three triangle vertices. Such a case is called "degeneracy." In the presence of degeneracy, the Delaunay Principle fails to characterize a TIN uniquely for a given set of sites. Indeed, four sites on a circle can be triangulated in two different ways in accordance with the

Delaunay Principle. In the absence of degeneracies, however, the TIN constructed in accordance with the Delaunay Principle is unique. It is frequently assumed that the Delaunay TIN covers the maximum area, namely, the convex hull of all coordinates. As stated earlier, a TIN need not cover the maximum area--in fact, any triangulation process, aiming to fully cover the convex hull of a given set of points, tends to generate boundary triangles that are long and narrow, and may adversely affect displays and perhaps even some calculations. Typically, such triangles can be removed from the TIN while keeping all points covered and reducing the total area of the TIN by only a negligible amount. It is recommended, however, that software packages for TIN generation allow the user control over which boundary triangles to remove or at least document their rules for deleting triangles, if such rules are built into the software. Software packages such as HYPACK MAX allow for such input options when generating TINs

c. Terrain and design surfaces. The salient feature of the TIN volume methods is that they construct two surfaces, a TIN "terrain surface" developed from depth (elevation) measurements and a "design surface" which represents the design specifications. Terrain information consists typically of a list of X-Y-Z coordinates, with the horizontal coordinates specified by X-Y and the spatial coordinate z recording the measured elevation. When a TIN is generated for the given measurement sites (x_i,y_i) and the corresponding triangles and vertices (x_i,y_i,z_i) are joined in space, a terrain surface results. The design surface consists of polygonal surfaces. A desired design surface (navigation channel), for instance, is sometimes specified as a long rectangle with adjacent polygons for side slopes. X-Y points on the channel are termed "nodes." Polygonal surfaces are represented by their constituent planar polygons or "facets" in space. For input purposes, they are mainly defined in terms of "design breaklines," the line segments at which facets are joined. Those breaklines terminate at "design breakpoints." Typically three breaklines meet in a breakpoint.

d. Polygonal surfaces. TIN surfaces are also instances of polygonal surfaces. They represent the special case in which all polygonal facets are triangles. Polygonal surfaces are often represented, somewhat artificially, as a TIN surface if the polygonal facets are partitioned into triangles. In that case, breaklines are generic to all such surfaces. The design surfaces encountered in road construction, as well as in hydrographic applications, tend to be of a special form: their cross sections perpendicular to a center line are similar to each other. Some commercial packages, therefore, offer an alternate surface specification method suited to surfaces of this particular kind. The idea is to "push a template," that is, to interpolate a design surface through a sequence of cross-sectional design delineations or "templates." This design specification method is ideal for long stretches of channels. However, if a channel changes direction, side slopes vary, or more complex designs such as turning basins are used, the template method characterizes the true design surface only approximately.

e. Cut volume. The space bounded by the terrain and design surfaces defines the volume to be determined. This space is subdivided into vertical triangular prisms, that is, polytopes with three vertical edges capped by two, not necessarily parallel, triangles, as shown back in Figure 15-1. The volume of such a prism is rendered exactly by the formula

$$V = [(h_1 + h_2 + h_3)/3] \cdot (A_0) \qquad \text{(Eq 15-4)}$$

where

h = height of vertices above design (pay) prism
A_0 = triangular area of prismoidal element projected on design surface

Thus, h_1,h_2,h_3 represent the lengths of the three vertical edges of the prism, and A_0 denotes the area of the triangle that arises as a vertical projection or footprint of the prisms onto a horizontal plane. Indeed, A_0 is the area of the underlying TIN triangle. The volumes of all the prisms that constitute the cut body are then added to arrive at its total volume. The cut volume is therefore calculated on a triangle-by-triangle basis. This requires, however, that the dredge area (that is, the projection of the cut body onto the reference plane) be fully triangulated.

(1) Note that some TIN triangles of the dredge area may be clipped by the boundary of the dredge area so that their remainders within the dredge area are non-triangular polygons, typically quadrangles. A straightforward way of dealing with this situation is to subdivide these polygons into triangles. In this fashion, the volume of the cut body, as defined by the TIN terrain surface, is rendered exactly. There are, in general, several different ways to subdivide a non-triangular polygon into triangles. Since each of the polygons to be subdivided is part of a TIN triangle corresponding to a planar region on the terrain.

(2) As with the average-end-area computation discussed previously, the user should be cautious of areas in which the design surface extends, in the x-y plane, beyond the terrain surface. In such areas, there exists no terrain surface with which to compare for volume information. Similarly, no volumes can be obtained for areas in which the terrain model has no corresponding design surface. TIN routines usually assume vertical bounds at the edges of the terrain and design surfaces. Therefore, volumes are only determined for those X-Y areas in which terrain and design information exists. Note that if vertical bounds are not created by the TIN routine, the program may produce erroneous results in those areas of discrepancy. The user should check the TIN routine for proper handling of terrain/design surface gaps.

f. Automated dredge volumes from TIN models. The TIN MODEL Program in HYPACK MAX is capable of calculating the volumes between two different surfaces. Three different options are currently available:

(1) Survey Surface vs. Level. This option compares a TIN surface against a level plane. This would be applicable to disposal or borrow area surveys. See example at Figure 15-8.

(2) Survey Surface vs. Channel. This is the most common dredging application--comparing a TIN surface against a standard channel prism that may contain irregular boundaries and side slopes. This would be the most common application for Corps navigation projects.

(3) Survey Surface vs. Second Survey Surface. This compares two TINs irrespective of any payment prism.

Details for automated volume computations using TIN models are found in the software manuals specific to the automated hydrographic data acquisition and processing system being used. Not all data acquisition software packages provide options for TIN volume computations relative to Corps navigation projects. Many programs regenerate cross-sections from a TIN model and compute quantities using AEA methods--an unnecessary and complex process if the design surface can be clearly defined.

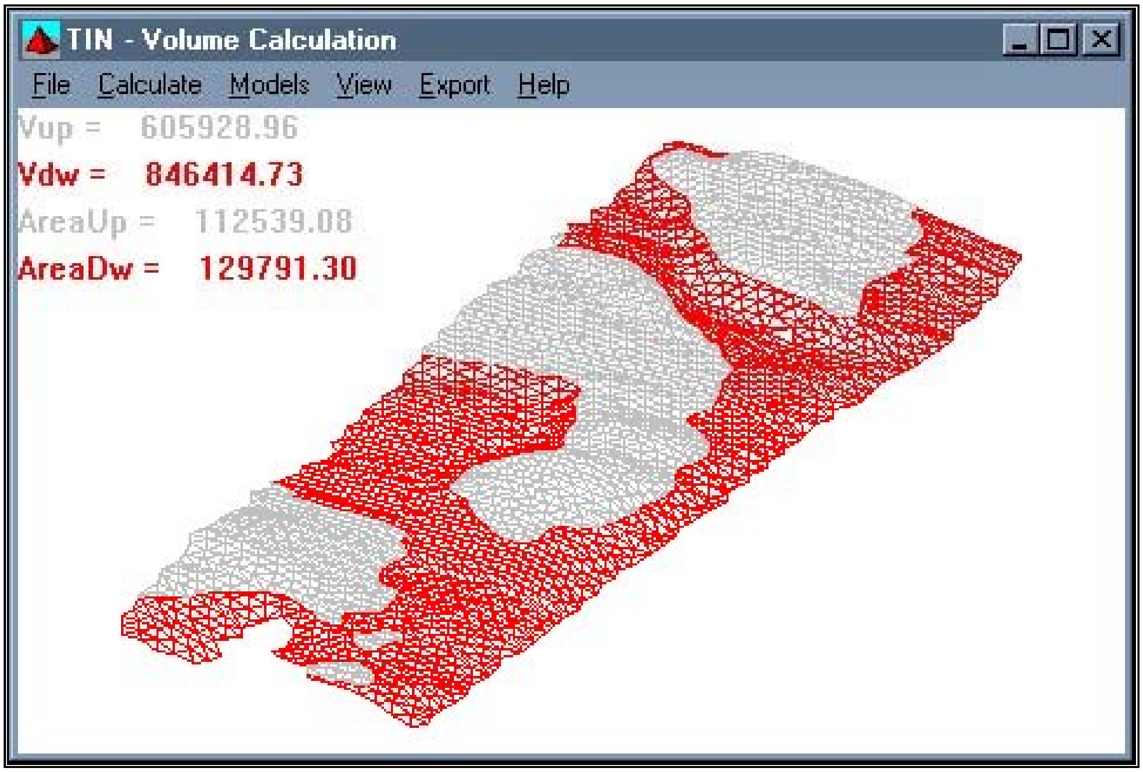


Figure 15-8. Example of TIN volume computed between TIN surface model and a level reference plane (Coastal Oceanographics, Inc.)

15-5. Reference Surfaces and Payment Templates used in Corps

There is no commonality among Corps districts in dredge payment methods or templates. Even Area Offices within districts are known to have unique payment methods. There at least a dozen distinct dredge payment methods used by Corps districts--e.g., Jacksonville Method, Grand Haven Method, Philadelphia Method, and Savannah Method. This variation adds complexity to attempts to standardize quantity computation software and impacts dredging firms working in different commands. Figure 15-9 depicts some, but not all, of the variations in dredge payment methods found in the Corps. This section describes some of the current variations is these payment methods.

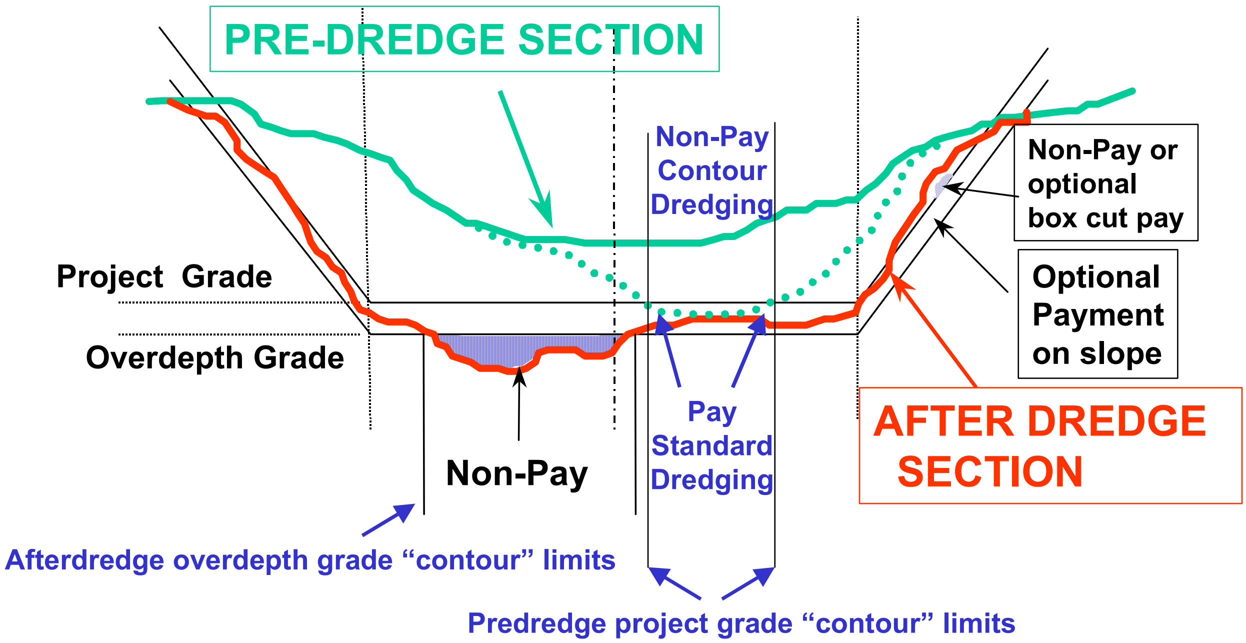


Figure 15-9. Various in-place dredge payment grades and templates used in Corps

a. Standard and Contour Dredging payment templates. In general, there are two somewhat common payment methods between the channel toes--the Standard Payment Method (Figure 15-10) and the Contour Dredging Payment Method (Figure 15-11). The major difference between the two methods is how material between the project grade and overdepth payment grade is handled. As shown in Figure 15-9, neither method pays for material excavated below the overdepth grade--the vertically shaded area lying to the left of the centerline. Both methods would pay for material excavated below the design grade (down to the overdepth grade) *provided the* Predredge (or P&S) survey indicated material existed above the design grade. If the predredge survey indicated the area was clear to the design grade (i.e., the dashed Predredge line in Figure 15-9), then the Contour Dredging Method would *not* allow payment for material excavated below the project grade. The Standard method would provide payment allowance for material removed in this area. Thus for the Contour Method, dredging payment limits are defined by the project grade depth contour for the predredge survey; the dredging pay limit for the Standard Method is defined by the overdepth grade contour for the afterdredge survey. Some districts using the Standard Method will place physical dredging limits within the channel for areas below project grade. This is, in effect, another form of Contour Dredging except the rigid dredging limits are used instead of the Predredge contours. This is illustrated in Figure 15-10 .

b. Side slope payment. Districts vary widely on payment for excavation in side slopes. Some districts treat side slopes the same as the main channel, and pay relative to the Standard Method or Contour Method. Others do not allow payment for any material removed from the side slopes (presumably such removal is factored into the unit price in the main channel). Some districts provide side slope excavation payment only on new work, not on maintenance dredging projects. Other districts provide for a box cut payment allowance, as was previously described and illustrated in Figure 15-3.

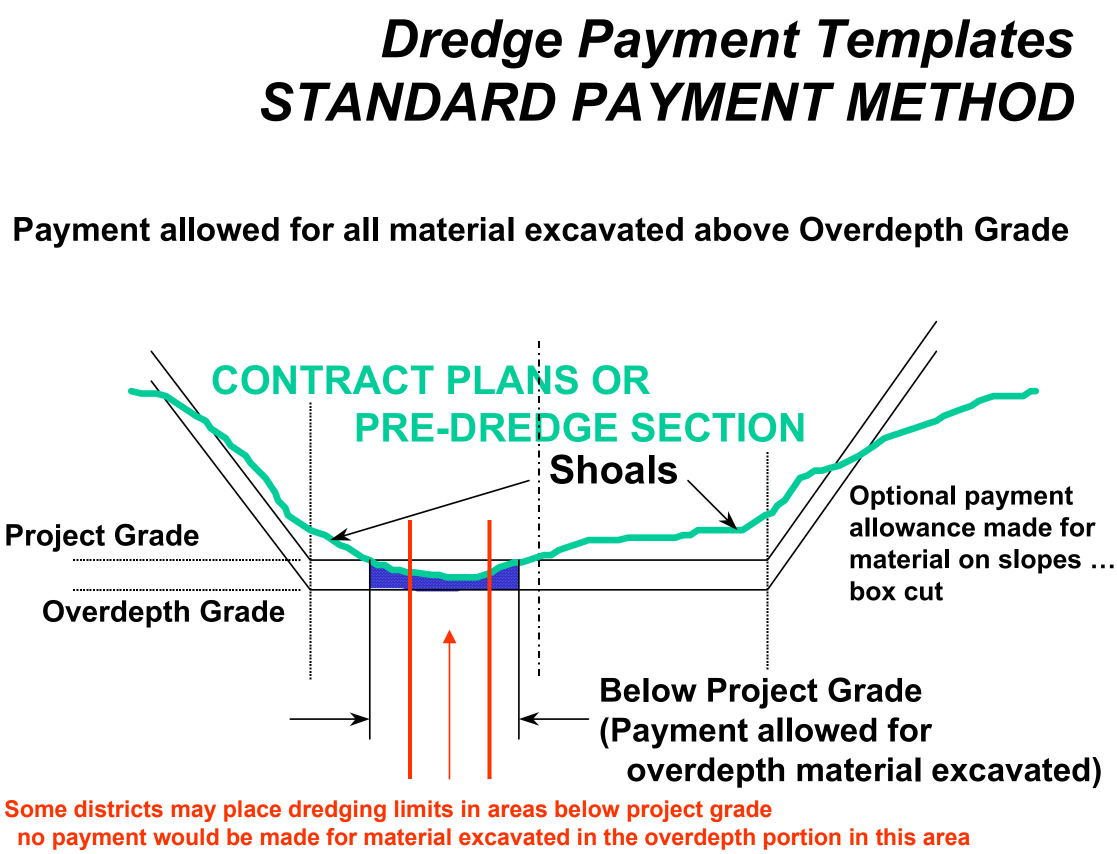


Figure 15-10. Standard Payment Method of computing excavated quantities

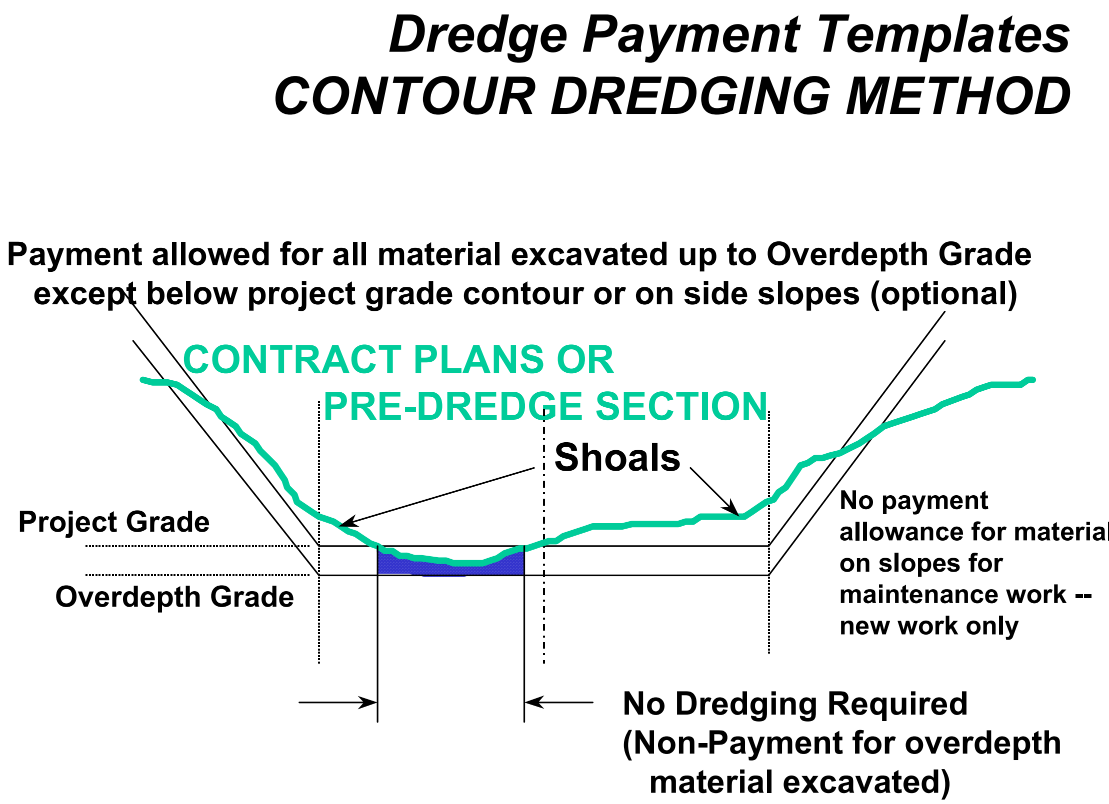


Figure 15-11. Contour Dredging Payment Method of computing excavated quantities

c. Automated software for computing dredged quantities. A number of software packages are available to compute AEA , TIN, or Binned volumes. Not all are designed to support the varied Corps dredging templates outlined above. Coastal Oceanographics' HYPACK MAX "Cross-Sections and Volumes" module is tailored to these varied payment templates; providing methods to determine both Standard and Contour Dredging payment computations, side slope restrictions, box cut allowances. This is illustrated in the cross-section in Figure 15-12. This example contains both the project grade ("design" grade) and overdepth grade ("subgrade") areas/volumes. It also adds a third template--termed a "supergrade"--that could be an advance maintenance grade limit or used for estimating quantities at different grades. Figure 15-12 also shows some of the subdivisions used by HYPACK to cover the various payment methods used in the Corps. These subdivided areas in the cross-section allow for separating Standard/Contour methods, side slope payment variations, and box cut allowances. All the subdivisions used in HYPACK MAX end area pay computations are listed below:

V1: The volume of material above the design surface in the center of the channel.

V1L: The volume of material above the design surface of the left bank.

V1R: The volume of material above the design surface of the right bank.

V2: The volume of material between the design and the overdepth grade surfaces in the channel center.

V2P: The volume of material between the design and the overdepth grade surfaces in the channel center where the depth is less than the design surface.

V2NP: The volume of material between the design and the overdepth grade surfaces in the channel center where the depth is greater than the design surface.

V2L: The volume of material between the design and the overdepth grade surfaces of the left bank.

V2R: The volume of material between the design and the overdepth grade surfaces of the right bank.

V3: The volume of material between the overdepth grade and the supergrade surfaces in the channel center where the depth is less than the design surface.

V3L: The volume of material between the overdepth grade and the supergrade surfaces of the left bank.

V3R: The volume of material between the overdepth grade and the supergrade surfaces of the right bank.

X2: The amount of material removed beneath the design surface by a box cut inside the channel toes. You may enter the distance used to consider box cuts.

X1: The amount of material on the left or right banks that is above the design surface. X1 can be credited to fall into an X2 hole.

Y1: The amount of material which has been deposited during the dredging process.

As an example of how the above zones are used to accommodate the differing payment methods, the V2 sector represents all material in the overdepth zone (between the toes); all of which would be paid under the Standard Method but only a portion of which is paid under the Contour Method. That portion is defined by the sectors V2P (Pay) and V2NP (Non-pay). The Contour Method would provide payment for the V2P sector, but the V2NP sector would not be paid since there was no material lying above the required depth. Contour Dredging Method volume computations require comparisons between the pre- and post-dredge surveys since payment is restricted to areas where material lies above the required grade on the pre-dredge survey. If material in the sector V2NP is excavated during dredging, it is not paid. The Contour Method presumes a degree of dredging accuracy that may not be achievable--especially in hopper dredging. Its intent is to avoid paying for substantial quantities of material lying below the required grade but above the overdepth grade. This material is paid in the Standard Method unless physical dredging limits are placed in areas where material lies below the required grade but above the overdepth grade.

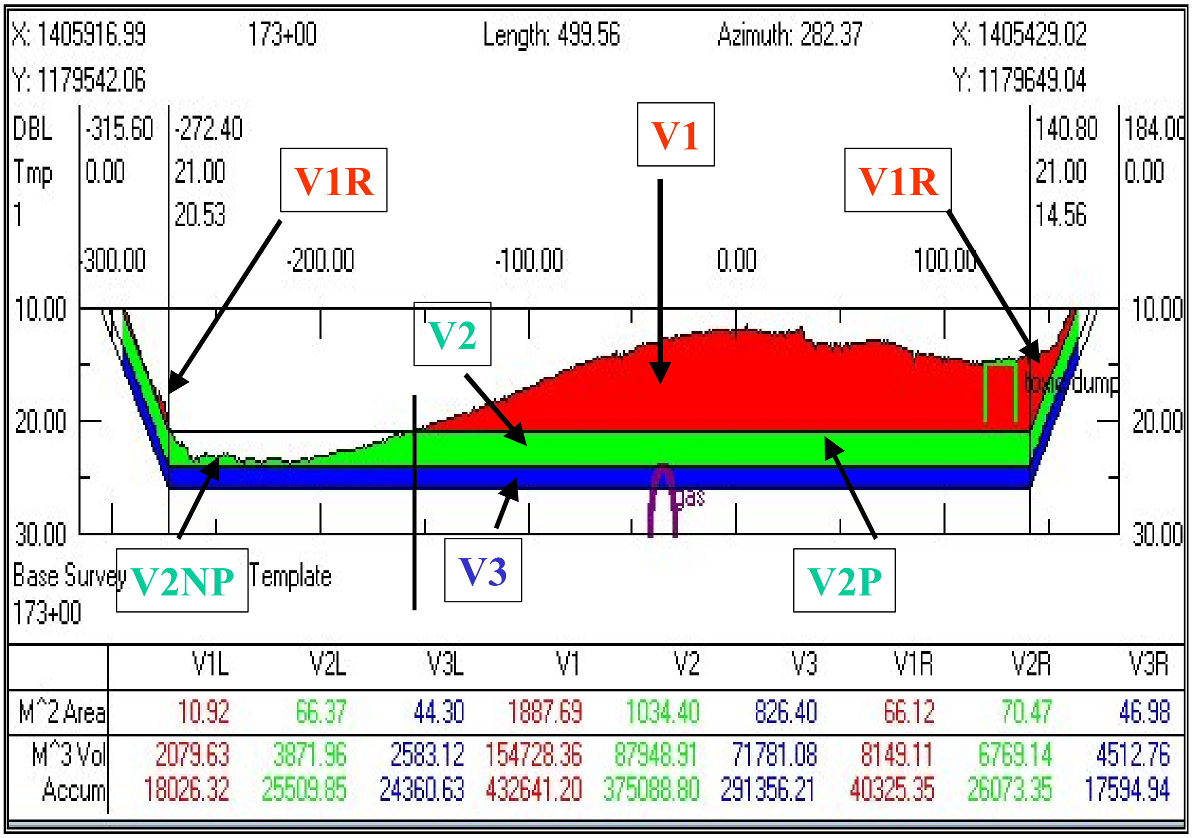


Figure 15-12. Channel cross-section with areas/volumes for various portions of excavation areas Not all subdivisions shown (Coastal Oceanographics, Inc. End Area Method)

The following sample computation is performed over a 1,188 ft dredging acceptance section. The output is from Coastal Oceanographics' HYPACK program and uses the "Philadelphia Method" option for volume computations. The channel limits are irregular as shown by varying offsets for each cross-section—this dredging section encompasses a channel widener. The final yardage values represent the material available on the pre-dredge survey. A similar take off would be made on the after-dredge survey and any remaining material from that survey would be subtracted from the pre-dredge results.

Tampa Harbor, Cut-D (HB), Acceptance Section - 3
Office Engineering Section, Survey Branch, Jacksonville District
Pre-Dredge Survey (No. 98-C041) Cont. No. DACW17-98-C-0004
Date of Survey: 24 February 1998

Station to Station		Project Depth	Over Depth	Left Slope	Right Slope
61+00	72+88	34.0	36.0	3.0/1	3.0/1

Dredging Quantities Summary
==========================

Total Material to Project Depth ..... 11309.4 CY
Total Allowable Overdepth .... 11853.4 CY
Total Pay Place .... 23162.8 CY

Dredging Quantities Computation
==============================

Station	Reference Depth = 34.0 ft: Left Slope	Left Channel	Right Channel	Right Slope	Volume (CY)	Overdepth = 2 ft: Left Slope	Left Channel	Right Channel	Right Slope	Volume (CY)
61+00	0.0	0.3	0.0	0.0	0	2.0	4.0	0.0	0.0	0
Offset:	-302	-200	+200	+302						
62+00	11.6	99.2	50.3	5.9	309.8	20.0	134.0	98.0	12.0	500.1
Offset:	-302	-200	+200	+302						
63+00	24.5	172.3	33.5	5.6	746.2	26.0	144.0	98.0	14.0	1011.2
Offset:	-302	-200	+200	+302						
64+00	24.4	204.4	26.6	4.6	918.7	26.0	158.0	72.0	12.0	1018.6
Offset:	-302	-200	+200	+302						
65+00	33.5	191.5	0.5	0.1	900.2	28.0	166.0	8.0	2.0	876.2
Offset:	-302	-200	+210	+317						
66+00	29.3	188.5	7.9	1.5	837.9	26.0	170.0	34.0	6.0	812.9
Offset:	-302	-200	+239	+346						
67+00	27.5	194.2	24.7	12.0	931.3	30.0	174.0	50.0	22.0	969.3
Offset:	-303	-200	+262	+367						
68+00	37.8	261.4	10.3	2.1	1093.6	34.0	202.0	32.0	8.0	1045.7
Offset:	-303	-201	+290	+394						
69+00	38.2	277.7	0.0	0.0	1210.2	34.0	200.0	0.0	0.0	978.6
Offset:	-305	-201	+314	+418						
70+00	33.9	239.1	5.4	1.1	1143.2	32.0	200.0	24.0	6.0	946.2
Offset:	-306	-203	+341	+444						
71+00	29.2	214.7	53.5	5.7	1095.9	30.0	190.0	132.0	12.0	1150.8
Offset:	-309	-204	+369	+469						
72+00	22.8	201.6	84.4	13.5	1145.0	24.0	202.0	142.0	20.0	1349.4
Offset:	-312	-206	+395	+497						
72+88	10.0	176.8	96.9	14.3	977.4	16.0	218.0	124.0	18.0	1194.5
Offset:	-315	-208	+419	+521						

15-6. Volumes of Irregular Channels or Basins

Average End Area computation methods become complex when channel sections have varying limits, at channel intersections with widener sections present, in irregularly shaped turning basins, or when survey cross-sections are not run perpendicular to the channel alignment. When cross sections are not run normal, or perpendicular, to the project centerline, the section's projected intercept with the side slope must be adjusted in section plots or automated software when computing end areas. This commonly occurs in turning basins and widener sections. The plotted side slope is corrected as a function of the sine of the angle of intercept (e.g., if a survey line intersects a 3-on-1 slope at 75 deg, the plot of the intersection would be shown as 3.1 to 1). Average-end-area projections are made relative to the actual survey spacing interval, not to the project alignment stationing. In areas where different sectional alignments merge, irregularly shaped triangular or trapezoidal surface areas result. Various methods are employed to proportionately distribute end areas over these irregular areas (see Figure 15-13).

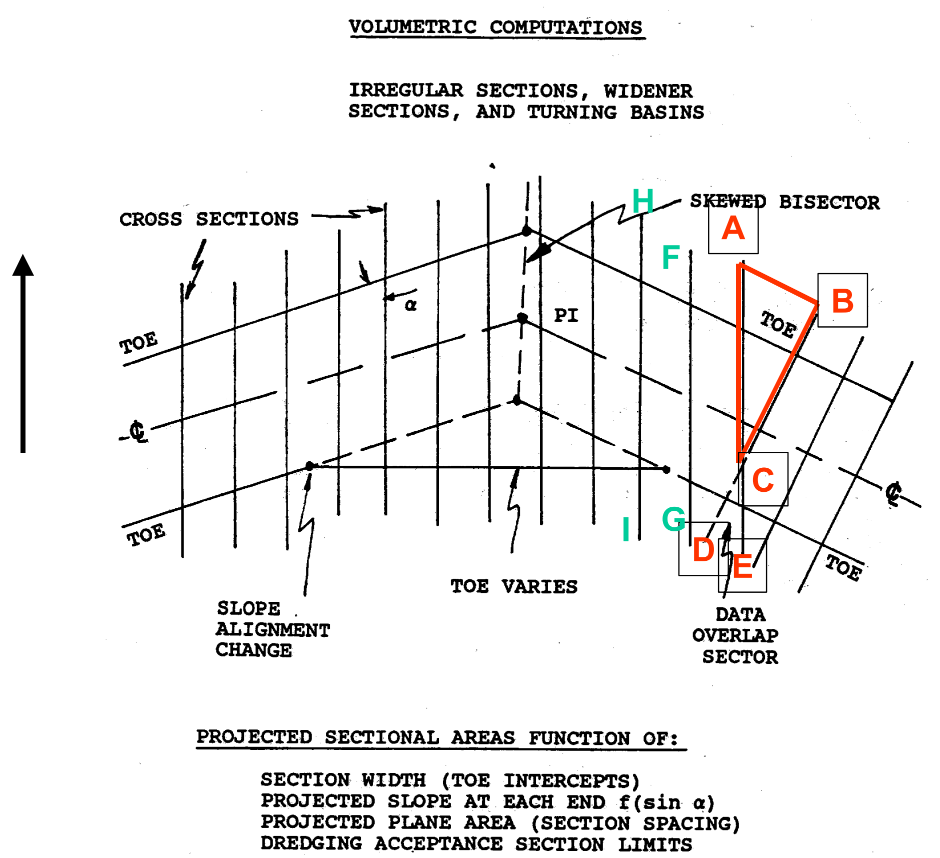


Figure 15-13. Volumes of irregular channels and non-normal cross-section alignments

a. In Figure 15-13, volumes for each of the irregular sections must be computed. An example is the triangular area (A-B-C) where the cross-sections from two different alignments overlap. The end area for the cross-section B-D is not projected to the left of the section. It is broken up into end areas B-C and C-D which are projected to varying distances depending on the surface area of the irregular figures between sections--i.e., triangles A-B-C and C-D-E.

b. The volume within triangle A-B-C illustrates the complexity in determining average end area quantities for irregular areas. Since the cross-sections are not on the same alignment, the distance to project the "average" of their end areas is difficult to determine--it can only be approximated. In addition, section A-C intersects the side slope at an angle, requiring a correction for the end area of the upslope portion of the section. It is often simpler to treat the area A-B-C as a vertical prismoidal element, computing the volume of the prism using averages of depths along the sides. The triangle could be further broken to separate out the channel portion from the side slope. Likewise the volume of the element C-D-E could be similarly computed. This element would be deducted from volumes computed from the cross-sections A-E and F-G.

c. Volumes beginning with cross-section F-G may be computed from average end area projected along the original cross-sectional spacing (e.g., 100 ft). The end areas for each section need to be corrected for the non-normal slope intersect. This may require plotting and viewing cross-sections in profile. In addition, once the widener section is reached at section H-I, both toe ranges begin to vary and must be computed. The slope on the widener is normal but skewed on the north side of the channel.

d. The above example clearly illustrates the difficulty in using average end area techniques for irregular shapes or non-normal sections. Quantity estimates in such areas are truly "estimates" and are often educated guesses. For this reason, TIN or Bin volume computation techniques should be employed. The irregular channel template surface (nodes and slopes) can be input as a terrain model, as shown in Figure 15-14. The surface model (TIN or bin) is then not dependent on the survey alignment method. The volume is simply computed between the two surfaces as explained earlier. HYPACK MAX contains an optional volume program ("Standard HYPACK") that is designed to compute quantities in irregular basins or where survey lines are non-parallel. "Standard HYPACK" slices horizontal wedges between cross-sections--similar to TIN elements--as illustrated in Figure 15-14.

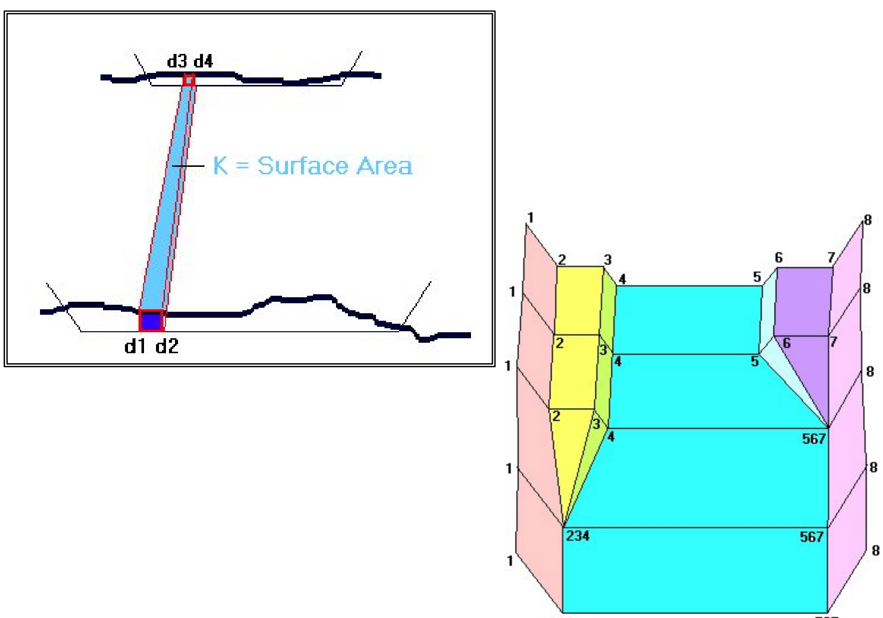


Figure 15-14. Standard HYPACK method for computing quantities in irregular sections. This method is designed for irregular basins and/or non-parallel cross-sections

e. Curved channel sections. Some Corps navigation projects are defined relative to a circular alignment and cross-sections are taken normal to that alignment. These sections may be in the navigation or flood control project or up the overbank levees. In the case of curved alignments with cross sections run perpendicular to the alignment, average end areas are projected about the radius of the centroid for each section in order to compute the volume. Various mechanical and numerical methods exist for computing the centroids of irregular areas (see Figure 15-15).

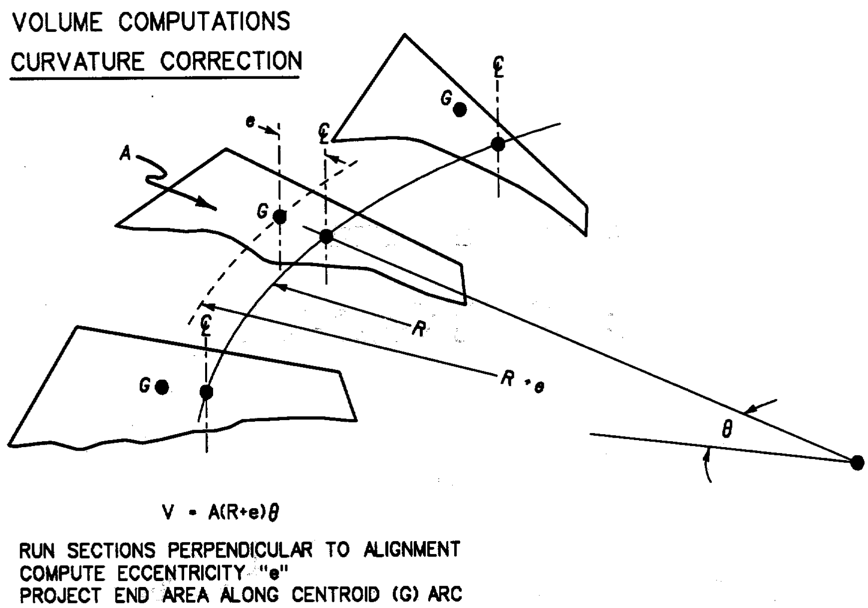


Figure 15-15. Curved channel volume computations

15-7. Obtaining Complete Coverage for Quantity Computations

A major survey deficiency exists when complete coverage is not obtained over the entire payment area. This often occurs when deep-draft survey vessels are unable to survey into shallow waters where excavation was performed. In other cases, the slope-grade intersect point may be above the surface, requiring land topographic survey coverage at the junction area. In either case, volume computations are impossible without full coverage through the slope-grade intersect points. This is the case regardless of the computation method (AEA or TIN). The distance that coverage is required outside the toe of a channel may be estimated by the following:

$$d = Slope \cdot (Required\ depth - Upslope\ depth) \quad \text{(Eq 15-5)}$$

where:

	d	=	slope-grade intersect distance from toe
	Slope	=	design slope ratio (H/V)
	Required depth	=	project design or overdepth
	Upslope depth	=	average minimum depth atop slope/bank

It is essential that coverages be verified prior to computing quantities using automated software. Most programs have no alarm to indicate inadequate coverage. Verifying coverage is done by viewing 3-D models or section views of the project to ensure coverage.

15-8. Accuracy of Excavated Quantity Estimates

As described in detail in Chapter 4, the accuracy of a resultant volume is dependent on many random variables, each with its own accuracy estimates. These include horizontal positioning accuracy, elevation (or depth) measurement accuracy, data density or ensonified footprint size relative to the overall area, terrain uniformity, and the volume computational method employed. When average end area computations are made from widely-spaced cross-sections, three options are available to increase the accuracy of a given reach of channel:

- Decrease cross-section spacing
- Increase density and accuracy of data along the section
- Account for variations in cross-section spacing; do not assume spacing is constant on adjacent cross sections.

a. With single-transducer surveys, all of the above options have practical and economic limitations. Decreasing the cross-section spacing is easily achieved by use of multiple transducer or multibeam systems. This provides the greatest increase in accuracy. Increasing the density of data along a given cross-section will not improve the volume computations if the sections are spaced 200 feet apart. Likewise increasing the accuracy of data points in sections spaced 200 feet apart will not significantly improve the overall accuracy of the volume. No increase in section spacing will compensate for a constant 0.5-ft bias in depth. Likewise, the impact of a constant 20-ft horizontal bias on the side slopes cannot be compensated for in the volume algorithms. A large variance between two end areas can cause a significant error in yardage when the AEA formula is used.

b. In an effort to standardize average-end-area applications for single-transducer surveys, the following guidelines are specified:

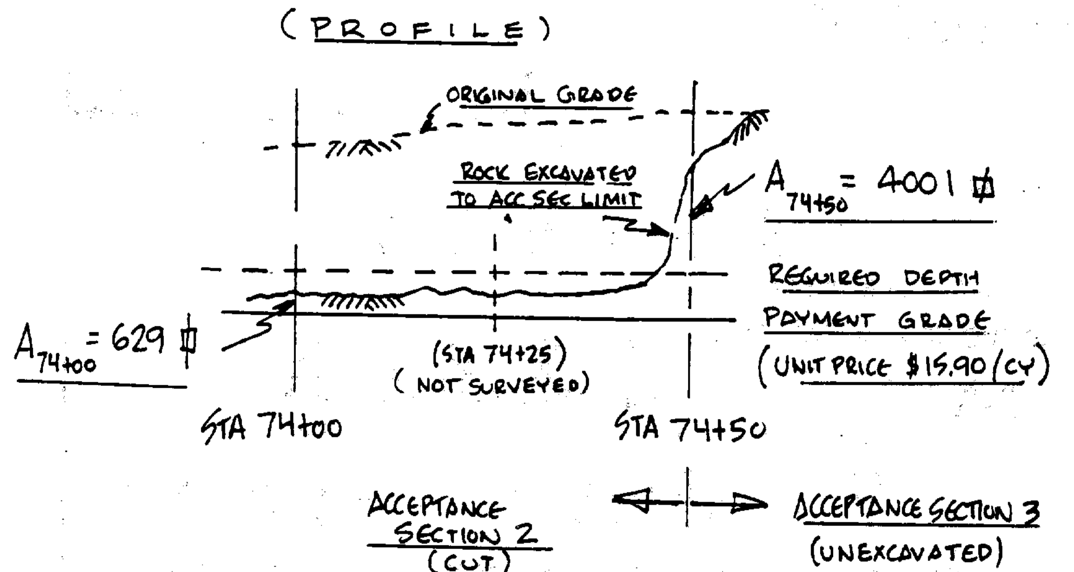
(1) Care should be taken to reestablish the same section lines at each subsequent survey of the same area (i.e., predredge and postdredge surveys).

(2) Survey coverage should be slightly extended into undisturbed areas atop the slope, well clear of any excavation. When preconstruction and post-construction surveys are plotted and superimposed, these undisturbed regions should match in elevation. If not, a survey deficiency is indicated.

(3) Adhere to the survey coverage and line spacing specifications in Table 3-1. Standardizing cross-section spacing will help standardize volume computations. Obtaining full-bottom coverage provides the greatest benefit in increasing accuracy of volumes.

(4) The areal extent of all irregularities shall be fully determined. When a particular cross-section detects a bottom feature not considered typical of the entire space between adjoining sections, this feature should be densely covered with additional cross sections (e.g., 25 or 50 ft O/C; see Figures 15-16 and 15-17).

SUBJECT:	COMPUTED BY:	DATE:	FILE NO.
CROSS-SECTIONAL DENSITY	WA BERGEN	JAN 90	1110-2-1003
	CHECKED BY:	DATE:	SHEET NO.



AFTER DREDGE SECTIONS RUN 50 FT O/C

PAYMENT DEDUCTION FROM AVERAGE END AREA COMPUTATION

$$V_{AEA} = \frac{L}{27\,CF/CY}\frac{(A_{74+00} + A_{74+50})}{2} = \frac{50}{27}\frac{(629+4001)}{2} = 4287\ CY \quad (\$68,163)$$

PAYMENT DEDUCTION USING PRISMOIDAL COMPUTATION (ASSUME $A_{74+25} \approx A_{74+00}$)

$$V_{PRI} = \frac{L}{27\,CF/CY}\frac{(A_{74+00} + 4 \times A_{74+25} + A_{74+50})}{6} = \frac{50}{27}\frac{(629 + 4(629) + 4001)}{6}$$

$$V_{PRI} = 2205\ CY \quad (\$35,060)$$

[UNDERPAYMENT (TO CONTRACTOR) -- $33,103]

PRISMOIDAL COMPUTATION MORE CLOSELY APPROXIMATES ACTUAL EXCAVATED QUANTITY

Figure 15-16. Effect of inadequate cross-sectional density

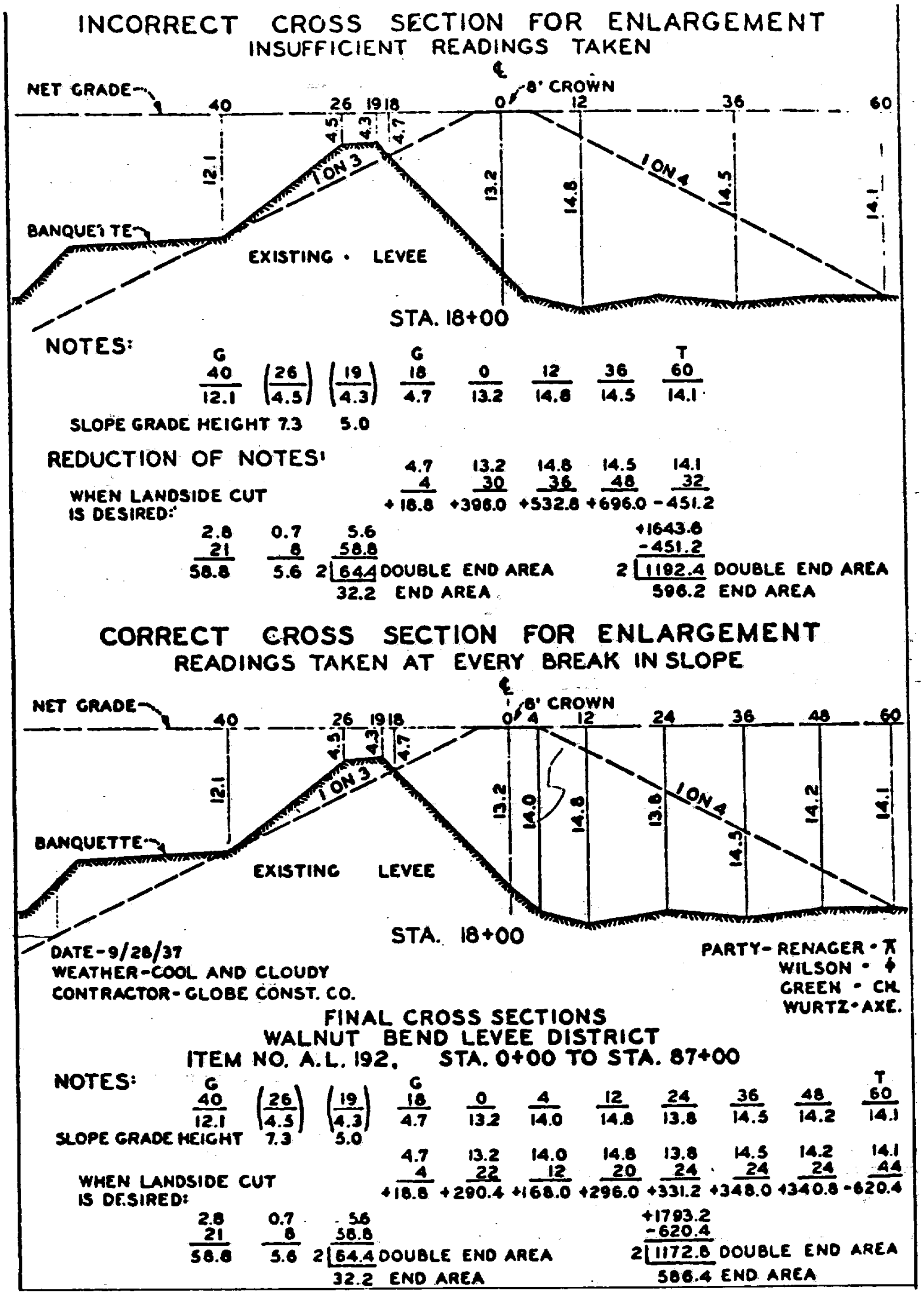


Figure 15-17. Effect of insufficient density along a levee cross-section

c. Accuracy and refinement of volume estimates. As with the average-end-area and any other volume computation technique, TIN volume estimates are improved with additional survey data. Conversely, the absence of data around bottom features could lead to large inaccuracies. For example, if no survey data is collected on a mound or shoal, the resulting computed volume would be an underestimate. Although there is clearly a benefit from more survey data, there is certainly a limit to the amount that can be collected from conventional single-beam sounding systems. However, an efficient means to obtain more survey coverage is the addition of longitudinal lines for cross-section surveys, or the addition of cross-section lines for longitudinal surveys. Unlike the average-end-area method, the TIN technique can process these combined data sets. Note also that the TIN technique offers a method of effectively processing data from multibeam survey systems for volume estimates. TIN routines commonly offer a method of refining the triangulated terrain model based on breaklines. Such line segments, entered by the user, prevent triangles from crossing these lines. This procedure might be used to break up large triangles or better model a feature, such as a ridge or channel toe. Although the addition of breaklines may not always be feasible or even possible, the use of additional terrain data will nevertheless only improve results.

15-9. Combined TIN and Average-End-Area Volume Computations

A variation of the TIN technique commonly available in site design packages involves a combination of TIN and average-end-area methodologies. This combination, which sometimes is simply labeled an average-end-area method, uses the flexibility of the TIN method in employing all survey data, yet permits the user to utilize average-end-area procedures.

a. Like the TIN technique, this combined method creates a TIN terrain model from the survey coordinates. Cross-sectional areas, as described earlier, are then extracted from the TIN at fixed intervals. These areas are bounded by a design template and the corresponding cross-sectional pass through the TIN. The end-area volume between two cross-sections is calculated by Eq 15-1.

b. This combined TIN/average-end-area method can be used on any dataset, including combined cross-sectional/longitudinal survey data. Cross sections can also be placed at arbitrary spacing and locations. However, if only cross-sectional survey data is used, note that no additional volume accuracy is gained if the spacing of the extracted cross-sections is closer than that of the original survey data cross-sections.

c. Since the volume results of the combined method are based on end-areas and not the full terrain model, this technique is generally less accurate than the TIN method. However, results in most cases will be more accurate than average-end-area, since cross sections are based on interpolated, and not projected, terrain data. The combined method also offers more flexibility in the collection of survey data.

d. This method also has application when full-coverage survey models are available and cross-sections need to be cut (generated) from the model--for profile viewing or other purposes. HYPACK MAX surface modeling (TIN) program has options to create regularly spaced cross-sections from TIN models, and to use these cross-sections for average end area computations if desired.

15-10. Example of Using TIN Methods to Compute Dredged Volumes (Baltimore District)

A dredging project on a tributary to the Potomac River was conducted by the Baltimore District using the TIN technique for dredged material volumes. This site featured a turning basin 200 ft long by 160 ft wide, and a channel 4,000 ft long by 60 ft wide leading to the Potomac River. The channel was dredged to 6 ft with an additional 2-ft overdepth. The survey data, derived from before- and after-dredge surveys, totaled 16,250 points and 15,112 points, respectively. The design surface was created using an interactive software package that allows a user to create basic channel designs with the input of only some basic parameters. Three software packages were used to calculate the dredged material volumes: Volest, a Fortran routine written by the National Institute of Standards and Technology (NIST), which runs on a UNIX workstation; Inroads, a civil/site UNIX software package written by Intergraph Corporation; and Roadworks, a civil/site PC software package written by AEC Group, Inc.

a. The volume results from a before-dredge survey for dredge depths of 6, 7, and 8 ft are seen in Table 15-1. The before-dredge data shows excellent correlation between all three software routines. There was no difference in results obtained from the INROADS and ROAD WORKS packages, and only minute differences with the Volest routine. As can be seen from Table 15-1, as the channel depth increases, the relative difference between the three routines decreases. If volumes for a deeper channel had been calculated, the relative differences between the routines would have become nonexistent. However, volumes for channel depths much greater than 8 ft could not be calculated because the side slopes of the channel would not intersect the narrow DTM created by the survey data.

b. Further TIN analysis for dredge applications. A characteristic of TINS that can cause concern is the occurrence of relatively large triangles. Large triangles can be caused when both cross-sectional and longitudinal lines of survey data are included in the triangulation. These triangles are most pronounced when there is only one longitudinal line through the cross sections. With more longitudinal lines added the big triangles are reduced in size and the corresponding volume calculation becomes more accurate. However, it has been shown that even with cross-sectional and a single line of longitudinal data (and resultant big triangles), the volume result is more accurate than that obtained with cross-sectional data alone. To illustrate this point, a test case was run using data obtained from Bonum Creek. Station 2575-2700 was used and the design surface was taken to be at a depth of 8 ft. The volume computed for station 2575-2700 using all the data at 8 ft was 1,781 cu yd. This can be considered a highly accurate volume because of the large amount of data collected and the resultant accurate TIN model. The average-end-area volume calculated was 1,618 cu yd, an underestimate of 9.2%.

Table 15-1
Change in Volume Computation with a Change in Channel Depth

		Navigation Channel Volumes (cubic feet)			
Depth of the Design Surface	Software Package	Between Stations 0-200	Between Stations 200-300	Between Stations 1827-3982	Total Volume
6 ft template	INROADS	845	81	10206	11132
	ROAD WORKS	845	81	10207	11133
	VOLEST	845	81	10198	11124
7 ft template	INROADS	2099	320	15542	17961
	ROAD WORKS	2099	320	15542	17961
	VOLEST	2099	320	15532	17951
8 ft template	INROADS	3414	582	21851	25847
	ROAD WORKS	3414	582	21851	25847
	VOLEST	3414	582	21845	25841

15-11. USACE Dredge Volume Computation Standards

Table 15-2. Dredge Payment Standards for Corps of Engineers Surveys

QUANTITY TAKE-OFF STANDARD	PROJECT CLASSIFICATION Navigation & Dredging Support Surveys Bottom Material Classification Hard	 Soft
CORPS-WIDE STANDARD PAYMENT TEMPLATE		
New work or Deepening	Standard Method	Standard Method
Maintenance dredging		
Hopper/hydraulic	Standard Method	Standard Method
Bucket/cutterhead	Contour Dredging Method	Contour Dredging Method
SIDE SLOPE EXCAVATION PAYMENT		
New work	Payment required	Payment required
Maintenance dredging	Payment required	Optional
BOX CUT PAYMENT ALLOWANCE		
New work	Optional	No allowance
Maintenance	Optional	No allowance
Limits of payment	25 ft inside toe	N/A
MAXIMUM BIN SIZE FOR GRIDDED DATA	1 m x 1 m	5 m x 5 m
DATA SET THINNING ALLOWED	No	Optional

VOLUME COMPUTATION METHOD	**Average End Area**	**TIN or Bin/Grid**
CROSS-SECTION DATA		
spaced > 100 ft C/C	No	recommended
spaced < or = 100 ft C/C	optional	preferred
MIXED CROSS-SECTIONS AND CROSS-LINES	N/A	recommended
MULTIPLE TRANSDUCER OR MULTIBEAM SWEEPS	only at high density	recommended
IRREGULAR BASINS OR WIDENERS	No	recommended
SOFTWARE COMPUTATION VERIFICATION	Yes	Yes
Average end area accuracy	0.1 sf	0.1 sf
TIN accuracy	1 cy	1 cy

a. Corps standard payment template. Both the Contour and Standard payment templates may be used, depending on the dredging platform and purpose, as shown in Table 15-2. These two payment methods are depicted in the templates shown in Figures 15-10 and 15-11. Note that the Standard payment template shown in Figure 15-10 is used for hopper dredging.

b. Side slope payment. In general, payment should be made for material lying above either the overdepth or required grade on the side slopes. Side slope payment is optional on maintenance dredging in soft material. No payment might be made where there is minimal build up of shoal material along the toes, say less than 2 feet above required grade. If there is a major build up of material along the toe and extending into the side slope, then side slope payment would be warranted. Standard Methods should be used for computing side slope quantities.

c. Box cut allowance. A box cut payment may optionally be paid on hard material only. Pay allowance should be made in non-pay areas lying any distance outside the channel toe and up to 25 feet inside the toe. Payment is not restricted to any depth below project grade. Payment cannot exceed the amount of above-grade material capable of sloughing into the cut areas. Continued use of the box cut allowance is discouraged due to excessive computational biases, computational complexities and disparities in software packages, disputes over payment techniques, and usually insignificant yardage allowances for box cuts on actual projects--see paragraph 15-3c. If box cut allowances are computed from full-coverage sweep data contained in a TIN model, AEA cross-sections should be generated through the TIN model at a high density--say every 5 or 10 feet.

d. Volume computation method. Average end area methods should be used only for closely spaced cross-sectional or gridded data. Otherwise, digital terrain model or TIN differencing methods are recommended. TIN methods should be used where cross-sections exceed 100 ft and/or where AEA cross-sections indicate large area variances between successive sections--see paragraph 4-9 (Evaluation of Dredge Quantity Estimates Based on Depth Accuracy and Density). TIN methods should also be used for mixed cross-section and cross-line data in order to utilize the full data set. Where full-bottom coverage is available, TIN or bin volume techniques are recommended even though AEA methods using the full data set would yield approximately the same results; provided AEA cross-sections are generated through the TIN model at a high density. Terrain model differencing is recommended for irregular basins or channels. Construction contract specifications shall specify specific computation requirements.

e. Thinning and binning data sets. Thinning data sets is not recommended for dredge volume computations. There is no need to bin data sets if TIN volume computations are performed. Binning may be necessary if there are overlapping data sets. If multibeam data sets are binned, the bin size should be kept to a minimum--i.e., less that 1 meter or smaller. The shot point nearest the bin centroid should be used. If the terrain is smooth, then the bin size may be increased.

f. Volume computation software verification. Automated volume computation software shall be initially tested to ensure accurate, repeatable values are being computed. This is done by comparison with a manual computation. An average end area computation may be checked by using data points from a single cross-section and computing the section end-area by the exact coordinate method described in paragraph 15-3. At least 100 data points on the cross-section should be used. The manual and automated sectional end areas should agree to well within 0.1 sq ft. Both Standard and Contour Payment Templates shall be tested with data points located over all payment zones. Box cut computational accuracy should similarly be tested and verified, using data from simulated pre and post dredging surveys. The survey data should have multiple intersect points with the template. TIN volume computations may be tested by comparing volumes computed from densely spaced AEA sections passed through the TIN model--e.g., 1-ft cross-sections cut through a 100-ft section of the model. Volumes should agree within one cubic yard. Automated software should be reverified at each upgrade.

15-12. Mandatory Requirements

The standard requirements specified in paragraph 15-11 and Table 15-2 are mandatory. These criteria are reflective of Corps and industry goals for nationwide uniformity and equity in dredge payment templates, allowances, and software--see paragraph 1-7.

Chapter 16
Real-Time Kinematic Differential GPS Surveys

16-1. Real-Time Carrier Phase DGPS Technology

The DGPS carrier phase is capable of yielding decimeter accuracy on a moving dredge or survey boat--both horizontally and vertically. This technology can provide real-time elevations of survey vessels. If adequate motion compensation equipment is used, and project tidal datum modeling has been accomplished, accurate, real-time elevations (depths) can be directly obtained without observing tidal or river stage data--see Figure 16-1. A real-time kinematic (RTK) DGPS positioning system is based on DGPS carrier phase technology similar to the kinematic techniques currently used for static GPS geodetic surveys where millimeter level accuracies are achieved. RTK procedures allow for the movement of a GPS receiver after the initial integer ambiguity (i.e., whole number of wavelengths) between satellites and receiver has been resolved, as was outlined in Chapter 7. This chapter outlines the procedures for performing hydrographic surveys using RTK DGPS. It focuses on a deep-draft coastal navigation project as an example of the initial geoid modeling that must be performed before RTK surveys can be conducted.

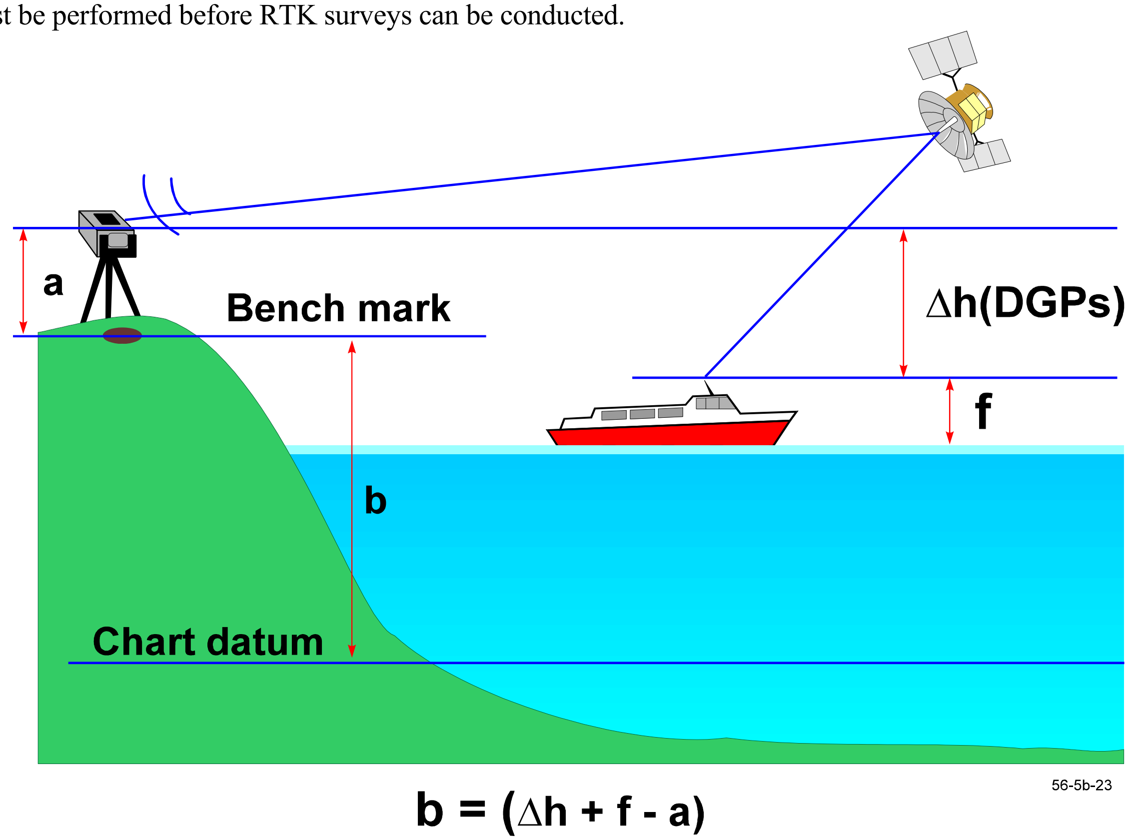


Figure 16-1. Principle of Real-Time Kinematic DGPS elevation determination

16-2. Reference Station

The carrier phase positioning system is very similar to the current code phase tracking technology described in Chapter 7. A shore GPS reference station must be located over a known survey monument; however, the reference station must be capable of collecting both pseudo-range and carrier phase data from the GPS satellites. The reference station will consist of a carrier phase, dual frequency, full wavelength L1/L2 with cross-correlation technique during times of P-code encryption tracking, using a GPS receiver with its associated antenna and cables, high-speed processor, and communications link. The receiver should be capable of a 1-sec update rate. The location of the reference station will be the same as for a code phase tracking DGPS system. The processor used in the reference station will compute the pseudo-range and carrier phase corrections and format the data for the communications link. The corrections will be formatted in the RTCM SC-104 v.2.1 format for transmission to the remote user.

16-3. Communications Link

The communications link for a RTK positioning system differs from the code phase tracking DGPS system in the amount of data that has to be transmitted. The RTK positioning system may require a minimum data rate of 4800 baud, as compared to a baud rate of 300 for the code phase tracking DGPS system. This high data rate eliminates many of the low-frequency broadcast systems and limits the coverage area for high-frequency broadcast systems. VHF and UHF frequency communications systems are well suited for this data rate.

16-4. User Equipment

A desktop computer will be needed to process the hydrographic survey data. Currently, laptop computers are used separately to process the satellite information into the proper broadcast formats (RTCM SC-104 v2.1). One laptop resides at the reference station (master), and a second laptop resides on the survey vessel (remote). This arrangement may change as GPS receivers build the format capability into the receiver units. Two GPS receivers (master and remote) are needed for positioning. These receivers must meet the requirements to process real-time carrier phase tracking information. The proposed user equipment on the survey vessel or dredge consists of a carrier phase dual-frequency full-wavelength L1/L2 with cross-correlation technique during times of P-code encryption tracking GPS receiver. A communications link is needed to transfer corrections to the dredge or survey vessel. Frequency approval may be necessary for communication link broadcasts using a power source in excess of 1 watt. RTK technology should normally not be used for surveys in excess of 20 km from the master station. The position output for the helmsman is code phase tracking using pseudo-ranges (accurate at the meter level) for vessel navigation in real time. Alternatively, a USCG radiobeacon signal may be used for vessel navigation. The decimeter-level carrier phase DGPS data will be timed/tagged to allow for recording the true vessel position needed for survey processing. The minimum update rate from the reference station to the vessel(s) is 1 sec.

16-5. Kings Bay Entrance Channel Tidal Modeling for RTK Surveys

This section details the measurements of a tidal datum in the Saint Mary's Entrance Channel for the purpose of dredging and surveying. The channel is located at the boundary between the States of Florida and Georgia and provides access to the Kings Bay FBM Submarine Base, Georgia. The Entrance Channel is maintained to a project depth of 46 feet--out to the east channel limit eight miles offshore--Figure 16-2. The project has an approximate tide range of 7 feet and has always been difficult to survey due to uncertain tidal modeling.

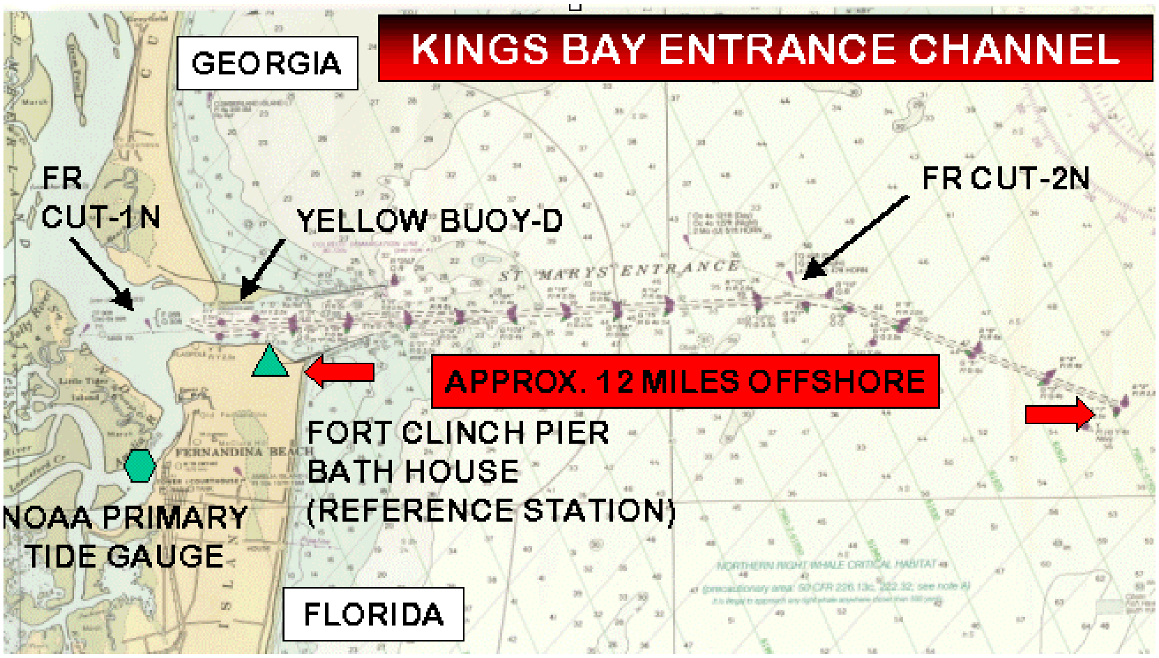


Figure 16-2. Kings Bay (St. Mary's) Entrance Channel

a. In May 1997, the Jacksonville District contacted the US Army Topographic Engineering Center (USATEC) to establish a tidal datum in the Saint Mary's Entrance Channel. The purpose was to update the entrance channel to reference the MLLW Datum. In addition, the Jacksonville District wanted to implement RTK DGPS technology to allow hydrographic surveys to be performed without using tide gages. The Jacksonville District began the actual field work by performing wide area GPS static surveys during the later part of 1997. Two acoustic tide gages were installed in Cut 1N between December 1997 and January 1998. The tidal datums at these two gage sites were computed by NOAA using four months of data. In order to mesh GPS water measurements and conventional tide gage measurements, the Jacksonville District's Survey Vessel Florida performed GPS tidal measurements between March and June 1998. The Surveyboat Florida anchored six times for 25 hour periods to provide intermediate datum points in the channel and correlate conventional tide gage methods to the GPS tidal datum method. The vessel anchored twice at tide gage locations to check the change in ellipsoid heights received on-board from the GPS reference station (kinematic mode) against the ellipsoid heights at the tide gages (static mode) over a tide cycle. A software configuration in the hydrographic survey package developed by Coastal Oceanographics, Inc. allows for the ellipsoid separation values to MLLW to be used to compute tide measurement from the waterline of the survey vessel.

b. The entire project depended on the tidal measurements from the primary NOAA tide gage located in the Amelia River at Fernandina, Florida, two miles south of the Saint Mary's Entrance Channel. This gage was the primary tide gage used to measure the Mean Lower Low Water (MLLW) in the Saint Mary's Entrance Channel. A reference was needed to incorporate tidal datum measurements along the channel made relative to the Fernandina Gage. Two vertical references were used, the GPS ellipsoid and the North American Vertical Datum of 1988 (NAVD 88). The Jacksonville District accomplished the vertical references by performing the GPS static survey over the entire project area. The GPS survey included two offshore range lights used to guide submarines into port.

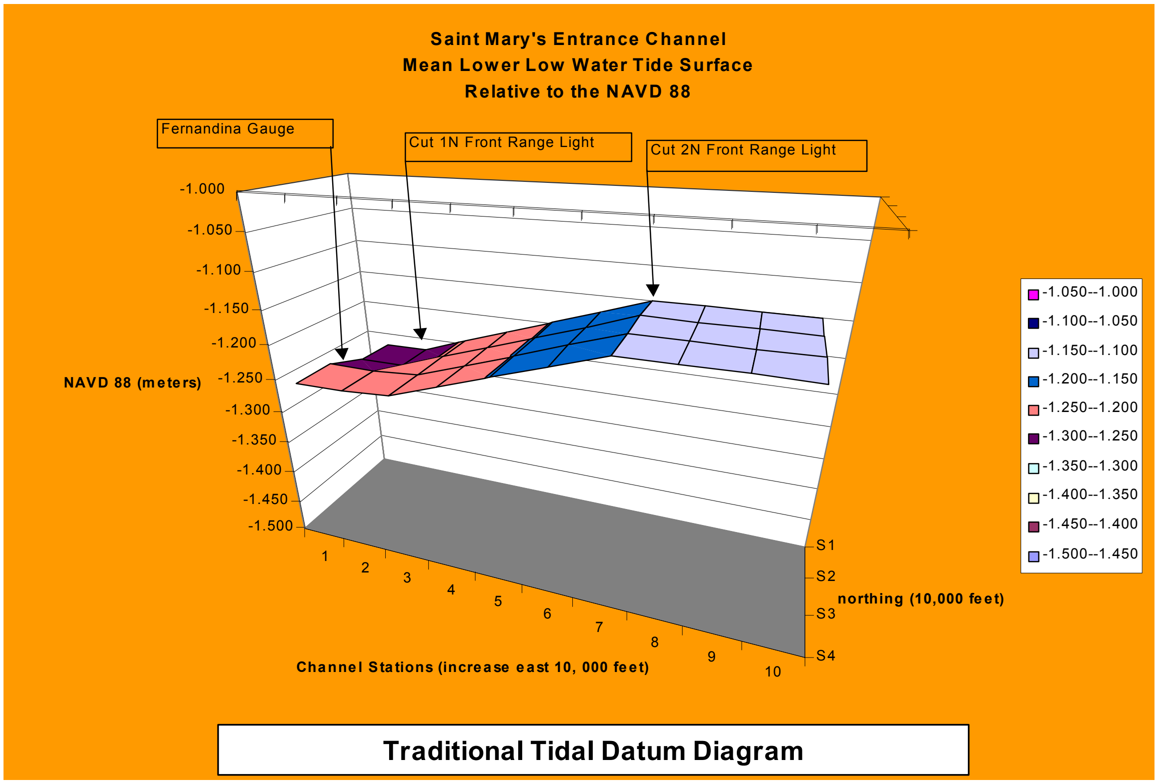


Figure 16-3. Traditional tidal diagram for Kings Bay Entrance Channel

16-6. Tidal Datum Diagram

A traditional tidal relationship for the Entrance Channel is shown in Figure 16-3 above. The primary focus of modeling a project for RTK surveys is to develop the ellipsoidal tidal datum diagram shown in Figure 16-4. The results shown on the tidal datum diagram provide the MLLW reference for the Saint Mary's Entrance Channel well within acceptable tolerances for dredging applications. This diagram uses the geodetic reference of NAVD 88. The mean sea level values on the diagram should theoretically be parallel to geodetic reference surface; however, the currents generated by the water moving through the inlet may help explain why the height values drop five centimeters (0.16 feet) from the ocean through the inlet to the confluence with the Amelia River. Ellipsoid height values can be plotted that map the relationship between the computed MLLW and the ellipsoid. These values and the GPS reference station used to measure the ellipsoid-MLLW separation allows Kinematic GPS hydrographic surveys without tide gages.

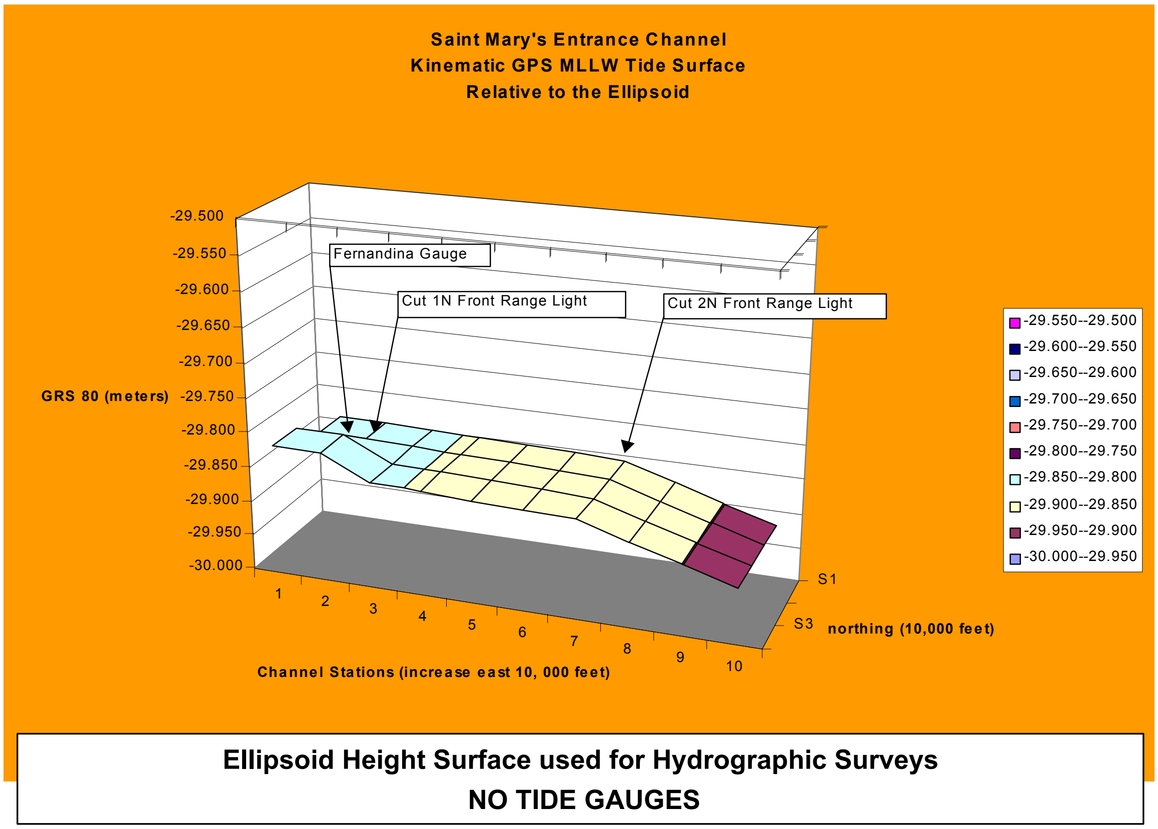


Figure 16-4. Tidal model of Kings Bay Entrance Channel

16-7. GPS Reference Station

A permanent GPS reference station (Figure 16-5) was established at Fort Clinch for future hydrographic surveys in the Saint Mary's Entrance Channel. An antenna height of (-) 20.015 meters should be entered into the GPS receiver during GPS hydrographic surveys. If the GPS reference station antenna is moved, the value is invalid. If the antenna must be moved, the vertical difference between the bottom of the antenna and the reference benchmark must be remeasured--and to confirm that the benchmark is (20.015 + 3.645 = 23.660 meters) below the ellipsoid. Run levels through the old antenna location and the new antenna location starting from the benchmark.

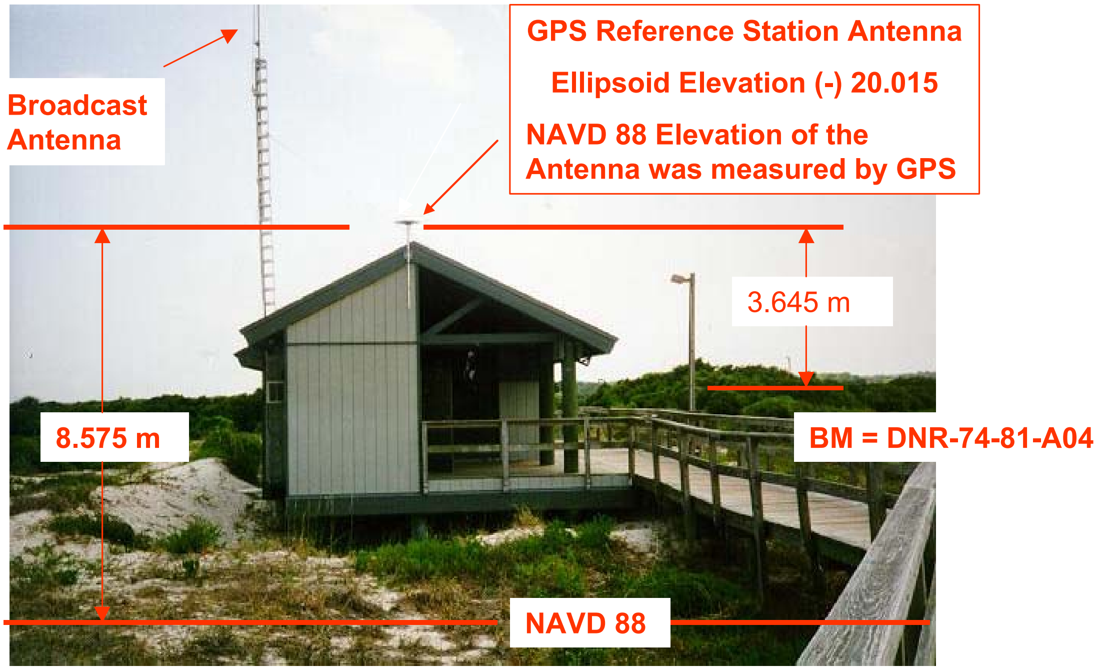


Figure 16-5. RTK DGPS reference station parameters

16-8. Resultant RTK DGPS Elevation Accuracy

The target accuracy for real-time RTK elevations was ± 0.25 feet. The resultant absolute project accuracy is estimated to be ± 0.22 feet (7 cm). The absolute accuracy refers to the MLLW relative to the geodetic reference datum, NAVD 88. No local project modeling of the ellipsoid-geoid separation was attempted for the project. Geoid 96, a computer program written by the National Geodetic Survey, was used by entering the surveyed horizontal positions to compute the NAVD 88 /ellipsoid separations.

a. The relative accuracy of points in the channel is estimated to be ± 0.13 feet (4 cm). This includes the accuracy of RTK DGPS between the boat and the reference station. The relative accuracy excludes the NAVD 88 monuments and the MLLW datum. A centimeter difference between adjusted GPS static vectors and uncertainty variations of two or three centimeters in DGPS water levels observations using extremely short data series were the most difficult issues to resolve in modeling the project. The errors are insignificant for dredging. Of all the estimated vertical errors, only the GPS static survey provides a standard error of the actual measurements.

b. Hydrographic surveys for dredge payment volumes are associated with relative accuracies from the GPS reference station or relative accuracies from a tide gage. Use ± 0.13 feet (4 cm) for RTK GPS as set up for this particular channel or use ± 0.2 feet (6 cm) at best by interpolating from the acoustic tide gages. Using only one tide gage, expect the accuracy to drop to at least ± 0.4 feet (12 cm). Accuracy is a range not a number. This information can be used as part of the error budget associated with the accuracy of a group of soundings from a particular survey (e.g. a Mean Square Error).

16-9. Survey Vessel

The most important vertical measurement on the survey vessel is the GPS antenna phase zero measurement down to the water line of the vessel. In a static measurement condition, the measurement is as shown in Figure 16-6. Underway the vessel speed through the water will change this measure. The nautical term for this phenomenon is called 'squat.' The vessel squat is not entered as a correction in the survey system in that the transducer depth is reduced by the same amount the antenna height is reduced.

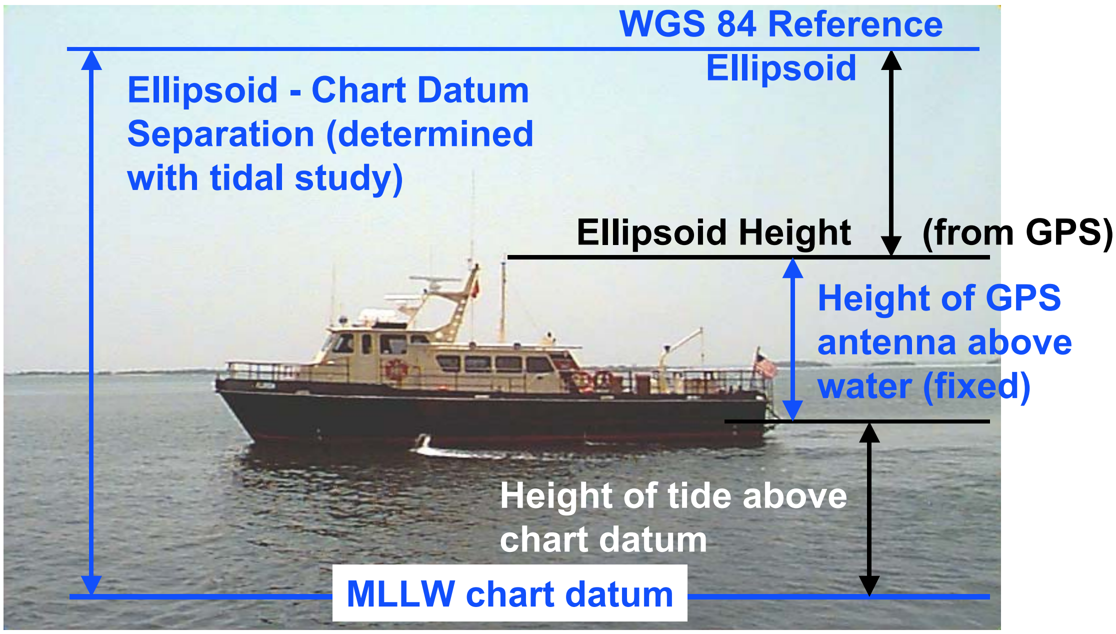


Figure 16-6. RTK measurements on survey vessel

16-10. RTK DGPS Hydrographic Survey Procedures

Two survey methods are available in the Saint Mary's Entrance Channel. The traditional method will be discussed first. Two acoustic tide gages are currently running in Cut 1N on the front range light structure. The gage located on the east range light offshore has a Geostationary Operational Environmental Satellite (GOES) uplink. This data can be retrieved three hours later over the Internet as well as the Fernandina gage data. The data sets will produce a six minute time series. The inside gage is operated by the US Army Corps of Engineers (USACE) and must be downloaded by USACE personnel. The data from these acoustic tide gages should be interpolated to the station numbers in the channel where surveys are being conducted. Both gages should be used to eliminate actual time differences in the channel from average time differences between the gages. Using one gage and surveying four miles from it can result in errors to 0.4 feet (12 cm) on average. The gages are separated by 8.5 nautical miles. Using both gages, surveys conducted on different days should overlay on the outside portions of the cross-sections unless dredge material has settled on the outside areas. The second method precludes the use of a tide gage during the hydrographic survey. This tidal datum diagram was used to build a MLLW surface in the Coastal Oceanographics, Inc. program HYPACK. The HYPACK manual explains the procedure. The survey vessel must have equipment to receive specific GPS information from the USACE reference station. The Jacksonville District uses Trimble 4000 SSi RTK GPS equipment and a 25 watt (joules per second) radio transmitter that broadcasts carrier corrections every second on a frequency of 164.200 MHz. To implement this technology on a survey vessel, refer to the Survey Vessel Section. Levels must be performed on the survey vessel to obtain the vessel information.

16-11. Test Results

The first test of the RTK GPS Tides separation values (ellipsoid minus MLLW) was conducted on 29 June 1998. A matrix of the separation values was constructed in the Coastal Oceanographics hydrographic survey program called HYPACK. The Surveyboat Florida ran twenty cross-sections at 100 foot spacing in Cut 1N midway between the acoustic tide gages 8.5 miles apart. The personnel then traveled to the gages and downloaded the tides for that day. Both tide gages were interpolated to establish a tide curve time series midway between the acoustic tide gages. The interpolation method was tested and found to work in this particular channel. The survey vessel ran lines of channel cross-sections in the mid-channel area under normal survey conditions. The survey was then processed in two ways: the conventional method and the GPS method. The conventional method uses the horizontal GPS coordinates but not the vertical coordinate. The tide gage data was then used to reduce the raw soundings into reduced depths relative to the MLLW. The same survey was then processed by RTK GPS. The first depth and last depth of each line was selected for a comparison with the GPS depths differenced relative to the tide gage reduced depths.

16-12. Scope of Work for Modeling Kings Bay Entrance Channel (Jacksonville District)

The following scope of work was designed to develop a DGPS tidal model for the Kings Bay Entrance Channel. It was developed jointly by the Jacksonville District and the US Army Topographic Engineering Center. This scope is representative of the modeling required in a navigation project.

SCOPE OF WORK

Tidal Datum for Dredging
Saint Mary's Entrance Channel

0. Background:

0.1 The US Army Engineer District, Jacksonville has identified a need to establish a new tidal datum for the Saint Mary's Entrance Channel. Mr. Fran Woodward of the Jacksonville District (CESAJ-CO-OM) and Mr. Brian Shannon of the US Army Topographic Engineering Center (CEERD-TS-G) assessed the effort necessary to establish a tidal datum in the Saint Mary's Entrance Channel on the Florida-Georgia state boundary during a two day period beginning 20 May 1997. They inspected the project aboard the SV Florida and also visited primary National Oceanic and Atmospheric Administration (NOAA) tide gages in the vicinity of the navigation channel.

0.2 A plan was developed to use both conventional tide gages and On-The-Fly (OTF) Global Positioning System (GPS) to measure the tide. The benefit of the GPS will be to eliminate the need for tide gage readers during hydrographic surveys as the boat can be used as a water level record as soundings are being collected. A second benefit of GPS is to use a heavy boat as a tide gage to develop a datum point at any location adjacent the navigation channel as needed. This eliminates the uncertainty of tide phase measurements between gages at the boat marina and tide phase at the boat location. Mr. Shannon proposed a target tidal accuracy between a vertical reference on shore and a measured datum point in the channel to be 0.25 feet (8 cm) for this channel using direct relative GPS ellipsoid measurements to measure the height of Mean Lower Low Water (MLLW).

1. Description of Work:
1.1 The tidal datum for the cut "1N" will have 5 tidal station measurements as a minimum to insure a MLLW along the reach to an accuracy of 0.25 feet. The five tidal station locations selected for this reach are shown in Figure __. The locations from west to east are: 1) Cut 1N Front Range Light Structure, 2) Yellow "D" Buoy, 3) Red #20 Buoy, 4) Red #16 Buoy, and 5) Cut 2N Front Range Light Structure. A sixth point, 6) Red #6 Buoy, at the midpoint of Cut 2N, will be

selected for tidal measurements. A combination of traditional tide gauging and OTF GPS methods will be used to measure the MLLW at these six points. Land GPS surveys, postprocessing, project management, report writing and CESAJ-CO-OM tide gage installation and maintenance training are included in this scope of work. Final MLLW determination along the channel will be coordinated with the NOAA, Silver Spring, Maryland. Coordination for tide gage installation and training will be through the State of Florida, Department of Environmental Protection (FLDEP), Tallahassee. The CESAJ-CO-OM will provide boat transportation for FLDEP as needed.

1.2 The tidal project will begin 10 November 1997. Field work will continue through December 1997.

2. Survey Control

2.1 A minimum of 2 horizontal marks and 3 vertical marks from the National Spatial Reference System (NSRS) plus the GPS reference station will be used for survey control for this project. The survey marks selected for GPS occupation will have a vertical tolerance not to exceed 0.05 feet (1.5 cm). The primary vertical datum of the marks will be the North American Datum of 1988 (NAVD 88). The marks selected will list corrections to the National Geodetic Vertical Datum of 1929 (NGVD 29). The NGVD 29 correction shall be listed as ADJUSTED or ADJ UNCHANGED. A tidal benchmark is recommended to be used as one of the marks if the benchmark is within the relative vertical tolerance. The Jacksonville District will select the survey control and perform a GPS static survey on the survey control before 10 November 1997.

2.2 The CESAJ-CO-OM will install three monuments on both structures before 3 November 1997. Beginning 10 November 1997, GPS vectors from the selected survey control on the land to the range light structures will commence. Only one monument per structure will be occupied with the GPS receiver. Two GPS sessions with a change in antenna height over the mark on each range light structure will be measured from the survey control.

3. Tide Gauging

3.1 The two acoustic tide gages will be mounted on existing range light structures for channel navigation. Photographs of the structures are shown in Figure __. The gages will be mounted by FLDEP such that the transducer is at the height of the top platform. FLDEP will then level to the gage zero mark. These tide stations will have a minimum uninterrupted time series of 30 days and both stations will be measured concurrently. The gages will run for a period between 60 and 90 days following installation. The tidal datum point for the west project limit (Cut 1N Front Range Light Structure) will be computed relative to the Fernandina Gauge (NOAA). Figure __ depicts the 3 NOAA gages close to the project. The tidal datum point for the east location limit (Cut 2N Front Range Light Structure) may be computed relative to both the Jacksonville Pier (30 miles) and the Saint Augustine Pier (55 miles). NOAA may have other data to improve the tidal datum computations at the project limits and will do so as needed.

3.2 Tide gage installation may be done with the technical assistance of Mr. Randy Harrel of FLDEP. CESAJ-CO-OM will provide vessel accommodations, materials, and personnel to assist and be trained in tide gage installations. FLDEP will provide the essential materials to install the gages. The USACE personnel and vessel will need to be available for at least one week, including a Saturday. Eight days will be scheduled for the installation.

3.3 The FLDEP will download the gage data on a monthly basis. The CESAJ-CO-OM will provide transportation for FLDEP to the range light structures.

4. Tide Gauge Removal

4.1 The FLDEP will dismantle the tide gages. Before the gages are dismantled, FLDEP will perform levels on the gages and turn through the three benchmarks on the top of each structure. The stilling wells, brackets, and other materials necessary for a future gage installation will be abandoned by CESAJ-CO-OM intact. The FLDEP intends to place their own tide gages at these locations to develop a longer tidal series for the St. Mary's Entrance Channel.

5. OTF GPS

5.1 The three middle tidal datum points will be measured by precise OTF GPS methods. A heavy vessel will be needed for the GPS platform. The SV Florida is recommended. The CESAJ-CO-OM will outfit the survey vessel to measure OTF GPS information as well as heave, pitch, and roll data. Computers on board the vessel must be capable of storing and downloading large amounts of data as necessary to insure the 2 second data rate GPS information is preserved for post processing. Daily download and backup is recommended. An electronics technician from the CESAJ-CO-OM will be available to install and troubleshoot equipment during this project. The ship should anchor (one anchor only) outside the channel at the depicted locations in good weather to obtain a tidal series over a 25 hour period. Measurements will not be conducted during weather front passage. Five of these periods are required to obtain a datum point at each location. The 25 hour periods do not have to be consecutive but consecutive periods are recommended. The data must be collected while the gages on the light range structures are operational (NOTE: This will not be necessary for future additional datum points.). The ship may pay out as much chain as needed; the vertical GPS component is the only required data to be used for computation.

5.2 Concurrent with ship GPS activity, a GPS reference station will be operating at the "bath house" on Fort Clinch near the fishing pier. This GPS receiver will be downloaded on a daily basis by CESAJ-CO-OM while the survey vessel is collecting GPS signals in the channel.

6. Postprocessing
6.1 Postprocessing of the GPS data will be necessary for the static survey. Postprocessing of data will be assessed at a rate equal to the time spent in the field collecting GPS data. The same GPS data will be processed by CESAJ-CO-OM. Copies of all GPS data will be mailed to TEC within 30 days of collection. The data will be sent to:

US Army Topographic Engineering Center
ATTN (CEERD-TS-G, Shannon)
7701 Telegraph Road
Alexandria, Virginia 22315-3864

7. Computer Programming
7 .1 The CESAJ-CO-OM wants to compute the tidal datum relative to the ellipsoid in order to bypass the national geodetic vertical datums and the need for tide gage readers during hydrographic surveys. No computer programming is necessary for this option following a phone call to Pat Sanders, President, Coastal Oceanographics Incorporated, 29 May 1997. The HYPACK program can interpolate the MLLW as a function of the vessel's present position during a survey and subtract the correct distance from a sounding to obtain a reduced depth. A data base of six ellipsoid heights relative to the GPS reference station will be entered into the HYPACK Computer Program for the project (Saint Mary's Entrance Channel). NOTE: Be advised OTF GPS will be needed on the survey vessel as well as an operating GPS reference station with radio broadcast during survey operations if this option is executed.

7.2 Tide Data Programming: TEC will develop a computer program to average the 2-second GPS data into a 6-minute data series using all NOAA requirements necessary to enable sufficient tidal datum results from the NOAA Data Processing Analysis Subsystem (DPAS) program. TEC will process all CESAJ-CO-OM tide data into the 6-minute tidal series and submit the files to NOAA for processing.

8. Project Management Tasks for the project management will be divided among TEC, CESAJ, and NOAA. The tasks and the agency responsibilities include: writing memorandums of agreement (TEC), writing scopes of work (TEC), developing cost estimates (TEC), coordination of project schedules (CESAJ), obtaining permits (CESAJ), coordinating field effort (CESAJ, TEC), computing tidal datums (NOAA), constructing the tidal datum diagram (CESAJ, TEC), and report writing (CESAJ, TEC).

16-13. Mandatory Requirements

Geoidal-ellipsoidal modeling and tidal modeling procedures described in this chapter are mandatory if elevations are obtained through the use of RTK DGPS techniques.

Chapter 17
River Engineering Hydraulic and Channel Stabilization Surveys

17-1. General Scope and Applications

This chapter describes hydrographic survey procedures used in support of the Corps flood control and river engineering missions. These activities include survey support for hydrologic and hydraulic studies, investigation of river stabilization structures, scour surveys around bridges, locks, and dams, and other investigations needed to model physical aspects of river navigation systems (Figure 17-1).

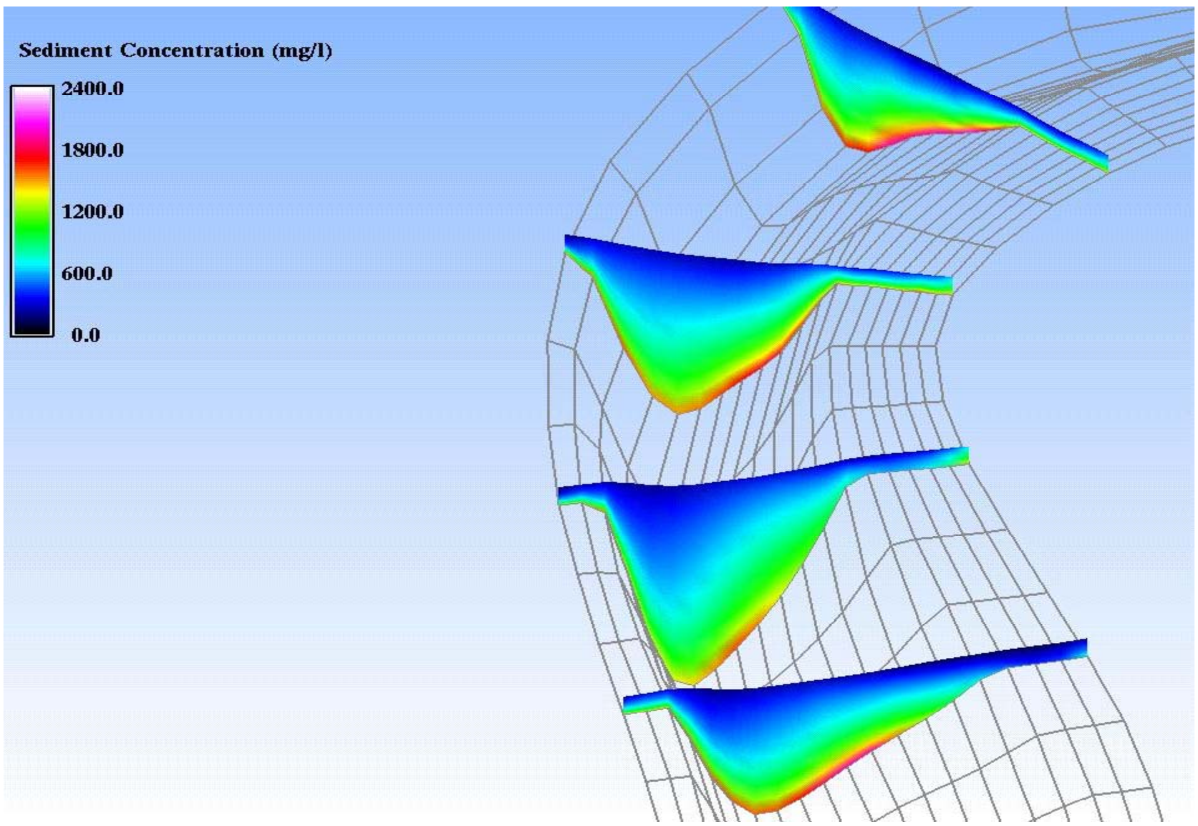


Figure 17-1. Typical multi-dimensional hydraulic and sedimentation model--for modeling flood damage reduction and channel restoration projects

17-2. River Hydraulics Studies

River hydraulic investigations and studies include the evaluations of flow characteristics and physical behavior of rivers--e.g., prediction of stage, discharge, velocity, and sediment transport rates. Basic hydrographic survey data is a critical component of these studies. Other hydraulic studies requiring field survey support may involve the determination of the elevation of dams, spillways, levees, and floodwalls. Hydrographic, topographic, and/or photogrammetric surveys may be required to support hydraulic modeling of floodplains, flood control channel design, navigation modeling, water quality assessment, and environmental impact and assessment analysis. Survey data is incorporated into physical and numerical hydraulic models used for analyzing or predicting the physical processes of a river system. For more detail on hydraulic investigations see EM 1110-2-1416 (River Hydraulics).

a. Hydraulic engineering studies. A variety of hydrologic engineering studies require hydrographic survey support to define the basic models. Some of these studies or models include the HEC/GEO-RAS (River Analysis System), steady flow water surface profiles, unsteady flow simulation, UNET (unsteady flow network hydraulic model), sediment transport modeling, flood inundation modeling, hydraulic flood stage modeling and forecasting, flood inundation modeling and mapping, and flood damage assessment. Hydraulic studies typically require three general data categories: (1) discharge, (2) geometry, and (3) sediment. Hydrographic surveyors may be called upon to obtain basic field information for any of these three categories. Obtaining stream section and adjoining bank and floodplain geometry is by far the most prevalent.

b. Discharge studies. Flood control projects are usually designed for the discharge corresponding to a specific flood frequency (design event) while navigation studies use a discharge for a specific low flow duration or frequency. Discharge data may include measured flows along with frequency, velocity, duration, and depth information. Surface profile elevations are also measured during flood events as an aid in flood routing studies. Water depth and channel cross-section profile is a critical component in computing or predicting discharges.

c. Channel Geometry. Channel geometry derived from hydrographic surveys is required for any hydraulic study. Geometric data include channel and overbank topography, stream alignment, bridge and culvert data, channel roughness information, changes in stream cross-section shape or channel alignment. Hydrographic, photogrammetric, and conventional topographic surveys may be required to fully define a streambed, adjacent banks and floodplains. For movable bed studies, repeat surveys may be needed to evaluate a model's performance in reproducing geometric changes. Thalweg profiles or repetitive hydrographic surveys may be needed for analysis of bed forms and the movement of sand waves through rivers.

17-3. Obtaining Cross-Sections for Hydraulic Studies

Cross-section data are used to determine the conveyance and storage of a river channel and overbank areas. Stream section requirements are defined by the hydraulic engineer or study manager. Required cross-sections are typically plotted on a small-scale map (e.g., USGS quadrangle) of the study area. Cross-section spacing will vary depending on many hydraulic factors associated with the purpose of the hydraulic study. They must be obtained at sufficient intervals to define the flow carrying capacity of the stream and its adjacent floodplain, and at locations where changes occur in discharge, slope, shape, roughness, at locations where levees begin and end, and at hydraulic structures (bridges, weirs, and culverts)--see example layout at Figure 17-2. The type of hydraulic model (e.g., unsteady flow or steady flow) will also dictate cross-section locations. On the Mississippi River system, cross-section spacing varies from 500 ft to 5,000 ft. The width of the section depends on the extent of the floodplain (if any), existence of levees, and other factors. Some cross-sections may be run bank-to-bank in the river with overbank topographic sections run to the top of a levee and into the floodplain. If extensive flood inundation studies are involved, then the cross-section may be extended far out into the floodplain--to the so-called "bluff" line where maximum flood stages would be limited. These lines could extend significant distances on some river systems--5 to 10 miles or more.

a. Mixed survey methods. Obtaining cross-sections of floodplain basins requires a combination of survey methods. Hydrographic surveys performed in the river must be supplemented by conventional surveys in the overbank and flood plain areas. Surveys of the floodplains are usually more efficiently performed using automatic photogrammetric methods whereby a gridded digital elevation model (DEM) is created using standard stereoplotter methods. Recently, airborne LIDAR techniques have been developed to provide DEM models of the floodplain. Airborne methods are limited by vegetation cover, which is usually dense along river banks. Conventional topographic survey methods (e.g., differential leveling, total station) will be required to develop obscured areas near river banks and to set breaklines in the final terrain model.

b. Digital elevation models. Since a variety of survey methods are used to obtain cross-sections, it is important that these independent data sets be accurately consolidated into a database from which cross-sections are generated. The hydrographic cross-sections are typically run over finite lines, as are topographic overbank sections and breaklines. The photogrammetric DEM, however, is typically obtained at a prescribed grid interval (i.e., "post" spacing). The accuracy of these data sets also varies. The topographic survey elevations may be accurate to ± 0.2 ft, the hydrographic surveys to ± 0.5 ft, and the photogrammetric DEM to only ± 2 ft.

c. Digital terrain model. Typically, the hydrographic, topographic, and photogrammetric DEM data sets of the river, banks, levees, and floodplains are combined into a continuous digital terrain model (DTM) in a CADD or GIS database (e.g., design files, Arc-Info). Using this DTM, hydraulic cross-sections are cut at the prescribed orientations--based on the hydrographic cross-section alignment. If full-bottom hydrographic coverage was obtained using multiple transducer or multibeam methods, then more flexibility is available is selecting cross-section alignments and locations for the hydraulic model. If a full, dense DTM of hydrographic and topographic coverage is available, then an unlimited number of hydraulic cross-sections are available--at any desired alignment or spacing. The following mapping specifications are representative of those used in overbank and flood inundation areas on the Upper Mississippi and Missouri Rivers:

(1) Vertical Accuracy Requirement
- 4 ft contour interval
- DEM grid elevation accuracy-- ±1.33 ft
- DTM hard spot elevation accuracy-- ± 0.67 ft

(2) Digital Elevation Model (DEM)
- 5 meter post spacings in flood plain
- add "mass points" on levees … i.e., "Digital Terrain Model (DTM)
- cut in all breaklines manually

d. Deliverables. The cross-sections are converted into the particular hydraulic model format -- e.g., HEC-2/HEC-RAS. Usually the surveyor (or A-E firm) is responsible for delivering the cross-section data in a specified model format. Scopes of work will typically define specifications, lateral coverage (Figure 17-3), format requirements, and deliverables for many of the following items:

- Horizontal Datum -- NAD 27 or NAD 83
- Coordinate grid system -- SPCS or UTM
- Vertical Datum -- NGVD 29, NAVD 83, LWRP 74, IGLD 88
- DEM & DTM breaklines/mass points
- River, River Reach & River Station Identifiers
- Cross-Section cut lines
- Cross-Section surface line
- X-Y coordinates of section end points
- X-Y-Z coordinates for each point on section
- Transformed coordinates to station-elevation format

- Main Channel Bank Station Points
- Left and Right Overbank Lengths
- Stream sections (Plan)
- Stream bank, levee, structure detail & breaklines
- In-channel & overbank flow paths

Geometric cross-section data must be entered in hydraulic models in specific formats. These are fully described in operating manuals for these models--e.g., HEC-RAS River Analysis System User's Manual (HEC CDP-68, 1998).

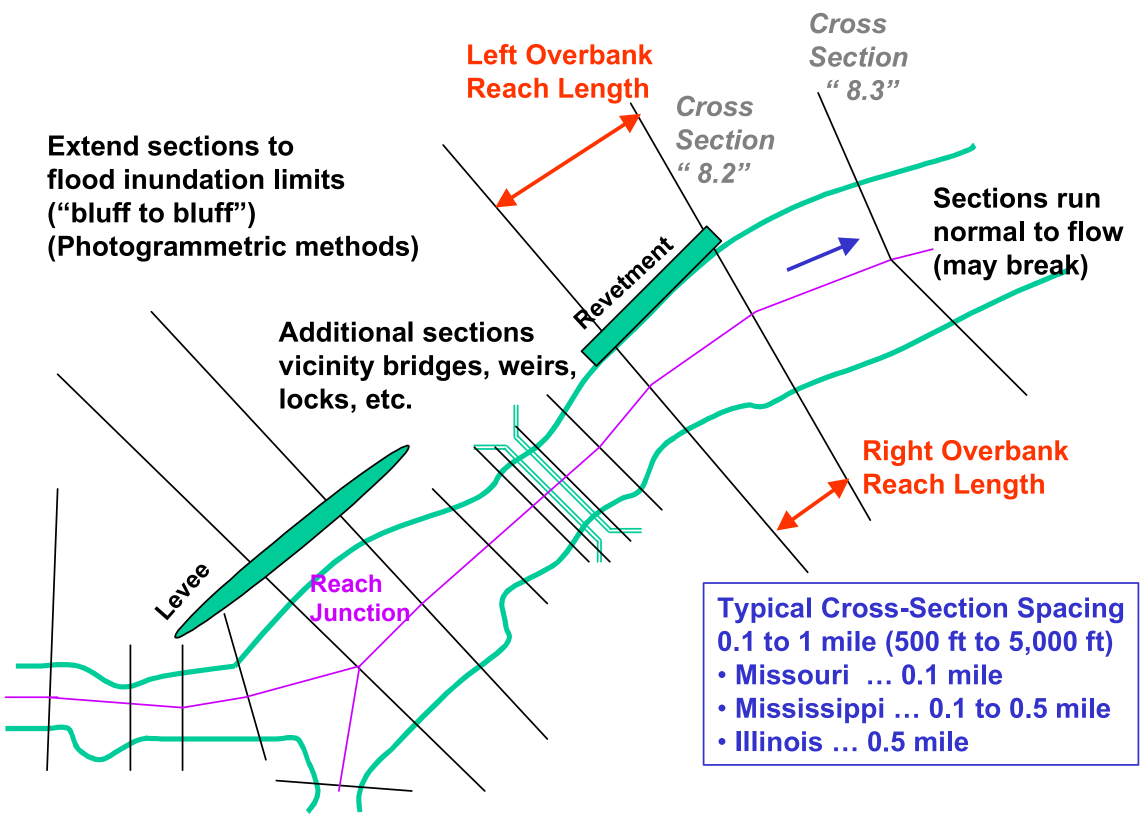


Figure 17-2. Typical cross-section configurations for a HEC-2 or HEC-RAS hydraulic model

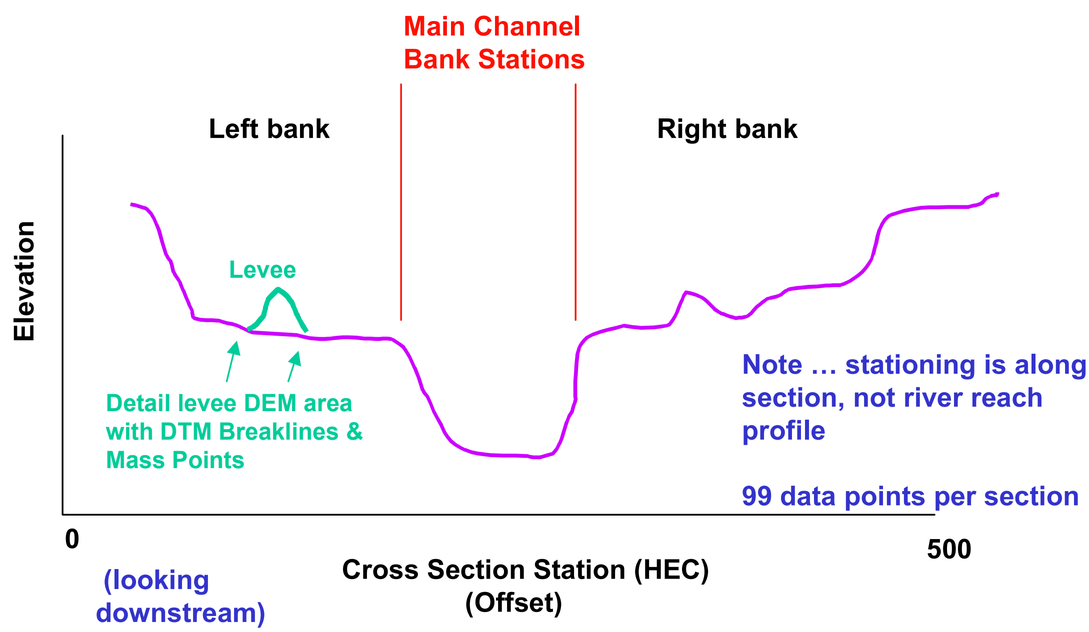


Figure 17-3. Cross-section convention for typical HEC river and floodplain coverage

e. Survey methods. Hydraulic cross-sections are surveyed using similar equipment and methods as standard navigation project surveys. The main difference is that each cross-section is on a different alignment. The end points of each cross-section must be transferred from the map and input into the data acquisition guidance system. The end points coordinated can be digitized from the planning map or scaled by hand. The local SPCS (referenced NAD 27 or NAD 83) should be used. The X-Y coordinate values of the cross-section endpoints can be directly input into line planning software, such as LINE EDITOR spreadsheet in HYPACK MAX (Figure 17-4). A single, unique line is created for every cross-section, with no offsets. The line name should correspond to HEC naming convention. Once this spreadsheet is completed, it can be pulled into the survey guidance program to align individual stream sections.

(1) Small, shallow-draft vessels are used in order to obtain depths as close to the bank as possible. Leadline or sounding poles may be needed in shallow bank areas. Depths are logged using standard data acquisition software. A dense sounding density is not necessary for stream sections in that surface areas will be generalized (smoothed) in the hydraulic modeling programs due to data point per section limitations (99 points). Thus, there is no point to obtain 20 depths/sec when only one depth per 100 ft will end up being used in the overall model.

(2) Vessel positioning accuracy is not critical for hydraulic surveys. USCG DGPS Radiobeacon accuracy is more than adequate; in fact, SPS GPS accuracy (10-20 meters) might be adequate in many cases. Since USCG DGPS is available over much of CONUS, it is recommended for river engineering survey positioning. Code phase USCG DGPS may also be used for horizontal positioning of overbank surveys.

(3) Cross-section elevations are referenced to a consistent vertical datum, such as NGVD 29 or NAVD 88. A dense network of benchmarks must be available along rivers or atop levees in order to set river staffs or gages to control hydrographic surveys. The required density of the vertical network will be a function of the river slope and the distance reliable interpretations can be made between gages. In general, the river surface elevation interpolation accuracy should be kept under ± 0.5 ft. Gages should be spaced at intervals to maintain this accuracy. Additional reference gages may be required if abrupt changes in slope occur in bends or around control structures.

(4) Bank and short overbank sections may be run at the ends of lines if equipment and personnel are available. Normally, however, overbank sections are performed relative to baselines on the bank or using RTK DGPS techniques from a single reference point. Overbank cross-sections must connect with and be aligned to the hydrographic sections to ensure the full streambed is profiled.

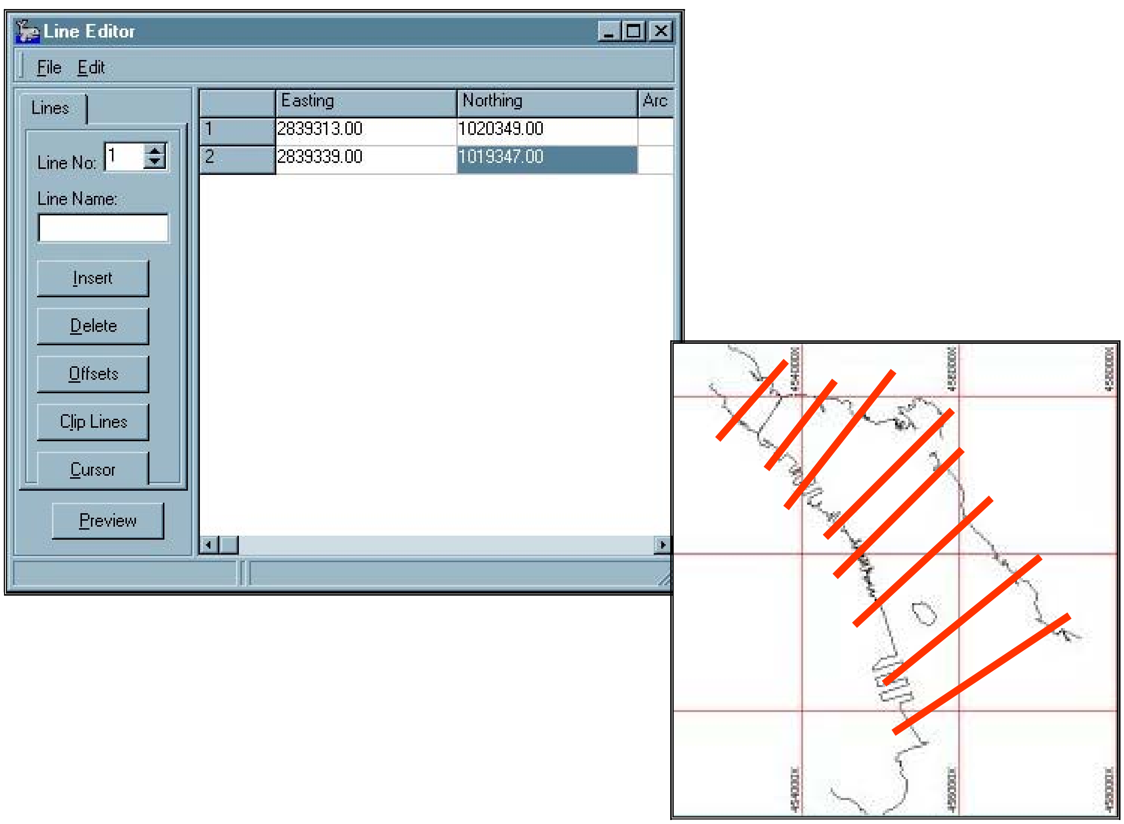


Figure 17-4. Setting up stream sections using HYPACK MAX Line Editor spreadsheet--a separate line is created for each cross-section

17-4. Hydraulic Engineering Guidance on Cross-Section Locations

EM 1110-2-1416 (River Hydraulics) contains detailed guidance for determining the location and spacing of stream cross-sections. Surveyors performing these studies should be aware of the hydraulic considerations that dictated the intended placement and alignment of stream sections. This is important in that field conditions may prevent sections being aligned as desired (due to vegetation, barge blockage, structure blockage, etc.). If new stream alignments or structures are discovered in the field, then additional cross-sections might be required. The field surveyor should make contact with the hydraulic engineer to determine alternate locations or need to include additional sections due to changed field conditions. Often, slight adjustments in section alignments can be made in the field without impacting the hydraulic model. Thus, knowledge of the engineering rationale for locating cross-sections is required by field surveyors in order to make reasonable adjustments or recommend modifications to the project engineer. The following guidelines on locating cross-sections for river hydraulic studies are summarized from EM 1110-2-1416.

a. Cross-section location. Cross-sections should be located at:

- All major breaks in bed profile.
- At minimum and maximum cross-sectional area.
- At points where roughness changes abruptly.
- Closer together in expanding reaches and in bends.
- Closer together in reaches where the conveyance changes greatly as a result of changes in width, depth, or roughness.
- Between cross sections that are radically different in shape, even if the two areas and conveyances are nearly the same.
- Closer together where the lateral distribution of conveyance changes radically with distance.
- Closer together in streams of very low gradient which are significantly nonuniform, because the computations are very sensitive to the effects of local disturbances and/or irregularities.
- At the head and tail of levees.
- At or near control sections, and at shorter intervals immediately upstream from a control (sub-critical flow).
- At tributaries that contribute significantly to the main stem flow. Cross sections should be located immediately upstream and downstream from the confluence on the main stream and immediately upstream on the tributary.
- At regular intervals along reaches of uniform cross section.
- Above, below, and within, bridges.
- Cross sections should be representative of the reaches adjacent to them, and located close enough together to ensure accurate computation of the energy losses. If the average conveyance between cross sections is used to estimate the average energy slope, then the variation of conveyance should be linear between any two adjacent cross sections.
- Cross sections should be located such that the energy gradient, water-surface slope, and bed slope are all as parallel to each other between cross sections as is pragmatic. If any channel feature causes one of these three profiles to curve, break, or not be parallel to the others, the reach should be further subdivided with more sections.
- On large rivers that have average slopes of 2 to 5 feet per mile or less, cross sections within fairly uniform reaches may be taken at intervals of a mile or more.
- More closely spaced cross sections are usually needed to define energy losses in urban areas, where steep slopes are encountered, and on small streams. On small streams with steep slopes it is desirable to take cross sections at intervals of 1/4 mile or less.

- Recommended maximum reach lengths (distances between cross sections) are: (1) 1/2 mile for wide floodplains and slopes less than 2 feet per mile, (2) 1,800 feet for slopes less than 3 feet per mile, and (3) 1,200 feet for slopes greater than 3 feet per mile. In addition, no reach between cross sections should be longer than 75 - 100 times the mean depth for the largest discharge, or about twice the width of the reach. The fall of a reach should be equal to or greater than the larger of 0.5 foot or the velocity head, unless the bed slope is so flat that the above criterion holds. The reach length should be equal to, or less than, the downstream depth for the smallest discharge divided by the bed slope.

b. Additional guidance in EM 1110-2-1416. EM 1110-2-1416 notes the following considerations that are applicable to field surveyors acquiring cross-sectional data.

(1) Cross-sections are run perpendicular to the direction of flow at intervals along the river. The "reach length" is the distance between cross-sections. Flow lines are used to determine the cross-section orientation. The hydraulic engineer will provide these orientations to the surveyor.

(2) The cross-section should be referenced to the stream thalweg and by river mile as measured along the thalweg. From this the reach lengths between sections is computed. End points on the cross-section should be geographically coordinated using the local State Plane Coordinate System.

(3) End station elevations. The maximum elevation of each end of a cross section should be higher than the anticipated maximum water surface elevation.

(4) Local irregularities in bed surface. Local irregularities in the ground surface such as depressions or rises that are not typical of the reach should not be included in the cross-sectional data.

(5) Bent cross sections. A cross section should be laid out on a straight line if possible. However, a cross section should be bent if necessary to keep it perpendicular to the expected flow lines.

(6) Avoid intersection of cross sections. Cross sections must not cross each other. Care must be taken at river bends and tributary junctions to avoid overlap of sections.

(7) Inclusion of channel control structures. Channel control structures such as levees or wing dams should be shown on the cross section, and allowances in cross-sectional areas and wetted perimeters should be made for these structures.

17-5. Cross-Sections Adjacent to Bridges or Culverts

Cross-sections need to be densified near bridges and culverts in order to analyze the flow restrictions caused by these structures. Required sections are shown in Figure 17-5.

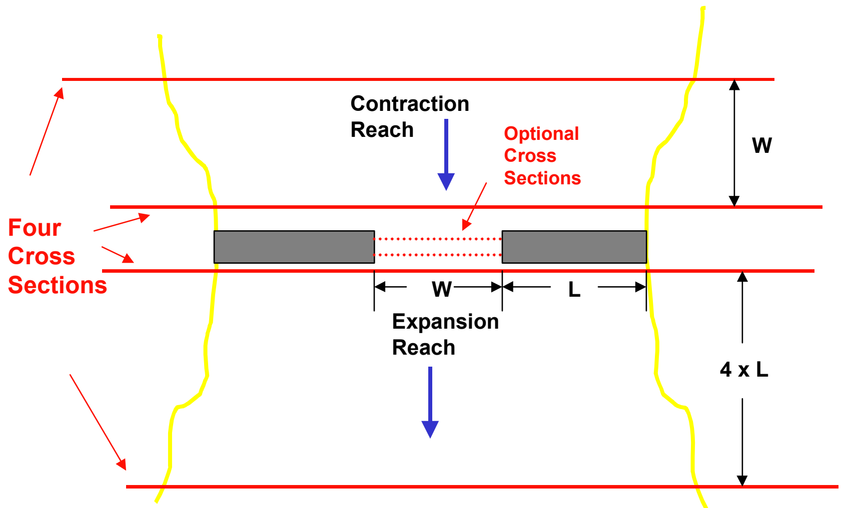


Figure 17-5. Cross-section locations at a bridge or culvert

The downstream section is located such that the flow is not affected by the structure--a distance of about four times the average length of the side constriction caused by the structure abutments. Two cross-sections are run a few feet upstream and downstream of the structure. The upstream section is located slightly further away from the structure--prior to the flow constriction. The upstream section is typically located at a distance equal to the width of the bridge opening or the length of the abutment. Variations in this general scheme exist--see HEC CPD-68, 1998. Other bridge detail is also required, such as dimensions of the bridge deck, abutments, piers, etc. If this information is not available from as-built drawings of the structure, then they will have to be measured as part of the field survey.

a. Navigation locks and dams. Most of the inland navigation projects maintained by the Corps contain navigation locks and dams. The flood profile characteristics in the regulated pools between these structures requires hydraulic modeling. Survey cross-sections may need to be taken more frequently around locks and dams and within the pools due to sediment build up.

b. River control structures. Controls are natural or artificial structures that affect the upstream water surface profile. Control can be dams, rock outcrops, falls, or drop structures. Dikes (i.e., wing dams or jetties) or weirs also impact the flow of water in a channel, depending on the stage. Cross-sections need to be taken on and adjacent to such areas.

c. Levees. Levees prevent floodwaters from entering the floodplain. Levees constrict river flow, resulting in a higher water surface. When levees fail, the protected floodplain becomes available for storage; thus the need for detailed cross-sections over levees and well into the floodplain. Cross-sections are taken at the beginning and end of levees. Floodplain storage can be computed from the DEM model or from cross-sections generated from the DEM surface. In addition, continuous top of levee profile elevations may be required. These can be accurately and efficiently obtained using topographic RTK DGPS survey methods. Levee cross-sections can also be run from the same RTK DGPS set up.

17-6. Required Accuracy of River Cross-Section Data

The accuracy requirements for cross-sections on a river and floodplain are highly dependent on other factors that make up the overall hydraulic prediction model. Other factors, such as Manning's coefficient, have a far more significant impact on the accuracy of computed water surface profiles. In general, horizontal accuracy is not as critical for hydraulic studies as for other navigation surveys. Vertical accuracy is also not as critical, provided there are no systematic errors or blunders in the data. The Hydrologic Engineering Center (HEC) conducted a study of survey accuracy requirements relative to the resultant accuracy on a predicted water surface model--HEC RD 26, 1986. Following are conclusions derived from this 1986 study.

a. For areas with high Manning n-value reliability, the effect of cross-section elevation inaccuracy is insignificant on the computed water profile accuracy. For example, on a river slope of 1 ft/mile, cross-section elevation points accurate to $\pm$ 2.0 ft (1-σ standard error) will affect water surface profile accuracy by less than 0.1 ft. A $\pm$ 2.0 ft elevation accuracy can be easily achieved by most conventional topographic and hydrographic surveying methods. A $\pm$ 2.0 ft (1-σ standard error) can also be obtained by manually digitizing the cross-section directly on a photogrammetric stereo model which has been designed to achieve an equivalent 10 to 12-foot contour interval standard--i.e., flown at an altitude that results in a negative scale of 1 inch = 3,333 to 4,000 ft.

b. For cross-sections developed by photogrammetric methods (i.e., a standard HEC cross-sectional DTM is directly developed by an operator on the stereo plotter) there is no significant impact on water surface profile accuracies between stereo models designed for 2-ft ($\pm$ 0.3 ft 1-σ) and 5-ft ($\pm$ 0.8 ft 1-σ) contour accuracies--the accuracy of the computed water surface profile is not significantly improved by using the presumed more accurate 2-ft contour standard. For areas with highly reliable n-values, there is no significant difference on the surface profile's accuracy between 2-ft and 10-ft ($\pm$ 1.7 ft 1-σ) contour mapping accuracies.

c. Cross-section elevations digitized directly from photogrammetric stereo models (i.e., "spot elevations" in 1986 study) are more accurate than cross-section elevations indirectly derived (e.g., scaled--manually or electronically) from topographic contour maps. Thus cross-sections indirectly derived from an existing contour map, or from a digital terrain model (DTM)--which has been constructed using triangulated irregular networks based on a gridded digital elevation model (DEM) and auxiliary breaklines--will not be as accurate as cross-sections directly digitized on the stereo model. (The 1986 study did not assess the effect of DEM "post" spacing density on indirect elevation accuracy since these techniques were not commonly used at that time. In addition, the old manual process of generating cross-sections by scaling intersecting contours is more rarely used given elevations can be obtained directly from DEM/DTM/TIN models).

d. Mean water surface profile errors resulting from less reliable estimates of Manning's coefficient are several times those resulting from survey measurement errors alone.

e. Error prediction equations (in the 1986 study) can be used to determine the mapping technique and accuracy needed to achieve a desired computed profile accuracy. Conversely, the error prediction equations can be solved for required digital elevation point accuracy given a specified mean water surface profile accuracy and other hydrologic factors.

f. Assuming a mean water surface profile modeling accuracy requirement of between 0.2 ft and 0.5 ft, a reliably known n-value, and low gradient stream slope, the required digital elevation accuracy along a cross-section is needed to no better than $\pm$ 2.2 ft. This accuracy level can be easily achieved by conventional (terrestrial) topographic surveying methods and hydrographic surveying methods. It also could be obtained by digitizing cross-section elevation points from a photogrammetric stereo model designed to meet a 10-ft contour interval accuracy standard--a low accuracy product.

g. If cross-section elevation points are indirectly derived from a newly mapped DTM (DEM) surface, then the point accuracy of the DEM grid (posts) must be better than that needed for directly digitized cross-section points. This increased accuracy will be a function of the "post" spacing (density) and local terrain gradient. Accuracy differences will not be significant in low gradient plains regardless of the post spacing density. Overall, directly observed cross-sections should be obtained in lieu of indirect methods.

h. In low gradient flood plains, cross-sections may be derived using indirect DEM/DTM/TIN model methods. DEM post-spacing should be variable and a function of the (1) required point accuracy, and (2) average terrain gradient. For example, given ± 2 ft required cross-section point elevation accuracy and a 2% gradient, a 50-ft DEM post spacing would be recommended. Breaklines are added at critical points, e.g., tops/bases of levees, roads, etc.----resulting in an "irregular network of mass points with breaklines."

i. In high-gradient areas (e.g., levees, road/rail embankments, etc.), photogrammetric cross-sections should be directly digitized from the stereo model. DEM/DTM derived cross-sections would not be recommended due to the dense post spacing that would be required to achieve the equivalent accuracy.

j. Digital elevation data from USGS quadrangle DEMs may be sufficiently accurate for cross-sectional data outside Federal levees--provided these maps are relatively current. Any additional mapping in these potential overbank areas could be performed to standard 10-ft contour interval standards.

k. Levee, roadways, railroads, and other similar flood controlling embankments should be profiled to around ± 0.5 ft accuracy. It will likely be more cost-effective to perform this profiling photogrammetrically rather than using DGPS/RTK (carrier phase) techniques--if concurrent mapping/cross-sections are being performed over the same area. On levees with excessive vegetation, ground-based cross-sections will be needed to supplement the photogrammetric sections and/or profiles.

l. Inundation mapping accuracy requirements are independent from water surface profile accuracy requirements. No photogrammetric mapping technique will cost-effectively measure ± 0.1 to ± 0.2-foot first-floor elevation accuracy throughout the study region. However, RTK DGPS methods will not normally reach these accuracy levels either.

m. Inundation mapping accuracy requirements will depend on the flood plain gradient, land use, and control features (embankments, etc.).

n. Unnecessary or unanalyzed topographic mapping accuracy specifications will significantly deplete existing mapping resources as mapping costs vary exponentially with the vertical accuracy requirement.

o. A ± 2 ft elevation data point standard error may now be achievable with Airborne GPS (ABGPS) control and LIDAR topographic mapping techniques-- i.e., no ground photo control points required. If this is achievable, significant cost savings could result. Thus, use of ABGPS in less critical overbank floodplain might be considered.

17-7. Surveys of Navigable Rivers, Locks and Dams, and River Stabilization Structures

The Corps performs numerous hydrographic surveys throughout its inland navigation system. Many of these surveys involve underwater mapping and investigation of channel reaches, crossings, cutoffs, and bends, sediment movement and deposition, scour in bends, channel stabilization structures, and training structures such as spur dikes, longitudinal dikes, vane dikes, and closure dikes. Investigative hydrographic surveys are also performed around the approaches, guide walls, guard walls, and lock walls in navigation locks. Such surveys are used for planning and design of improvements to these structures. Details on these requirements can be found in ER 1110-2-1458 (Hydraulic Design of Shallow Draft Navigation Projects) and EM 1110-2-1611 (Layout and Design of Shallow Draft Waterways).

a. Survey methods. Due to the variety of projects surveyed, different hydrographic survey techniques are used. Not all river structures are fully submerged, requiring combined hydrographic and topographic survey methods. Fully submerged structures can be mapped using all the acoustic techniques covered in this manual, i.e., single beam, multiple transducer, multibeam, or side scan. Recently, multibeam surveys have proven useful in detailing underwater structures, such as locks and dams, weirs, dikes, and levee revetments. The following paragraphs contain examples of surveys of various river navigation and stabilization projects.

Figure 17-6. MV Boyer (St. Louis District) -- used for river engineering surveys and investigations on the Middle and Lower Mississippi River

b. St. Louis District MV Boyer. The Mississippi Valley Division (St. Louis District) uses the MV Boyer for river engineering surveys and investigations on the Middle and Lower Mississippi River (Figure 17-6). This 26-ft vessel is equipped with twin 250 HP Yamaha outboards and is outfitted with the equipment listed below. The trailerable vessel has the ability to map underwater features of most flood control and river stabilization structures in the Mississippi River. Its on board data processing equipment provides a "field-finish" capability, enabling same- or next-day delivery of edited data sets to requesting districts in the Mississippi Valley Division.

- Isis Sonar Data Acquisition and Processing System (Triton Elics, Inc.)
- SeaBat 8101 240 kHz Multibeam Bathymetric and Sidescan Imaging Sonar (Reson, Inc.)
- HYPACK and HYSWEEP software (Coastal Oceanographics)
- Position Orientation System with a Trimble Differential GPS and Inertial Block to collect Position and Heave, Pitch, Roll and Heading Corrections (TSS-UK Ltd.)
- 300 kHz, 600 kHz and 1200 kHz Acoustic Doppler Current Profiler (RD Instruments)
- 200 kHz Single Beam Echo Sounder with Hull Mounted Transducer (Innerspace Technology)
- Sound Velocity Probe with Salinity and Temperature Recorder (Marimatech)
- DT 5000 120 kHz Dual Beam System for Locating Fish or Biomass (BioSonics)
- DT 4000 200 kHz Dual Beam System for Identifying Bottom Classification (BioSonics)
- RoxAnn to Identify Bed Material Types (Marine Microsystems Limited)
- Triton Isis Built Computer (700 MHz CPU, 512 MB RAM, 27 GIG Hard Drive, Dual Monitors, CD-RW, 250 MB Zip)

c. Bendway weir and dike surveys. As shown in Figure 17-7, multibeam systems can be effectively used to provide detailed surveys of bendway weirs. Periodic surveys can be performed to monitor sediment erosion and deposition in the bends and adjacent to the weirs. Figure 17-8 depicts a dike failure picked up during a multibeam survey of the structure.

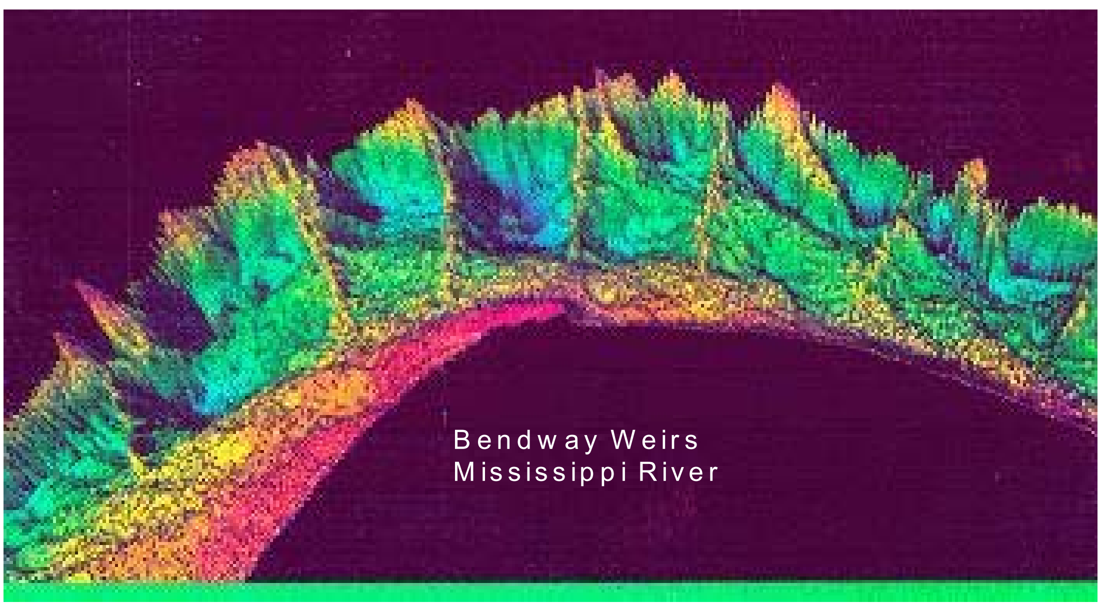


Figure 17-7. Bendway weir multibeam surveys (St. Louis District)

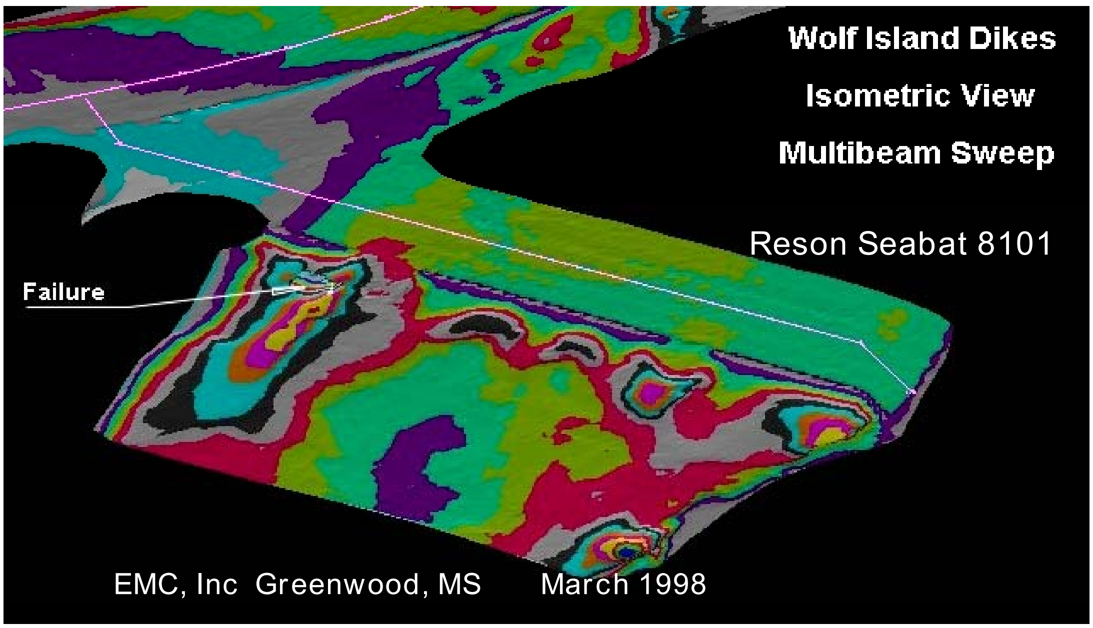
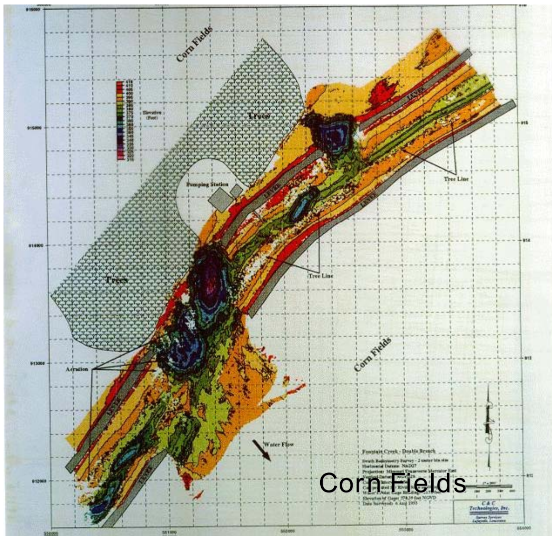
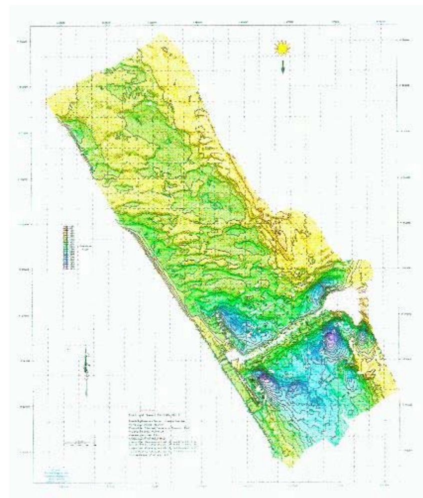


Figure 17-8. Multibeam surveys of Wolf Island Dikes--Cairo, IL (Memphis District)

d. Levee breech surveys. Figure 17-9 illustrates the use of multibeam systems during the Mississippi River flood of 1993. During high water stages in which levees were overtopped, breeches were located and mapped, allowing repair estimates to be made. Figure 17-9 also depicts a multibeam survey performed over Lock and Dam 25 when much of the structure was covered during high water.



Fountain Creek -- Double Levee Breach
6 Aug 93



Mississippi Lock/Dam 25
17 Aug 93 (Mile 241.5)

Figure 17-9. Levee breech and lock & dam surveys during 1993 flood (JE Chance & Associates for St. Louis District)

e. Mississippi River sand wave mapping. Multibeam systems are used in the Corps to map sand wave movement and elevations in the Mississippi River. A typical survey is shown in Figure 17-10.

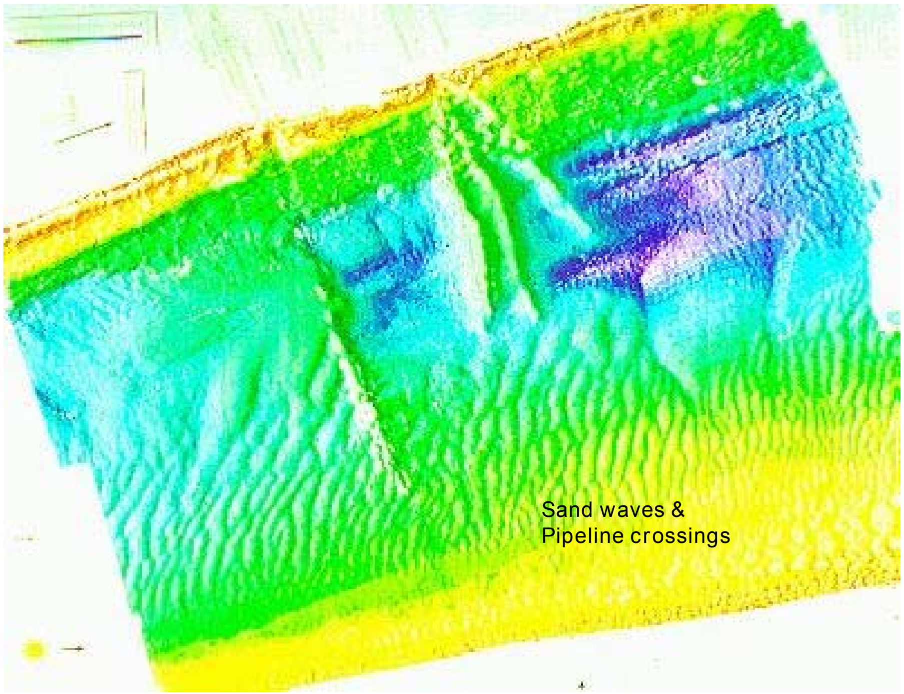


Figure 17-10. Lower Mississippi sand wave surveys using multibeam

f. Sheet pile wall surveys. Figure 17-11 depicts a underwater survey of a sheet pile wall performed as part of a wave surge study.

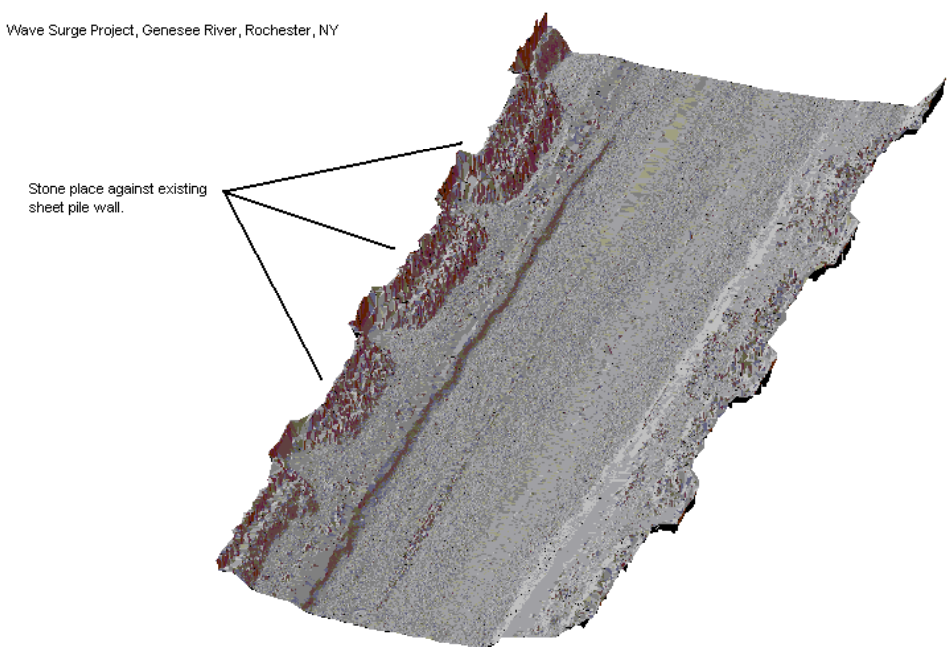


Figure 17-11. Sheet pile wall multibeam surveys. Genesee River, Rochester, NY (Buffalo District)

g. Bridge scour surveys. Figure 17-12 shows a bridge scour survey performed using a single beam transducer. The survey was done for the New Your City Triborough Bridge and Tunnel Authority by Lichtenstein Engineering using Innerspace Technology data collection equipment and software. The vessel was positioned with a total station. Processing and plotting was done on AutoCad.

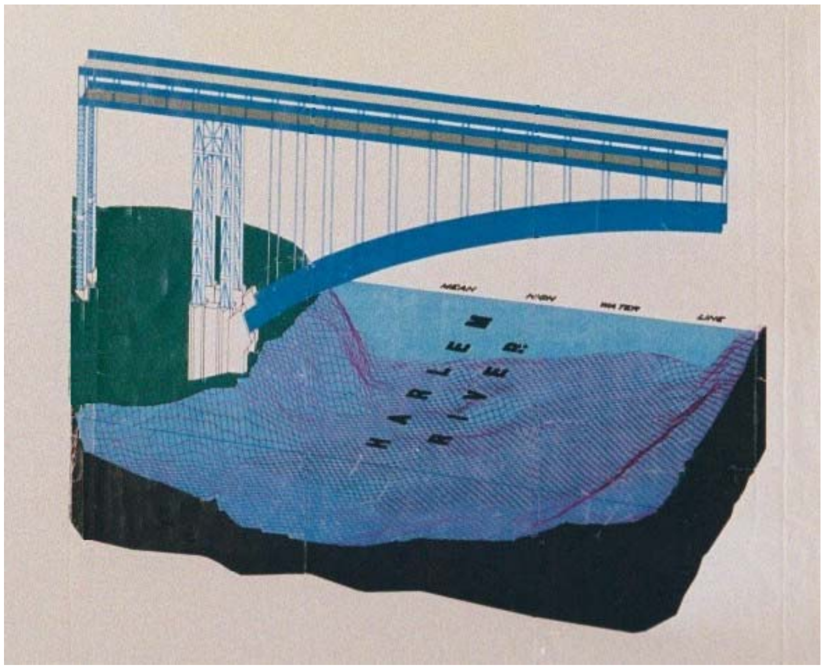


Figure 17-12. Triborough Bridge scour survey (Lichtenstein Engineering and Innerspace Technology)

h. Lock and dam surveys. Figure 17-13 depicts a multibeam survey of Columbia Lock and Dam to locate sunken barges behind the spillway. The survey was performed by EMC, Inc. of Greenwood, MS.

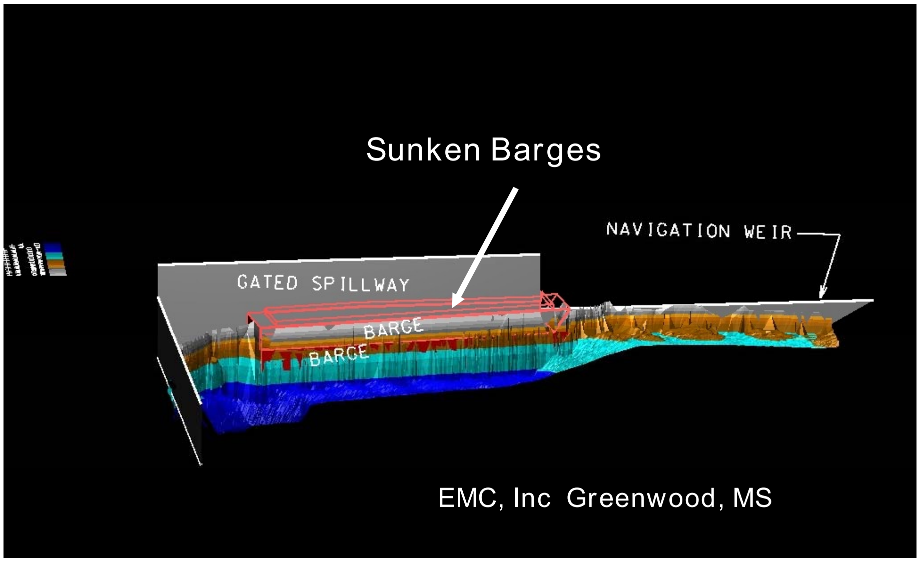


Figure 17-13. Columbia Lock & Dam (Vicksburg District)

i. Lock approach surveys. Figures 17-14, 17-15, and 17-16 depict multibeam surveys of approaches to Corps navigation locks. Small bin sizes provide details of the approach wall pilings, baffle blocks, and scour areas in the approaches to the chambers.

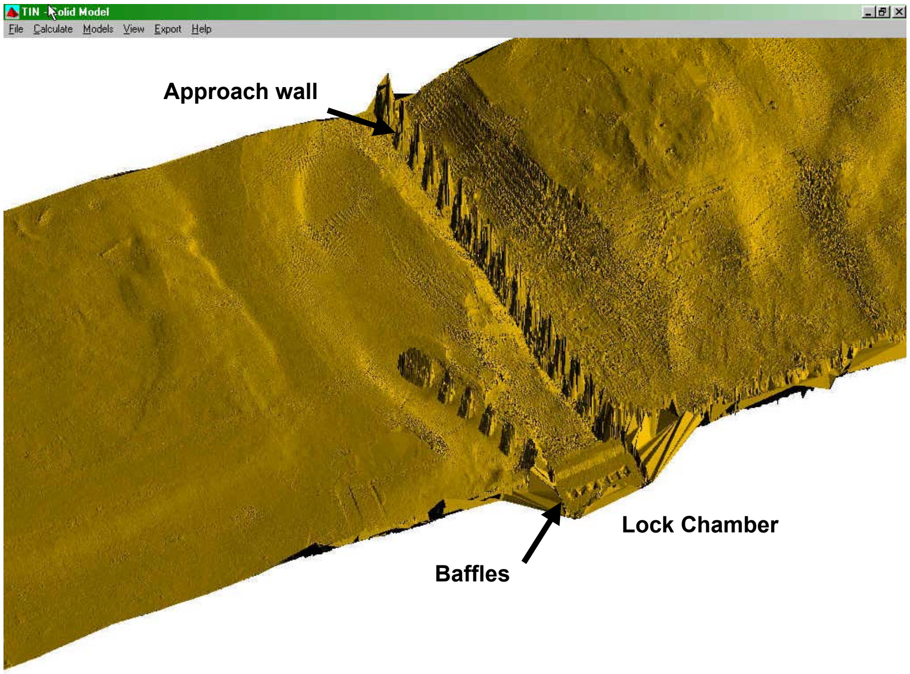


Figure 17-14. 3-D terrain model from multibeam survey of approaches to Woodruff Lock and Dam (Mobile District--EMC, Inc.)

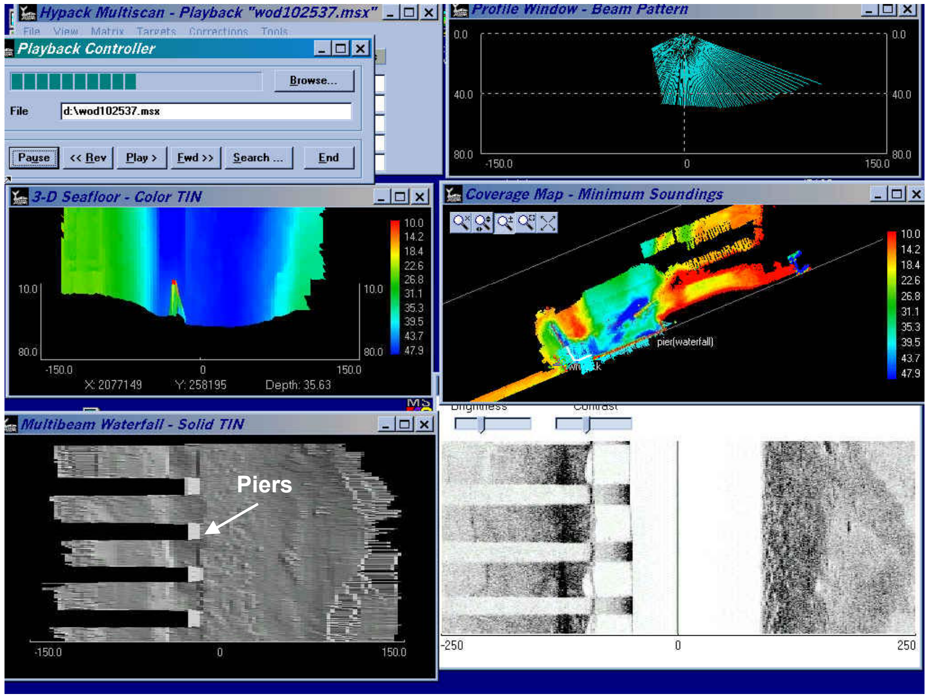


Figure 17-15. Multibeam screen display of approach wall piers. Topographic model (lower left) and side scan sonar (lower right) depicts imagery between pilings. Woodruff Lock and Dam (Mobile District--EMC, Inc.)

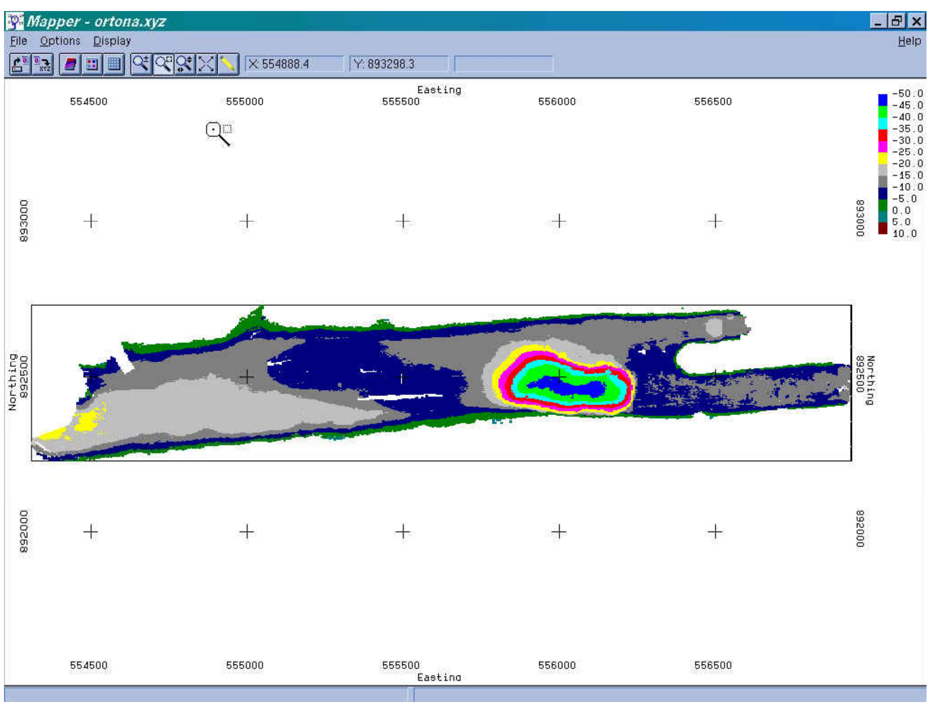


Figure 17-16. Deep scour hole vicinity approaches to Ortona Lock (EMC, Inc.)

j. Revetment surveys with side scanning multibeam systems. Multibeam transducers can be tilted upward to detail revetments, bridge piers, fenders, pilings, lock guide walls, breakwaters, jetties, and other structures. Topographic coverage up to near the water's edge is possible. In deeper draft areas, coverage under moored barges is feasible. The sketch at Figure 17-17 illustrates side viewing multibeam coverage on a rip rap embankment.

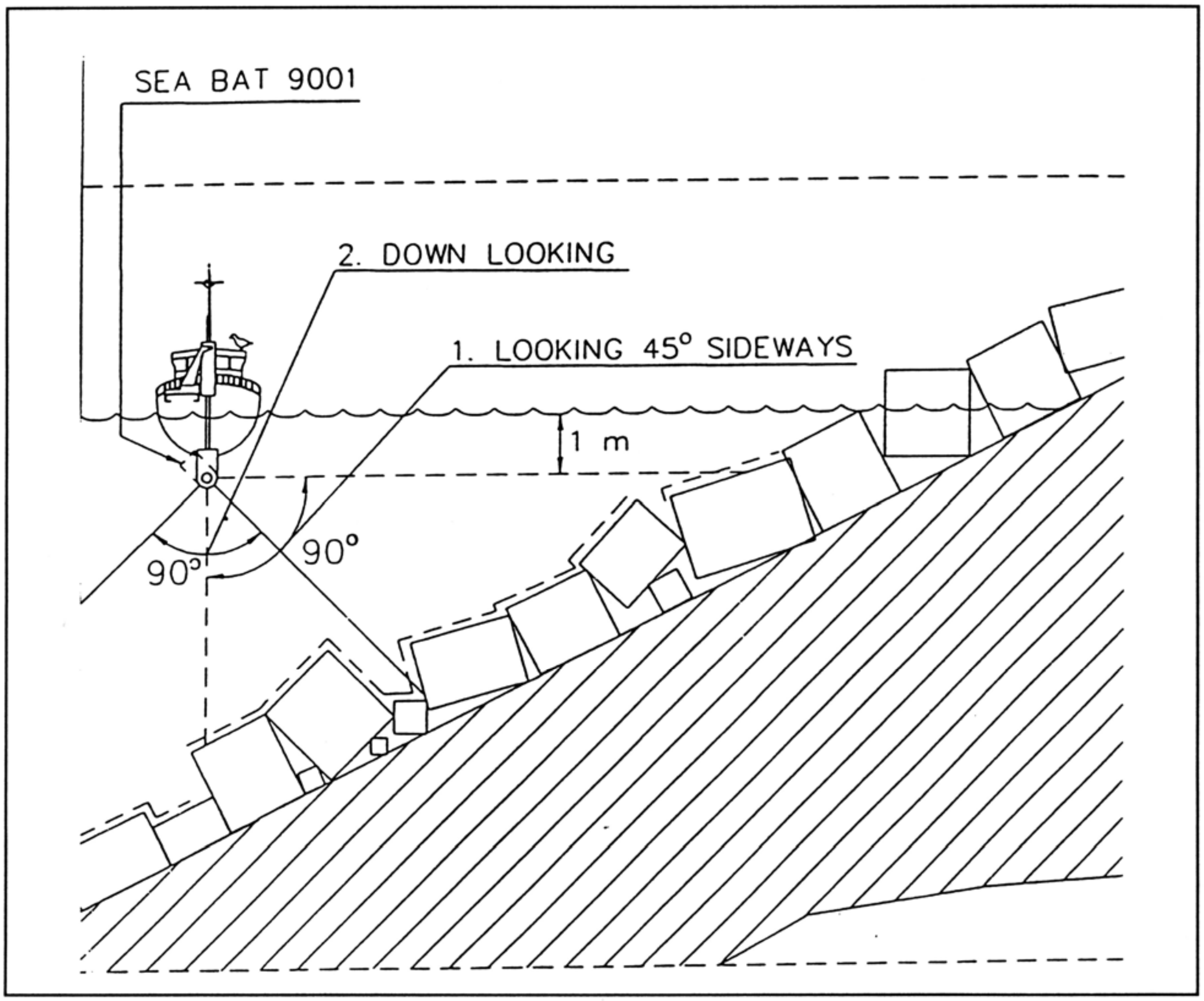


Figure 17-17. Tilting multibeam transducer head for surveying lateral structures (Reson, Inc.)

k. Revetment construction and maintenance. Revetment grading, construction, and maintenance projects require a variety of surveys. During placement of articulated concrete mats (Figure 17-18) control surveys are needed to accurately align the sinking plant equipment. Subsequent hydrographic condition surveys are periodically performed to assess the condition of the concrete mats.

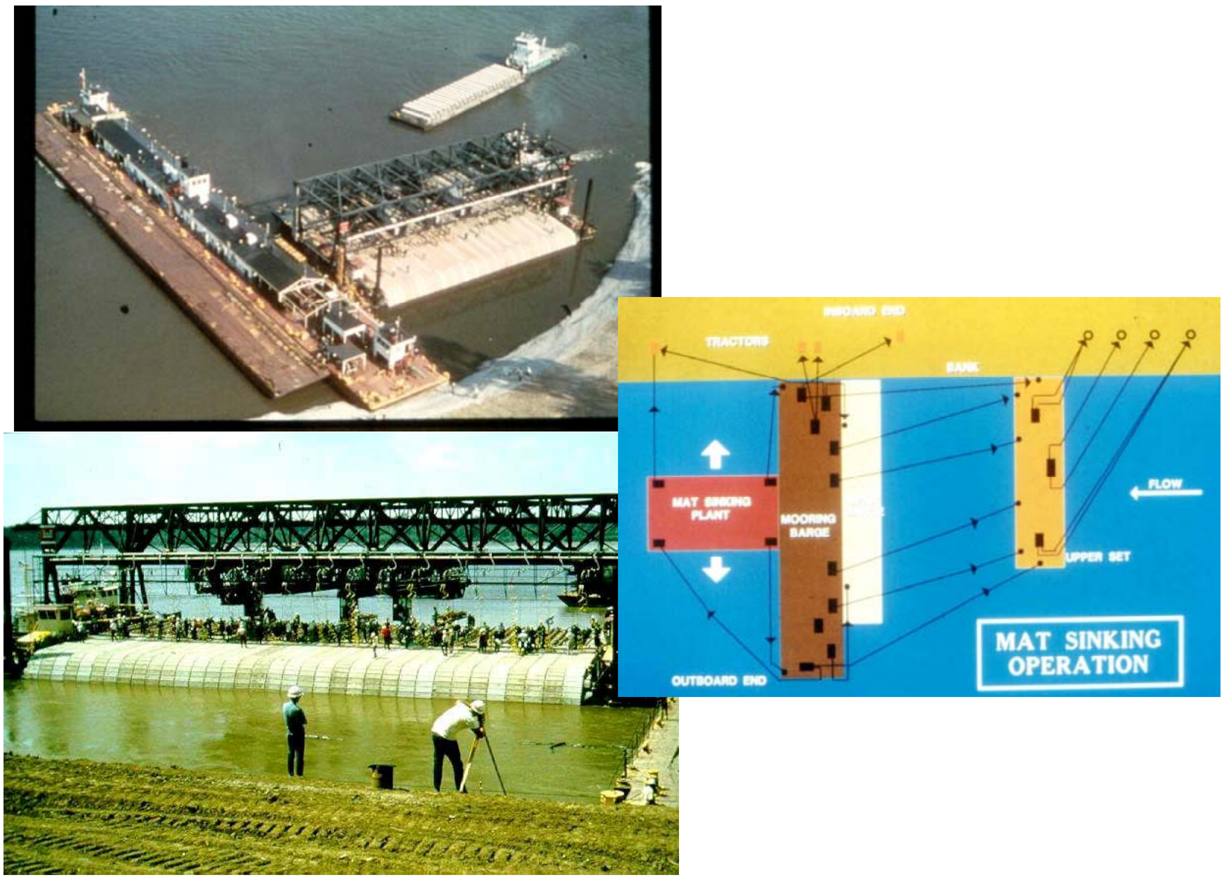


Figure 17-18. Alignment surveys for placement of concrete mats along Mississippi River revetments (Memphis and Vicksburg Districts)

17-8. References

HEC RD 26 1986
Hydrologic Engineering Center (HEC) Research Document 26 (HEC RD 26*), Accuracy of Computed Water Surface Profiles,* 1986, incl. Supplemental volumes

HEC CPD-68 1998
Hydrologic Engineering Center (HEC) CPD-68, *HEC-RAS River Analysis System User's Manual*, Version 2.2, September 1998

Note that references to HQUSACE publications are listed in Appendix A.

17-9. Mandatory Requirements

There are no mandatory requirements in this chapter.

Chapter 18
Coastal Engineering Surveys

18-1. Introduction

This chapter addresses guidelines and considerations for planning the type and scope of beach and nearshore surveys and provides an overview of the methods used to perform these types of surveys. An important component in this process is understanding and selecting the appropriate survey tools to collect data that meet project requirements and needs of data end users. Guidance in this direction will be valuable in assisting project planners, designers and surveyors in reaching a common knowledge base for specifying and cost estimating effective survey data collection programs. This chapter also presents summary information on traditional, as well as, newer technologies for surveying. The US Army Coastal Engineering Research Center (CERC--now Coastal and Hydraulics Laboratory) developed most of this chapter in 1998.

Figure 18-1. Coastal surveys (Arc Surveying and Mapping, Inc.)

18-2. Background

Coastal projects of all types typically require extensive and accurate beach and nearshore survey data. Acquiring such data is a labor intensive (Figure 18-1), time consuming and complex process, and it is often difficult to establish the success and quality of the data set after the fact. Part of this problem can be attributed to a lack of consistent guidance for planning, conducting, and properly evaluating coastal surveys. Guidance is lacking especially for defining survey requirements based on the eventual end-use of the data. To date, there are no definitive industry or Federal standards designed to cover these types of survey requirements. Most beach and nearshore surveying standards being used today are based on local practice. Beach and nearshore surveys normally consist of five general survey types: beach profiles, nearshore borrow areas, ebb deltas, coastal structures, and special projects such as dredged material placement (Figure 18-2). For example, surveys are necessary in order to determine construction progress and payment for most of the typical project types. However, the amount and precision of the required survey data may differ between a beach fill project and jetty project. Beach surveys are also performed to monitor beach renourishment projects along the Atlantic and Gulf Coast--common in Jacksonville, Philadelphia, Norfolk, and New York Districts. Hydrographic surveys are performed during design to locate suitable offshore sand sources. During beach pump out operations, profile surveys are run to check placement and compute material quantities placed on the beach.

Figure 18-2. Beach renourishment project--Miami Beach, FL (Jacksonville District)

a. The exact end use may vary, but the essential goal of most survey projects is to characterize the features of a relatively large area, often the equivalent of several square miles. The principal type of survey used to accomplish this has been a series of profile lines and this is the most familiar type of technology still in use. However, there are a variety of newer technologies and alternate approaches available for coastal surveying, summarized later in this chapter. In addition, the same basic technology frequently can be used or applied in more than one way to produce results, which vary in accuracy, coverage density, time, cost and other factors. Interest in these approaches arises from concerns about the numerical inaccuracies of interpolating between traditional profile lines and the possibility of significant bathymetric anomalies being hidden in the blind areas between profiles. Alternate approaches that could provide denser data coverage even at the expense of having less precision in individual measurement points may produce an overall result that better represents those features important to the project.

b. It is important to match the surveying scope, including the selected technology and procedures, with the true requirements based on the eventual data use and it is essential that survey specifications originate from the project's functional requirements and that the requirements are realistic and economical. However, too frequently a survey method is pre-selected based on a combination of peripheral factors, and this selection in effect defines the type, accuracy and characteristics of the data. Surveying a coastal structure, for example, requires a different effort than documenting general changes on a dynamic beach several times a year; reconnaissance or condition surveys may be able to use less accurate, but broader covering, faster technologies than "pay" surveys. If numerical models require profile-type data eventually to be extrapolated and converted into gridded depths or contours, the data can be collected in that manner to start with if the need is identified as part of the surveying scope. Data end-users must have and be able to communicate a complete understanding of their needs.

c. A related issue is who should be responsible for specifying, defining or otherwise deciding among choices for each technical question. In almost all cases the in-house survey branch will ultimately be responsible for accomplishing the work, but limitations on the number of in-house crews and their workload often result in the work being contracted. For most reconnaissance, planning, design and similar projects, the surveys are performed by A-E or specialty surveying firms under delivery order contracts. For construction progress, as-builts, or pay measurement, especially on dredging-related projects, the surveys are often part of the construction contractor's scope of work and are spot-checked by in-house crews.

d. In both basic scenarios, however, a critical point is that the work is often done by outside personnel not under the direct supervision or coordination of the end users. Once a survey request goes from the originator/end user into the survey branch/contract system, there is a danger that the originator no longer has control nor input, and the final surveying contract specifications and standards may not address the original requirements. This type of situation underscores the importance of ensuring a high level of awareness and communication on the part of all the people involved in the data collection planning and decision-making processes for a project.

18-3. Beach Profiling Surveys--General Procedures

Coastal beach surveys are performed in support of beach erosion and/or hurricane protection projects, primarily to measure and monitor beach renourishment placement or condition, or for construction payment of beach fill placed. These surveys combine land topographic cross sections with offshore hydrographic sections.

a. Beach profiles (i.e., cross sections) are run perpendicular to the shoreline relative to fixed monuments on an established baseline or coastal setback line--see Figure 18-3. The fixed baseline is normally established well beyond (inland from) the dune line to ensure permanency for subsequent surveys. Permanent reference azimuths are established for each profile line. Profile elevations are obtained using boats, sleds, aircraft, hand-held rods, and other measuring platforms described in the remainder of this chapter.

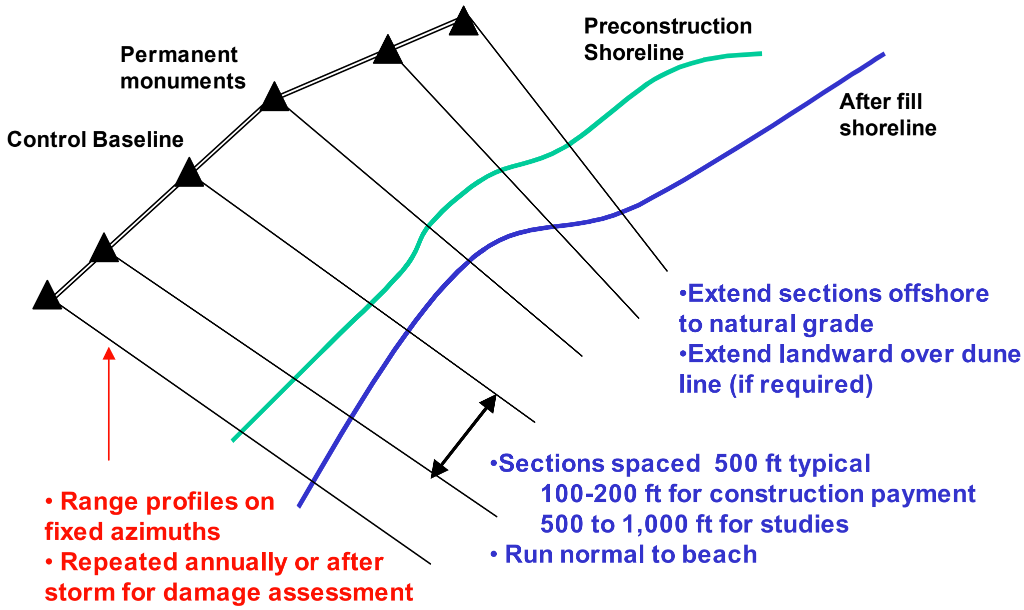


Figure 18-3. Standard configuration for beach profile lines

b. Profile spacing is highly project-dependent. For general coastal erosion studies it may be from 500 to 2,000 ft, depending on the regularity of the coast. Beach renourishment construction measurement surveys for payment require denser spacing--typically at 100- to 200-ft intervals.

c. The junction/overlap point between the two surveys is critical and often subject to large error, especially when heavy surf conditions are present or where tidal modeling is uncertain. Land sections are run at low tide, and are extended as far as possible with the rodman wading into the surf. These concepts are illustrated in Figure 18-4. To obtain maximum overlap, the hydrographic portion of each profile is run at high tide, with the boat operating as close to the beach as surf conditions will safely allow. In heavy surf conditions, survey errors can approach 5 ft; thus, maximum reliance/weight should be given to land-based topographic profiles. The same reference baseline station is used for both land and water sections. Positioning and depth measurement may be accomplished by any acceptable method.

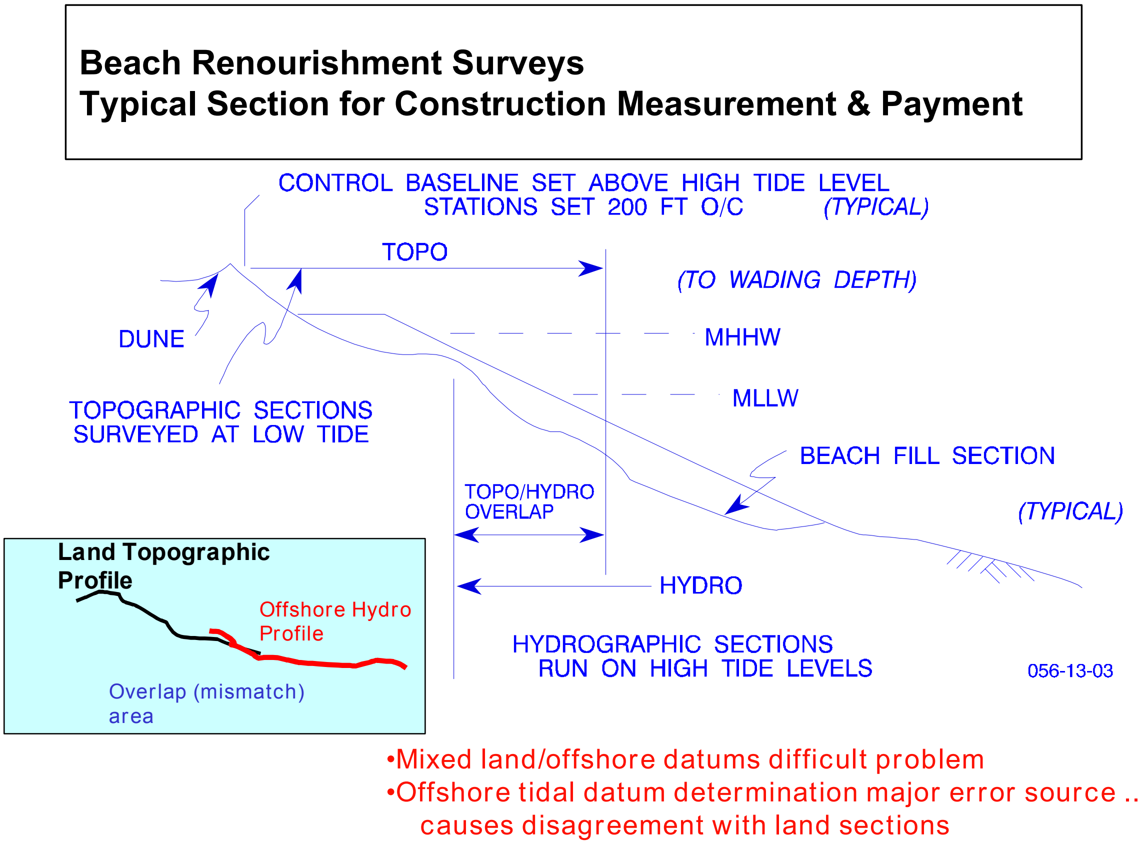


Figure 18-4. Running land and offshore hydrographic sections

d. Some beach protection projects are jointly funded by federal, state, county, city, or other agencies. The land sections to be surveyed may be bounded on the land side according to state tideland boundaries. The many different state laws may appear to be complex to a federal surveyor. Specific procedures for determining these tidal boundaries are usually defined by state regulations.

18-4. Accuracy Requirements

a. The accuracy of beach and nearshore survey data is often stated as a major concern, but accuracy frequently means different things to different groups. Accuracy should be broadly viewed as more than the ideal or theoretical accuracy associated with a particular instrument or system. It includes operational influences such as the site conditions, overall field collection and data reduction procedures used, and any constraints due to datum problems, lack of monuments or other control, or historical incompatibility. Project data planning goals should be less directed toward improving absolute or ideal accuracy and more toward properly understanding, characterizing and communicating the errors and limitations in existing or proposed systems and procedures. The calculation and presentation of realistic error bands on all data is consistent with and supports the trend toward risk-based analyses in project design

b. Although they may recognize the need to do so, many end-users are unable to identify a specific use or type of analysis, which directly translates into a requirement for nearshore hydrographic survey accuracy, spacing or a similar standard. In addition, situations sometimes occur in which ambiguous project goals, together with the inherent lack of precision in many coastal engineering design tools and other inputs such as wave data, result in project personnel feeling that survey precision is not their highest priority. This point can be especially contrasted by surveys in the planning community with the requirement for 3rd order accuracy in real estate maps and the dramatic effect which inaccuracies in that type of data (i.e. building floor elevations and foundation positions) could have on the calculation of project storm damage reduction benefits. It is often recognized that a more formal, comprehensive error analysis to establish the effect of survey limitations on a particular project or calculation should be performed in order to better assess risk and uncertainty, but resources are not typically available for the necessary effort.

18-5. Data Density, Formats, Processing and Archiving

a. The issue of data density or coverage is closely related to accuracy and end-use. A general phrasing of the problem might be: "what changes, features or other data are really important?" Newer technologies are capable of rapidly collecting data over entire surfaces rather than profile-by-profile. However, the trade-off is in additional processing time and computing power, QA/QC difficulties in terms of checking such data, and very significant storage requirements. Procedures for intelligently editing or "decimating" can be developed, but the basic question is more one of knowing how much data is necessary to adequately characterize the site or problem of interest.

b. Some survey sections are still working with paper copies of profile line and "spot" elevations on plan views, however, most district end users use processed data provided to them on disk or tape in one of the many standard CADD formats. This makes subsequent calculations and data manipulation very convenient and is one of the derivative positive results of using outside private surveying contractors.

c. A negative aspect with the more highly pre-processed data is that the user is no longer directly involved in data reduction tasks such as corrections for datum, tides, or waves and does not develop an intuitive appreciation for the variability and limitations of the data. Because the raw survey data itself is no longer "handled" directly by the end users and survey data files often are not plotted and inspected for their own merit, major errors may not be noticed until problems subsequently develop while performing calculations or interpreting model results. By that point the survey data has been so co-mingled with other potential data problems and issues that it may take considerable time and effort to identify the survey as the source of error.

d. Whether the ultimate purpose of a set of surveys is planning, design, construction or pay, the intermediate step in all projects is some type of volumetric change calculation. These calculations are most often performed using a software program, which automates some type of algorithm involving interpolations, point-by-point differencing and extension of 2-dimensional area changes to 3-dimensional volumes. The use of "high resolution" technologies has subsequently established the ability to compare 3-dimensional surfaces derived from digital terrain matrices (DTM).

18-6. Coastal Processes Affecting Surveys

a. The coastal margin is a unique physical environment and as a result, it presents unique challenges for collecting and interpreting all types of data including survey data. The coast is the triple interface of the atmosphere, ocean and land (USACE, 1984). Surveying this interface cannot be done through the straightforward application of conventional terrestrial surveying principles; neither can adequate data be collected exclusively with traditional hydrographic surveying techniques. Both approaches - used with innovation, creativity and intuition - are necessary to properly characterize the beach and nearshore environment.

b. Unlike most terrestrial sites, the coastal margin changes and moves constantly, even within time frames as short as the time of the field survey itself. The coast is said to exist in a state of dynamic equilibrium. That is to say, it is shaped by a unique balance among wind, waves, tides and sediment characteristics (USACE, 1984). The concept of dynamic equilibrium suggests that significant changes to one of these parameters can disturb the balance and produce a new system. Unfortunately for coastal engineers, planners and surveyors, sufficiently significant changes can occur within a time frame of hours, days and weeks.

c. Understanding the equilibrium condition at a particular site is further compounded by the fact that the natural forces producing the equilibrium may not be those observable on the survey day, nor even the average condition observable over a short period of time. Often extreme events or perturbations in the average energy condition are responsible for the equilibrium profile or other features observed weeks or even months after the event. This phenomena may be more important to the analyst reviewing the data set and drawing conclusions for design, but it is useful knowledge for the surveyor planning the program and collecting data in the field as well. A sufficient familiarity with the natural process can ensure that modifications to a scope are made, if appropriate, in the field based on conditions observed and that any atypical events or features are noted which might make data interpretation more meaningful to the problem.

d. Very frequently in coastal planning and design, historical data is either sparse or of questionable accuracy. The reasons for this are varied, but certainly can include a lack of past interest or concern in a site and its problems, or a lack of attention to properly archiving and describing a collected data set. One result of this problem is that the coastal professional may be required to hindcast a historical condition from a very limited present or short-term past data set, and then use the hindcast condition for forecasting a future condition. This process of predicting the future based, not on the "true" past but on a "prediction" of the past is not unique to coastal projects, but is certainly more common than in most other fields of engineering design.

e. This section briefly summarizes those coastal processes that most affect the collection of survey data and is necessarily a very brief overview because of the complexity of the subject. Also, while coastal processes occur at most sites, the range and significance vary greatly from site to site and requires specific analysis of the local conditions as part of the scoping phase. In addition, the problems associated with the physical environment are made more complex by the fact that different data end uses may require different accuracies and density. More detailed information on the natural environment is available from a number of references and resources including: EM 1110-2-1414, Water Levels and Wave Heights for Coastal Engineering Design; EM 1110-2-1810, Coastal Geology; EM 1110-2-3301, Design of Beach Fills; EM 1110-2-1502, Coastal Littoral Transport; The Shore Protection Manual (USACE 1984); and the series of Coastal Engineering Technical Notes (CETN).

18-7. Overview of Coastal Processes

As noted, the coastal margin is a dynamic system that can change significantly during the time it takes to complete the field portion of a survey program. The survey program planner must have an understanding of those features most likely to change, the range of variation, and the time scales associated with each. Some aspects of time scales are straightforward and familiar to most people collecting and using coastal data. For example, it is well understood that if the water level itself is being used for a reference plane, as in most hydrographic segments of a coastal survey, that level must be continuously corrected for tidal variation if the survey extends over an appreciable portion of a tidal cycle. For most traditional surveying methods, in contrast however, wave height variations usually are not individually corrected.

18-8. Time Scales

Classical oceanography introduced this same concept of a relationship between the length and time scales of various physical processes, called *Lagrangian times and scales.* Simply stated, the time frame over which a process is observed or measured should be consistent with the length scale over which the effect is felt. For example, a rough order of magnitude of the time scale for tidal cycles is $\sim 10^4$ seconds. At typical water velocities, the length scale of this single cycle should also be very roughly 10^3 to 10^4 feet. This type of analysis would suggest, therefore, that if a mile-long section of shoreline would require more than three to four hours ($\sim 10^4$ seconds) to survey, tidal influences could be significantly different at the starting point of the survey than at the ending point. While the process time scale influence may not be important for every survey or site, it is necessary to perform some type of scale analysis in order to establish the level of importance. This is especially true in using newer surveying technologies for which the influence of various factors is either unknown or unfamiliar to many users.

18-9. Waves

a. At most sites wave energy is probably the primary natural forcing function responsible for shaping the bathymetry and shoreline alignment (USACE, 1984). As waves approach the shore and move into shallower water depths, the water particles that have been set into orbital motion by the waves increasingly "feel" the sea floor. One effect of this is to transform a portion of the kinetic energy of the traveling waves into potential energy. The visible effect of this energy transformation is that the waves shoal or increase in height, growing steeper and more peaked, until finally they become unstable and collapse or break in the nearshore.

b. A second equally important, but perhaps somewhat less obvious effect, is that the friction imparted to the sea floor by the transforming waves produces a shear stress which may be sufficiently great to lift sediment into the water column and make it available for transport and redistribution. The wave-induced shear is usually too transient and non-directional to drive the sediment very far. However, once it is lifted into the water, other background currents such as those resulting from the angle the waves make with the shoreline, from tides, or direct wind stresses can take over and move the suspended sediment. In any case, the result is that the waves can move sufficient unconsolidated sediment to reshape the bathymetry. The altered bathymetry then produces a new set of water depths, which, in turn, transform the wave field differently. This iterative and continuous interaction between incoming waves and the nearshore bottom is one of the principal sources of complexity and dynamic change in the coastal environment.

c. A further complicating factor in this process is that the waves are not constant either in height or period. For illustration and rough planning purposes, waves are often characterized as regular or "monochromatic," meaning that successive waves in the incoming field are assumed to have the same, constant height and period, and the wave form is sinusoidal in shape. These assumptions result in mathematical simplifications which allow for the use of linear wave theories. However, real waves exist in an irregular spectrum composed of inter-mixed heights, periods, translation speeds and steepness. To an observer at a fixed point in the water, the passing waves appear as a varying time series. In addition, the time series observed on one day, at one location may be very different the next day at the same point, or the same day, but a few thousand feet away. A detailed analysis of such waves requires statistical techniques and so-called non-linear or "higher order" wave theories.

d. The reason such analyses are important and are performed in spite of their complexity is that wave energy and resulting sediment transport potential is proportional to the *square* of the wave height ($\sim H^2$). Alongshore variations in the wave time series cause gradients in energy which can be very significant in influencing local shoreline alignments and on the impact of any existing or proposed coastal structures or other alterations. In addition, because the water depth at which a wave begins to be influenced by bottom friction depends on the wave height and steepness, the different waves in the time series in a given section of shoreline will break over some cross-shore width (i.e. a range of depths) representative of the degree of variability in the wave series. This determines the width of the visible "surf zone" at any time and location, but is important because it may affect total sediment transport volumes and the position and prominence of features such as submerged bars or run-out channels.

e. The wave climate at a particular location is a combination of locally generated wind waves and (usually) longer-period waves that have traveled over some appreciable distance of open water. Local seas respond rapidly to changes in local winds and the arrival timing of waves produced by distant events is unpredictable. As a result, the time scale for significant changes in wave energy and its effect on local bathymetry is often on the order of hours or days. Field work begun at a project site before a weather front moves in, and completed a day or two after it passes when the waves have laid down enough to resume work may be capturing very different and unrelated conditions.

f. Because of the mathematical relationships among different components of all statistical distributions, even limited data or observations - as long as they are consistently taken - can provide insight into the entire wave climate at a site. One parameter often used is the *significant wave height,* H_S, which is defined as the average height of the one-third highest waves in the series. This is a convenient approximate field measure because experience has shown that this is the height an observer will tend to notice anyway when watching a variable time series. Accuracy can be improved by observing the waves for several minutes and comparing their heights, from trough to crest, to some reference object such as a range pole, rod, piling, pier, boat railing or similar. An associated representative wave period is determined by measuring the total time it takes for several waves (typically 20) to pass a fixed object and dividing the total by the number of waves. Several trials should be measured and compared. Lastly, a very rough approximation of the water depth at which a wave will begin to shoal and break is a depth between three-quarters and one full wave height (i.e. solitary wave theory breaking limit, $H_b \sim 0.78d$)

18-10. Currents

a. Along most sections of open coast any sediment suspended by wave action typically is transported parallel to the shoreline by background currents. These currents most often result from the fact that the breaking wave crests form some angle with the shoreline. Waves surging obliquely toward the beach and reflecting at the complementary angle produce net alongshore water movements which are roughly proportional to the size of the approach angle and the square of the wave height. These currents may be either reinforced or opposed by other water movements resulting from tides, local wind shear on the water column, or any similar force which results in a dynamic setup or mounding of the water surface differentially at one location compared to another.

b. Although alongshore transport currents are relatively weak under average conditions, they are persistent and can be much stronger during storms when the wave heights are larger and the seas more directional. The result is that the total sediment transport integrated over the width of the nearshore zone and over a long time period can be very substantial. Average annual transport can range from as little as 30,000 to 40,000 cubic yards to as much as 300,000 to 400,000 cubic yards; values as large as 700,000 cubic yards are not unheard of. The direct measurement of sediment transport has been attempted using traps and various optical instruments, but the techniques are cumbersome and results have been mixed. Most often transport is either predicted using one of several mathematical formulae based on wave height and angle (e.g. energy flux), or it is inferred from dredging records at nearby inlets, comparative surveys, or balancing sediment budgets.

c. Because most sediment transport is related to the wave climate at a particular location and time, the instantaneous transport magnitude and even the direction may change as the wave field changes. The most common pattern of change is a seasonal one in which higher energy periodic winter storms approach a shoreline from a consistent direction (e.g. northeasters, etc.) which is different from the prevailing wave direction under average, milder summer conditions. In such cases there will be associated reversals in transport direction for varying lengths of time. The magnitudes of the transport in each direction are algebraically combined to produce values known as the net annual transport magnitude and direction. This approach is useful in many analyses, but can be misleading in others. As can be seen, if the transport is roughly balanced in both directions, the net value can be very small even though many hundred thousand cubic yards are actually moving in the system.

18-11. Profile Closure

a. Coastal project designs usually focus on that portion of the beach that is actively changing or fluctuating. This zone is defined by seeking to identify the opposite situation: those boundary points - landward and seaward - which appear to be stable or at least changing very infrequently. Such a point on the seaward end of a beach cross-sectional profile is often referred to as the *closure point or closure depth*. To establish an accurate assessment of an entire beach system, surveys should extend from the dune crest seaward to depth of closure, which ranges from between 5 and 18 meters depending upon location (Dally, 1993). The coastal engineering community has been criticized recently for implying that this closure point is a point of 'no change' or one at which 'nothing' ever happens. Sediment actually may be transported offshore and onshore through the closure point, and other changes may be occurring over longer periods which are too subtle to be distinguished using typical surveying techniques. Perhaps a better perspective is that some point on the profile exists at which the net change is either not measurable or is of no engineering significance.

b. In any case, it is desirable that surveys (using any technology) should extend seaward to the closure depth. The best method for determining this point is experience gained by looking at past data to assess any changes noticed. Because the bathymetry and profile shape is determined largely by the wave climate, there should be some theoretical relationship between closure depth and wave height. One such suggestion is that the limiting offshore depth can be approximated as twice the height of the extreme wave likely at the site. Obviously judgment and experience must be applied to the manner in which the wave height is estimated.

18-12. Tides and Other Water Level Changes

a. Tidal fluctuations and other water level changes are of particular interest in coastal surveying when the water surface itself is used as a measurement reference plane. The basic procedures for accounting for water level variations, using tidal benchmarks and adjusting to specific datums are familiar to most survey personnel and are extensively discussed within this manual. Only two additional points will be mentioned in this chapter: project variability and vertical changes from other sources.

b. Most tidal reference stations are located in sheltered waters, not on the open coast. It can be challenging to correlate the water level data at an interior reference station to the fluctuations at a beach location. Tidal phase and amplitude shifts are related to hydraulic distances and not necessarily geographic proximity. For example, because of complexities in bathymetry, channel characteristics and frictional effects, beaches at the opposite ends of a barrier island may have very different, even anti-correlated, water level variations when compared to the same tide station equidistant between them on the bay side of the island. Simultaneous observations at several locations in the project area (over a short time period) may be the only feasible way to assess the variability and correlate station data.

c. Other factors may affect local water levels on the open coast. One such influence is the dynamic setup caused by mass transport of water shoreward by waves after breaking. The still water setup is proportional to the wave height and can be as great as 5% of the breaker height (e.g. ~0.3 ft of super-elevation for 6-foot waves). The real difficulty with dynamic setup is that it is not uniform. No setup is present outside the surf zone (a "setdown" effect may even occur), and the setup increases inside the breaking point the closer to shore the depth is measured. It may not be practical to make sufficient simultaneous observations to correct for setup. It should, however, be recognized as a potential source of uncertainty when data are analyzed and reported.

18-13. Survey Planning Considerations

a. Planning a data collection program obviously should take place in advance of the field effort. The objective of the planning process should be to carefully think through the eventual uses for the data and the manner in which they will be analyzed, develop the equipment and procedural requirements and anticipate as thoroughly as possible what the site conditions might be and what the data should look like. However, in most cases over-planning and over-specifying the work is just as counter-productive as not planning at all. Situations will always arise in the field that require judgment and flexibility. The planning goal should be to communicate among all interests the purposes and uses for the survey and the ranges or thresholds of "typical" data, so that atypical conditions are noted and evaluated, even by further discussion while field work is in progress.

b. A survey program ideally should be developed as a team effort among the data users, a representative familiar with the available surveying technologies and procedures, and perhaps a contracting representative if work will be done by outside sources. It is extremely helpful for the team to research and have access to any existing data, past surveys or similar information about a particular site or project area. Existing or historic information is valuable in several ways. A principal use of such data is to allow for a pre-project, preliminary analysis of the area to identify any natural features, shoreline segments or coastal structures which are of particular interest or potential impact on the final project, research effort or monitoring assessment. This type of analysis may suggest areas in which the survey data, however it is collected, may need to be more densely spaced to evaluate an important feature, or can be relaxed to save time and money in more uniform, less critical sections. Another value in carefully reviewing all existing information during planning is to help estimate the likely ranges in the various coastal processes discussed previously and to assess what impact they might have on the field effort. This could include the basic approach to tide corrections, expected wave climate, influences of nearby inlets, and the offshore extent of the data (closure depth). The review can also provide a preliminary look at the existing horizontal and vertical control in the area and the need for any additional benchmarks and/or datum conversions.

18-14. Additional Considerations in Survey Planning

There may be a number of other factors that the planning team might consider along with any existing data or information about the site and personal experience in order to select appropriate surveying methods and to optimize the data collection effort. The goal is to provide the planning team with information which will allow for matching requirements to capabilities. Several of these additional planning considerations are presented in Table 18-1. The table lists a number of typical types or uses of survey data. It is recognized that in some cases surveys may be performed and the data used for more than one of these purposes over the planning and engineering design cycles of a major project. Some uses are listed twice to suggest that one type of survey may be better at the preliminary stages of a project and a different type for similar data, but at a more detailed stage of the work. Similarly, different considerations may be appropriate for a Project Feasibility study if the *principal* design approach will be based on historic conditions, or if it will be based on extensive numerical modeling.

Table 18-1. Considerations Affecting Coastal Surveys

Purpose or Type of Survey	Accuracy Requirements (Table 3-1) Nav	General	Data Collection Patterns Pnt	Lin	Spat	Process Time Scales Hour Days	Month Season	Annual Years	Responsibility In-Hse	A-E Cont	Const Cont	Data Processing Requirements Low	Avg	Advan
Dredge/Disposal posit monitoring		X	X	X		X			X		X	X		
Post-storm damage assessment		X		X		X			X	X			X	
Nav Proj Cond	X			X	X			X	X	X			X	X
Beach fill project monitoring	X			X			X	X	X	X	X		X	X
Borrow area feasibility	X				X			X	X	X			X	X
Shore/inlet evaluation		X		X	X	X	X		X	X			X	X
Dredged mat'l movement	X				X		X	X	X	X	X		X	
Coastal proj plan feasibility historic		X		X	X		X	X	X	X			X	
Coastal proj plan feasibility modeling		X			X		X	X	X	X			X	X
Borrow area detailed investigation	X			X	X		X		X	X			X	X
Plans & Specs	X		X					X	X	X			X	X
Pre-post project pay quantities	X		X				X	X	X	X	X	X	X	
Final as-builts	X			X	X		X				X		X	

The following are brief explanations of the fields in Table 18-1:

a. Accuracy Requirements. Accuracy requirements for coastal engineering surveys fall under the special survey category listed in Table 3-1. Thus, accuracy standards in Table 3-1 are not mandatory but are recommended.

b. Data Collection Patterns. "Point" (Pnt) is intended to suggest that one or a very few individual data points are used to describe or characterize a feature. In the case of detailed borrow area investigations or plans and specifications, it is understood that many such points may be collected, but each soil boring, each break in elevation on a design template, etc., is represented as a "point." "Linear" (Lin) data are the typical profiles, cross-sections and similar lines of data which also certainly are comprised of individual points, but which are usually analyzed and used as a group or whole. "Spatial" (Spa) refers to data collected and analyzed in a more three-dimensional manner.

c. Process Time Scales. These time frames are rough approximations of the periods over which significant changes might occur in the coastal processes primarily affecting each type of project. For example, a post-storm assessment of beach conditions ideally should be performed within days of the storm, or else natural recovery processes will have begun to mask the effects of the storm at the site. Significant changes in an inlet shoal can occur in a period of days to months and, therefore, data collection should not take longer than that time or results will not be synoptic *for that type of feature.* Some types of data collection may be affected by more than one time scale depending on specific site conditions and project goals.

d. Responsibility. This consideration addresses both the availability of specific technologies in a district office versus those available by contract, and the degree of supervisory control necessary and desirable for certain types of surveys.

e. Data Processing Requirements. Some of the newer surveying technologies require substantially greater post-processing than more conventional methods. This means that, if the computing and storage capability is not available in-house, either it will have to be a part of the contracted work or such technologies should not be specified. "Average" implies typical 486DX or Pentium processor-based personal computers, while "advanced" might be networked workstations on a mini computing system. The point is simply that post-processing, including editing, calculations, printing and storage should be considered as part of the pre-project planning.

In summary, the recommended approach is that a team-based planning process take place prior to specifying a survey method or field procedure. That planning process should begin with a preliminary characterization of the coastal environment at the project site, and proceed by using a decision-guiding matrix such as Table 18-1, or other local adaptation, in combination with the technical information on various technologies presented below in order to better define and match the requirements to the capability.

18-15. Overview of Surveying Methods

a. There will always be a need for accurate beach and nearshore survey data. However, several surveying technologies are available for collecting survey data in these zones with each method having its advantages and disadvantages for specific applications and requirements. However, it is essential that survey specifications originate from the project's functional requirements and that the requirements are realistic and economically attained. This section presents the most commonly used technologies in performing beach and nearshore surveys and summarizes their performance capabilities and limitations. The information presented here is intended to provide engineers and scientists with the essential knowledge to select the appropriate survey technology in order to meet project requirements.

b. Several survey technologies are available that may meet the requirements for specific projects. These technologies range from basic rod and transit methods to complex airborne platforms. Some methods directly measure topographic elevations through direct contact with the surface being surveyed, while others remotely measure water depth and must be corrected for water surface conditions such as waves and tides. Each method has its own inherent performance specifications, operational limitations, cost of operation, and special considerations. The type of technology selected to survey a project will largely depend upon a combination of requirements related to data end use accuracies, spatial data density, and survey budget.

18-16. Technology

Included in the following sections is a summary of the most commonly used techniques for performing beach and nearshore surveys as well as some of the more recently developed high technology methods that are now available for collecting this type of data. Technologies addressed in this section include conventional rod and transit, survey sleds, acoustics, airborne LIDAR, GPS, and jet ski boats.

18-17. Rod and Transit

a. Description. The rod and transit (Figure 18-5) is among the most traditional and very adequate methods used in performing beach surveys. It is capable of providing highly accurate survey data. A level (or transit) and survey rod is used to directly measure surface elevation while a distance measurement is obtained using a tape or stadia producing a set of distance-elevation points along selected shore-normal lines at a specific range. Points are measured at regular intervals or in some cases only where there is a break in elevation. This method is typically used to collect two-dimensional cross shore profiles spaced about 30 - 300 meters (300 - 1000 feet) apart that originate from the dune or backshore extending seaward to wading depth. Data collection does not have to be restricted to cross shore applications. The technique can be used to establish longitudinal shoreline or dune crest positions relative to a vertical datum such as NGVD, MHW, MLW, etc.

b. Surveying using the rod and transit relies on a person traversing the survey line with a survey rod and stopping at regular intervals while another team member reads and records the elevation data. The rod holder progresses seaward until waves and water depth prevent the rod from being held steady. For this reason, it is desirable to conduct this type of survey during low tide so that the profile extends as far seaward as possible. When collecting longshore measurements, data can be collected until the rod becomes too far away to obtain clear readings. Errors associated with this method typically occur as a result of human error such as incorrect stadia readings, improper instrument leveling, or inability to steady the survey rod.

Figure 18-5. Rod and transit beach surveying provides accurate beach profiles to wading depth along widely spaced range lines

c. Combining the use of more sophisticated equipment such as an electronic total station (ETS) can automate the process and improve positioning accuracy (Dally, 1993). This method combines a distance meter with an electronic theodolite to measure distance and horizontal and vertical angles from reflective prisms on a staff. A data reader can be added to automatically record data. Data collected in this manner can be easily downloaded to a PC computer for required processing.

Performance Characteristics:

vertical accuracy:	+/-1 cm to +/- 10 cm
horizontal accuracy:	3 meters RMS
spatial resolution:	typically shore-normal lines 300 m (1000 ft) apart
positioning system:	ranging/ETS relative to established benchmarks
minimum crew:	2
cost:	about $1000/Km ($1600/mile) of beach assuming 300-m profile spacing

d. Surveys performed using this method provide a fast and cost effective means of collecting beach data to represent general coastal trends. Inherent limitations exist with these surveying methods in that they may not produce adequate spatial resolution potentially missing information which may lead to a misinterpretation of coastal conditions. The wading portion of the survey is typically limited to calm conditions where breaker heights are less than 1 m. As the rod-man enters the surf zone, vertical accuracy quickly deteriorates (Dally, 1993). In circumstances where surveys extending beyond wading depth are required, other methods and technologies should be considered.

e. A variation of the fixed rod survey method is the Coastal Amphibious Research Buggy (CRAB) used by the US Army Coastal Engineering Research Center (Coastal and Hydraulics Laboratory) at its field research facility in Duck, NC. The CRAB is shown in Figure 18-6.

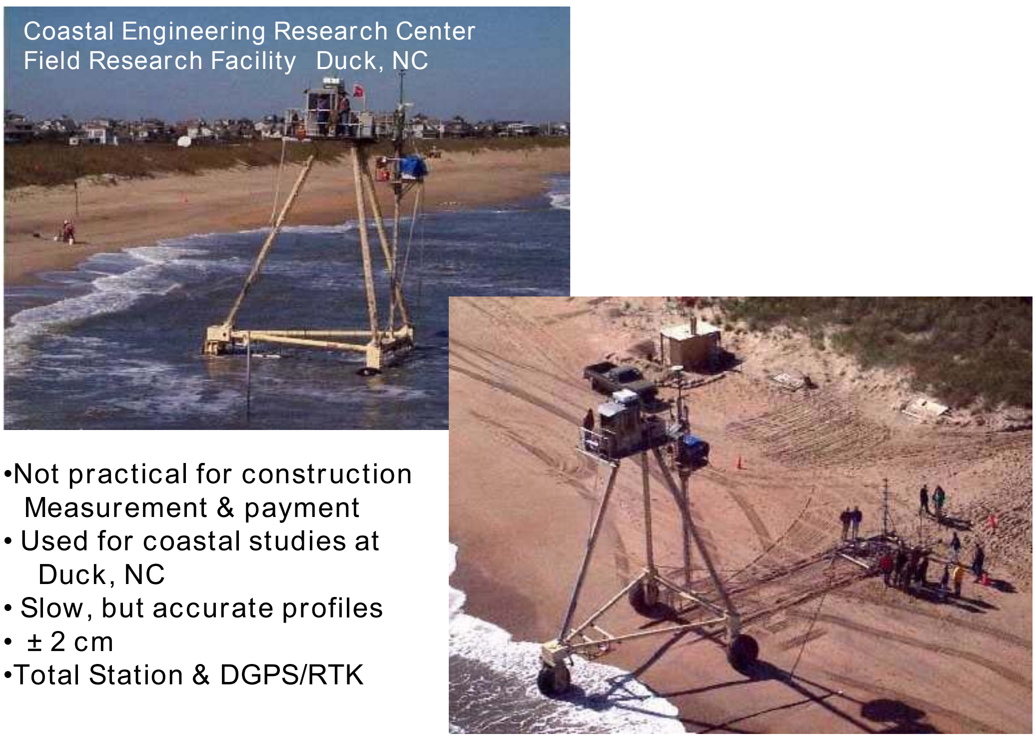


Figure 18-6. CRAB. Hydrographic survey platform used for research purposes by the Coastal Engineering Research Center (Duck, NC)

18-18. Survey Sled

a. Description. Sled survey systems were developed to collect continuous survey data from the dry beach, through the surf zone, and into the nearshore (Langley, 1992). As with the rod and transit method, sled surveys provide direct elevation measurements. The system consists of a mast 10 to 11 meters tall with a cluster of reflective prisms at the top--see Figure 18-7. The mast is mounted to an aluminum frame sled. The sled and mast can be pulled along predetermined lines across the beach and into the nearshore by a vessel as small as an inflatable boat to a maximum depth of about 10 meters (Miller, 1991). A land vehicle may be necessary for pulling the sled onto the beach from the water. As the sled is being towed, an electronic instrument such as an ETS or geodimeter (Lee and Birkemeier,

1993) automatically tracks the prisms on top of the mast and records the horizontal and vertical positions at regular time intervals. Horizontal and vertical control are typically taken from existing benchmarks. This method provides a fast, portable, and economic means of collecting complete profile surveys. As with the rod and transit method, sled surveys provide a shore normal profile typically spaced at about 30 - 300 meters. Line spacings can be adjusted closer or farther apart depending on project data density requirements. However, as line spacing decreases, the total survey time and associated costs increase. Approximately 25 - 30 minutes are required to sample along a 300-m profile (Birkemeier, 1994).

b. Performance Characteristics. (Clausner et al., 1986) (Howd and Birkemeier, 1987)

vertical accuracy:	+/- 3 cm
horizontal accuracy:	3 meters RMS
spatial resolution:	typically shore-normal lines 30 - 300 m apart
positioning system:	ETS/Geodimeter relative to established benchmarks
minimum crew:	2-3
cost:	approx. $4500/Km ($7500/mile) of beach assuming 300-m profile spacing. Additional costs may be required for mobilization and/or data processing)

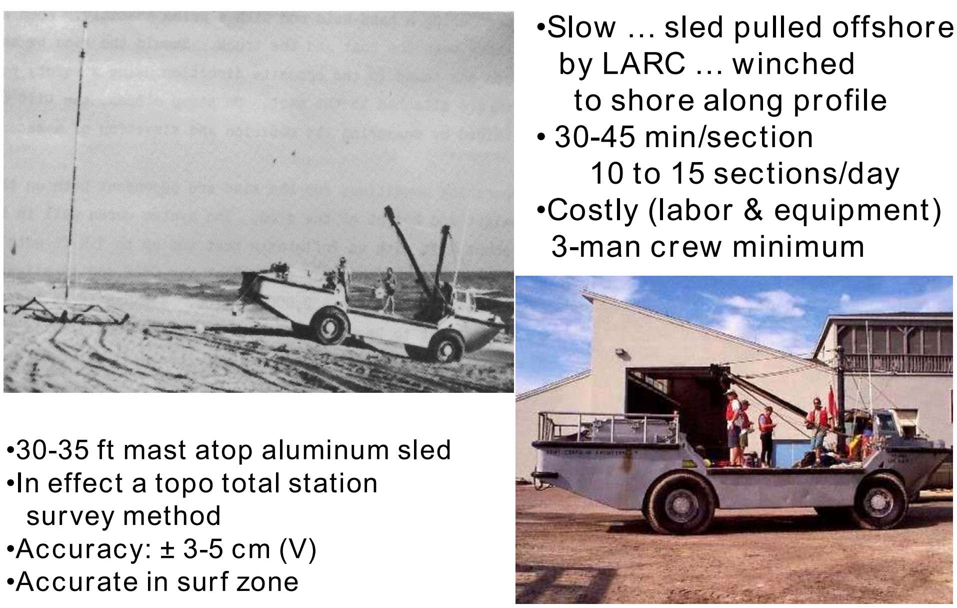


Figure 18-7. Sled profiling system--LARC with towed sled. Used to collect profile data through the surf zone and into the nearshore areas

c. Other Considerations. For projects that do not require a high degree of spatial resolution, sled survey methods provide a portable, low cost means of acquiring accurate beach and nearshore survey data, including the surf zone. Sled surveys are often supplemented with traditional rod-based methods to capture the dune and back-shore areas. As with the rod and transit method, survey sleds may not produce adequate spatial resolution, which may introduce error during data interpretation or when conducting volumetric calculations. Survey sleds do not perform well on irregular bottoms or areas where rock or reef outcroppings are prominent. Such conditions can cause the sled to tip over or become snagged. Surveys can be conducted using this method in areas where the beach is easily accessible. Sleds have been shown to be stable in breaking waves up to 5 m (Sallenger et al., 1983), however, these instruments are typically towed by boat in the nearshore and should, therefore, be restricted to breaking waves one meter or less (Dally, 1993).

18-19. Single Beam Fathometer

a. Description. Single beam fathometer systems or echo sounders utilize sonar to acquire depths by measuring the time of travel of an acoustic pulse or ping between a transducer and the sea bottom. Single beam fathometers are commonly used to survey the offshore portion of coastal projects in conjunction with beach profiles collected out to wading depth with attempts to overlap the two data sets. The extent of overlap and survey accuracy are highly dependent on the amount of wave action at the time of the survey. Fathometer soundings are a measure of water depth. Therefore, actions must be taken to correct for water level variations such as tides and waves, making it necessary to collect water level information at the time of the survey (Clausner et al.). Accounting for water level fluctuations in the coastal zone is difficult and may have an effect on vertical accuracy. Motion compensation sensors can be utilized to isolate and remove some fluctuations due to vessel motion resulting from wave action (Dally, 1993). Horizontal accuracies are highly dependent upon the type of positioning system used.

b. Characteristics. This technology has undergone major advances in recent years with the advent of sophisticated GPS technology, motion compensation sensors, and computerized data processing. Highly accurate three-dimensional positioning technology may eliminate the need for water level corrections.

Performance Characteristics.

vertical accuracy:	+/- 30 cm (1 foot)
horizontal accuracy:	3 m RMS
spatial density:	30 - 300 m (nominal)
platform:	small boat
positioning system:	variable - ranging, Loran, GPS
minimum crew:	2-3 (assuming a support person onshore)
cost:	approx. $1000/Km ($1600/mi) of offshore portion of profile.

c. Other Considerations. Single beam fathometer systems provide a fast, cost effective method of extending beach surveys into the nearshore areas. The effects of wave motion may be difficult to remove which may drastically decrease vertical accuracy . In most cases, overlapping the wading beach profiles with the fathometer portion of the survey is difficult and may lead to large gaps in the data. For this reason, it is best to conduct the wading profile at low tide and the fathometer portion at high tide (Clausner et al.). Coordinating the survey times as such will maximize the opportunity for data overlap. Even when an overlap is achieved, water level fluctuations and platform motion may lead to closure problems.

18-20. Multibeam System

a. Description. In recent years there have been major advances in sonar technology for scanning pulse-based acoustic sensors that can be applied to coastal areas. Expanding upon single beam technology, multibeam systems use multiple frequencies and receiving channels to collect soundings over a swath that can be four times as wide as the water depth. Echosounders used with this type of technology are capable of utilizing 60 (+ or -) beams covering large corridors with each pass and literally providing 100% bottom coverage. Systems utilizing this technology are restricted to the offshore portions of the coastal zone. Used in conjunction with sophisticated positioning systems they can provide an effective means of improving vertical and horizontal accuracies for collecting high resolution bathymetry. Minimum depths are dependent upon the size of the platform used. In addition to the collection of nearshore bathymetry, some systems have the capability to laterally direct the echosounding beam for surveying submerged coastal structures such as jetties, breakwaters, or groins. Related advances in motion compensation sensor technology have further added to the suitability of this method for use in the coastal environment.

b. Performance Characteristics.

vertical accuracy:	+/- 15 cm
horizontal accuracy:	2 m RMS
minimum depth:	platform dependent
spatial density:	up to 100%
operating speed:	platform dependent
platform:	boat
positioning system:	GPS
minimum crew:	3
cost:	approx. $2000/Km (3,250/mi) full bottom coverage of offshore portion of beach.

c. Other Considerations. Because multibeam technology requires a boat platform, it is not suitable for extreme shallow water applications and is subject to the same shortcomings as single beam systems when used to supplement rod surveys. The shallower the water, the narrower the bottom coverage. Due to the multiple channel characteristics and to provide the spatial coverage, this technology generates high volume data sets. Data users should be prepared to handle large volume data sets or to account for data processing in the survey budget.

18-21. Airborne LIDAR Bathymetry

a. Description. A state-of-the-art LIDAR system coupled with high precision GPS positioning is an emerging technology that can be utilized for conducting both hydrographic and topographic beach surveys. The term LIDAR stands for <u>LI</u>ght <u>D</u>etection <u>A</u>nd <u>R</u>anging. The SHOALS system operates by emitting laser pulses from an airborne platform that travel to the water surface. For each laser pulse, some of the light is reflected back from the surface to onboard receivers. The remaining energy propagates through the water column, reflects off the sea bottom, and returns to the airborne sensor. The time difference between the surface light return and the bottom return corresponds to water depth (Guenther et al. 1996). The maximum depth detection is limited predominately by water turbidity. As a rule-of-thumb, the system is capable of sensing depths equal to two or three times the visible depth (Estep et al, 1994). The laser is scanned in a 180^0 arc across the flight path of the helicopter producing a swath width approximately one half the surveying altitude. At a speed of 60 knots and an altitude of 200 meters, the system can provide a survey coverage of 16 km^2/hr. (Lillycrop et al, 1996). Sounding densities can be adjusted by flying higher or lower at different speeds or by selecting multiple scan widths. With the ability to collect both topographic and hydrographic survey data this method can simultaneously conduct complete beach and structure surveys above and below the waterline and could be particularly useful in areas where human access is difficult or restricted. The technology is a useful tool for post-storm erosion assessments. Data acquired using this type of technology can be used to generate vertical profiles, cross sections, contours, and volumetric analysis..

b. Performance Characteristics. (Lillycrop et al. 1996)

vertical accuracy:	+/- 15 cm)one-sigma)
horizontal accuracy:	3 m RMS (one sigma)
spatial density:	4 meter grid (nominal)
coverage:	9 km^2/hr (nominal)
	60 knots (nominal operating speed)
	200 Hz data acquisition rate
platform:	Bell 212 helicopter
positioning system:	GPS
minimum crew	5
cost:	approx. $1800/Km (3000/mile of beach.

c. Other Considerations. This technology is capable of rapidly collecting dense survey data over large areas in a short amount of time. However, the technology is highly dependent on water clarity and should not be considered for areas with chronic high turbidity. Costs pertaining to system mobilization can be high and may be a limiting factor when considered for surveying small projects. It is beneficial to schedule surveys along with other projects in the same general vicinity to share and minimize mobilization costs. Users of LIDAR survey data should possess data processing equipment and software capable of handling large data sets.

18-22. Airborne LIDAR Topography

a. Description. Other airborne LIDAR systems are available that are used exclusively for topographic applications. The system shown here (Figure 18-8) operates at 6000 Hz, flies at a speed of 30 knots, and collects data over a wide swath. Its state-of-the art kinematic OTF (On-the-Fly) satellite positioning system allows for highly accurate three-dimensional geographic positioning. The system is small, cheap to operate, and produces high resolution survey data for use in various mapping applications. Although not yet widely used in coastal areas, this type of technology could be useful for surveying subaerial beaches, dunes, and the above water portions of coastal structures. As with other airborne sensors, this technology could be useful where direct access is difficult or restricted. The technology could prove useful for above- water storm damage assessments. Data acquired using this technology can be used to generate vertical profiles, cross sections, contours, and volumetric analyses.

Figure 18-8. Airborne LIDAR topographic survey system. Used exclusively for topographic applications. The system shown here called FLI-MAP was developed by John E. Chance & Assoc.

b. Performance Characteristics.

vertical accuracy:	+/- 5 cm
horizontal accuracy:	10 cm RMS
spatial density:	0.5 m grid spacing
coverage rate:	approx. 5 km^2/hour 30 knots (nominal) operating speed 6000 Hz data acquisition rate
platform:	small helicopter or fixed wing aircraft
positioning system:	GPS
minimum crew:	2 (pilot and operator)
cost:	approx. $1200/km ($2000/mi) of dry beach. May have associated data processing costs.

c. Other Considerations. This technology can only be used for topographic surveying. This instrument detects whatever is on or covering the ground. Care must taken when collecting data near vegetation or other ground cover to assure that the data collected is what the user intends to survey. If hydrographic survey data are also required, this technology must be used in conjunction with other technologies. A high resolution system such as this generates extremely large data sets. Data users should possess resources capable of handling large data files or be prepared to budget for data processing costs.

18-23. GPS Total Station Backpack

a. Description. Another alternative for the collection of detailed topographic information is through the use of a GPS total station (receiver and antenna) contained in a backpack and staff or mounted on a motorized vehicle such as an ATV. Differential GPS positioning (DGPS) for improved accuracy levels is possible but would require establishing a base station. This type of configuration permits rapid detailed digital elevation data to be collected on a continuous basis by walking or driving over the project survey area (Solomon, 1996). Sample rates for collecting real time positions are 0.5 - 1 second. For normal walking rates this translates to readings roughly every meter (3 feet) (Solomon, 1996). Sampling intervals using a motorized vehicle would be greater depending upon the survey speed. Conventional profiling methods (rod and transit or sled) involve re-occupying a series of profiles marked by benchmarks, stakes, rebar, etc. Unfortunately, such benchmarks are frequently removed, buried, or obscured in some manner by natural processes or human activity. The GPS technique allows reestablishment of profile lines without multiple benchmarks as long as a single base station point is well known. This capability can be extremely beneficial when surveying in areas where control data are deficient or absent such as in remote areas or in areas of severe storm damage. This system can also be useful for rapidly and cheaply mapping reference contours such as high water lines, back beach and dune lines, etc.

b. Performance Characteristics.

vertical accuracy:	15 cm or less (depending on GPS receiver)
horizontal accuracy:	5 - 10 m
data acquisition rate:	0.5 - 1.0 sec sampling rate
spatial density:	1.0 m spacing depending upon operating speed
operating speed:	variable
platform:	backpack or suitable motorized vehicle (ATV)
positioning system:	GPS/DGPS
minimum crew:	2
cost:	about $1200/Km ($2000/mile) of beach assuming 300-m spacing. May require some processing costs.

c. Other Considerations. This method would be suitable only for conducting beach surveys extending to the low tide line or out to wading depth maximum. If hydrographic survey data are required through the surf zone and nearshore, this type of technology must be used in conjunction with other survey methods. As with any technology involving GPS positioning, problems may be encountered with unfavorable satellite configurations which may degrade positioning accuracies. In such instances, survey work should be coordinated during times of optimal satellite configurations. Most GPS systems provide software to facilitate this process (Solomon, 1996).

18-24. Jet Ski Beach Surveys

Jet ski boats have recently been adapted to performing surveys in surf zones (Figure 18-9). They have proven more effective than conventional skiffs in running with wave troughs into shallow beach areas. When equipped with RTK DGPS and inertial roll-pitch-heave sensors, date quality is maintained in the difficult surf zone. These survey techniques have applications in other difficult or inaccessible survey areas, such as near power plants, ponds, and in wetlands. A Yamaha Wave Runner system owned by

Brunswick Surveying (Supply, NC)--Personal Watercraft Surveying System (PWSS)--includes an Innerspace 455 Survey Depth Sounder, Innerspace 453A RF modems, Innerspace 603 Remote Indicator and Innerspace Datalog with Guidance Software (DLWG). The GPS used in Brunswick's PWSS is an Ashtech GG24 RTK system. Position accuracy can be either sub-meter DGPS or a few centimeters RTK. Depth resolution is 0.1 foot or 1 cm as selected by the operator. A special multiplexer was developed, the Innerspace 905, to synchronize the depth and RTK position data at 1PPS available in the GPS receiver. A bi-directional voice radio system is also included. The balance of the equipment includes: system batteries for power & associated charger and wiring junction box. All the equipment is mounted out-of-sight, in closed compartments, except for the 603 which provides guidance for the operator and the GPS and RF antennas and depth sounder transducer. The instrumentation is all mounted with quick release mechanisms to facilitate easy removal so the equipment may be used on projects where the personal watercraft is not applicable. The Innerspace 455 Survey Depth sounder is mounted under the rear seat. The Innerspace 603 Remote Indicator is mounted above the steering bars in full view of the operator. The GPS antennas and three separate RF systems antennas are located about the craft and the depth sounder "kickup" transducer is transom mounted. The watercraft's electronics systems are powered from a separate battery/charger installation located under the 455 sounder in the rear compartment. The watercraft's engine/starter power system is not used for the electronics except to power the battery charger that charges the separate battery that powers the electronic systems.

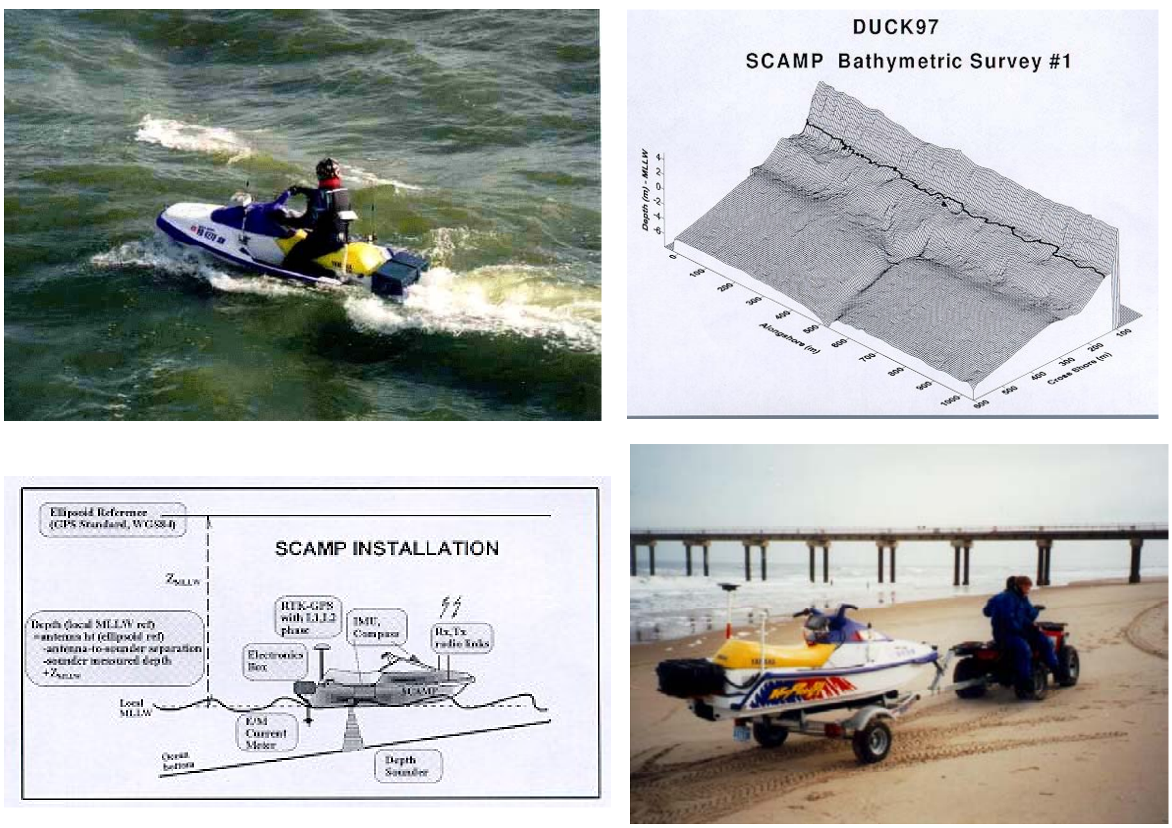


Figure 18-9. Yamaha Wave Runner equipped with hydrographic survey equipment (SCAMP at Duck, NC)

18-25. Offshore Jetty, Breakwater, and Groin Surveys

Surveys for these structures are performed for design, construction, and maintenance. Typically, a baseline is established atop the centerline of the structure (if above water), and cross sections are run (by tag line or total station EDM normal to the structure every 50 or 100 ft O/C, extending past the toe of the foundation stone (Figure 18-10). Depths are measured by lead line, level rod, or sounding pole at a relatively dense interval. Echo sounding (vertical beam or multibeam) may be used if return signals are adequate. During stone placement submerged areas may be surveyed using standard hydrographic echo sounding methods. Condition survey of offshore breakwaters or jetties are performed using a variety of techniques, depending if the structure can be occupied or if portions are below water. Multibeam systems may be pointed horizontally to assess underwater conditions of the armor or foundation stone. On inaccessible or broken breakwaters, airborne topographic LIDAR surveys can be flown to map the rock placement and voids above the surface--see Figure 18-11. The LIDAR topography and multibeam hydrography models may then be merged in order to evaluate the overall condition of the structure and estimate repair quantities needed.

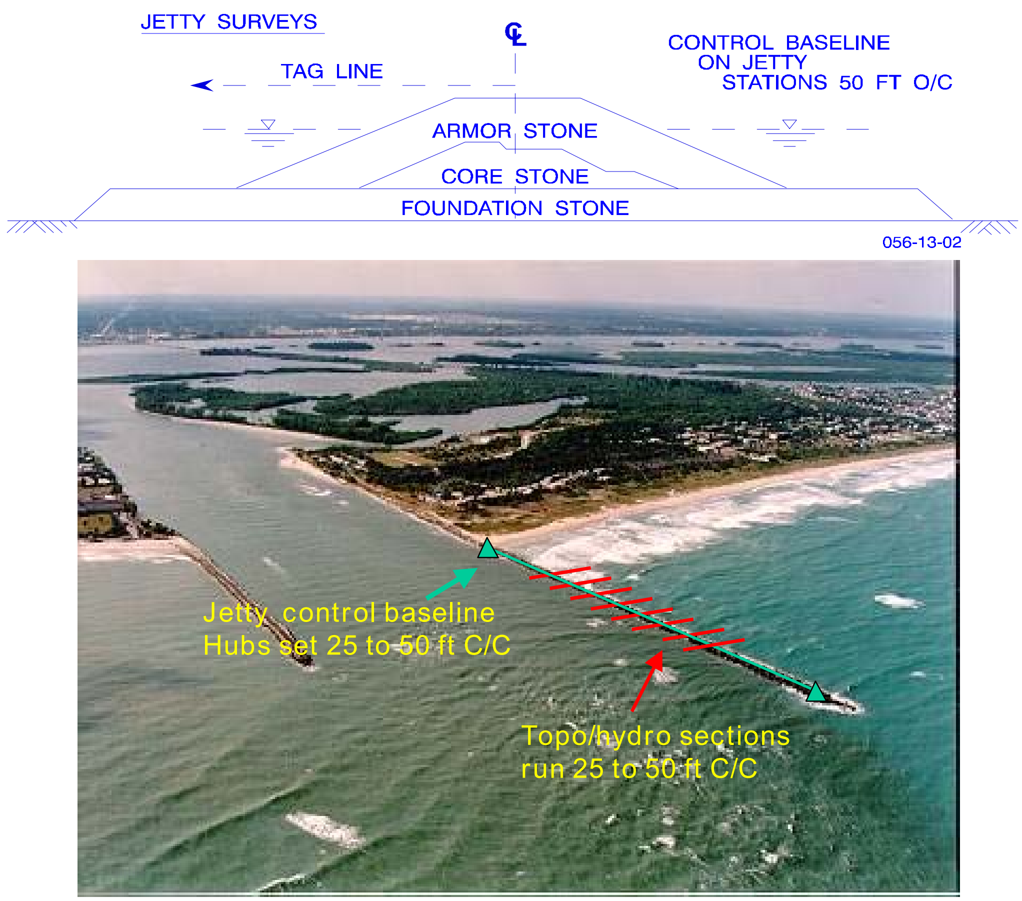


Figure 18-10. Jetty and breakwater surveys

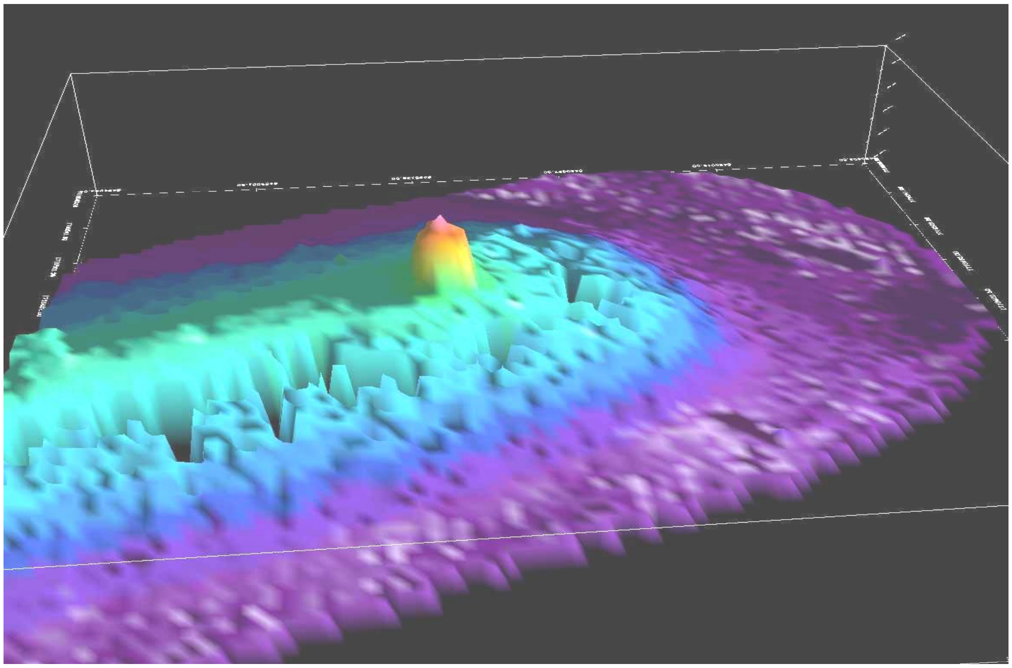


Figure 18-11. Combined LIDAR topographic and multibeam hydrographic surveys of San Pedro Breakwater, Los Angles District (JE Chance & Assoc.)

18-26. Probings

Hydrographic survey crews are occasionally tasked to obtain either dry rod or washed offshore probings, often over potential sand sources for proposed beach renourishment projects. When such geotechnical data are intended for use in contract plans and specifications, DGPS survey positional accuracy is required for the probe location and offshore elevation reductions. Sample field notes are shown in Figure 18-12.

STA	+ROD	H.I.	-ROD	SDG.	PROBE
BM-1					
	5.15	35.20			
10+00			5.6		
					0
					12.2
12+00			6.6		
					0
					14.2
			9.2		
13+50				5.0	
					0
					5.0
					16.0+
BM-2			5.05		

NOTE: THE FIELD NOTES WILL SHOW IF DRY ROD OR PUMP USED FOR PROBINGS. IF PUMP USED SEE CRITERIA FOR DRIVE BORINGS AND PROBINGS WHICH WILL BE FURNISHED WITH REQUEST FOR SURVEY.

ELEV	REMARKS: 10 MAY 70
30.05	
29.6	TOP GROUND
29.6	TOP GROUND
17.4	TOP HARD MATERIAL, UNABLE
	TO PENETRATE
28.6	TOP GROUND
28.6	TOP GROUND
14.4	TOP ROCK
26.0	WATER SURFACE OF CANAL
21.0	TOP WATER
26.0	BOTTOM CANAL
21.0	BOTTOM CANAL
10.0	REQUIRED PROBING
30.15	PUB. ELEV = 30.13

Figure 18-12. Probing field notes

18-27. Sub-bottom Profiling by Seismic Reflection Methods

Seismic reflection systems operating between 400 Hz and 14.0 kHz are useful for continuous high-resolution profile recordings of the top 30 m of material below the sea floor. The high-energy signal will penetrate and reflect from interfaces between nonhomogeneous materials. The receiving package will detect the reflected signals and convert them into a profile recording. The display is real time with relatively high ship speeds of 10 to 12 knots. Typical resolution is 0.5 m. When properly calibrated, the systems can also be used for obtaining bathymetric profiles. Depth of sub-bottom penetration varies inversely with frequency. Sub-bottom depths over 200 ft have been recorded.

a. Sub-bottom reflection data have been very useful in numerous investigations in which information pertaining to the sub-bottom strata is important. These include predredging investigations, pipeline route locations, and offshore foundation investigations.

b. In operation, an instrument package is towed which contains both transducer and receiver. Outputs can be either analog strip charts or in digital form, which facilitates post-survey processing that enhances resolution. Other systems rely on ship-mounted transducer/receivers. For these, resolution can be reduced by ship heave, but accelerometer packages are available to measure heave for correction purposes.

18-28. Sub-bottom Profiling by Ground Penetrating Radar (GPR)

Recent experience with GPR indicates that under some conditions this technique can provide sub-bottom information. Radar designed to obtain subsurface information usually operate at frequencies between 20 and 500 MHz. To best resolve echoes from subsurface interfaces, broadband antennas are used to radiate a very short duration pulse. Low-frequency (20-100 MHz) antennas with high radiated power (0.5-2 kW) provide the greatest penetration and in most situations would be best suited for sub-bottom profiling. The depth that radar can penetrate is strongly limited by attenuation in the water and bed material, with greatest signal loss in electrically conductive water and sediment. High attenuation limits the use of this technique, making it best suited for surveys in low-conductivity fresh-water lakes and streams. On-site conductivity measurements should be taken before using radar equipment. These measurements will estimate the radar penetration. The radar frequency used will also be a trade-off between resolution and penetration. Plots of amplitude versus time for the returning pulses are usually compiled into a graphic display, producing an apparent profile of subsurface reflectors and interfaces. When the electrical properties (dielectric permitivity) of a layer are known, propagation time to the base of the layer can be converted to layer thickness, with resolution of about 0.5 m. More information on GPR techniques may be obtained from the US Army Cold Regions Research and Engineering Laboratory (CRREL).

18-29. Offshore Disposal or Borrow Area Surveys

Disposal areas (Figure 18-13) are frequently surveyed during planning, design, construction, and maintenance phases of a project. The most frequent surveys are conducted during dredging operations and for subsequent general condition purposes. The purposes of these surveys are varied. Normally, offshore submergent disposal areas are periodically surveyed to monitor material placement grade during construction--to ensure minimum depths are not exceeded. Surveys are also performed to locate any misplacement of dredged material outside the disposal area limits. Subsequent surveys may be required to monitor settlement or material movement. Offshore borrow area surveys are similar; however they are used to monitor the amount of material removed from the site--usually a sand source for renourishment projects. Emergent disposal areas in offshore locations and upland confined disposal areas are periodically surveyed during construction and later to monitor settlement and available quantities for additional placement.

a. Submergent disposal and borrow areas are typically cross-sectioned at 100- to 200-ft spacing. Survey lines are run 200- to 1,000-ft outside the disposal area limits to monitor for any misplaced material. Material quantities can be computed using either average-end-area or grid methods.

b. In the past, single, vertical beam echo sounders were used for disposal area surveys. For deep water disposal areas, multibeam survey systems are now recommended. Multibeam systems can be set at maximum beam width to obtain maximum swath widths of coverage.

c. During construction, offshore disposal areas may be surveyed weekly or biweekly. Subsequent monitoring surveys are performed at quarterly or annual intervals, depending on any environmental requirements/restrictions that may have been imposed on the use of the area.

d. Upland disposal areas are surveyed using standard topographic techniques. Fixed baselines are established along the top of the confining dikes and standard cross-sections are run internally within the disposal area and externally into the water. Total station or DGPS RTK survey methods may be employed. In cases where the confined material has not settled, a small skiff may be needed to obtain measurements. Extreme caution should be exercised when spoil material has only crusted on the top--the rodman should use a life jacket and/or lifeline should there be a danger of breaking through to water-suspended material. A sounding pole with a bottom plate may be needed in soft material.

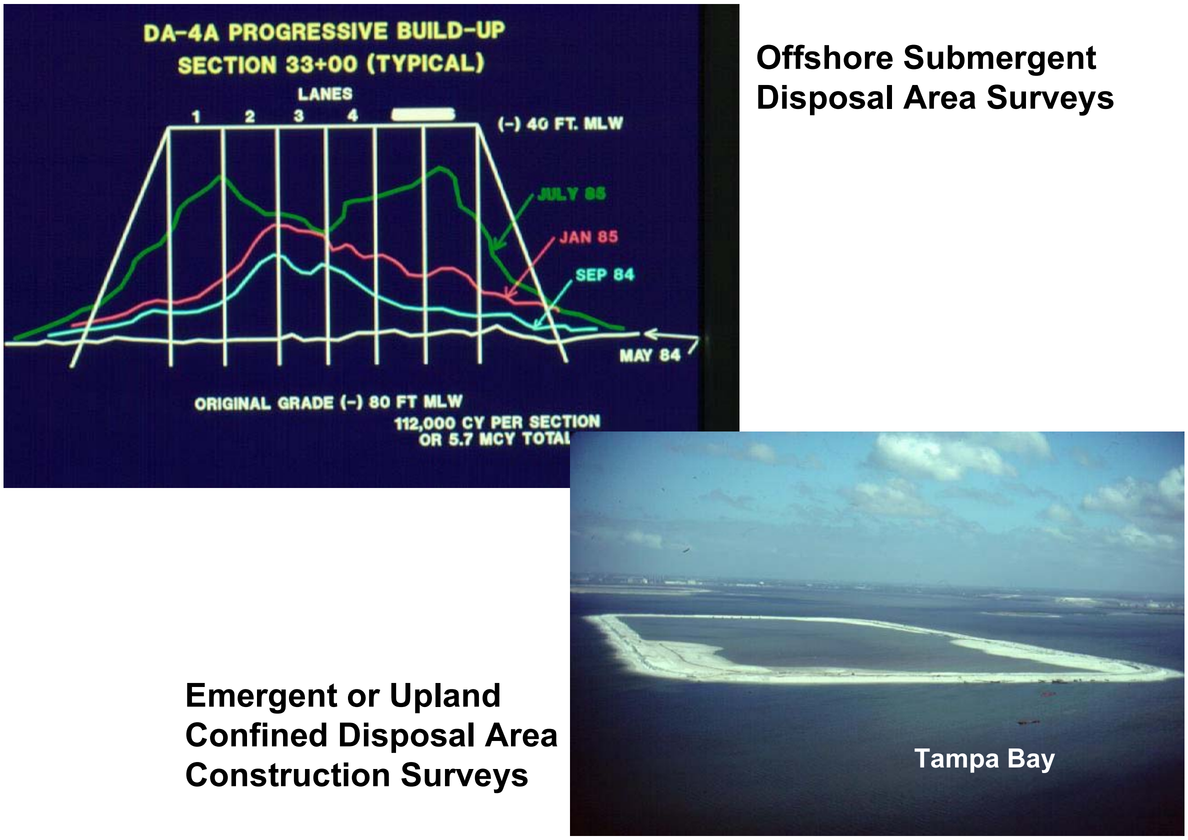


Figure 18-13. Submergent and confined disposal area surveys (Jacksonville District)

18-30. References

Birkemeier, W.A. 1994
"Topographic methods," Coastal Engineer Field Methods Prospect Course Notebook, Coastal Engineering Research Center - Field Research Facility, Duck, North Carolina.

Clausner, J.E., Birkemeier, W.A., and Clark, G.R. 1986
"Field comparisons of four nearshore survey systems," Miscellaneous Paper CERC-86-6, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Dally, W.R. 1993
"An overview of coastal surveying technology documenting beach-inlet interaction," *Journal of Coastal Research*, Special Issue No. 18, pp. 291-300.

Estep, L.L., Lillycrop, W.J., and Parson, L.E. 1994
"Estimation of maximum depth of penetration of a bathymetric LIDAR system using a Secchi disk database," *Marine Technology Society Journal*, Vol. 28, No. 2, pp. 31-36.

Guenther, G.C., Thomas, R.W.L., LaRocque, P.E. 1996
"Design considerations for achieving high accuracy with the SHOALS bathymetric LIDAR system," *Laser Remote Sensing of Natural Waters: From Theory to Practice, Selected Papers*, The International Society for Optical Engineering, Vol. 2964, pp. 54-71.

Howd, P.A. and Birkemeier W.A. 1987
"Beach and nearshore survey data: 1981-1984 CERC Field Research Facility," Technical Report CERC-87-9, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Langley, T.B. 1992
"Sea sled surveying through the surf zone," *Shore and Beach*, Vol. 60, No. 2, pp. 16-19.

Lee, G. and Birkemeier, W.A. 1993
"Beach and nearshore survey data: 1985-1991 CERC Field Research Facility," Technical Report CERC-93-3, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Lillycrop, W.J., Parson, L.E., and Irish, J.L. 1996
"Development and Operation of the SHOALS airborne LIDAR hydrographic survey system," *Laser Remote Sensing of Natural Waters: From Theory to Practice, Selected Papers*, The International Society for Optical Engineering, Vol. 2964, pp. 26-37.

Miller, H.C. 1991
"A topographic survey system for the surf and nearshore," *Proceedings, US Army Corps of Engineers 1991 Surveying Conference*, US Army Engineer Topographic Laboratories, Fort Belvoir, VA.

Sallenger, A.H., Howard, P.C, Fletcher, C.H. III, and Howd, P.A. 1983
"A system for measuring bottom profile, waves, and currents in the high-energy nearshore environment," *Marine Geology,* Vol. 51, pp. 63-76.

Solomon, S. 1996
"Applications of precise differential global positioning systems (PDGPS) to beach morphodynamics research," Geologic Survey of Canada (Atlantic), Dartmouth, Nova Scotia.

USACE 1984
Shore Protection Manual. 4th Ed. Vol 2, US Army Engineer Waterways Experiment Station, Government Printing Office, Washington, DC.

Note that USACE Engineer Manuals referenced in this chapter are listed in Appendix A.

18-31. Mandatory Requirements

There are no mandatory requirements in this chapter.

Chapter 19
Electronic Charts of Inland and Coastal Navigation Systems

19-1. Purpose

A USACE Master Plan is currently under development for production and dissemination of electronic chart data that will primarily benefit navigation on US waterways. Such data will follow the international S-57 hydrographic data exchange standard, and will be implemented in two parts: inland waterways and coastal/Great Lakes areas. Production and dissemination of such data products will benefit safety of navigation, aid in industry training of vessel operators, enable more efficient use of waterways and navigation infrastructure, foster better coordination among USACE, NOAA and USCG, and reduce time spent by districts assisting users of USACE charts. Development of the Master Plan and implementation Corps-wide is expected to occur over five to six years, and will begin with pilot projects to convert existing hydrographic data into S-57 format. Currently, districts can begin structuring and disseminating data to navigation users in ways that will ease conversion to formats and structures being defined in the Master Plan. Therefore, this chapter provides interim accuracy requirements, data content standards, technical compilation criteria, and Internet distribution procedures for digital data, maps, and hard-copy charts of inland navigation projects, such as the sample chart depicted in Figure 19-1. It also provides guidance for the development of digital and hard copy navigation products of coastal navigation projects--i.e., Project Condition Surveys and Reports. The guidance outlined in this chapter is intended to provide Corps-wide uniformity for both electronic and hard copy map/chart products furnished to NOAA, commercial waterway users, and the general public; and begin data organization for eventual implementation of the Master Plan for electronic chart data.. These technical standards will help ensure that USACE navigation project data is consistent with, and fully supports USCG Vessel Traffic Systems (VTS), and Automatic Identification Systems (AIS). These standards also ensure digital navigation products will be consistent with the positional accuracy standards currently achieved by the USCG-USACE maritime Differential Global Positioning Systems (DGPS). This guidance additionally supports the maritime navigation safety recommendations issued by the National Transportation Safety Board in 1994. This guidance supplements applicable portions of ER 1130-520, Navigation and Dredging Operations and Maintenance Policies, and EP 1130-2-520. See references in Appendix A.

19-2. Scope

This chapter covers electronic charting of inland navigation and coastal deep/shallow draft projects. It covers source products, such as hydrographic surveys, maps, charts, condition reports, drawings, tracings, etc. This data includes, but is not limited to, planimetric, topographic, hydrographic, tabular, and related geospatial data contained in Geographic Information Systems (GIS) or other computer-based systems that are used to collect, process, or store data on projects covering the inland waterways, Great Lakes and coastal areas.

19-3. Background

Executive Order (EO) 12906, *Coordinating Geographic Data Acquisition and Access: The National Spatial Data Infrastructure (NSDI)*, prescribes Federal policy and establishes mechanisms for acquiring, processing, storing, distributing, and improving utilization of geospatial data, including making this data readily and freely available to the public via Internet and other media resources. ER 1110-1-8156 provides implementing guidance for the EO, as outlined in Chapter 6. This EO states that Federal agencies shall develop a plan to make geospatial data holdings available to the public and identify additional technologies and policies needed regarding releasing data to the public.

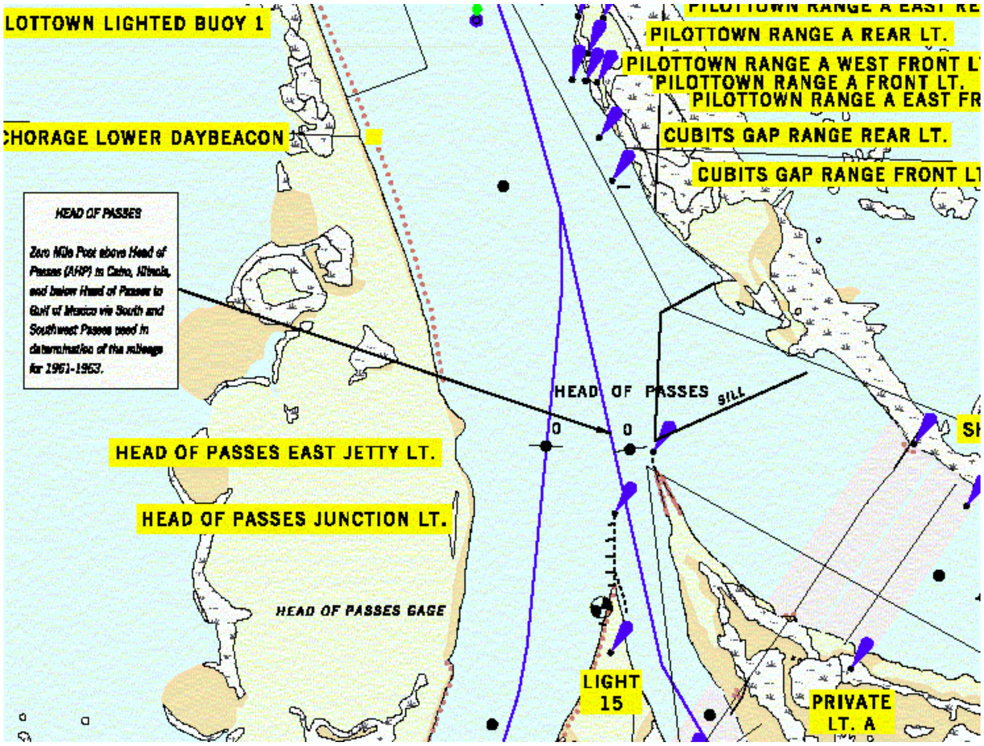


Figure 19-1. Portion of river chart book published by New Orleans District--45-ft maintained project at Head of Passes, Mississippi River

a. Current guidance. Chapter 2 of both ER 1130-2-520 and EP 1130-2-520 provides current policy and technical guidance on the publication of hard-copy charts and project condition reports of USACE navigation projects and related civil works water resource activities. These guidance documents were intended to cover traditional commercial and recreational navigation requirements--i.e., distribution of tabular project condition data or relatively small-scale (1 in. = 2,000 ft) hard copy maps and charts of river and harbor projects. These technical guidance documents do not address electronic chart systems (ECS) or Internet data access processes.

b. Data and ECS standards. The USACE Master Plan for electronic chart data will follow the International Hydrographic Office S-57, Edition 3.1, "IHO Transfer Standard for Digital Hydrographic Data" for all electronic chart and related products disseminated outside the Corps. This standard is recognized internationally by ECS vendors and users, as well as most government hydrographic offices, as the accepted format for ECS data. Although details of data conversion to the S-57 standard have not yet been determined, guidelines for current data organization are presented in this chapter.

c. Maritime differential GPS impacts. Since the mid-1990s, significant technical developments have occurred which require reanalysis of the type and accuracy of navigation information furnished to the waterway industry. These major developments include the highly accurate (i.e., meter-level) maritime Differential Global Positioning System (DGPS) network, and vessel traffic systems (VTS). As a result of these developments (still on-going), many inland and coastal navigation hard-copy chart products are neither sufficiently accurate nor contain vectorized data structures and attribution to support real-time electronic navigation systems. The critical need for coordinated electronic navigation standardization was contained in National Transportation Safety Board Recommendation M-94-30. The NTSB specifically recommended that the USACE and USCG coordinate efforts to expand maritime DGPS coverage in the inland waterways and supplement this coverage with electronic chart coverage in those waterways.

d. Coastal deep-draft and shallow-draft projects. Coastal and Great Lakes navigation projects are surveyed at varying intervals, ranging from daily to annually. Each USACE command prepares and distributes these coastal project/channel condition surveys in different formats, symbologies, and media—typically in large-scale (e.g., 1 in = 100 ft to 400 ft) engineering drawing format. These data are provided to NOAA in varying forms for incorporation on NOAA charts covering these navigation projects. NOAA charts covering navigation projects are usually at much smaller scales—typically in the 1 in. = 500 ft to 3,000 ft range. As a result of these scale disparities, USACE survey data is rarely included on NOAA charts, but is tabularly summarized as channel clearances. In order to support real-time DGPS navigation requirements, NOAA is currently developing large-scale electronic chart bases for major CONUS ports. These new electronic chart bases will be closer in scale to USACE project condition survey drawings and will allow detailed USACE channel parameters and depth data to be directly viewed by outside users. By adopting the S-57 standard, surveys and channel information will easily be interpreted and exploited by NOAA. Chart supplements might also be possible, where USACE districts produce S-57 electronic navigation charts (ENCs) within the channel, which navigation users can then overlay on the NOAA ENC. Although an implementation plan for the S-57 standard has not yet been developed, USACE districts should begin standardizing existing formats and symbologies, and provide the data files to NOAA.. This chapter provides standardization guidance for large-scale coastal project condition surveys

e. Inland navigation projects. On the inland waterway systems, USACE-published chart books are produced and distributed to the public in a variety of formats, symbology, scales, and electronic media; in accordance with the recommended guidance currently provided in EP 1130-2-520 for these hard copy products. Currently, these product formats vary significantly between districts and/or waterways. In order to support electronic charting and navigation requirements, and to provide a seamless connection between coastal, Great Lakes, and the various USACE inland navigation projects, standards for preparation, update, and electronic distribution of these products are essential. This standardization requires complete coordination between all the agencies involved, i.e., USACE, NOAA, and USCG; as is currently being pursued by HQUSACE.

19-4. USACE Current and Planned Electronic Charting Policy

It is USACE policy that all electronic or hard copy navigation products should have consistent and standardized feature accuracies, scales, data definition content and attributes, symbologies, digital file formats, and Internet viewing and downloading mechanisms. Electronic chart products should also have a uniform maintenance and update plan. This policy is being implemented in close coordination and cooperation with NOAA and the USCG to ensure seamless, standardized navigation products are provided nationwide. Pilot projects and products are being initiated to begin coordination among federal agencies and the navigation industry. Currently, USACE activities should take the following steps to make navigation data available to outside users in usable formats.

a. Digital surveying and mapping data of both coastal harbor and inland navigation projects should be furnished to users in formats that are exploitable for electronic chart databases.

b. Small-scale hard-copy inland charts and river books should be disseminated over the Internet in either digital (vector) or raster format. In addition, large-scale electronic versions of inland navigation projects should be made available for use in commercial navigation. Smaller scale hard copy navigation charts covering inland waterway systems should be produced directly from the detailed large-scale digital databases used in preparing charts.

c. Digital data generated on USACE navigation projects should use FGDC- Corps- and NOAA-prescribed chart feature standards, formats, file standards, and symbologies--see Chapters 3 and 6 for references to standard criteria. The Master Plan will establish standard features and methods of conversion from the existing features.

d. Planimetric, topographic, hydrographic, and other related geospatial project data developed by USACE, should be made freely available to public and private users through the Internet. The Master Plan will establish a standard server structure and a central interface to databases distributed among districts. Until this structure is established, districts should post data on their own web sites.

e. Planimetric navigation features shown on project drawings and charts should have positional feature accuracy (i.e., base map scales) compatible with the accuracy now being obtained by maritime DGPS technology—i.e. 1 to 3 meters RMS (95%).

f. CADD/GIS data layers/levels depicted on electronic/vectorized charts should include the following features, where possible. Refer also to more detailed CADD/GIS layer/level assignments listed in Table 19-2 at the end of this chapter.

Bridge piers	NAVAIDS
Shoreline/coastline	River mile
Safety contour (project depth)	Pipelines
Zero contour	Overhead cables
Locks	Anchorage areas
Dredge areas	Sailing line
Navigation hazards	Flow Regulation Structures
Channel centerline	

g. Navigation data should be collected, processed, and distributed in standardized vectorized formats with individual feature CADD or GIS layers/levels that separate feature categories as much as possible. Text and annotation should also be separated by layers/features.

19-5. Navigation Product Standards and Specifications

The following standards should be followed in disseminating charting and related navigation data to the marine industry and the general public as a step toward the Master Plan. These product standards are intended to provide Corps-wide consistency for all navigation data products, both in hard copy and electronic format. They apply to basic digital navigation data collected by the USACE and to electronic and hard copy navigation chart products. They also represent significant technical revisions to portions of Chapter 2 of EP 1130-2-520. Base maps, channel condition survey drawings, and/or charts of river and coastal harbor navigation projects should meet the following standards.

a. Base mapping accuracy standards for navigation projects. A significant surveying and mapping effort may be required to increase base mapping accuracy on many USACE inland and coastal navigation projects. This mapping (or remapping) must be performed at an accuracy consistent with maritime DGPS accuracy, in order to ensure mutual consistency with positioned features on NOAA or USACE electronic charts. Prior mapping performed for small-scale river charts will not meet these requirements. Most of this work will have to be performed using photogrammetric mapping techniques.

In some cases, recent large-scale mapping for hydraulic modeling studies, flood inundation studies, and other engineering purposes, may be recompiled for navigation purposes.

(1) Minimum accuracy standards for horizontal features. Planimetric navigation features should be positioned to an accuracy not to exceed 10 feet (3 meters) RMS at 95% confidence level. This 10 foot (3 m) feature accuracy tolerance falls within the average accuracy of typical DGPS receivers using the USCG/USACE maritime DGPS radio beacon network along coastal and inland waterways, i.e., 1 to 5 meters RMS (95%), depending on distance to beacon, receiver quality, Horizontal Dilution of Position variances, etc. Given future vessel traffic control system positional accuracy requirements, base maps of USACE projects need to meet or exceed these accuracies—especially in restricted areas--lock approaches, docking, etc. For coastal and inland waterway systems, a minimum base map compilation scale of 1 in = 400 ft (1 : 4,800) is specified for topographic/planimetric features critical to maritime DGPS referenced navigation. Scales larger than this standard (e.g., 1 in = 50 ft to 200 ft) may be used in/around critical navigation features--e.g., locks, dams, bridges; however, basic map scales should not be less (smaller) than 1 in = 400 ft value without specific HQUSACE approval. The 10 ft (3 m) RMS feature accuracy should be obtainable from a photogrammetrically-compiled map in accordance with ASPRS Class I Large Scale Mapping Standards, as defined in EM 1110-1-1000, Photogrammetric Mapping--see also Figure 19-2. Critical navigation features may need to be located to a higher accuracy than 10 ft RMS by using conventional survey methods. These features might include fixed navigation aids, lock chambers and lock approach walls, bridge piers/fenders, etc. Static positions with maritime DGPS will provide sufficient accuracy for these critical features. Existing as-built drawings may also be used if geographically referenced. A centralized, coordinated resurvey and collection of features across district and division boundaries is being planned. However, districts should survey and compile information for features listed in, but not restricted to, paragraph 19-4-f, where resources and current project plans permit, according to the following guidance.

US Army Corps of Engineers.

Photogrammetric Mapping Accuracy Standards
(to Support Base Maps for Electronic Charts)

ASPRS Class 1 Positional Accuracies for Various Map Scales

Map Scale	Radial accuracy 95% confidence	
100 ft/in	2.5 ft	0.8 m
200 ft/in	4.9 ft	1.5 m
400 ft/in	9.8 ft	3.0 m
1000 ft/in	25 ft	7.6 m
1500 ft/in	38 ft	11.4 m
2000 ft/in	50 ft	15.2 m

Maritime DGPS Accuracy Levels (200 ft/in to 1000 ft/in)

Accuracy Levels of existing river charts (1500 ft/in to 2000 ft/in)

6

Figure 19-2. Photogrammetric mapping accuracy standards relative to navigation chart planimetric feature accuracies

(2) Line mapping feature requirements. Base maps should consist of standard planimetric line drawings depicting critical navigation features within and adjacent to the navigation channel. Features should be separated by attribute/layer/level assignments. Care should be taken to ensure a linestring depicting a feature is continuous or linked, rather than a series of disconnected graphic elements. Area features should also be depicted with closed polygons or shapes. Digital imagery (e.g., orthophotos) is not needed for electronic navigation purposes. Except for significant landmark items, features should generally be confined to the waterway and area between top banks of the levees. Overbank topography needed to define bankline limits on rivers with significant stage variations should also be included. If these base map products will be used for other planning, engineering or construction purposes, then topographic, DEM/DTM, and/or digital orthophoto images may be included as separate layers/levels with the base planimetry.

(3) Accuracy standards for measured depths shown on navigation products. Follow performance standards outlined in Chapter 3 and Table 3-1. Depth accuracy standards vary with (1) type of measurement equipment, (2) nominal water depth, and (3) hardness (hazard) of bottom.

(4) Requirements for depth data on inland navigation chart products. Depth data obtained from periodic channel condition surveys is valuable information for electronic data bases developed for digital charts and will be included in the Master Plan. For current practice, full inland river coverage is not necessarily required when routine surveys are performed only at critical bends or approaches. Hydrographic survey data may be obtained from any available source, e.g., hydraulic model stream sections (HEC models), inundation surveys, etc. Densely acquired hydrographic depth data--e.g., that collected from LIDAR or acoustic multibeam systems--should be thinned to a bin size (or post spacing) consistent with the largest display scale use of the data. For most deep-draft coastal projects, this would equate to viewing at approximately 1 in = 100 ft, or 1:1,200. The recommended procedures and software used for such data thinning/binning is covered under the chapter on multibeam survey systems in this manual. It is critical that data thinning routines do not adversely corrupt or erroneously warp the reduced model.

b. Horizontal chart datum standards. All engineering drawings of USACE coastal and river navigation projects should be horizontally referenced to the GPS reference ellipsoid/system--WGS 84. The reference datum should be North American Datum (NAD) 83. Navigation projects still referenced to NAD 27 should be transformed to NAD 83.

c. Coordinate reference system for electronic base maps and coastal project condition surveys. All CADD/GIS databases (and CADD file reference origins) should be referenced to the North American Datum of 1983 (NAD 83). Currently, coordinates should be based on the local State Plane Coordinate System (SPCS) for the area When implemented, the Master Plan will require geographical coordinates (latitude-longitude), and conversion procedures will be defined.

d. Coordinate reference system for hard copy river books (small scale). Use geographical coordinates (latitude-longitude) based on NAD 83 as a coordinate reference for all published river books. SPCS coordinates may optionally be added.

e. Local reference systems. Chainage-Offset coordinates and River Mile systems should be included on all products where applicable.

f. Vertical reference datum standards. The intent of the Master Plan is to use vertical datums common to USACE, although S-57 convention may require other systems. Currently, the following datums should be used, and conversions will be defined if other systems are required.

(1) Coastal—MLLW throughout CONUS tidal waters.

(2) Great Lakes--IGLD 85.

(3) Inland navigation and river systems--varies per local low water datum/pool reference (e.g. LWRP 74).

(4) Reservoir systems (controlled/regulated). Typically absolute elevations relative to NGVD 29 or NAVD 88 are used on controlled reservoirs. If depths rather than elevations are used, then the NGVD 29/NAVD 88 elevation of the reference low water or pool reference plane should be clearly indicated on the drawings and data files.

(5) Shoreline/Bankline Depiction. In order for ECS systems to display shoreline or bank line limits at varying river stages, topographic data of adjacent revetments and flood control structures should be incorporated as a separate layer/level in the database. Topographic elevation data may be obtained from any available source; such as overbank surveys, revetment as-built surveys, or HEC model cross sections, although accuracy of the data must be consistent.

g. Feature content and electronic data file standards. The CADD/GIS (Tri-Service) Technology Center at WES has developed a series of standards for CADD and GIS applications. These include: (1) Architectural, Engineering, and Construction (A/E/C) CADD Standards (A/E/C CADD Standards, and (2) Spatial Data Standards (SDS, known formerly as the Tri-Service standards). The SDS includes a delineation of graphic elements and non-graphic attribute tables and domain lists describing these elements which are indexed into a schema or data dictionary. It also includes graphic symbology and other display and digital characteristics. The SDS have been expanded to include hydrographic and bathymetric data sets. SDS should be used for all geospatial data used in the generation of maps, charts, CADD, GIS, or other digital data provided to the public, and direct correlation between SDS and S-57 will be determined in the Master Plan.

(1) National Hydrography Data Content Standard for Coastal and Inland Waterways (FGDC*)*. A "National Hydrography Data Content Standard for Coastal and Inland Waterways" was designed by the FGDC Bathymetric Subcommittee to develop a nationally focused hydrographic data content standard for spatial data that supports safety to navigation. An excerpt of the latest draft is at Appendix C. This feature content standard was designed to facilitate semantic consistency when capturing hydrographic information in a spatial database and provide consistent data for ECS type applications that query, analyze, and/or display spatial data. All planimetric, topographic, and related navigation features shown on USACE electronic or hard-copy drawings or charts should follow this standard. This standard provides a consistent catalog of terms and definitions (semantics) to ensure uniform interpretation of information across a variety of maritime organizations that develop and use hydrographic feature data and applications. Features in this standard were taken from (Tri-Service) Spatial Data Standards (SDS), USACE Regional Engineering and Environmental GIS (REEGIS) data dictionary, IHO S-57, and from standards used by various inland and coastal districts. It is based on a well known logical data model for geospatial data of features, attributes, and domain values that is consistent with the FGDC Spatial Data Transfer Standard/Federal Information Processing Standard (SDTS/FIPS 173 part 2).

(2) Chart symbolization standards. NOAA has developed a feature symbology library that should be used as the Corps-wide standard for all navigation data products. This library is based directly on International Hydrographic Office S-52 Standard for hydrographic data presentation . Use of this symbology library ensures full compatibility between coastal NOAA charts and USACE inland charts. The symbology library is incorporated in the (Tri-Service) A/E/C CADD Standards.

(3) Electronic data file type and format standards. The vast majority of USACE districts currently utilize CADD technology for the preparation, distribution, storage, and maintenance of engineering and architectural drawings, including navigation project data and related maps. Standardized file structures for these CADD platforms should be followed to simplify conversion to S-57, which will be required in the Master Plan. These file structures include defined drawing file origins, units, naming conventions, sheet layout, level/layer assignments, symbology, exchange formats, etc. These standards are defined in the (Tri-Service) A/E/C CADD Standards. In general, the following file types are suitable for USACE hydrographic data for current dissemination to the navigation industry and eventual conversion to S-57.

(a) CADD Platforms:

Vector—use DGN, DXF, or DWG only
Vector with Attribute—use DXF with attributes

(b) GIS Platforms (Vectors and Polygons with Attached Database):

Use ESRI Shape files, Intergraph MGE, or AutoDesk MAP only. Provide feature level metadata and use (Tri-Service) CADD/GIS Center TSSDS Entity (Feature) Sets.

(4) GIS-based technology. Districts should strive to adapt software that will allow posting of vector files containing full feature attributes—i.e., GIS-based software as opposed to traditional CADD-based. Use of GIS provides spatial relationships between all geographic features (entities); allowing for more enhanced data query, analysis, retrieval, and display than traditional CADD systems. Such files are more useful to EC vendors and are more suitable for conversion to S-57. Pending transition to use of GIS-based software, the above general standards should be followed.

h. Internet Web posting standards of engineering drawings.

(1) Standards for posting navigation data to web and clearinghouse. Districts should use uniform and standardized procedures for posting vector files and raster images of condition survey drawings on Web sites. Using these procedures, periodic condition survey drawings are automatically uploaded to the Web server; typically within one day of receipt of field survey data. This rapid data processing and posting process provides near-real-time receipt of channel condition data by project users, for potential immediate use for electronic chart applications once HQUSACE has developed standardized uploading procedures and distributed server system for public access. Currently, districts should post available data on their own sites for open availability.

(2) *Posting raster imagery data to Web sites*. In addition to digital data files of CADD/GIS engineering drawings of mapping and hydrographic survey data, raster type files of condition survey drawings may be posted on the Internet server. These raster images can be in a format that is Web browser compatible—i.e., without need for plug-ins. These formats may include PDF, CGM, JPEG, TIFF, CALS, HMR, and IPLOT. .

(3) Metadata standards for navigation data. A metadata file describing the geographic data file(s) content and format should be generated and placed on the Internet. The metadata file can be placed on the USACE NSDI Clearinghouse Node server along with the appropriate links to the geographic data file(s)--refer to Chapter 6 for details on Clearinghouse procedures. Tools and instructions for creating the

metadata files are available on the USACE NSDI Clearinghouse Node. Metadata files should be generated following guidance in EM 1110-1-2909 (Geospatial Data and Systems).

(4) Liability considerations. No additional liability is associated with providing digital data as compared to its equivalent hard copy form, if due diligence is used to inform users of data characteristics, such as accuracy, date of collection, period of validity, units of measure, datums, and other information important to navigation users. Proper and complete metadata files, posted with the data, satisfy this obligation. Users of digital data, like hard-copy data, are responsible for their technical misuse of the data, such as enlarging it beyond the scale/accuracy limits specified in the metadata file. Digital and hard copy files should not include disclaimers cautioning against inappropriate use of data—e.g., “Do Not Use for Navigation.” Data accuracies and other related information should be posted within metadata files. When the S-57 standard is implemented, metadata will be included within the file structure.

(5) User access fees. No charge should be made for geospatial data downloaded from the Internet.

(6) Distribution of digital data to other federal agencies, project sponsors, port authorities, pilots, and other private entities. Other federal agencies and public and private users will be encouraged (and in the future expected) to access the Internet for USACE data and information. Districts should honor specific requests for hard copy paper drawings from agencies, sponsors, or individuals that cannot yet access the Internet or cannot print out large-format channel condition survey drawings.

(7) Third party chart vendors. Private vendors are encouraged to use USACE developed geospatial data in preparation of electronic charts or use in electronic chart systems (ECS) that integrate USACE data with satellite or other positioning systems to improve navigation safety on inland, Great Lakes, and coastal projects.

i. Standards for publishing hard copy river chart books and channel condition survey drawings.

(1) *Standards for publishing hard copy river chart books*. The following standards supplement portions of EP 1130-2-520 and apply to USACE charts of inland navigation systems.

(a) Units: Use common English units only—no metric.

(b) Scale Ratios: Use only standard, common engineering ratios (e.g., 1 in = 400 ft, 800 ft, 1,000 ft, 1,200 ft, 1,600 ft, 2,000 ft, 2,400 ft).

(c) Use standard scale along entire waterway if feasible and practical. Optimize scale to paper size and waterway width following above scale ratio restrictions.

(2) Hard copy river book publishing format standards. The following standards for small-scale hard-copy charts and river chart books supplement portions of ER 1130-2-520 and EP 1130-2-520 and apply to USACE charts of inland navigation systems.

(a) Derive small-scale products directly from high-resolution electronic chart base files.

(b) Use same feature content and symbology standards prescribed above for digital electronic chart products.

(c) Conform to a standard page size -- 8.5" x 14". This standardized format allows for eventual user “print-on-demand”.

(d) Primary user will be recreational. In time, will phase out published river books, given expanding user capability to print-on-demand page updates.

(3) Coastal project channel condition survey standards. Periodic project condition surveys represent a major source of digital data generated by the Corps. These surveys may also include post dredge (as-built) surveys, levee revetment surveys, and airborne LIDAR surveys. The most recent hydrographic surveys of USACE projects should be placed on the Internet for public use as soon as practical after the survey is completed. Outdated surveys being superseded should be taken off the server to eliminate confusion.

19-6. Project and Channel Condition Reports

A variety of formats are used to provide project condition reports to local marine interests and other federal agencies. Plan and profile drawing formats are commonly used. Eventually, condition reports in CADD and GIS formats will be converted to S-57 format and disseminated through the USACE electronic chart data distribution system. Until the Master Plan is implemented, districts should continue posting reports in familiar formats. A typical tabular report used by Wilmington District is shown in Figure 19-3 and one from Savannah District is shown in Figure 19-4.

REPORT OF PREVAILING CHANNEL DIMENSIONS

WILMINGTON HARBOR, NC SHIP CHANNEL
US ARMY ENGINEER DISTRICT, WILMINGTON

			PROJECT			MINIMUM DEPTH IN EACH 1/4 WIDTH OF CHANNEL ENTERING FROM SEAWARD				
NAME OF CHANNEL	MAP FILE NO. WH 105-	DATE SURVEY	FEET WIDTH	MILES LENGTH	FEET DEPTH	LEFT OUTSIDE QTR-FT	LEFT INSIDE QTR-FT	MID-CHANNEL	RIGHT INSIDE QTR-FT	RIGHT OUTSIDE QTR-FT
BALDHEAD SHOAL	89-20	03-89	500	4.54	40	33.5	35.5	37.0	37.0	32.5
SMITH ISLAND	89-18	03-89	500	0.98	40	24.0	36.5	42.0	41.5	39.5
BALDHEAD CASWELL CHANNEL	89-5	01-89	500	0.38	40	39.5	40.0	40.0	41.5	38.5
SOUTHPORT CHANNEL	89-6	01-89	500	1.02	40	42.5	43.5	41.5	42.0	37.5
BATTERY ISLAND CHANNEL	89-24	04-89	500	0.49	40	43.0	44.0	44.0	39.0	33.5
LOWER SWASH	89-19	03-89	400	1.60	38	33.5	40.0	40.0	40.5	34.0
SNOW MARSH	89-23	04-89	400	3.06	38	36.0	37.5	38.5	38.0	34.5
HORSESHOE SHOAL	89-25	04-89	400	1.22	38	31.5	38.0	38.0	38.0	38.0
REAVES POINT	89-26	04-89	400	1.17	38	35.0	38.0	38.5	38.0	37.0
LOWER MIDNIGHT	89-28	03-89	400	1.64	38	34.5	37.5	37.5	38.0	35.0
UPPER MIDNIGHT	89-22	03-89	400	2.69	38	37.0	38.0	38.0	38.0	35.5
LOWER LILLIPUT	89-29	04-89	400	1.94	38	36.5	37.0	37.0	36.5	36.0
UPPER LILLIPUT	89-31	04-89	400	1.94	38	36.0	36.5	38.0	36.5	37.0
KEG ISLAND	89-32	04-89	400	1.35	38	37.0	38.5	38.5	37.5	33.0
LOWER BIG ISLAND	89-35	04-89	400	0.76	38	36.0	38.5	38.0	37.0	29.0
UPPER BIG ISLAND	89-35	04-89	400	0.50	38	36.0	39.0	40.5	40.0	31.0
LOWER BRUNSWICK	89-34	04-89	400	1.64	38	19.5	39.0	39.5	38.5	35.0
UPPER BRUNSWICK	89-33	04-89	400	1.00	38	21.0	39.5	39.0	39.5	32.5
FOURTH EAST JETTY	89-30	04-89	400	1.24	38	36.0	40.0	39.5	40.0	38.5
BETWEEN CHANNEL	89-16	03-89	550	0.80	38	33.5	40.5	40.5	39.5	38.5
ANCHORAGE BASIN & APP CHANNEL	89-15	03-89	450- 1090	1.30	38	36.0	38.0	38.5	37.0	35.5
BATTLESHIP TO HWY 74-76 BRG 32	88-18	02-88	300	0.62	32	26.5	35.5	36.5	36.0	34.5
HWY 133 TO BTLSHP & TB 32'	89-1	01-88	890	0.00	32	27.0	28.0	31.5	30.5	25.0
HILTON BRG (ACL RR) TO HWY 133	88-20	03-88	300	0.00	32	30.0	31.5	32.5	33.0	29.0
NORTHEAST (CFR) ABV HILTON BRG	89-12	02-89	200	1.23	25	21.0	24.0	18.5	18.0	13.5

NOTE: DEPTHS ARE EXPRESSED TO THE NEAREST HALF-FOOT AND REFER TO LOCAL MEAN-LOW-WATER.
·89

Figure 19-3. Tabular channel condition report for Wilmington Ship Canal (Wilmington District)

REPORT OF CHANNEL CONDITIONS 100 TO 400 FEET WIDE (ER 1130-2-316)	Page 1 of 1 June 2000
TO: Port Director, Canaveral Port Authority P.O. Box 267, Cape Canaveral, FL	FROM: USACE, District Engineer Attn: CESAJ-CO-OM Jacksonville, Florida
RIVER/HARBOR NAME AND STATE Canaveral Harbor, Brevard County, FL	MINIMUM DEPTHS IN EACH 1/4 WIDTH OF CHANNEL ENTERING FROM SEAWARD

NAME OF CHANNEL	Date of Survey	AUTHORIZED PROJECT Width (feet)	Length (miles)	Depth (feet)	Left Outside Quarter (feet)	Left Inside Quarter (feet)	Right Inside Quarter (feet)	Right Outside Quarter (feet)
Outer Reach Entrance Channel: Cuts 1A & 1B, from entrance to 500 feet landward of red lighted Buoy-6	Apr-2000	400	3.1	44	43.6 (1)	43.7 (1)	43.2 (1)	43.6 (1)
Entrance Channel: Cut-1, from 500 feet landward of red lighted Buoy-6 to red lighted Buoy-10	Apr-2000	400	2.4	44	41.9 (2)	41.9 (2)	42.0 (2)	42.4 (2)
Widener: Cuts 1 & 2	Apr-2000	400	0.9	44/41	40.1 (3)	43.6 (4)	43.1 (4)	42.6 (4)
Middle Reach Entrance Channel: Cut-2, from red lighted Buoy-10 to the west side of the Trident Entrance Channel	Apr-2000	400	1.1	44	44.4	44.7	44.9	44.1

1. Minor spot shoaling halfway into Cut-1A.

2. Shoaling throughout channel from 700 feet landward of red lighted Buoy-8 to red lighted Buoy-10.

3. Minor shoaling in 41-foot project, 100 feet seaward of green lighted Buoy-13.

4. Minor shoaling throughout seaward half of widener.

5. Minor shoaling along north and south edges of channel.

6. Spot shoaling throughout 39-foot project.

7. Shoaling along east and north edges of turning basin (35-foot project).

8. Extreme shoaling along eastern edge of access channel in vicinity of red Light-2. Least depths occur approximately 250 feet north of Light-2.

9. Shoaling along northeast edge of turning basin.

ENG FORM 4021-R, NOV 90 EDITION OF JUL 59 IS OBSOLETE (Proponent:CECW-OW

Figure 19-4. Tabular channel condition report for Canaveral Harbor, FL (Jacksonville District)

Tabular channel condition reports can also be placed on a web site, as illustrated in Figure 19-5.

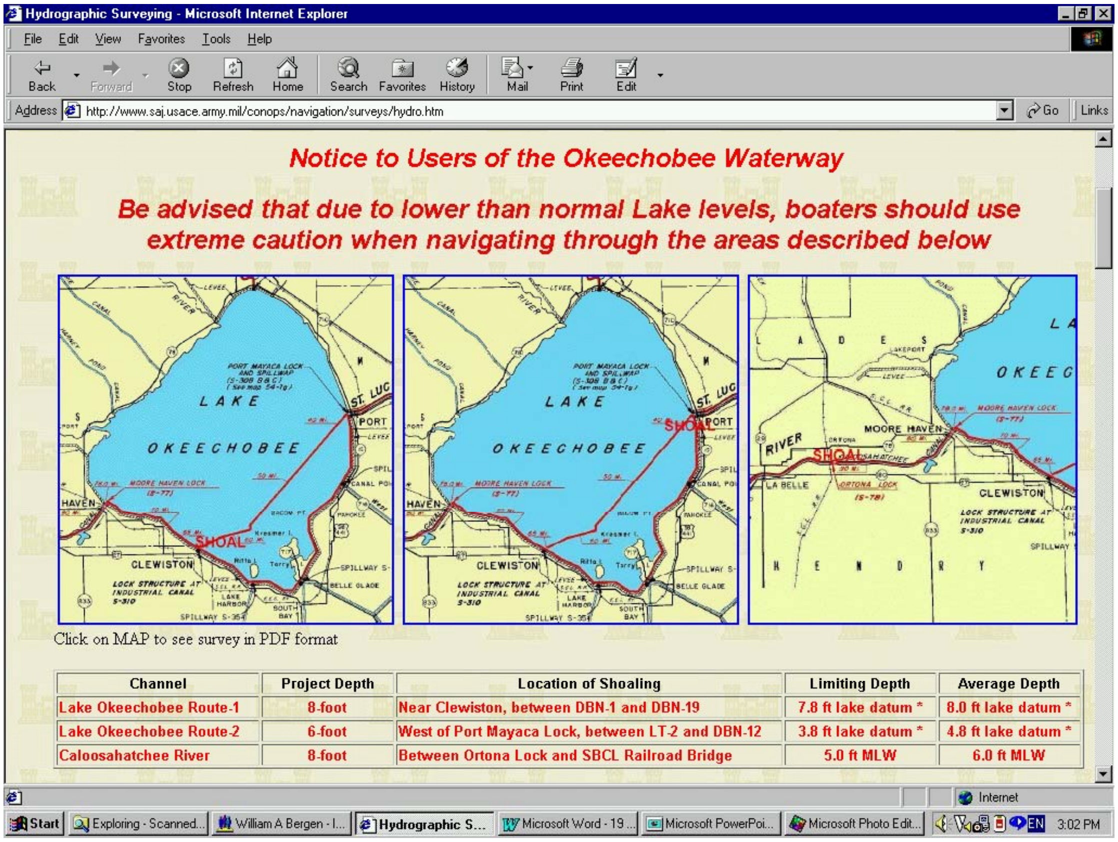


Figure 19-5. Internet channel condition report listing shoal areas on Lake Okeechobee Waterway (Jacksonville District)

Plan drawings of channel conditions shall be furnished to other agencies in accordance with the provisions of ER 1130-2-520 and EP 1130-2-520. Significant requirements in this regulation include coordination and cooperation with the USCG on NAVAID location or relocation during design and construction; USACE-maintained NAVAIDS; requirements to furnish channel condition reports to the National Imagery and Mapping Agency (NIMA), the US Naval Oceanographic Office (NAVOCEANO), NOAA, and the USCG; required tabular formats for reporting controlling depths; required grid systems; and required plotting and tabulation of NAVAIDS located during the course of a survey.

a. Grids and/or coordinate listings should clearly show their origin (NAD 27 or NAD 83), along with the applicable state zone and the relationship between the NAD 27 and NAD 83 datums.

b. In US coastal waters, MLLW datum shall be used exclusively. When a project vertical datum other than MLLW is used, condition drawings will contain a vertical datum diagram showing the relationship between the particular local datum used and the MLLW (if tidal) and/or NGVD 29 (if not tidal) datum. However, in the Great Lakes, all project datums shall be referred to IGLD (i.e., IGLD 85).

c. The USCG should be furnished project horizontal control data sheets for use in positioning NAVAIDS and monitoring waterways.

d. Representations of submarine cables and pipelines on condition reports or charts will follow the provisions of NOAA Chart No. 1 for symbols and abbreviations where applicable.

e. Charted or tabulated reference elevations, datums, obstruction clearances, and structural clearances in tidal areas shall follow the NOAA conventions.

19-7. Electronic River Charts and Related Navigation/GIS Data

Some districts have begun to furnish navigation data to pilots and the public on CD-ROM format. In the Master Plan, such data products in CADD, GIS, raster and other formats will be superseded by S-57 data. However, the new ENC products will be derived from the current data. If possible, districts should produce and publish river charts on CDs until the Master Plan is implemented. The following CD-ROM data set is typical of that furnished to the public for navigation projects maintained by the New Orleans District. The Atchafalaya River Navigation Folio duplicates the hard-copy chart books sold to the public--see sample chart at Figure 19-6. Actual hydrographic elevations and soundings are contained in the Hydrographic Survey Book--in both PDF and DGN formats (Figure 19-7). An Intergraph MGE format is also provided for Mississippi Valley Division REEGIS compatible data. The following listing is excerpted from the Atchafalaya River CD-ROM:

**1999 ATCHAFALAYA RIVER CHART BOOKS AND GIS
CD-ROM DATA CONTENTS:**

1999 Atchafalaya River Hydrographic Survey Book
(Adobe PDF and MicroStation DGN formats)

1999 Atchafalaya River Navigation Folio
(Adobe PDF format)

Atchafalaya Basin REEGIS-Format GIS
(Intergraph MGE format)

GIS Project Export
(Intergraph MGE format)

This CD is a product of the New Orleans District US Army Corps of Engineers.

It contains spatial information on navigation and hydrographic features within the Atchafalaya River Basin. It encompasses the geographic area south of the Red River, LA below latitude 31°N and the Old River Inflow Channel to Atchafalaya Bay, south of Eugene Island.

These products were developed under contract DACW29-97-C-0020 during 1998 and 1999.

This work was performed by:
3001, Inc.
5525 Mounes Street, Suite 102
New Orleans, LA 70132
Voice: (504) 733-3001.

For Additional Information:
US Army Corps of Engineers, New Orleans District
Attn: Map Sales/CEMVN-ED-SD
P.O. Box 60267

New Orleans, LA 70160-0267
Voice: (504) 862-1823
Fax: (504) 862-1585,
Email: Nathaniel.Griffin.Jr@mvn02.usace.army.mil

For Technical Assistance, contact:
US Army Corps of Engineers, New Orleans District
Chief/Drafting Section
Voice: (504) 862-2716
http://www.mvn.usace.army.mil/

DIRECTORY CONTENTS:
==================

.\ATCH-HYD Atchafalaya River Hydrographic Book files

.\ATCH-HYD\DGN MicroStation design files

.\ATCH-HYD\DGN\H31-001 thru H31-137
Hydrographic cartographic design files, sheets 1 thru 137

.\ATCH-HYD\DGN\H31-DX1 and H31-DX2 Hydrographic index sheets 1 and 2

.\ATCH-HYD\MAPPUB files needed to reproduce map sheets as published

.\ATCH-HYD\MAPPUB\IFT iplot feature tables for Hydrographic product

.\ATCH-HYD\MAPPUB\IFT\HYD feature tables for map sheets 1 thru 137

.\ATCH-HYD\MAPPUB\IFT\HYD-IDX feature tables for index sheets 1 and 2

.\ATCH-HYD\MAPPUB\LIB resource files used by MicroStation and MapPublisher

.\ATCH-HYD\MAPPUB\PERL Perl scripts used to generate final MapPublisher output

.\ATCH-HYD\PDF Hydrographic Book sheets in Adobe Acrobat format;
'Indx001' and 'Indx002' contain hyperlinks to map sheets

.\ATCH-NAV Atchafalaya Navigation Book files

.\ATCH-NAV\PDF
Navigation Book sheets in Adobe Acrobat format;
'Indx_01' and 'Indx_02' contain hyperlinks to map sheets

.\METADATA Metadata for products included on CD

.\REEGIS_DGN MGE-compatible design files representing GIS data set

.\REEGIS_MPD MGE format database dump

.\REEGIS_ORACLE ORACLE format database dump

.\REEGIS_RIS RIS format database dump

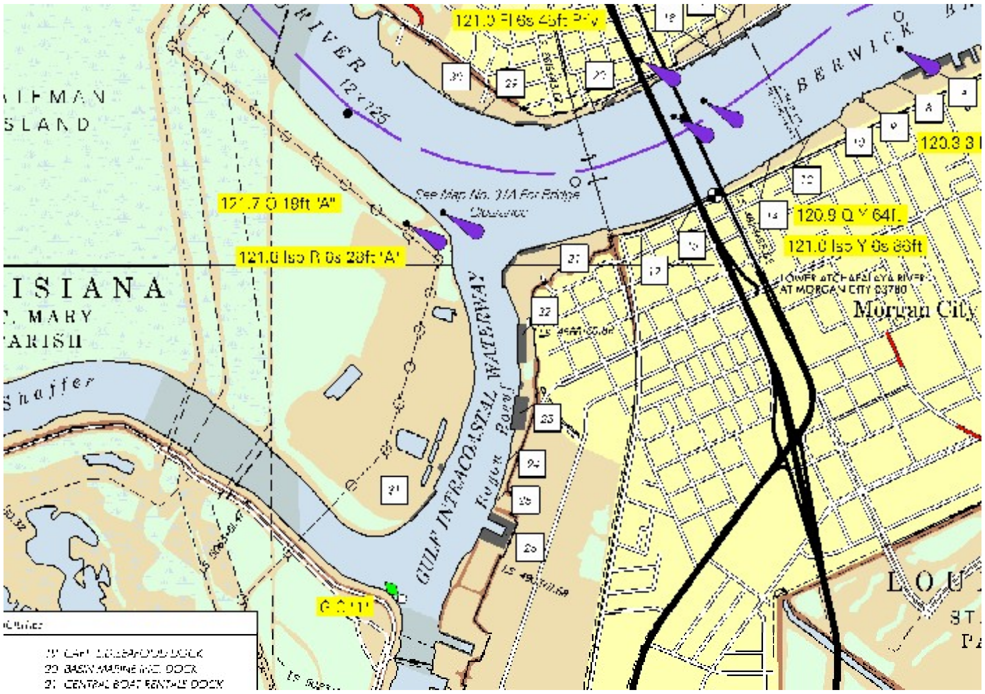


Figure 19-6. Portion of Atchafalaya River navigation chart on CD-ROM--Morgan City, LA area

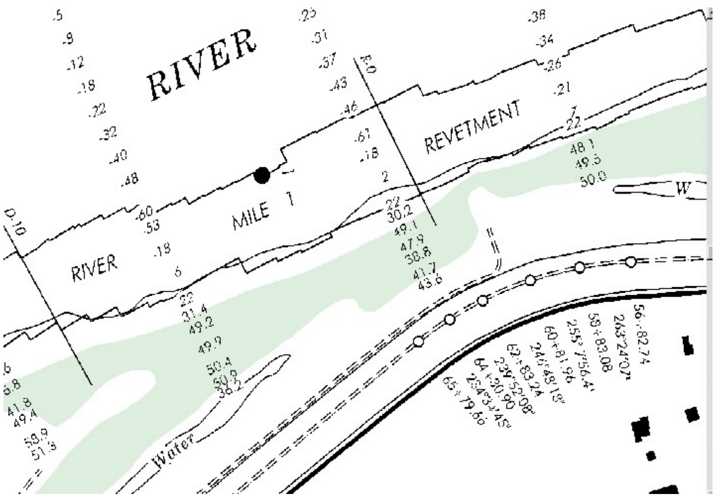


Figure 19-7. Portion of Atchafalaya River Hydro Book on CD-ROM--Atchafalaya River Mile 1 Revetment area

19-8. Web Posting of Navigation Charts and Surveys

As ENC and related S-57 data is produced under the Master Plan the S-57 files will be posted on the Internet for open public access. A uniform data server and file structure will be implemented across the districts, and access will be possible through each district web site. A central web site will also be established that will access each district server, enabling single access by all outside users to all electronic chart files. Currently, districts should maintain their own web sites and posted data files for download. The following web sites in Table 19-1 have been set up by Corps districts to distribute their navigation data. Coastal districts listed will generally provide data from the most current project condition survey--usually in a native format--e.g., DGN. Currently, not all sites provide digital copies of inland navigation river charts.

Table 19-1. Corps Navigation Data Web Sites (2000)

District	Navigation Chart Web Address	Division Code	District Code
Buffalo District	http://lrb.usace.army.mil/outreach/survey.html	LRD	LRB
Detroit District	http://huron.lre.usace.army.mil/OandM/o&m.html	LRD	LRE
Huntington District	http://cae.lrh.usace.army.mil/pub/ecda/river_charts/	LRD	LRH
Louisville District	http://www.lrl.usace.army.mil/or/text/chartinx.htm	LRD	LRL
Nashville District	http://www.orn.usace.army.mil/lakeinfo/NavCharts/TNRiver/tntext.html	LRD	LRN
Nashville District	http://www.orn.usace.army.mil/lakeinfo/NavCharts/CumbRiver/default.html	LRD	LRN
Pittsburgh District	http://www.lrp.usace.army.mil/nav/nav.htm	LRD	LRP
Vicksburg District	http://www.mvk.usace.army.mil/maps.htm	MVD	MVK
New Orleans District	http://www.mvn.usace.army.mil/eng/eng_data.htm	MVD	MVN
Memphis District	http://www.mvd.usace.army.mil/reegis/navbook/main2.htm	MVD	MVM
St. Paul District	http://www.mvp.usace.army.mil/pp/umrp/nav/ld.html	MVD	MVP
Rock Island District	http://www.mvr.usace.army.mil/navdata/nic.htm#Visual	MVD	MVR
St .Louis District	http://www.mvr.usace.army.mil/navdata/nic.htm#Visual	MVD	MVS
Baltimore District	http://www.nab.usace.army.mil/	NAD	NAB
New England District	http://www.nae.usace.army.mil/waterres/water.htm	NAD	NAE
New York District	http://www.nan.usace.army.mil/business/buslinks/navig/index.htm	NAD	NAN
Norfolk District	http://155.78.30.111/	NAD	NAO
Philadelphia District	http://www.nap.usace.army.mil/channel/list.htm	NAD	NAP
Kansas City District	http://www.nwk.usace.army.mil/mrknewmap.html	NWD	NWK
Omaha District	http://www.nwo.usace.army.mil/html/Lake_Proj/maps.htm	NWD	NWO
Portland District	http://www.nwp.usace.army.mil/info.htm	NWD	NWP
Seattle District	http://crunch.tec.army.mil/	NWD	NWS
Walla Walla District	http://www.nww.usace.army.mil/html/offices/pl/h/wm/wmpage.htm	NWD	NWW
Charleston District	http://www.sac.usace.army.mil/	SAD	SAC
Jacksonville District	http://www.saj.usace.army.mil/nav/index.html	SAD	SAJ
Mobile District	http://www.sam.usace.army.mil/op/nav/	SAD	SAM
Savannah District	http://144.3.144.48/lakes.htm	SAD	SAS
Wilmington District	http://www.saw.usace.army.mil/nav.htm	SAD	SAW
San Francisco District	http://www.spn.usace.army.mil/	SPD	SPN
Little Rock District	http://www.swl.usace.army.mil/pao/charts.html	SWD	SWL
Tulsa District	http://www.swt.usace.army.mil/navigation/navcharts.htm	SWD	SWT

New Orleans District provides inland navigation data to the public in a variety of formats and download options as illustrated in Figures 19-8, 19-9, and 19-10 below.

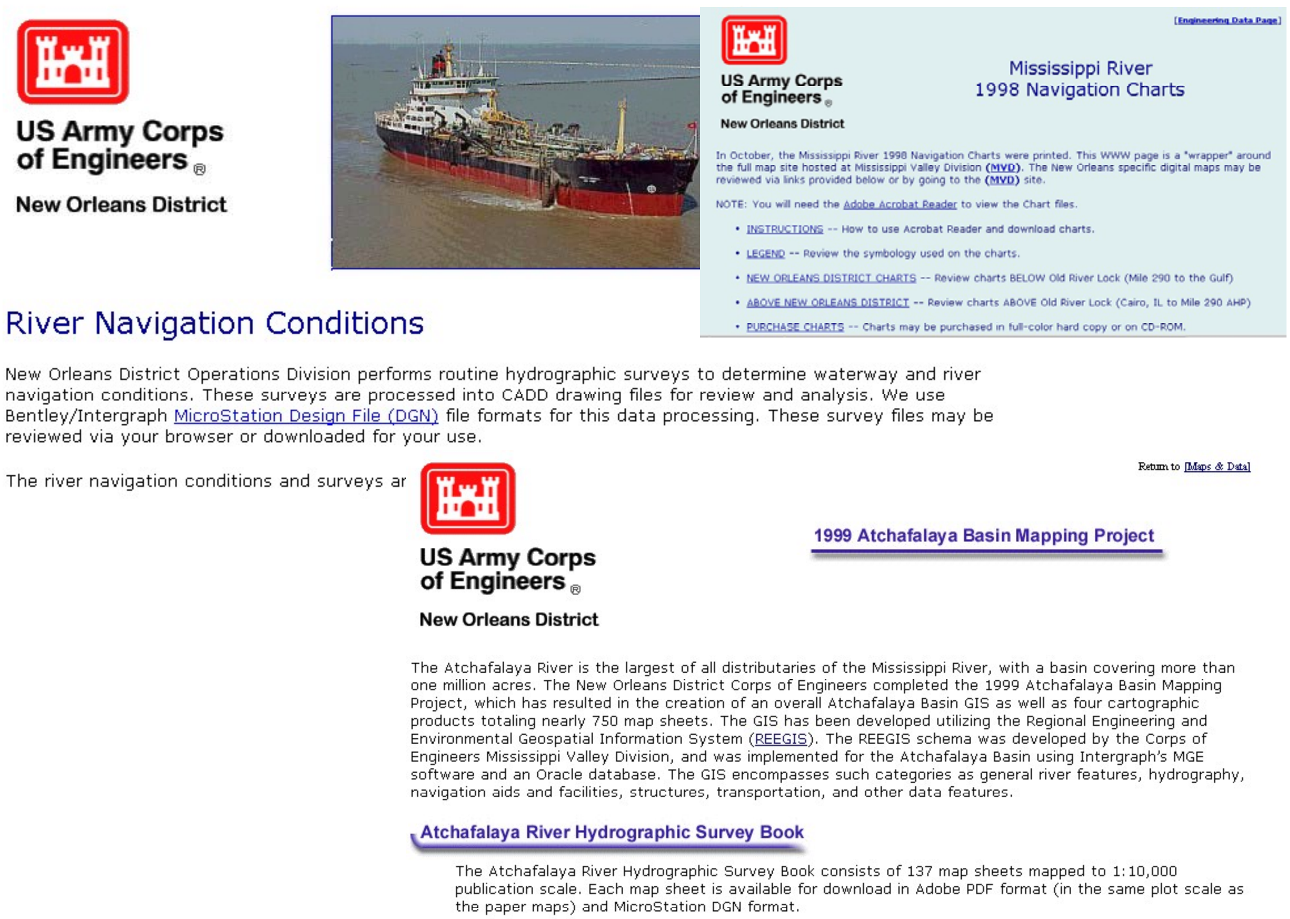


Figure 19-8. Sample navigation data web site--New Orleans District

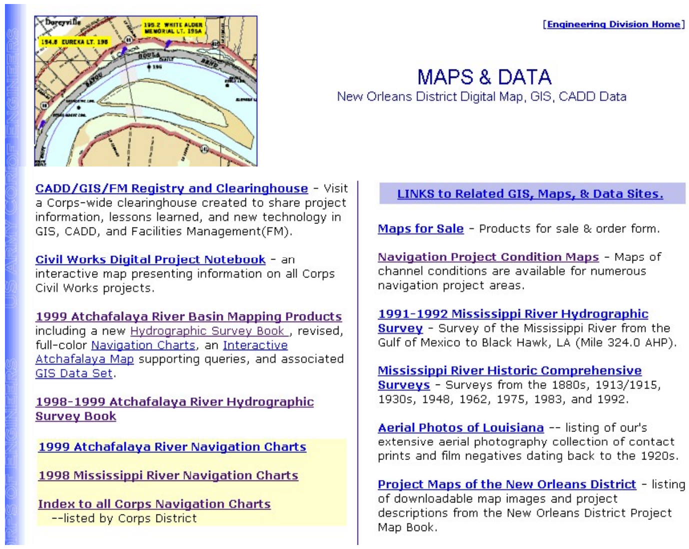


Figure 19-9. Listing of digital maps, charts, GIS, and CADD products available from the New Orleans District

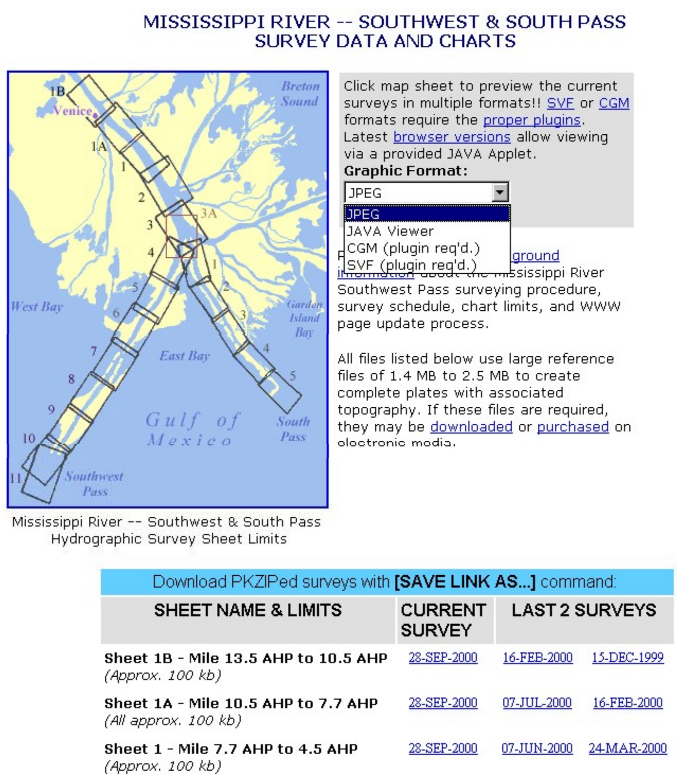


Figure 19-10. Mississippi River South Pass and Southwest Pass. Digital data may be downloaded from the New Orleans District server in any of the following formats: JPEG, JAVA, CGM, or SVF

Some coastal districts post channel condition reports and hydrographic surveys on their web servers. The native format (e.g., DGN) can be pulled down directly by other federal agencies and public users with CADD capabilities. A readable format, such as PDF, is included for the general public. An example of a typical public web site for project condition surveys is shown in Figure 19-11.

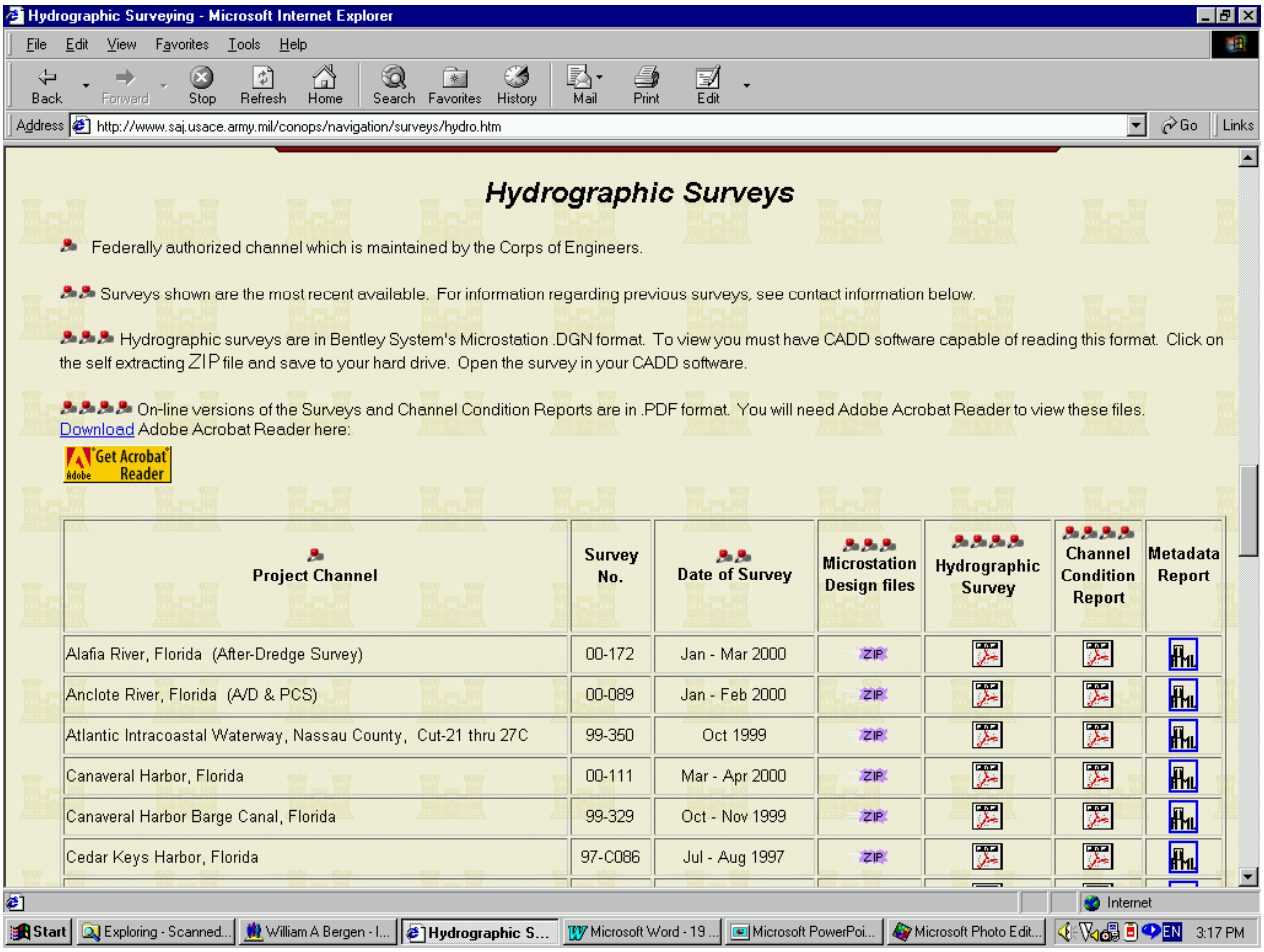


Figure 19-11. Sample web site for downloading coastal project condition surveys--Jacksonville District

Most channel condition surveys are indexed as shown in Figure 19-12. This index for the Atlantic Intracoastal Waterway outlines 89 individual full-size drawings that may be selected. Web sites can be configured to allow direct sheet selection from the index sheet. Each sheet may be pulled down in either native DGN (Zipped) or PDF format.

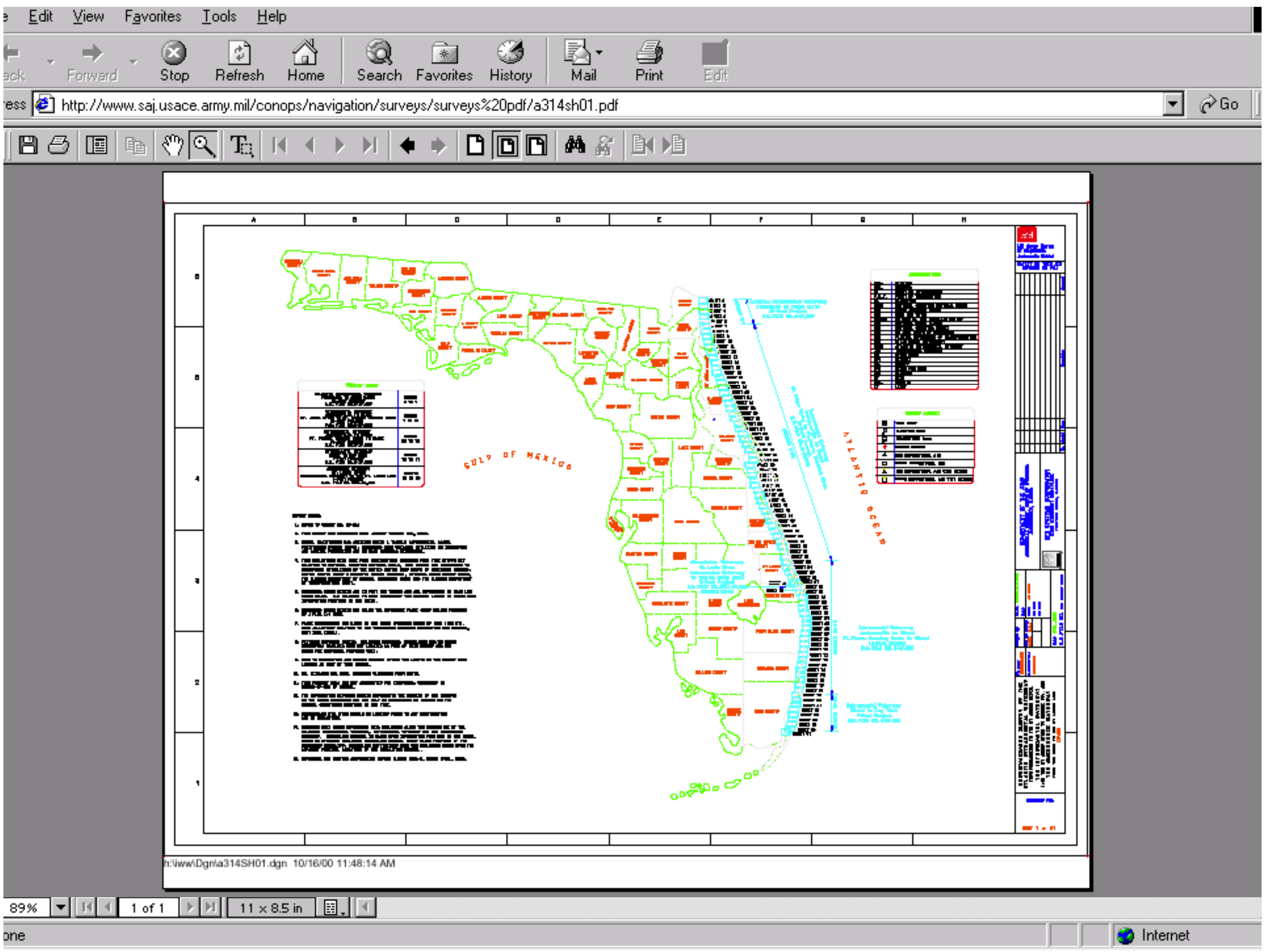


Figure 19-12. Web site index sheet for Atlantic Intracoastal Waterway (Jacksonville to Miami) Jacksonville District

Level #	Level/Layer Naming: AIA Format	ISO Format	Level/Layer Description	Graphics: Line Style	Line Width (mm)	AutoCAD Line Color/#	MicroStation Line Color/#
General Information							
1	V-ANNO-DIMS	V—DIP-	Witness/extension lines, dimension terminators, dimension text	0	V	V	V
2	V-ANNO-KEYN	V—KEP-	Reference keynotes with associated leaders	0	V	V	V
5	V-ANNO-NOTE	V—NOP-	General notes and general remarks	0	0.35	Y/2	Y/4
3	V-ANNO-NPLT	V—NPP-	Construction lines, reference targets, area calculations, review comments, viewport windows	V	0.18	B/5	B/1
4	V-ANNO-PATT	V—PAP-	Miscellaneous patterning, cross-hatching, poche	0	0.18	Gr/8	Gr/9
6	V-ANNO-SYMB	V—SYP-	Miscellaneous symbols	V	0.35	M/6	M/5
7	V-ANNO-TEXT	V—TEP-	Miscellaneous text and callouts with associated leaders	0	V	V	V
NA	V-ANNO-XREF	V—XRP-	Reference files (AutoCAD users only, see Chapter 4)	NA	NA	NA	NA
Survey Lines							
8	V-SURV-DATA	V-SURVDAM-	Survey data (PI, PT, etc.) information	0	0.35	M/6	M/5
9	V-SURV-LINE	V-SURVLIM-	Survey and control lines	2	0.50	C/4	C/7
10	V-SURV-IDEN	V-SURVIDM-	Survey and control line annotation	0	0.35	M/6	M/5
Miscellaneous Structures							
11	V-MISC-IDEN	V-MISCIDM-	Bridges, piers, breakwaters, docks, floats, etc. - annotation	0	0.35	Y/2	Y/4
12	V-MISC-OTLN	V-MISCOTM-	Bridges, piers, breakwaters, docks, floats, etc. - outlines	0	0.50	C/4	C/7
Channels							
14	V-CHAN-LIMT	V-CHANLIM-	Channel limits, anchorages, turning basins, disposal areas, etc.	0	0.35	M/6	M/5
15	V-CHAN-IDEN	V-CHANIDM-	Channel limits, anchorages, turning basins, disposal areas, etc.	0	0.35	M/6	M/5
16	V-CHAN-DACL	V-CHANDAM-	De-authorized channel limits, anchorages, etc.	0	0.25	G/3	G/2
17	V-CHAN-DAID	V-CHANDIM-	De-authorized channel limits, anchorages, etc. - annotation	0	0.25	G/3	G/2
18	V-CHAN-CNTR	V-CHANCNM-	Channel centerline and survey report lines	3	0.18	B/5	B/1
19	V-CHAN-CNID	V-CHANCIM-	Channel centerline and survey report lines - annotation	0	0.18	B/5	B/1
20	V-CHAN-AIDS	V-CHANAIM-	Navigation aids and text	0	0.35	Y/2	Y/4
Topography							
39	V-TOPO-BORE	V-TOPOBOM-	Boring locations	0	0.35	M/6	M/5
40	V-TOPO-COOR	V-TOPOCOM-	Coordinate grid tics and text	0	0.25	R/1	R/3
41	V-TOPO-MAID	V-TOPOMAM-	Major contours - annotation	0	0.35	Y/2	Y/4
42	V-TOPO-MAJR	V-TOPOMJM-	Major contours	0	0.35	Y/2	Y/4
43	V-TOPO-MIID	V-TOPOMIM-	Minor contours - annotation	0	0.25	G/3	G/2
44	V-TOPO-MINR	V-TOPOMNM-	Minor contours	0	0.25	G/3	G/2
45	V-TOPO-SHOR	V-TOPOSHM-	Shorelines, land features, and references	0	0.50	C/4	C/7
49	V-TOPO-SOUN	V-TOPOSOM-	Soundings	0	0.25	G/3	G/2
Note: V = Varies, NA = Not Applicable							

Table 19-2. Hydrographic survey and mapping plan--recommended CADD/GIS level/layer file assignments

19-9. Mandatory Requirements

Section 554 of the Water Resources Development Act of 2000 states that not later than 60 days after the Corps completes a channel dredging project, NOAA shall be provided a digital data format of the results of the survey. The only exception is for pre-dredging or pre-construction surveys. Since these surveys are only accurate for a short time, they are exempt from data dissemination requirements. There are no other mandatory requirements in this chapter--related channel condition reporting requirements are found in ER 1130-2-520. Within six years of this publication, mandatory electronic chart data format, content, dissemination, and maintenance procedures are anticipated.

Chapter 20
Reservoir Sedimentation Surveys

20-1. Introduction and Background

The Corps maintains some 383 flood control reservoirs such as the project shown in Figure 20-1. These reservoirs are primarily used for flood control water storage. Multipurpose reservoirs include some 75 hydropower projects operated by the Corps--generating nearly 25% of the nation's hydroelectric power output. Other secondary uses of these reservoirs include recreation and water supply. Reservoirs are impounded by either concrete or earth-fill dams. A variety of outlet works and spillways are used to regulate, control, or release outflows from the reservoirs. Reservoir storage capacity impacts hydroelectric power generation and flood control operation. Useful storage is the volume of water between the minimum pool (e.g., outlet invert elevation) and normal pool (e.g., spillway crest elevation) levels. Storage capacities are affected by sedimentation build up over time--typically below the minimum pool elevation. Reservoir sedimentation surveys are performed to monitor periodic build up of sediment in the reservoir, which allow computation of reductions in reservoir capacities. Other purposes may include base data for recreational navigation maps or charts in support of Natural Resources office activities--e.g., topographic/bathymetric maps depicting fishing or camping areas. Reference should be made to EM 1110-2-4000 (Sedimentation Investigations for Rivers and Reservoirs) for planning, conducting, and modeling reservoir sedimentation investigations.

Figure 20-1. Reservoir behind Mark Twain Dam (St. Louis District)

20-2. Survey Methodology

Reservoir sedimentation surveys require a combination of hydrographic and topographic methods. Hydrographic surveys are performed to determine the underwater topography. Topographic and photogrammetric methods are performed to map the areas above the pool in which the hydrographic surveys were performed. The surveys are merged into a digital terrain database from which quantity take-offs are made for reservoir capacities.

a. Survey boats. Hydrographic surveys are usually performed with small, trailerable boats, using standard automated hydrographic data collection systems. Many reservoirs have boat ramps for recreational purposes, so larger, trailerable boats can be easily launched. If there are no launching facilities, a small, carryable, 12- to 16-ft open skiff may have to be used--provided reservoir conditions are calm and protected. Jet ski boats have also been used to survey inaccessible reservoirs. Their use is expected to expand in the future.

b. Horizontal positioning. The most efficient positioning method is meter-level, code phase DGPS--using USCG radiobeacons or private provider networks. Alternately, electronic total stations may be used for small reservoirs or impoundment basins; however, this may require locating or establishing additional horizontal control points around the basin, adding considerable time and cost to the survey. Total station positioning may be needed near dams, power plants, or outlook structures if satellite signals are obscured or interfered with. Positional accuracy is not critical for reservoir sedimentation surveys--the 5 meter RMS level recommended in Table 3-1 is more than adequate. This is easily achievable with current DGPS methods. Positioning procedures and calibration checks should conform to the guidance in this manual.

c. Reference elevations. Depth measurement accuracy is critical in reservoir sedimentation surveys. Depths are measured relative to either NGVD 29 or NAVD 88 datums. The master gage or staff elevation reference used for the project should be used as a reference--usually located near the outlet works or dam. The elevation of the gage/staff should be checked by connection to existing benchmarks. For long reservoirs, a slope gradient may exist; requiring additional gages be set in the upper reaches. Gages must be continuously monitored if there are short-term fluctuations in the pool; otherwise, twice-daily readings may be adequate. Bar checks are critical to ensures no systematic errors are present--especially on small boats. Sound velocity probes are needed to measure and correct for velocity changes in deeper reservoirs, i.e., at depths beyond the bar check reach and where changes in water temperature are most likely. Since most velocity probes are designed for 50-75 ft navigation projects, additional cable must be added to reach down to 200-300 ft depths.

d. Density of coverage. The topographic relief and size of the reservoir will dictate the coverage requirements. Single beam echo sounders are used; however, a multibeam system might be employed if full coverage detail is required for scour studies near the dam or outlet works. Single beam survey lines are typically run bank-to-bank perpendicular to the axis of the reservoir. Since the objective is to compute the volume of an irregularly shaped impoundment basin, there is no rigid requirement for a specific cross-section alignment or spacing. Typically lines are spaced between 200 and 400 ft, with a not-to-exceed spacing specified. If the topography in the reservoir is fairly uniform, then line spacing may be increased. Specifying too tight a line spacing on a large reservoir is uneconomical. The accuracy requirements of the reservoir capacity computation must be fully considered in selecting a line spacing. Since volumes are typically computed by contour intersect methods, the accuracy of the reservoir storage volume is a primary a function of the computed areas for each elevation stage. Thus the digital terrain model (DTM) must have sufficient density to delineate accurate contours from which areas are computed.

(1) Since successive surveys are measuring storage trends, it is only necessary to obtain data at a density consistent with this requirement--e.g., 1% of capacity. Given a percent error in capacity (acre-ft), area (acres), and average depth at spillway elevation, the average accuracy of the 1-ft DTM contours (in ± acres) can be computed. In general, a contour acreage accuracy of ± 1 acre is easily achievable if the survey density is adequate.

(2) Depth accuracy must be absolutely free of any systematic biases. A bias of say (+) 0.3 ft over a 1,000 acre reservoir (i.e., 300 acre-ft) would represent a significant error (3%) even if the storage is only 10,000 acre-ft. Thus, accurate gage readings, bar checks, and velocity calibrations are critical to preclude against systematic errors in reservoir surveys. Random errors in the depth measurements are not significant as long as there is no bias--e.g., a depth accuracy of +0.0 ft (bias) ± 1.0 ft (random) is acceptable, whereas an accuracy of (-) 0.3 ft ± 0.3 ft is not. Refer to Chapter 4 for further discussion on depth accuracy requirements.

e. Topographic mapping. In order to compute the full capacity rating for a reservoir, topography must be obtained up to the normal pool or spillway crest elevation; or higher, to a surcharge elevation that may be specified. Existing maps or as-built drawings of the project may already be available for this data; otherwise, full topographic and/or photogrammetric mapping surveys of these areas will be required. Approximate computations may be made using USGS quad maps; however, their small-scale and poor vertical accuracy will often not provide adequate results.

f. Area and capacity computations. A variety of automated techniques are used to compute the storage area-capacities. Usually the hydrographic-topographic DTM is used to generate a TIN model when only sparse cross-section data are available. From this TIN, 1-ft contours are generated and the area (in acres) for each 1-ft contour section computed. The volume (in acre-ft) for each contour segment can be computed by projecting this area over the contour 1-ft interval. More refined prismoidal adjustments may be made. The areas and accumulated storage volumes are tabulated and plotted on a standard area-capacity curve format as illustrated in the following example project. Reservoir storage capacity relative to the watershed area runoff may also be computed and tabulated in acre-ft per inch of runoff.

20-3. Application: Hydrographic Surveys and Area Capacity Curves--Baltimore District

The following project illustrates a typical reservoir sedimentation survey for the purpose of updating area capacity curves. The overall project involved sedimentation surveys for seven reservoir projects in Baltimore District. Results for only one of these projects is illustrated herein. This hydrographic surveys on the reservoir were conducted by TVGA, Inc., Elma, NY. Another contractor subsequently completed the topographic mapping portion of the work. Baltimore District then merged the two files to obtain a DTM from which they computed reservoir storage area-capacities. St. Louis District managed the hydrographic and photogrammetric mapping contracts for the Baltimore District.

a. Task order scope of work. The following Scope of Work was sent to the contractor as part of a Request for Proposal on the project. This scope succinctly describes the work to be performed and deliverables.

**SCOPE OF WORK
TVGA ENGINEERING, SURVEYING, INC
ELMA, NY
SEVEN LAKES FOR BALTIMORE DISTRICT
HYDROGRAPHIC SURVEYS**

**CONTRACT NO. DACW43-96-D-0512
TASK (DELIVERY) ORDER NO. XXX**

1. Description of Work:

The Contractor shall perform hydrographic surveys in the Baltimore District at seven lakes to be used to update area capacity curves to reflect the changes in storage volumes as a result of sedimentation. The seven lakes are (1) East Sidney, (2) Whitney Point, (3) Bush Dam, (4) Stillwater, (5) Aylesworth Creek Lake, (6) Jennings Randolph, and (7) Almond Lake. The lakes are located in the vicinity of northern Pennsylvania, West Virginia, and New York.

2. Information Supplied by the Government:

a. Copies of USGS Quadrangle sheet covering the five lakes with pertinent areas outlined.

b. Copies of project maps for each lake.

c. Copies of mapping specifications, for merging hydrographic surveys with the mapping being performed by others.

d. Copy of list detailing specification for individual lake. Sounding range distance interval for the lakes are listed for each lake.

e. Copy of memo from Baltimore District detailing survey requirements to be coordinated with the St. Louis District.

3. Work to be Performed by the Contractor:

The Contractor shall provide equipment, supplies, personnel, and survey boat fully equipped to perform control and standard hydrographic surveys utilizing differential global positioning system technology. Specific work shall include:

a. Take sounding along range lines spaced at 100 ft to 250 ft. intervals, but close enough so each lake bottom can be adequately defined for mapping purposes, for hydrographic surveys on the seven (7) lakes furnished in 2.b above. The surveys must be obtained during periods when each lake is below the summer conservation pool (elevation on list provided in 2.d above. The Contractor is required to maintain close coordination with CELMS-ED-HG (Bob Mesko) or CENAB-EN-GW (Bill Haines) to ensure water conditions are being met for each survey. Calibration for fathometer shall be obtained and submitted for each lake surveyed. The surveys shall meet the requirements for class I hydrographic surveys at stated in EM 110-2-1003, 31 October 1994, "HYDROGRAPHIC SURVEYING".

b. Gage readings shall be recorded twice each day for the nearest upstream and downstream gages where soundings are being taken. Also, if surveying in an area where lake gages may not accurately reflect water surface conditions, levels shall be run to water surface.

c. All surveys shall also be submitted to the St. Louis District in 3D CADD files fully operational on ARC/INFO GIS system. For hydrographic surveys, reference soundings to the National Geodetic Vertical Datum (NGVD).

d. The Contractor shall prepare a bathymetric contour map for each lake showing 1996 conditions, extending from the lowest points in each lake up to the summer conservation pool elevation. The desired contour interval is two (2) feet and the horizontal scale is 1 inch equals 200 ft, unless other scales become required to match the mapping being performed by others. Plots shall be provided for both the soundings data in NGVD and contours.

e. Paper check plots shall be provided to the Government for checking and reviewing of the finished product. The maps shall be prepared on standard engineering size drawings (30" x 42"). The standard Baltimore District title block shall be placed in the lower right corner.

f. Using the hydrographic surveys, compute elevation-area and elevation capacity relationships for each lake from the lowest point in the summer conservation pool elevation. The Contractor shall furnish data in both tabular and graphical format.

g. Visits to each project site shall be pre-coordinated (date, time, purpose) with Mr. William Haines, who will advise the dam operator. Upon arriving at a project site, St. Louis District personnel or their contractors shall check in with the dam operator before beginning work

h. Lakes at the various projects are subject to rapid and frequent changes in water levels, depending upon hydrologic conditions. Field work should be scheduled and accomplished with the understanding that the lake levels may fluctuate daily or even hourly, and there may be times when vessels are prohibited on the lakes.

i. The Contractor shall compare the DGPS positioning system to a minimum of one known survey control point in the vicinity of each lake surveyed.

4. End Results Expected:

a. Listing (coordinates) of any additional horizontal control established. Include field books showing plan view, location, references, and procedures used to establish new points. Field books shall include neat sketches showing bearings, angles, and taped distances to at least three nearby distinct permanent objects.

b. Quality reproducible mylars and five black line copies of the 1996 contour maps and soundings. Electronic data files for bathymetry maps in both contour and elevation form, for use in an ARC/INFO system as described in para. 3.d above. Maps shall be prepared on standard engineering size drawings (30"x42"). The standard Baltimore District title block shall be placed in the lower right corner.

c. Fathometer scrolls showing sounding lines cross-referenced to plan view plots in 4.b. above, complete set of survey notes, 3.5-inch diskettes, and any other medium containing raw survey data. This package is to be accompanied by documentation indicating the data type, the data format, and general instruction for its retrieval.

d. New monuments established in the field as necessary to perform hydrographic survey.

e. Corps of Engineers Form DA 1959 completed with information concerning any new control points which may have been set.

f. Diskettes containing the 3D CADD digital data files of the hydrographic surveys, fully operational on the District ARC/INFO system.

g. Original and five copies of curves and tables for the 1996 elevation-area and 1996 elevation capacity relationships. Electronic data files for curves and tables will also be submitted.

h. Bi-weekly progress reports shall be submitted to the St. Louis District and Baltimore District. This report may be made electronically (e-mail) or via fax. The POC in Baltimore is Mr. J. William Haines, CENAB-EN-GW, Phone (410) 962-6768 and FAX (410) 962-4972.

5. Schedule and Submittal:

The Contractor shall prepare and submit all pertinent data to the Corps of Engineers, ED-HG (Attn: Bob Mesko), 1222 Spruce, St. Louis, MO 63103-2833 by 31 January 1997 for every project except Jennings Randolph Lake. For Jennings Randolph Lake all information and deliverables not later than 1 June 1997 shall be submitted. Close coordination is required with ED-HG (Bob Mesko) to ensure the surveys are being obtained during period of summer conservation pool and before draw down occurs. Incremental submittals of surveys are required for the District to comment on format and content of the data. Scheduled draw downs will occur in the fall at East Sidney Lake and Whitney Point Lake. Field work must be completed at these project not later than 15 November 1996. Jennings Randolph is already being drawn down for the winter season. Refilling normally occurs in the early spring, but remains at full conservation pool for only a few weeks before whitewater, water quality, and water supply releases begin. It is anticipated that the hydrographic survey for this project will be scheduled for late March or early April 1997.

Hydrographic surveys, bathymetric maps, and area/capacity computations may be submitted to the Baltimore District and St. Louis District as projects are completed.

6. Time Extensions:

In the event these schedules are exceeded due to causes beyond the control and without fault or negligence of the contractor, as determined by the Contracting Officer, this delivery order completion date will be extended one (1) calendar day for each day of delay.

---

b. Final survey report for Almond Lake. Following is the final survey report submitted by the contractor in May of 1997 transmitting the sedimentation survey results for one of the seven reservoirs included under the task order.

SURVEY REPORT

ALMOND LAKE, NY
CANACADEA CREEK
SUSQUEHANNA RIVER BASIN
HYDROGRAPHIC CONDITION SURVEY

CONTRACT DACW43-96-D-0512 (ST. LOUIS DISTRICT)
TASK (DELIVERY) ORDER NO. 003

TVGA Engineering, Surveying, P.C. was requested by the US Army Engineer District, Saint Louis to provide Professional Hydrographic Surveying Services to the US Army Engineer District, Baltimore under Delivery Order Number 003 of Indefinite Delivery Contract DACW43-96-D-0512. TVGA's general responsibilities related to this project consisted of the following:

1. Conduct a hydrographic condition survey to update area capacity curves that would reflect any changes in the storage volumes as a result of sedimentation. The survey operations were to be conducted at a time when the pool elevation was at/or above the recreation level. The limits of our survey were to extend to all portions of the lake which were navigable with a shallow water survey system.

2. Convey results of the field survey through preparation of deliverables that include but are not limited to: plan view mapping to present hydrographic data obtained by the survey and contours at a 2 ft interval and to provide an updated area/capacity table and curves.

RECORD RESEARCH AND SURVEY SETUP

TVGA retrieved 7.5-minute United States Geodetic Survey (USGS) quadrangle maps from in-house records to plan the survey. The contour depicting the recreation pool elevation of 1260' above the National Geodetic Vertical Datum of 1929 9 (NGVD 29) was digitized from the quadrangle maps and subsequently used to pre-plan the location of cross sections to be surveyed. Cross sections were spaced at a 250' maximum interval and generally situated perpendicular to hydraulic flow--[see Figures 20-2 and 20-3]. The digitized cross sections were uploaded into Coastal Oceanographics' HYPACK Software and subsequently used during field operations as a base reference for left/right navigation information on the survey vessel.

HYDROGRAPHIC CONDITION SURVEY

The survey was conducted at a time when the top of water elevation was above the recreation pool elevation of 1260'. An automated electronic survey system was used to collect hydrographic survey data. The survey system was mounted on-board a 16' aluminum boat. The survey vessel's hull draft of approximately 0.9' and a propulsion draft of approximately 2.0' permitted safe navigation into 2.5' of water. Horizontal positioning data was supplied by an Omnistar, Inc. Model 6300A Differential Global Positioning System (DGPS). Depth data was provided by an Odom Hydrographic Inc. Model DF 3200 Mark II Echo Sounder equipped with a single 208 kHz / 3 degree transducer. Horizontal positioning data and digital depth data were logged directly onto a Toshiba 4400C laptop computer equipped with Coastal Oceanographics' HYPACK Hydrographic Survey Software. HYPACK Software was utilized to plan the survey, display real time vessel navigation information and review survey data on a daily basis.

The survey was performed in accordance with Class I accuracy specifications as described in the US Army Corps of Engineers Engineering and Design Manual EM 1110-2-1003, dated October 31, 1994 and titled Hydrographic Surveying. A generalization of specifications contained in the above EM manual that were implemented during field survey operations included but were not limited to:

1. A daily check and/or calibration of the echo sounder to verify and/or adjust for draft, squat and sound velocity. The Daily Depth Sounder Calibration Logs are included in Section H of this report.

2. A relative check of the Omnistar positioning system was made on a daily basis. This was accomplished by recovering and subsequently comparing the published geodetic coordinates of a National Geodetic Survey (NGS) survey marker with geodetic coordinates derived by the Omnistar positioning system. Xerographic copies of the field notes documenting the daily comparison are included in Section H of this report.

3. Collecting and reviewing data along cross section check lines (longitudinal sections).

4. Compensation for system latency.

Reasonable care was taken in the preparation and performance of the survey to ensure the best possible results. Copies of daily calibration reports are included Section H of this report. Weather and atmospheric conditions at the time of hydrographic survey did not in our opinion contribute any degradation in the expected survey results.

At the conclusion of the survey, the US Army Engineer District, Baltimore supplied TVGA with a Xerox copy of hourly pool elevation data recorded by an electronic gage located near the dam. As a precaution to loss of this electronic gate data, TVGA periodically interrogated the gage during survey operations and reported the data in a hard bound field book.

PREPARATION OF PROJECT DELIVERABLES

The hydrographic survey data was up-loaded onto a office based computer equipped with Coastal Oceanographics' HYPACK Hydrographic Survey software. HYPACK Software was utilized to sort, edit and apply water level corrections to digital cross section data. Digital depth data was compared against analog depth charts to correct (edit) depth spikes or false bottom returns caused by interference in the water column. Cross section data was sorted (thinned) to a 20' interval.

The edited cross section data set was read into a Bentley Systems, Inc. MicroStation 95 Version 5.05 3D CADD format. The cross section data was reviewed and a series of terrain break lines were constructed through the low point of each cross section and around the perimeter of the lake. A Triangulated Irregular Network (TIN.) was developed by Intergraph Inroads Version 5.01 software. Contours at 1' and 2' intervals were derived from the digital TIN generated from field collected hydrographic survey data and digital terrain break lines. (Figure 20-4)

Plan view mapping that shows final elevations from echo soundings and contours at a 2' interval was drafted at a scale of 1"=200'. The mapping was finalized using the aforementioned MicroStation software. The mapping is in compliance with the US Army Corps of Engineers, Engineering and Design Manual EM 1110-1-1807, dated July 30, 1990 and titled Computer-Aided Design and Drafting (CADD) Systems. Copies of this mapping plotted at ½ the original size are included in Section E of this report.

The contours generated at a 1' interval were read into Eagle Point software through a Drawing Interchange Format (.DXF). This software was used to compute areas and storage volumes at a 1' interval. The digital ASCII reports produced by Eagle Point software were read into Microsoft Excel Version 7.0. to finalize the area/capacity table and curves.

A system of checks and balances were performed on data to ensure the data's integrity and completeness. A comparison between new and old area/capacity data revealed some differences. The reasons for these differences can most likely attributed to the dynamic environmental conditions (sediment transfer) inherent to this type project, dissimilarities in methodology and equipment used to conduct the original field survey and the new survey and methodology used to compute the storage capacities.

POINTS OF CONTACT (Phone 716-655-8842)

Project Manager: Clinton E. Johnson

Field Work: Aaron C. Kennerly

Processing: Scott E Waite

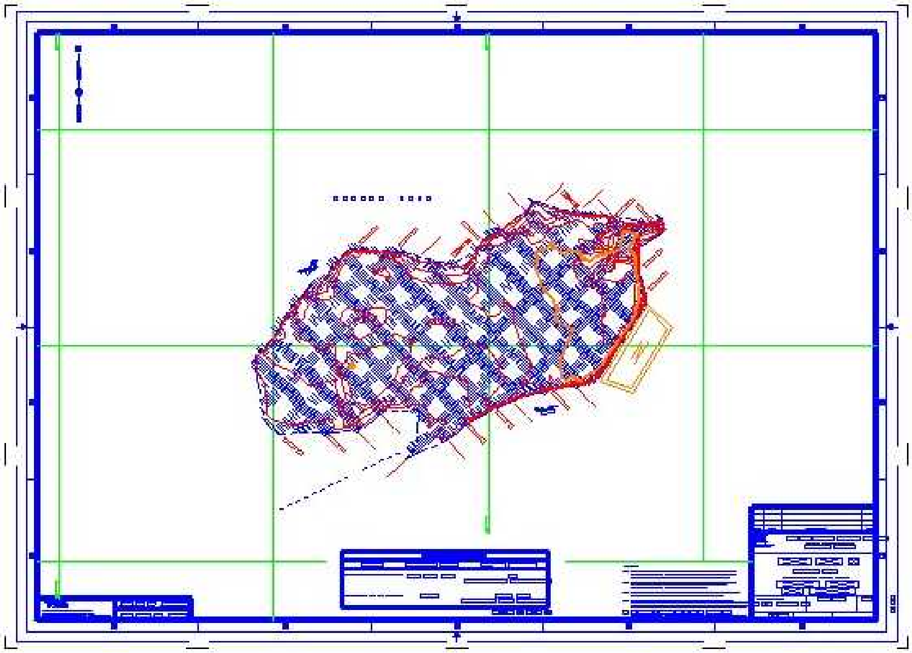


Figure 20-2. Line spacing and alignment layout for hydrographic surveys of Almond reservoir (TVGA, Inc.)

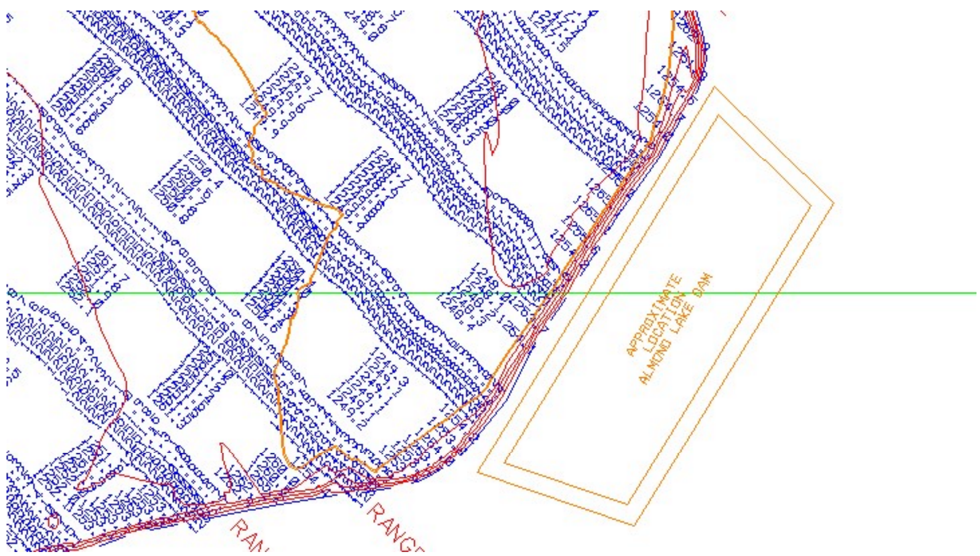


Figure 20-3. Detail of survey vicinity Almond Lake Dam. 2-ft contours shown on drawings--
1-ft contours used to compute storage capacities (TVGA, Inc.)

20-4. Area-Capacity Computations

The contractor submitted preliminary area-capacity computations between elevations 1244 and 1260 ft, using procedures described in the above report. The elevations between 1257 and 1260 ft were estimated using digitized quad maps. Once the subsequent photogrammetric DTM was delivered by Horizons, Inc., the district computed area-capacities using the full elevation range up to the top of dam at 1320 ft.

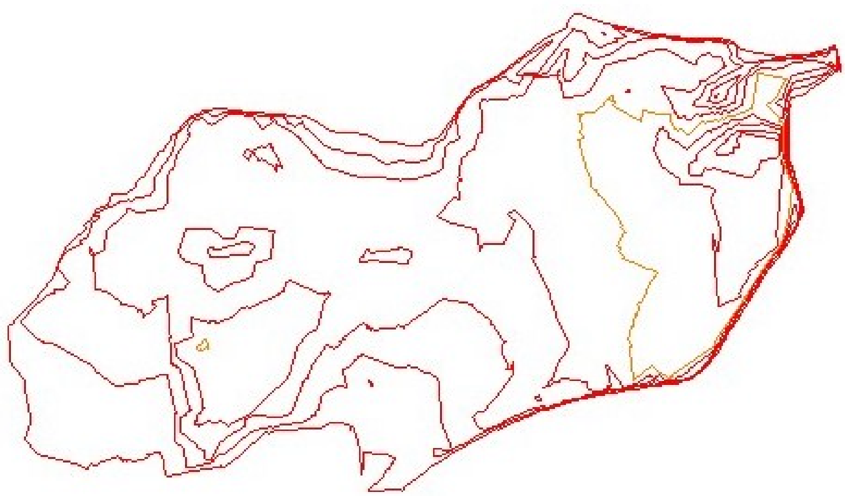


Figure 20-4. Reservoir storage contours generated from Triangulated Irregular Network using MicroStation Inroads. Note that only 2-ft intervals are shown

Area/Capacity Table -- Almond Lake, New York
Revised June 1998 by Baltimore District Water Control Management Section

Elevation NGVD 29 (ft)	Area Acres	Capacity Acre-ft	Inches of Runoff	
1229	0.0	0.0	< 0.01	Intake Sill elevation
1230	0.0	0.0	< 0.01	
……				
……				
1241	0.0	0.0	< 0.01	
1242	0.0	0.0	< 0.01	
1243	0.1	0.1	< 0.01	
1244	0.2	0.2	< 0.01	
1245	0.9	0.8	< 0.01	
1246	1.5	2.0	< 0.01	
1247	3.8	4.7	< 0.01	
1248	6.0	9.5	< 0.01	
1249	12	19	0.01	
1250	18	34	0.01	
1251	30	58	0.02	
1252	42	94	0.03	
1253	60	144	0.05	
1254	77	213	0.07	
1255	87	295	0.10	
1256	96	387	0.13	Areas below elevation 1260 ft
1257	104	487	0.16	from hydrographic surveys
1258	111	594	0.20	
1259	123	711	0.24	
1260	135	840	0.28	Conservation/Recreation Pool
1261	142	978	0.33	
1262	150	1125	0.38	Areas above elevation 1260 ft
1263	158	1278	0.43	from aerial mapping surveys
.				
.				
1300	492	13397	4.50	Spillway elevation
.				
.				
1306	540	16,277	5.47	

NOTES:

A. Drainage area = 55.8 sq miles
B. 1 in. of runoff = 55.8 mi^2 * 640 ac/mi^2 * 1 ft/12 in. = 2,976 acre-ft
C. Areas and capacities computed using TVGA, Inc. hydrographic project survey dated 20-21 November 1996 and Horizon, Inc. photogrammetric mapping surveys from June 1998
D. Spillway crest = 1,300 ft
E. Area/capacities for all elevations not shown

20-5. Area-Capacity Curves

Figure 20-5 illustrates a standard Area-Capacity curve for reservoir storage. This particular curve area-capacity curve is based on the hydrographic data obtained up to 1257 ft plus digitized quad elevations up to 1260 ft. The final area-capacity curve from the full DTM is not shown.

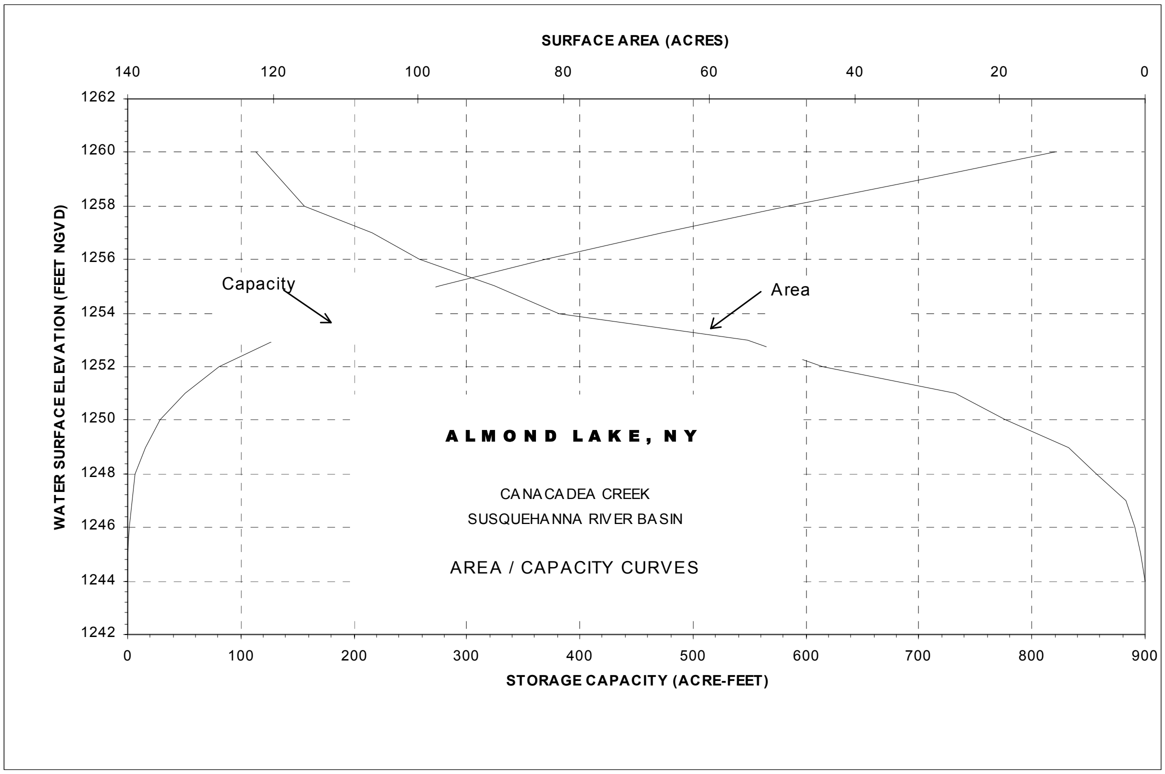


Figure 20-5. Preliminary area-capacity curve below conservation pool at time of survey

20-6. Mandatory Requirements

There are no mandatory requirements associated with this chapter.

Chapter 21
Depth Measurement Over Irregular or Unconsolidated Bottoms

21-1. General Scope

Determining the clearance or payment grade is difficult when irregular rock fragments, soft strata, or suspended sediments are present. This commonly occurs during dredging activities when the excavation process has agitated the bottom material, resulting in clouds of suspended sediment material, often termed "fluff." In some cases, low-density saturated soils are naturally present, and a finite reference grade is difficult to define (especially for contract purposes). Other difficult depth measurement conditions include fluid mud, gassy sediments, wavy bottoms, moving bottoms, and vegetated bottoms. Also, small rock fragments may not reflect sufficient acoustic energy to be detected on standard echo sounders. Industrial waste can create problem areas where there are large discharges of organic material, such as downstream of paper or pulp mills where the suspended organic material can be acoustically very reflective but have very low shear strength. When the upper sediment layer is not well consolidated, the three major depth measurement methods used in USACE (sounding pole, lead line, and acoustic echo sounding) will generally not correlate with one another, or perhaps not even give consistent readings from one time to the next when the same type of instrument or technique is used. These potential variations in depth are shown in Figure 21-1. This chapter presents information about the causes of difficult bottom conditions and describes means of obtaining acceptable depth data in spite of the difficulties.

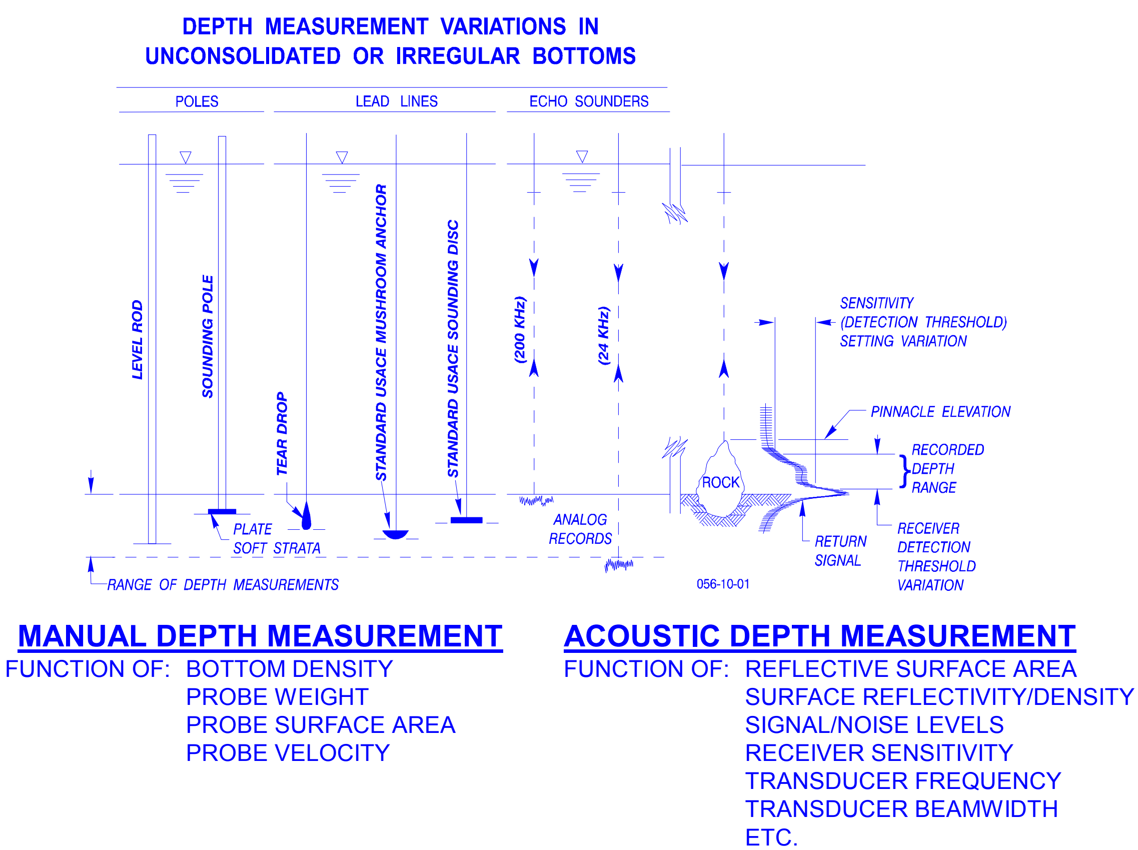


Figure 21-1. Depth measurement variations over hard and soft bottoms

21-2. Causes of Suspended Acoustically Reflective Material

Causes of fluff layers, fluid mud, and other soft bottom conditions are not understood very well. A significant amount of research has been conducted to improve an understanding of these effects and to develop improved methods of determining and defining the nautical bottom. Fluff conditions are reported most frequently from districts that maintain waterways in the warm-weather sections of the country. Fluff conditions are most prevalent in estuaries where mineral-laden fresh water mixes with salt water. In the mixing zone, the freshwater minerals react with the salt water and come out of solution as flocculates. These flocculate particles can be very close to the density of water and can hang in suspension for a long time. Several layers of progressively denser material can occur. The density within such a layer of suspended material tends to remain relatively constant.

a. Dredging impacts. Conditions downstream from a dredge will probably also be quite different from those described in the preceding paragraph. The suspended material will not become stratified for some time after being stirred up by the dredge, and a return signal can result from reflection and dispersion of the signal from a wide vertical portion of the water column. The acoustic reflection analysis given above, using the stratified layer concept, does not apply to turbulent non-stratified conditions such as this. While not applicable to depth measurements, acoustic reflection techniques have been used in research studies to trace the extent and time duration of the plume of suspended material resulting from dredge operations.

b. Currents. Swift natural currents also can cause turbulence that stirs up sediment material in clouds. This condition, like dredge turbulence, can cause acoustic reflection that will obscure normal reflection from the consolidated sediments of the waterway bottom. Acoustic reflection analysis of layer reflections does not apply to this condition.

c. Fluid mud. Fluid mud is sediment material that is heavy enough not to be suspended in the water but has no shear strength as does consolidated sediment material. Fluid mud can occur in layers 10 to 20 ft thick (as in the Europort channel), and the density can vary significantly from the top to the bottom of the fluid mud layer. A ship can pass through fluid mud without being grounded. The nautical bottom for this condition must be defined on the basis of effects that significantly impair the ship's steerage or speed. The nautical bottom, if defined on a density basis, may occur within the fluid mud layer. Acoustic reflection techniques, as currently developed, cannot define the nautical bottom within a layer. In such instances, direct contact methods must be used.

21-3. Acoustic Depth Measurement in Suspended Sediments

Figures 21-2 and 21-3 illustrate the kind of depth records that can occur when surveying over waterway bottoms with soft material surfaces or suspended material above the consolidated sediment surface. These records cannot be interpreted reliably unless other correlating information is developed. Automated depth digitizers will be even less reliable in providing a depth reading because such equipment cannot use any judgment in deciding whether to accept or reject the incoming information. Thus, the use of sophisticated computer-based survey systems does not help in this type of surveying environment, as far as getting good, reliable data is concerned. Records such as those depicted in the these figures result from the fundamental principle on which acoustic depth sounding is based. When there is a difference in density of the underwater material, some of the incident acoustic energy will be reflected. When using high-frequency transducers (i.e., 200 kHz), even very small density differentials will cause sufficient energy to be reflected, causing the depth sounder to print a return on the analog chart. For this reason, lower frequency transducers may be required to adequately depict the bottom.

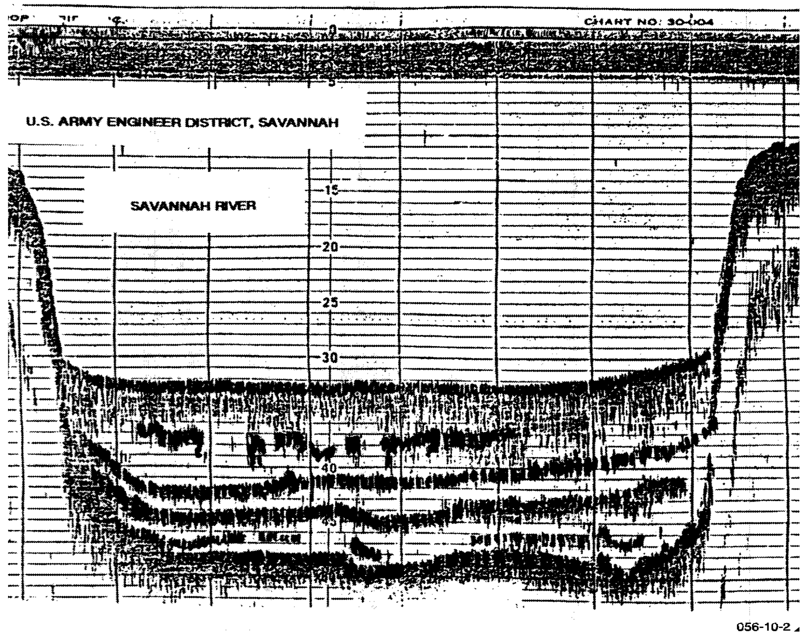


Figure 21-2. Suspended sediment record from Savannah River (Savannah District)

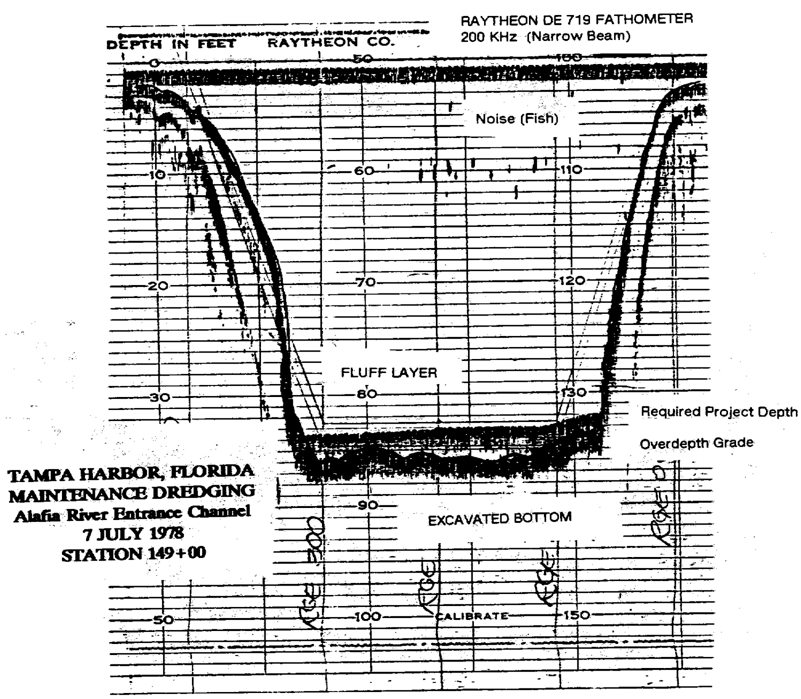


Figure 21-3. Suspended sediments on After-Dredge survey of Tampa Harbor (Jacksonville District)

a. Acoustic impedance. Figure 21-4 illustrates the reflection of acoustic energy from multiple stratified layers of underwater material. The percentage of acoustic energy reflected at each density interface surface is a function of the relative densities of the two layers. An equation for the acoustic reflectivity of an underwater surface is given in Figure 21-4. In this equation, the acoustic impedance of water is equal to the density of water in grams/per cubic centimeter times the velocity of acoustic energy in water in centimeters per second. Acoustic impedance of the underwater layers is equal to the density of each layer times the velocity of sound in that layer. This equation is valid only for the simplified case in which the change in material composition from one layer to another occurs in a short vertical length compared to the wavelength of the incident energy. A more rigorous analysis would require that the density gradient from one layer to the other be known. Such an analysis is beyond the scope of this manual.

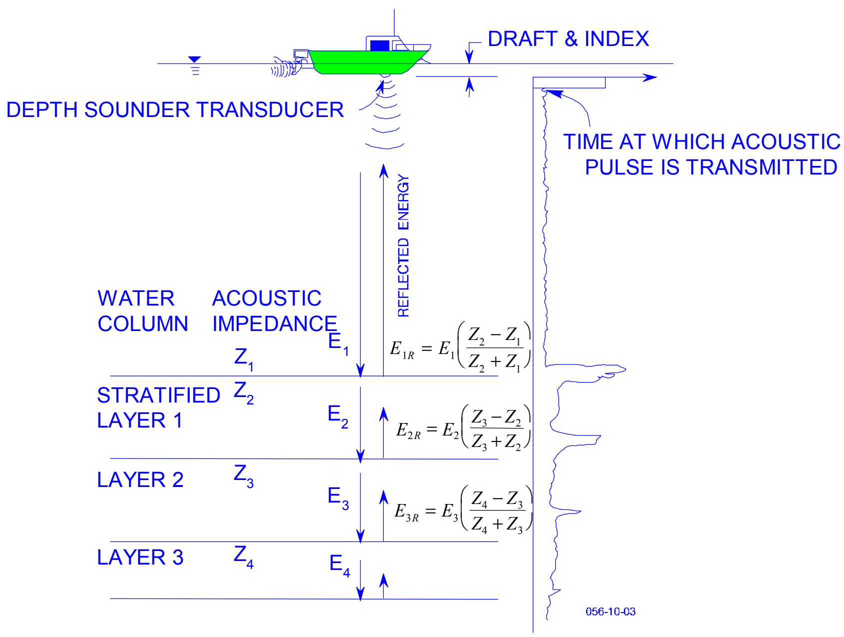


Figure 21-4. Acoustic impedance changes in differing sediment densities

b. Echo sounder sensitivity control. An important point to remember is that the amplitude of the first signal return is proportional to the density of the upper layer. Thus, a hard sand surface layer will give a much stronger signal return than a low-density fluff surface layer, no matter what frequency is used (see Figure 21-5). Keeping this fact in mind can be helpful in making a rational setting of the sensitivity control on a depth sounder. Consider the situation in which a survey is under way and the depth chart recording begins to print irregularly in a particular area. The natural tendency is to adjust the depth recorder sensitivity control until the depth chart prints a solid line again. Increasing the sensitivity of the recorder permits the chart to print a depth mark on the basis of a signal return from a softer bottom. The potential problem with this type of adjustment is that the higher sensitivity may cause the depth chart to register a "fluff" layer and not a true bottom. Thus, do not "crank up" the sensitivity control to keep a solid line on the recorder and do nothing else. If a sensitivity adjustment is necessary, it is also necessary to make a correlating depth check using one of the alternate depth measurement techniques described in this chapter. If the alternate method agrees with the depth chart, the sensitivity adjustment is probably warranted. If there is no correlation, use of the alternate depth measurement method is indicated (e.g. lead line, nuclear density probe).

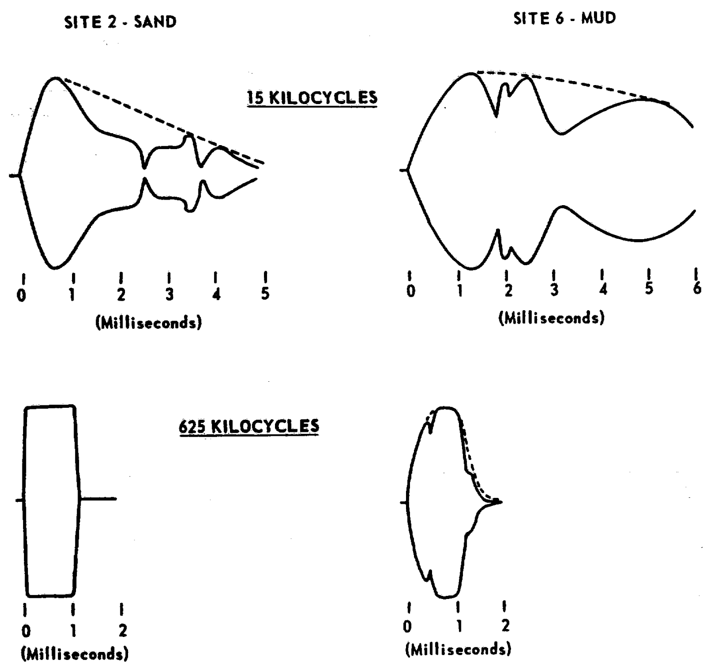


Figure 21-5. Signal return variations from sand and mud

c. Acoustic signal return in multiple sediment layers. When acoustic energy hits the upper surface of an underwater layer of material, some of the incident energy is reflected and some continues downward through that layer and hits the next layer. At the next interface, some of the energy is reflected and some continues downward. At each interface between layers, this process continues, with the incident energy becoming smaller with each transition due to reflection, attenuation, and scattering. Energy is reflected principally at the interface surfaces between layers and not in the interior of the layers, except where particles within a layer cause a local density gradient. Figure 21-6 depicts a 24-kHz signal return from multiple layers of material.

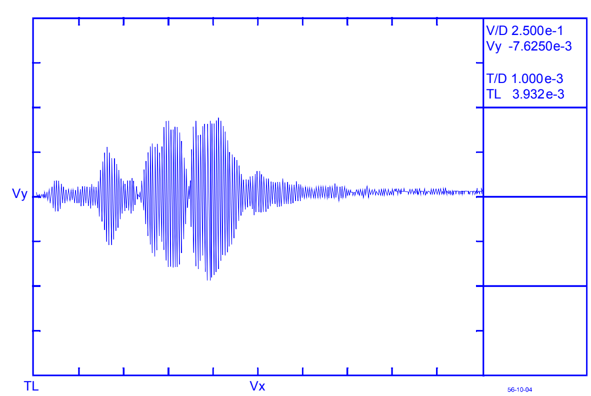


Figure 21-6. 24 kHz signal return in multiple sediment layers

21-4. Attenuation of Acoustic Energy in Suspended Sediments

As acoustic energy passes though a material such as water, underwater sediments, or suspended material, some of the energy is absorbed and the signal becomes weaker with the distance traversed. Energy absorption is referred to as "attenuation" and is usually given in decibels (dB). Different types of underwater materials will have different attenuation effects, and signal calculations must take this factor into account. At each interface surface, the downward-going acoustic energy will be reduced by both the preceding reflection reduction and the attenuation loss. The upward-going acoustic energy suffers the same reduction in amplitude ratio as does the downward-going energy (from attenuation and reflection redirection at each layer interface). These effects are doubled on the upward-going energy through the soil layers because it has twice the path length to traverse and must lose a proportion of reflected energy at each interface surface. Thus, because of the attenuation and reflection, a progressively smaller portion of the reflected energy comes from the lower layers of sediment, and the reduction in signal amplitude is drastic. The signal strength returning to the depth sounder transducer is an extremely small percentage of the transmitted energy. Only by electronic amplification is it possible to detect such minute signals.

a. Effect of frequency on attenuation. Attenuation of acoustic energy is directly proportional to the frequency, as illustrated in Figure 21-7. Thus, 200-kHz energy is attenuated ten times as rapidly as is 20-kHz energy when passing through the same material. Since high-frequency energy is attenuated more than low-frequency energy, a much smaller proportion of the high-frequency energy comes back to the depth sounder transducer from the lower layers of sediments than is the case with the low-frequency energy.

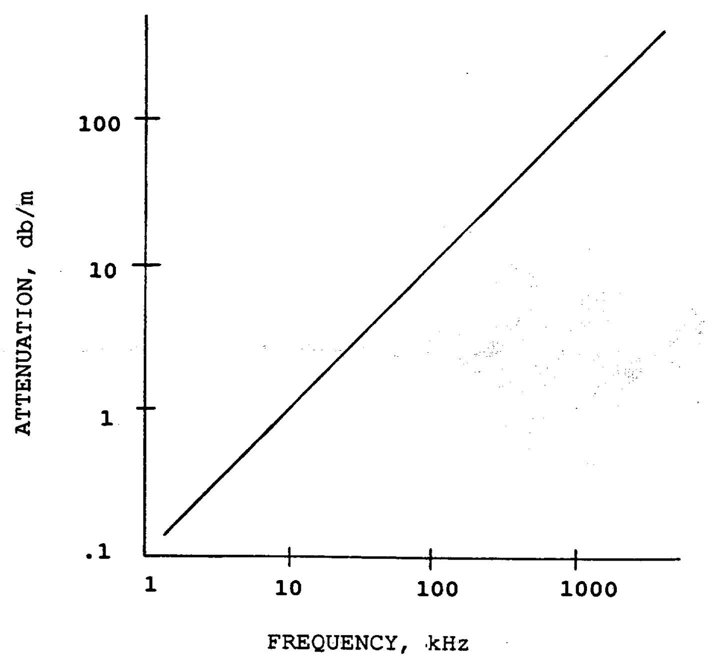


Figure 21-7. Acoustic signal attenuation versus frequency

b. Attenuation of different frequencies. An example showing the effect of attenuation as a function of frequency is given in Figure 21-8. This is a graph of the amplitude of the output from a 200-kHz transducer (upper curve) and the output from a 24-kHz transducer (lower curve). The two transducers were mounted side-by-side and aligned so that the response pattern of both transducers was vertical. Both transducers transmitted simultaneously, and the time scale is the same for both transducers. The 200-kHz channel was adjusted to have a higher gain than the 24-kHz channel so that the maximum amplitude of both channels, as viewed on the graph, was comparable. Due to the high attenuation of the 200-kHz signal, there is no detectable energy received from the lower sediment layers even though they had a higher density. The 24-kHz signal shows a maximum amplitude at one of the lower sediment layers because the attenuation of the 24-kHz signal in the upper layer is relatively low and the reflectivity of the upper layer is quite low. In this example, both transducers show the reception of first reflected energy at the same time. The 24-kHz energy reflected by the upper layer (the primary reflector of 200-kHz energy) appears to be very low in amplitude. The amplitude of the first layer reflection is, however, just as large at 24 kHz as it is at 200 kHz. However, the ratio of this reflectivity to the lower reflectivity gives the higher amplitude at the lower layer. The main point is that the reflectivity is about the same at both frequencies, but the attenuation is much higher for the higher frequency. The net result is that the high-frequency depth channel normally registers the upper layer of reflective material, even a very low-density one, and the lower frequency depth channel will register a lower layer if that lower layer has a higher acoustic reflectivity than the upper layer. Low-frequency depth sounders will always penetrate to a lower depth than will higher frequency energy at the same transmitting power level and receiver sensitivity. From a hard upper surface such as sand or rock, the surface reflection will be the maximum reflection amplitude for either a high- or a low-frequency signal.

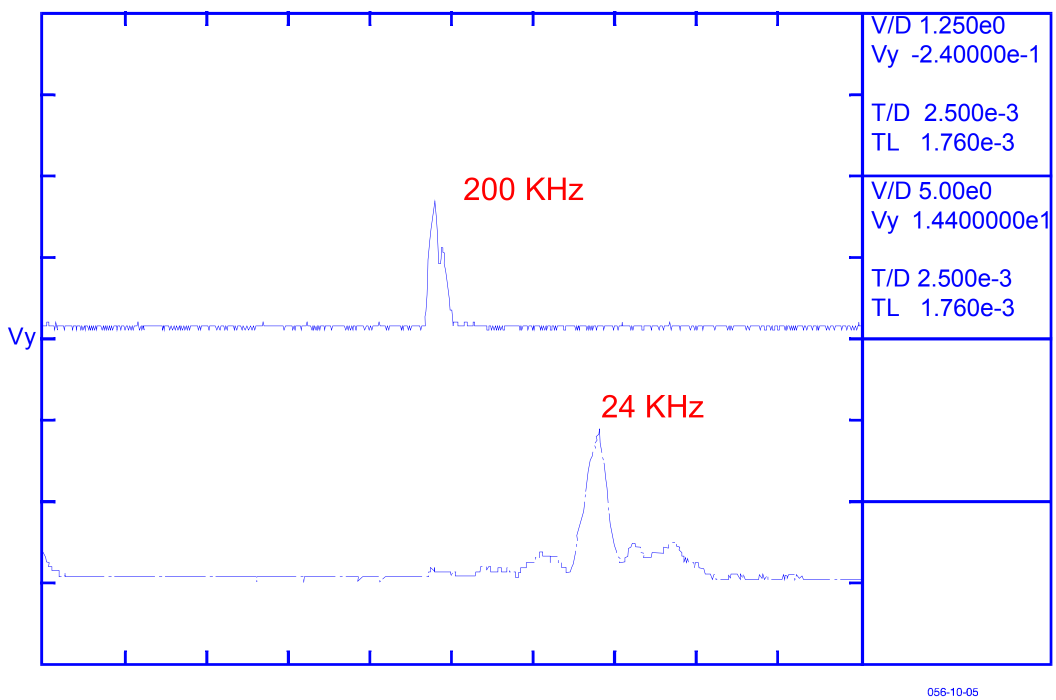


Figure 21-8. Comparison of 24- and 200-kHz signal attenuations

21-5. Effects of Surface Roughness and Incident Angle

Amplitude of the reflected signal will be affected by both the surface roughness and the incident angle. For depth sounding over level bottoms, the acoustic path will be close to vertical when using narrow-beam transducers or vertically aligned transducers. This simplified assumption is not valid for multibeam systems and when working with single-beam systems over sloping surfaces, when the survey boat is pitching and rolling, or when the transducer is not narrow-beam.

a. The four quadrants of Figure 21-9 illustrate some effects of surface roughness and bottom surface density. Quadrant 21-9a illustrates the reflection, refraction, and dispersion effects on a smooth hard bottom surface. Under these conditions, a high percentage of the incident energy is reflected and the dispersion of the reflected signal is low. Low dispersion results in a stronger signal along the reflection path. A vertical signal path and level bottom give the strongest possible signal return to the depth transducer. If the bottom surface is a sloping rock surface, a very low signal return may result because the energy would be directed away from the transducer in much the way a mirror reflects light. For this reason, small irregularly shaped rock fragments with smooth surfaces may go undetected by conventional echo sounders.

b. Quadrant 21-9b illustrates the reflection, refraction, and dispersion effects on a rough high-density bottom surface. In this instance, a much higher percentage of the incident energy is dispersed at angles different from the main reflection path. High dispersion results in a lower signal along the main reflection path. When the signal path is vertical and the bottom is level, there is a weaker signal return to the depth sounder transducer than under the conditions shown in quadrant 21-9a. When the bottom surface is not level, the rough surface illustrated in quadrant 21-9b may give a higher signal return than the smooth surface. As an example, a rough-surfaced boulder would be much easier to detect than a smooth-surfaced boulder.

c. Quadrant 21-9c illustrates the reflection, refraction, and dispersion effects from a smooth low-density bottom surface. A fluff layer in a channel without wind or currents to disturb the surface would approximate this condition. In this instance, low dispersion results in a stronger signal path along the reflection path. If the signal path is vertical and the bottom is level, most of the reflected energy is directed back at the transducer. The reflected energy would still be relatively low due to the low density. It is improbable that a low-density material will have other than a small surface angle because it will migrate down the slope.

d. Quadrant 21-9d illustrates the reflection, refraction, and dispersion effects from a rough low-density bottom surface. A fluff layer in a channel with wind or current to disturb the surface would approximate this condition. In this instance, the high dispersion in the surface reflection results in a weaker signal along the reflection path than the conditions illustrated in quadrant 21-9c.

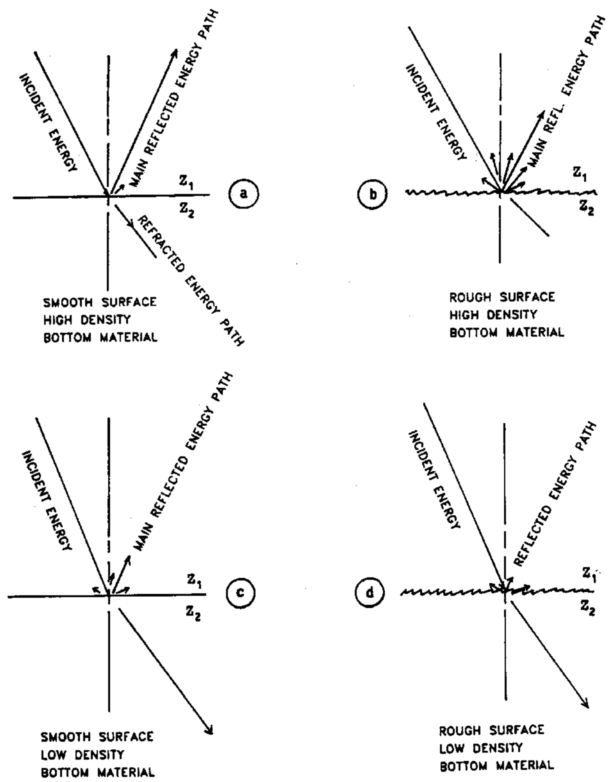


Figure 21-9. Effect of surface roughness

21-6. Alternative Depth Measurement Techniques in Suspended Sediments

The preceding paragraphs emphasize the principles underlying the operation of acoustic depth sounders and limitations of this technique under these difficult conditions. All depth measuring techniques have their limitations and constraints. The acoustic reflection technique was discussed first because it is by far the most widely used depth measurement technique. In the following paragraphs, the uses and limitations of other depth measuring techniques will be discussed.

a. Lead lines or sounding disks. Depth measurement using a lead line or sounding disk is usually considered a slow but very reliable method of determining depth. With hard bottom material, this assumption is valid. However, with soft bottom materials, it may not be. A lead weight will fall until the shear strength of the sediment is sufficient to stop the vertical movement of the weight. The high density of the lead weight is such that it will never come to an equilibrium depth on the basis of density. The shear strength of sediments can be affected by the velocity of the lead weight, stirring action, and the amount of time that the weight is allowed to rest on the soft sediment.

(1) As a result, two different people using the same lead line can get different results, depending on the length of time the weight is allowed to rest on the bottom and whether or not the weight is jiggled a bit to feel the bottom. With soft bottoms, it is difficult to feel when the weight actually touches bottom. Moving the weight while it is on the bottom tends to break down the internal structure of the soft sediment and convert it from a semi-solid to a viscous liquid, causing the lead line to sink deeper than if handled otherwise.

(2) In addition to not stopping at a consistent level, a lead line may not stop at a level that is an acceptable nautical bottom. For instance, a lead line pass through a sediment layer with a consistency of mayonnaise, but this kind of layer would probably so disrupt a ship's steerage that it would be unacceptable to shipping interests. A sediment with mayonnaise consistency would, however, probably give a good response on an acoustic depth sounder. This also would be the correct surface to call bottom for dredge need analysis. This example is given to show that when acoustic depth sounders and lead lines disagree, the assumption should not be made that the lead line is the correct depth. Other correlating information may need to be developed.

(3) Even with the above deficiencies in lead line measurements, it is still the most common method used to correlate echo sounder readings when suspended sediments are present. Lead line observations are compared with high- and low-frequency recordings to assess channel clearance and to arrive at an equitable payment for material removed.

b. Nuclear density probes. Nuclear density probes can be used to measure the density of bottom sediments. Most nuclear density probes work on the principle that a more dense material will absorb a higher percentage of the radiation passing from the source to the detector than will a less dense material.

(1) A typical probe is configured so that the sediment material passes between the source and detector as the probe is lowered. Nuclear density probes can give an accurate graph of sediment density as a function of depth if properly calibrated and used.

(2) Nuclear density probes are used as the standard depth measuring technique in the Netherlands, where fluid mud is a widespread condition and neither acoustic reflection nor lead line depth sounding techniques will give acceptable results. The Port of Rotterdam uses crane-supported nuclear probes to measure in-situ channel density from survey vessels. The probes describe the “nautical bottom.” The term “nautical bottom” has been used in Rotterdam at the maintained channel depth where the fluid mud is allowed to densify up to a 1.2 specific gravity maximum before dredging is required (USACE uses a specific gravity of 1.1 to define the nautical bottom). This definition for the maintained channel depth has amounted to a considerable savings in maintenance since the 1970s for Rotterdam's Europort.

(3) Nuclear density probes will not work in areas where there has been a discharge of radioactive material into the waterway. Calibration of nuclear density probes depends on having a uniform natural background radiation level in the area when the probe is to be used. Water discharged from industrial and government facilities has sometimes in the past contaminated the sediments with low-level radioactive wastes. These wastes distort the background radiation level and will cause the apparent density of the sediments to be seriously in error.

(4) Another limitation to the use of nuclear density probes is the severe regulations governing their use, including the extensive paperwork involved. Nuclear density probes can be used only by licensed personnel, and the license is difficult to obtain. Nuclear probes must be stored under special conditions that are expensive to implement and maintain. As a result, nuclear density measurements are generally not practical for most Corps applications.

c. Acoustic density probes. Acoustic density probes work in a manner similar to nuclear density probes. An acoustic signal passes between a source and a detector, with the material to be measured passing between the source and the detector. The probe is configured so that the sediment passes between the source and the detector as the probe is lowered. Calibration of an acoustic probe requires determining a correlation between acoustic signal attenuation and the density of the sediment material.

Acoustic signal attenuation is affected by more factors than just density, and the probe calibration is thus more site-specific than is the case for a nuclear density probe.

d. Calibrated acoustic reflection systems. Calibrated acoustic reflection systems are available from several manufacturers. A system manufactured by Caulfield Engineering Company can calculate the density of surface and subbottom stratified sediment layers. The Caulfield system works in conjunction with conventional depth sounders or subbottom profilers. The Caulfield system uses a computer and special software to calculate the acoustic impedance of sediment layers, and from this can calculate a good estimate of the density of the sediment layers at different depths. Further information on subbottom acoustic profiling systems is provided later in this chapter.

e. Electrical resistivity (ER) techniques. The ER is a drop probe used for fluff monitoring. The ER probe measures the change in electrical resistivity across two electrodes. This electrical resistivity is related to the acoustic impedance of the fluff, which equals density times the speed of sound. This technique is similar to the nuclear and acoustic density probes.

f. Radar methods. A working radar system was developed by the USACE Cold Regions Research & Engineering Laboratory. This short-pulse radar system was designed for sediment layer identification in freshwater lakes. It cannot operate in salt water environments.

g. Mechanical methods. A 260-lb towed sled system has been developed at the USACE Waterways Experiment Station (WES) to measure fluid mud shear strength and density measurements. This system models the ability of a vessel to navigate, given a resistance developed by the fluff layers. The sled (a direct contact method) depicts the boundary between suspended and consolidated silt. Sled sensors measure hydrostatic pressure, sled velocity, sled attitude, nuclear density, and cable tension. Nuclear density measurements are used optionally by WES for redundant field checks against the shear strength. A crane winch assembly may be required to operate this system. The towed sled may have maintenance dredging benefits despite the vessel and personnel requirements for safe operation. The depth of the sled is determined by the hydrostatic pressure (head) gages on the sled. For hard-bottom channels the head gage is inferior, but for unconsolidated channel bottoms the sled may measure the material density which can impede a ship's navigation in the channel. In tests conducted at Gulfport Channel, the 200-kHz transducer was more consistent than the sled after repeated runs along the channel centerline. The sled was more consistent than the 24-kHz system. Weight was added to the sled in order to follow a density of $1.2\ g/cm^3 \pm 0.1\ g/cm^3$ (specific gravity (SG) of 1.2). The 200-kHz transducer was estimated to reflect off material at SG of 1.05. This tool is not made to replace acoustic depth measurement, but to augment soundings in areas of fluff or fluid mud.

21-7. Bottom Imaging Using Acoustic Impedance Measurements

Prior to dredging in areas comprised primarily of consolidated sediments, reflection seismic techniques should be considered for continuous documentation of bottom and subbottom materials. This method relies on acoustic impedance principles to predict density and material type. When employed in the planning phases of dredging operations, it can appreciably minimize the number of exploratory borings and ensure that those thought necessary are optimally located. Following is a brief discussion of the acoustic impedance technique:

a. General principles. The acoustic impedance method is a modification of the seismic reflection technique commonly used in offshore oil exploration but tailored to shallow water environments. As energy generated from an acoustic source (in the form of a plane wave) arrives at a boundary between two layers of differing material properties, part of the energy will be reflected back towards the surface and part transmitted downward. Portions of the transmitted energy will undergo absorption or attenuation in the layer while the remainder propagates through to the next stratigraphic boundary. Ratios between transmitted and reflected energy, called reflection coefficients (Equation 21-5), are dependent on the density and velocity of the materials through which the energy is propagating.

(1) Wave velocities are controlled by elastic properties of the two-phase sediment mass (sea water in pores and mineral structure). Properties such as porosity (volume of voids to the total volume) and grain size affect sound velocity only through their effects on the elasticity of the sediment. In previous studies it was concluded that elastic properties of water-saturated sediment could be expressed through Hookean elastic equations unless attenuation is considered, in which case linear visco-elastic equations are recommended.

(2) The basic equation for the velocity of a compressional wave *Vp* is:

$$Vp = sqrt\ [\ (\kappa + 1.333\ \mu) / \rho\ ] \qquad \text{(Eq 21-1)}$$

where

κ = incompressibility or bulk modulus and equals ($1/\beta$)
μ = shear (rigidity) modulus
ρ = saturated bulk density
β = compressibility

When a medium lacks rigidity, Equation 21-1 becomes:

$$Vp = sqrt\ [\ (\kappa / \rho)\ ] \qquad \text{(Eq 21-2)}$$

or

$$Vp = sqrt\ [\ 1 / (\beta\rho\ ] \qquad \text{(Eq 21-3)}$$

Compressibility (β) and density (ρ) in Equation 21-3 have been expanded into:

$$Vp = sqrt\ [\ 1\ / \{\ (\ \eta\beta_w + (1-\eta)\ \beta_s\ )\ \ (\ \eta\rho_w + (1 - \eta\rho_s)\ \}\ ] \qquad \text{(Eq 21-4)}$$

where η is the volume of pore space occupied by water (fractional porosity), and subscripts s and w indicate mineral solids and water.

(3) The influencing parameters of this basic seismic wave equation suffice to answer the question: "Why acoustics to characterize bottom/subbottom materials?" To continue, the acoustic reflection coefficient *(R)* is defined as:

$$R = sqrt\ [\ E_R / E_1\ ] \qquad \text{(Eq 21-5)}$$

where

E_R = reflected energy
E_1 = total energy incident to the boundary

The reflection coefficient is also equal to:

$$R = (Z_s - Z_w) / (Z_s + Z_w) \qquad \text{(Eq 21-6)}$$

where

$Z_w = \rho_w C_w$ = water impedance (resistance)
$Z s = \rho_s \; C_s$ = soil impedance (resistance)
ρ_w = 1 g/cm3
C_w = 150,000 cm/sec

Hence, it is clear that the acoustic impedance *(Zs)* of the surficial layer can be calculated readily. The product of transmission velocity and density of material is the acoustic impedance and represents the influence of the material's characteristics on reflected and transmitted wave energy. The relationship between acoustic impedance and specific soil properties has been empirically based on an extensive database of world averages of impedance versus sediment characteristics. Table 21-1 displays benthic (water bottom) surface sediment type/acoustic impedance relationships.

Table 21-1
Soil Classification versus Acoustic Impedance Range

Material Medium	Acoustic Impedance (g/cm^2 per sec * 10^{-2})
Water	1450
Silty Clay	2016-2460
Clayey Silt	2460-2864
Silty Sand	2864-3052
Very Fine Sand	3052-3219
Fine Sand	3219-3281
Medium Sand	3281-3492
Coarse Sand	3492-3647
Gravelly Sand	3647-3880
Sandy Gravel	3880-3927

All values are corrected for temperature and salinity

b. Data acquisition and analysis. A seismic source of known energy content as a function of frequency, deployed just below the water surface, generates acoustic waves that propagate downward through the water column and sediments. High-resolution profiling systems specifically designed for shallow water are used with operating frequencies typically below 12 kHz. As a rule, lower operating frequencies allow greater energy penetration into the subbottom (due to longer wavelengths) but lack the vertical resolution of higher frequency systems.

(1) As transmitted energy propagates through sediment of varying densities and acoustic velocities, energy is reflected at geologic boundaries where there is a distinct contrast in the acoustic impedance between layers. Reflected signals are amplified, filtered, and recorded with a specially designed shallow seismic, digital data acquisition system.

(2) Due to the non-uniqueness of seismic reflection signatures, several combinations of geologic conditions could conceivably yield similar signal characteristics and computed impedance values. But in specific geologic regions such as the Mississippi Sound or San Francisco Bay, differing sediment units usually have a characteristic and relatively narrow range of impedance values. Therefore, using calibration procedures incorporating local core and laboratory data, seismic reflection data are processed

at known sample locations to yield acoustic impedance values of the known reflection horizons. Estimates of in-situ density are derived from computed impedance values and correlated with ground truth information. Acoustic predictions versus core data for consolidated materials were conducted in the Mobile Ship Channel. The results are within 1 percent. Acoustic impedance density predictions versus nuclear densitometer data were compared for fluff/fluid mud type materials in the Gulfport Ship Channel. Good correlation between the impedance-derived densities and the nuclear probe densities results from a database coupled with ground truth information (borings). Testing has shown that the data-based density estimates are within 5% of the in-situ values.

c. Presentation of results. In the normal course of data acquisition, field records related to amplitude of recorded signal, time, and distance provide the engineer/geophysicist with quick-look assessments of data quality and subbottom conditions. Data are oftentimes dually recorded by both analog and digital systems. Analog presentations are usually in shades of gray while digital data are displayed in color.

(1) Upon determination of the reflection coefficients and impedance function at known locations, the continuous seismic profiles are processed. The single-channel, digitally recorded data are read into the processing software, corrected for transmission losses due to spherical spreading, and compensated for absorption losses in each layer. Classical multilayer algorithms are used to compute equivalent reflection coefficients and impedances along the profile. This in turn provides density estimates of shallow subbottom layers and classifies the lithostratigraphy. The results are corrected for tidal fluctuations and correlated with survey positioning data. Processed results are presented in the form of annotated amplitude cross sections or 2- and 3-D views. The display is color-coded according to material density. This type of display delineates the extent of pertinent density zones of interest to the engineer, and the virtually continuous data coverage greatly decreases the possibility of significant material changes being undetected. Displays of this type provide much improved data interpretation and visualization for the end product user as compared to standard 2-D presentations generated exclusively from boring information.

(2) By incorporating the continuous coverage of subbottom materials with digital terrain modeling techniques, rapid and accurate computations can be made of volume and material type to be removed by dredging. Furthermore, a detailed database has now been established for project monitoring and long-term planning. Computed sediment densities within the project area can be displayed in a color-coded, 3-D view if desired by the user. The project planner may elect to view an area of interest from other angles or create different displays by stripping or slicing at any desired coordinate. Volume of any material to be removed can easily be calculated and displayed.

21-8. Procedures to Use in Unconsolidated Sediment Areas

When a survey is to be performed in an area where soft sediments or suspended material may exist, the following considerations should be observed if contract payment will be based on in-place measurements, or if payment is based on a daily rental basis. In fluff areas where resolution of in-place payment quantities is extremely difficult, then a rental basis should be considered. In either case, determination of final project clearance and release of the dredge will require use of some of the techniques described below.

a. Dredge and survey contracts should specify the equipment and techniques to be used during the survey work. The contract specifications should anticipate difficult bottom conditions and define mutually acceptable ways of achieving a satisfactory contract. For example, Savannah District uses the following contract measurement and payment clauses to address this problem:

Soundings for all dredging surveys under this contract will be obtained by the use of a marine depth recorder operating at a frequency of [24 kHz]. Sensitivity setting will be adjusted to reflect the type of bottom material in the area being surveyed. In areas where double bottom (fluff) conditions are encountered, soundings with an 8-lb lead with a 6-in. perforated disc will be taken in conjunction with sounding data secured by the depth recorder. Adjust the data thus secured to the depths equivalent to those obtained by lead line soundings.

If soundings obtained as stated in the above paragraph (adjusted by lead line soundings) indicate a fluff or double bottom condition that exceeds 5 feet above the adjusted firm bottom, the firm bottom line will be adjusted to 5 feet below the fluff line. This adjusted firm bottom line will be used for yardage (volume) calculations.

b. Use a dual-frequency depth measuring system (high-frequency 200-kHz nominal/low-frequency 24- to 50-kHz nominal). Record both the high- and low-frequency channels on the depth chart.

c. Monitor the depth chart frequently.

d. If the high-/low-frequency depth lines diverge in part of a survey section line, go back over this portion of the section line and check the depth with a lead line, nuclear density meter, or other independent direct contact method.

e. If the depth measured by the independent check method agrees with the high-frequency depth measurement, continue to use the high-frequency depth measurement.

f. If the depth measured by the independent check method does not agree with the high-frequency depth measurement but does agree with the low-frequency depth measurement, use the low-frequency depth measurement when the slope of the bottom is low and there are no structures nearby. Do not use the low-frequency depth reading on (or near) steeply sloped bottoms, pilings, or other structures.

g. If the depth measured by the independent check method does not agree with either the high- or low-frequency depth measurements, consider using the direct-contact method for the parts of the survey for which the two acoustic frequencies do not agree. A condition in which the lead line does not agree with either the high- or low-frequency depth chart readings may have a layer of fluid mud that causes this problem. If fluid mud is suspected, an alternate method (such as a nuclear density or acoustic density probe, radar, or STB) should be considered.

21-9. Dual-Frequency Depth Sounding in Areas with Suspended Sediment Conditions

Dual-frequency echo sounders are commonly employed in areas where fluff is present. In order to assess the data quality between the high and low frequency returns, it is helpful to be aware of some of the characteristics of each frequency, as listed below:

<u>High-frequency echo sounders – 200 kHz typical</u>

- Narrow Beam
- More Accurate Depth Measurement & Resolution
- Picks Up Small Density Changes
- Will Pick Up Multiple Fluff Layers ... Grass, Kelp
- Will Record Vegetation Above Hard Bottom
- Lower Power Requirements

- Side Echos Minimized
- Digital Depths Easier To Obtain
- Small Transducer Size
- Must Be Directly Over Object To Detect (Obtain Return)
- Limited In Depth Range... Few Hundred Feet
- More Difficult To Obtain Bar Check

<u>Low frequency echo sounders – 24 kHz typical</u>

- Wider Beam ... Side Echos Smooth Out Features
- Less Accurate Depth Measurement & Resolution
- Bar Checks Easy
- May Detect "True" Bottom
- May Read Through Bottom Grass
- Will Not Detect Small Density Changes
- Higher Power Requirements
- Large Transducer Size
- Increased Depth Range.

<u>General features of high and low frequencies</u>

- Acoustic Energy Is Absorbed At Each Density Layer
- Reflected Energy Also Absorbed On Return Path
- Returning Signal Strength Is Very Small (Amplifying Signal Becomes Problem)
- 200 kHz Energy Attenuated 10 Times More Than 20 kHz
- Low Frequency May Not Pick Up Initial Density Change If Small
- Low Frequency May Penetrate To Sub-surface Rock
- Signal Return Amplitude Proportional To Density Of Return Surface

The New Orleans District uses a low-frequency thermal depth sounder to identify shoaling areas in the Lower Mississippi River (Southwest Pass). This depth sounder, an Innerspace Model 449, provides dual frequency information with a low frequency operating at 20-50 kHz--see Figure 21-10. The gray threshold incorporated in the system allows the hard bottom to be printed in black and suspended sediments to be printed in gray using a single frequency. A second frequency module, at 208 kHz, can be mounted to the top of the 449 Unit. When this module is installed, the Model 449 can be used as a single-frequency or dual-frequency sounder with simultaneous sounding in both frequencies and dual digital depth outputs. The New Orleans District operates seven Model 449s, which are being used in high-speed (20 knots) condition surveys on the lower Mississippi River. These units operate at 27 kHz to penetrate the fluff materials and still digitize the hard bottom. Figure 21-11 is an example of a dual-frequency recording from a thermal shading echo sounder.

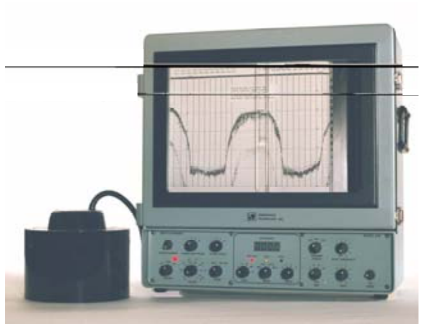


Figure 21-10. Innerspace Model 449 dual frequency depth recorder

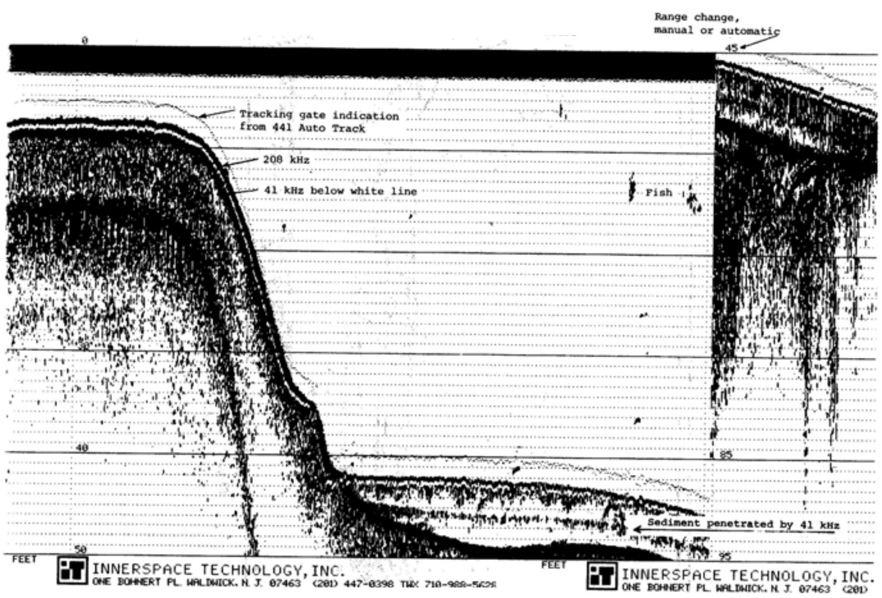


Figure 21-11. Recording from Innerspace Model 441 dual-frequency (41 kHz and 208 kHz)

The Knudsen Model 320M depth sounder has a dual frequency capability. Figure 21-12 depicts a dual frequency record from 38 kHz and 200 kHz transducers. The upper part of the figure shows the profiles recorded by the two separate frequencies. The bottom part shows the merged records in color-reverse grayscale. Figure 21-13 depicts low frequency (50 kHz) returns off bedrock--as plotted thermal hard copy paper. Figure 21-14 illustrates an Odom dual frequency return in soft sediment.

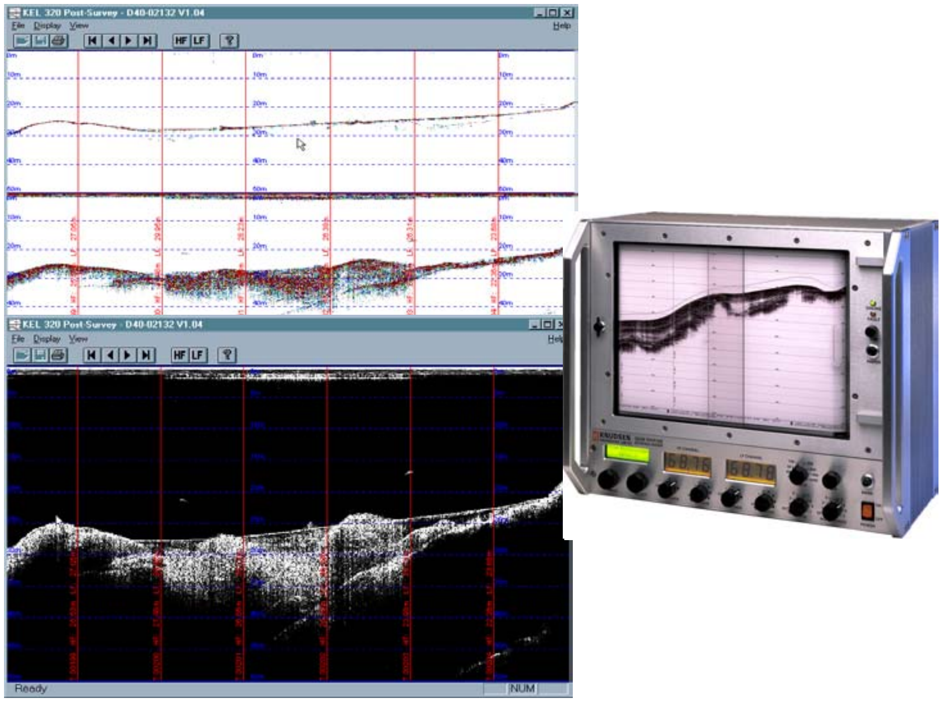


Figure 21-12. Knudsen 320M dual frequency recorder (38 kHz and 200 kHz)

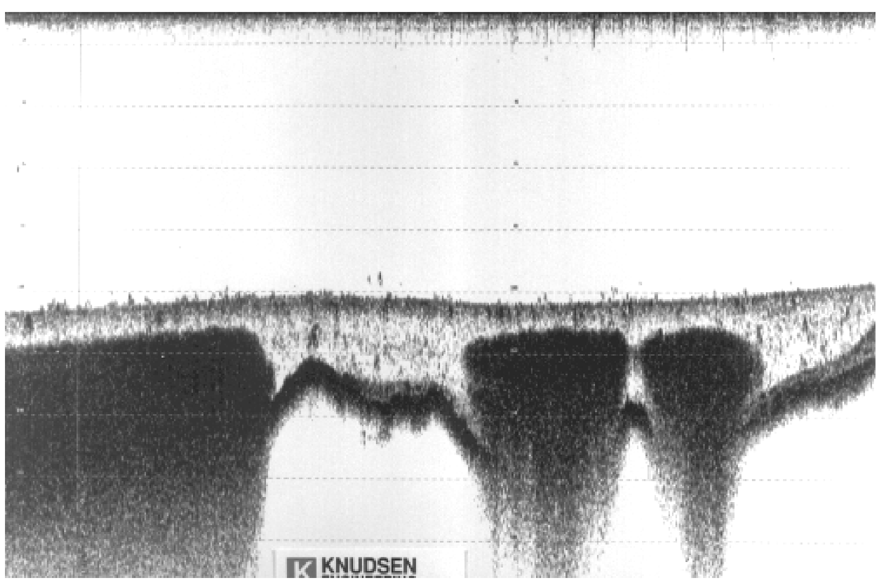


Figure 21-13. Knudsen 320M dual frequency thermal copy recorder (50 kHz and 200 kHz), depicting soft material over bedrock

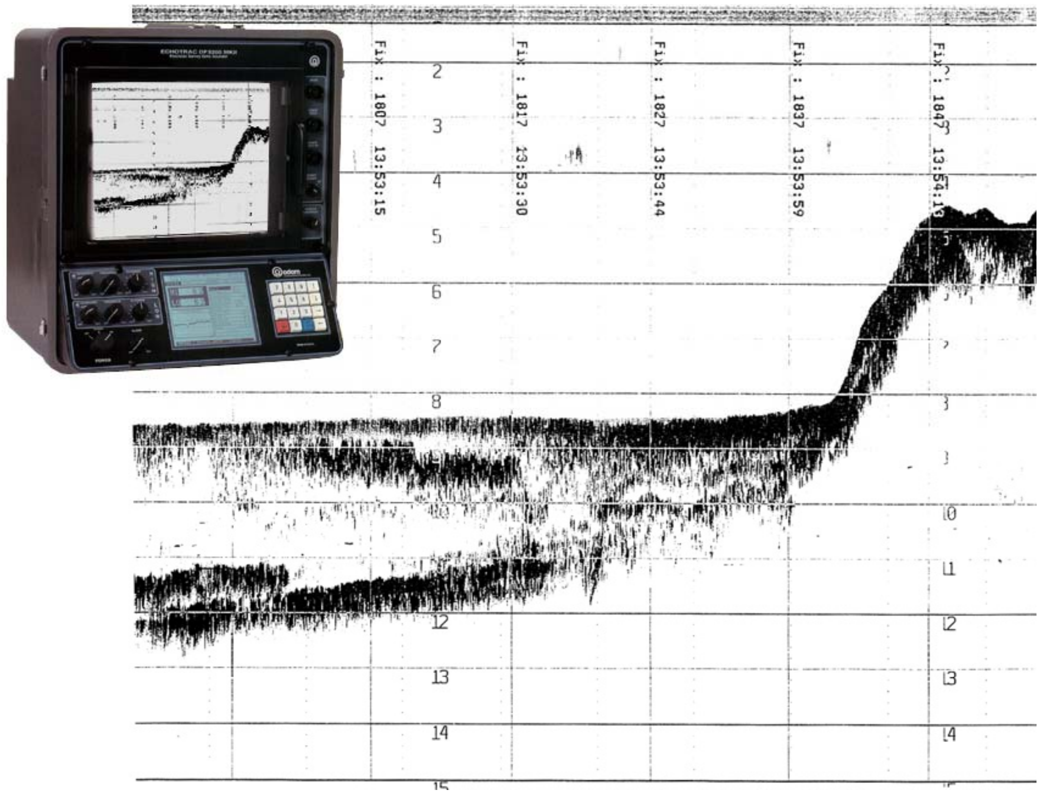


Figure 21-14. Odom Hydrographic DF3200 MKII dual frequency thermal echo sounder (24 kHz and 200 kHz), depicting soft sediment material over dredged channel

21-10. Dual Frequency Parametric Subbottom Profiling

The Odom Hydrographic Systems/Innomar SES-96 Parametric Profiling echo sounder uses the combination of two or more frequencies to measure subsurface layers and objects, such as pipelines. It can operate in water depths down to 400 meters with penetration up to 50 meters, and can resolve embedded objects or sediment layers as small as 5 cm. The term "parametric" refers to the mixing of frequencies to form sum and difference frequencies. Returns from the two high and low frequencies are added and subtracted, with the frequency difference being used to evaluate and measure penetrated sub-surface layers. Both frequencies have the same beam width. For small object detection, the survey vessel speed is kept to less than 2 kts during surveys. Applications of parametric frequency measurements include:

- Surveying the morphology of the bottom surface and evaluating muddiness for dredging tasks and environmental investigations
- Surveying sediment structures for geology
- Search for pipelines, sea cables, stones, navigation obstacles, and archaeological objects like wrecks and historical buildings
- Searchs for mineral resources

Figures 21-15 through 21-18 provided by Odom Hydrographic Systems illustrate some of the applications of the SES-96 profiling system.

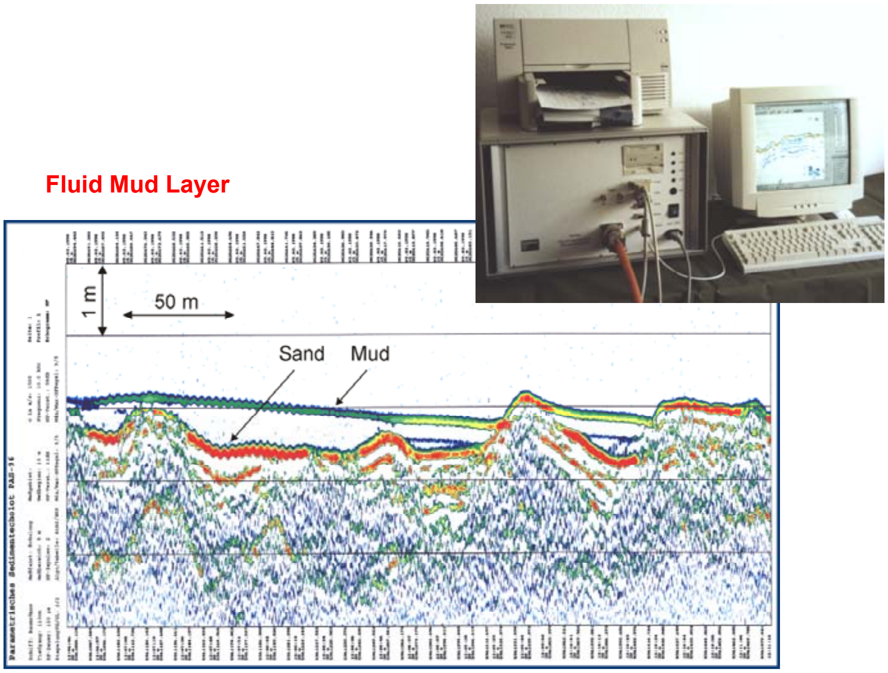


Figure 21-15. SES-96 Dual frequency profiling system. Enhanced processing of signals can identify different material layers in a channel, including fluid mud (Odom Hydrographic Systems)

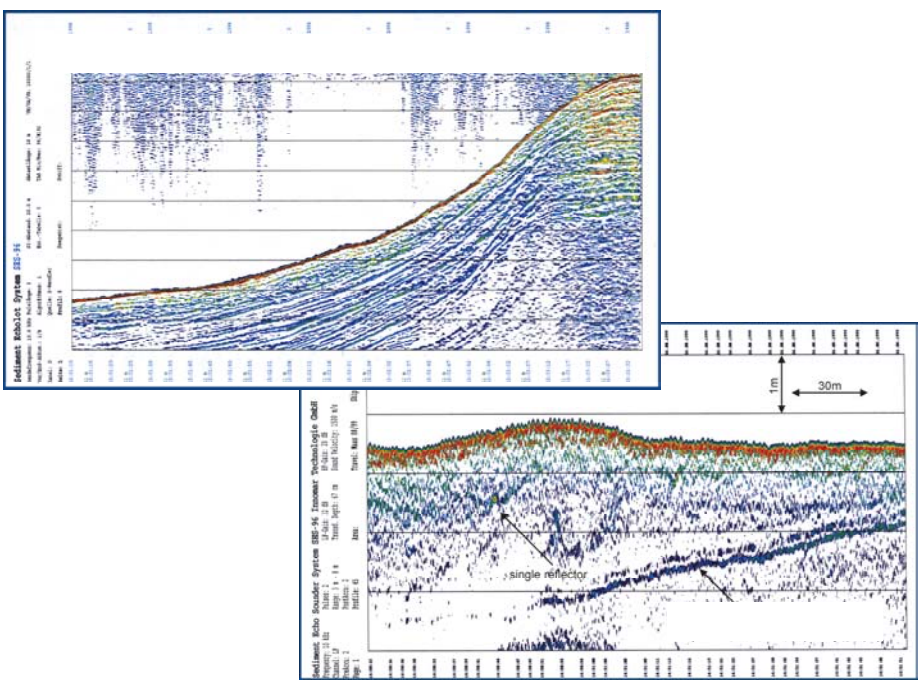


Figure 21-16. SES-96 imagery of subsurface sediment layers in channel (Odom Hydrographic Systems)

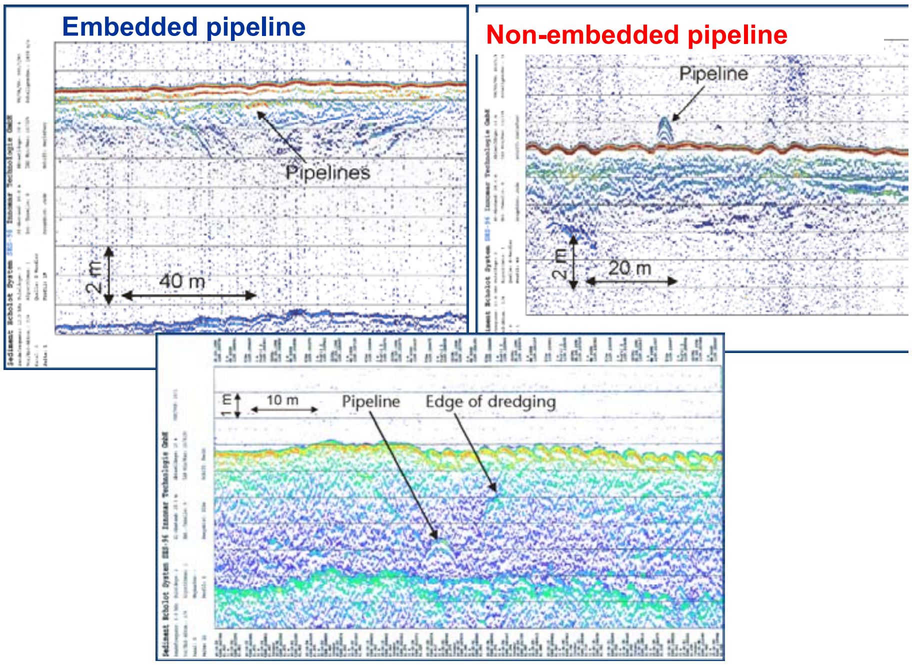


Figure 21-17. Search and monitoring of embedded and non-embedded pipelines and measurement of the pipeline´s depth in the bottom--SES-96 (Odom Hydrographic Systems)

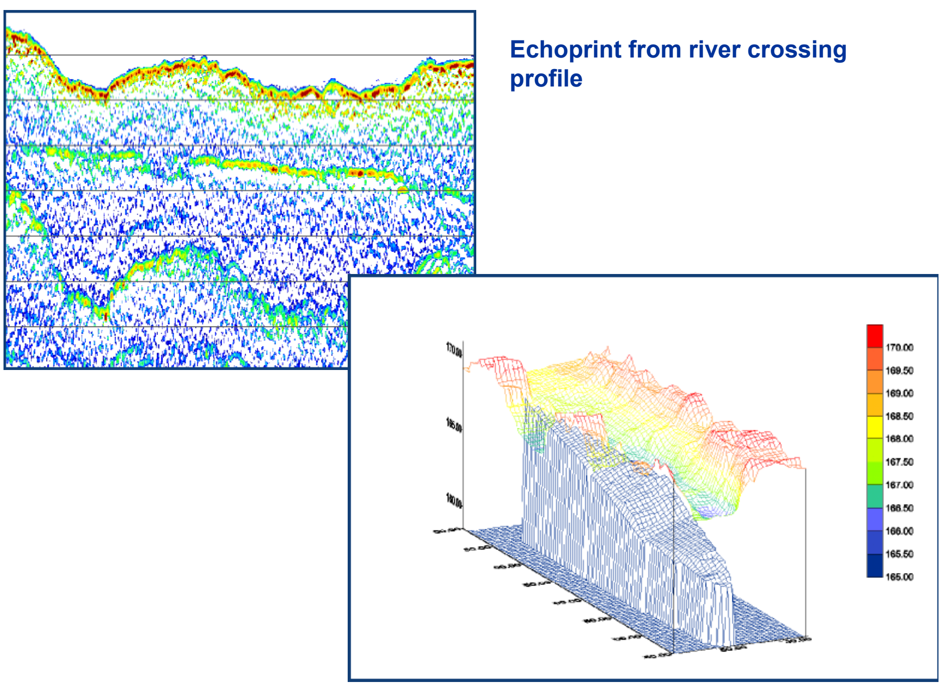


Figure 21-18. Combination of collected echo data allows calculation of 3D models for sediment structures (Odom Hydrographic Systems)

21-11. Standards for Depth Measurement in Irregular or Unconsolidated Bottoms

Table 21-2 below is a general checklist for surveys that will be performed in irregular or unconsolidated materials. It is intended for use in developing measurement and payment provisions in dredging contracts. It is not inclusive of all conditions encountered on Corps navigation projects.

Table 21-2. Checklist for Depth measurement--Dredging Contract Specifications

Identify potential existence of fluid mud or fluff in project--by station if available
Contract by in-place measurement or rental?

Describe measurement and payment or clearance procedure
- dual frequency
- pre & post dredge frequency used for payment
- lead line or sounding pole, including measurement refusal times
- other methods

Specify high and low frequencies to be used
- specific measurement system (echo sounder)

Describe volume computation procedure (if in-place payment method used)
- data processing method
- data thinning method
- data set binning methods

Specify specific gravity of nautical bottom--e.g. 1.10
- systems for measuring density or identifying materials
- use of density in volume computation

Clearance procedures for rock fragments, underwater hazards, pipelines, etc.:
- acoustic sweep methods (bar, acoustic, side scan, etc.)
- specific sweep system employed
- sweep overlap criteria (single or double coverage)
- required number of acoustic hits
- tolerances designed for hazards in required depth and overdepth prisms
- clearance methods

21-12. Mandatory Requirements

There are no mandatory requirements identified in this chapter.

Chapter 22
Contracted Survey Specifications
And Cost Estimates

22-1. General

This chapter describes the process for contracting hydrographic survey services. It covers development of survey scopes of work, performance specifications, and cost estimates for both fixed price A-E or construction contracts; and task orders under indefinite delivery contracts.

a. Procedures for developing hydrographic survey contract specifications and cost estimates are performed similarly to those for A-E design services. Similar technical discipline scheduling and production factors are used to determine the ultimate cost of a task.

b. Although this chapter is intended to provide guidance for estimating costs for hydrographic surveying services, the explanations herein regarding procurement policies and practices describe only the framework within which cost estimates are used. For detailed guidance on procurement policies and practices, refer to the appropriate procurement regulations: FAR, DFARS, EFARS, EP 715-1-7 (Architect-Engineer Contracting), and the PROSPECT course on A-E contracting.

22-2. Background

Prior to World War II, in-house forces primarily performed design and related surveying support services in the Department of Defense. In 1939, legislation was enacted which created an expanded military construction program and authorized contracting of A-E services. Surveying and mapping services are considered a subset of A-E services. This initial contract work for military design/construction spilled over into the Corps civil works programs after the war--for similar planning, design, and surveying services. Contracting for surveying services began to expand in the late 1950's and early 1960's--especially during the space program build-up. Hydrographic surveying was one of the last Corps field survey data acquisition functions to be contracted--mostly beginning in the 1970's. Prior to the 1970's, the Corps employed well over 200 in-house hydrographic survey crews, mostly using manual tagline/leadline survey methods. In the 1960’s and 1970's, administrative and political pressures mandated an increase in outsourced services, including transfer of construction quality control functions to contractors--e.g., dredging progress payment surveys. As of 1999, approximately 40% of all the Corps hydrographic work is contracted--either directly using A-E contracts or indirectly under construction contracts. The expanded use of A-E firms and dredging contractors to perform hydrographic surveying has many positive elements. These firms not only supplement the Corps declining in-house capabilities but also provide specialized expertise in technical areas not routinely performed by the Corps, or in areas the Corps has not maintained the latest technology. Most importantly, however, these firms represent a nationwide service base for use in a national emergency. This asset was clearly evident during the Great Flood of 1993 in the Upper Mississippi & Missouri Basin. During this high-water build up, many private hydrographic contractors were mobilized by the Corps to locate and map levee breeches and backwater flooding limits with multibeam survey equipment.

22-3. Brooks Architect-Engineer Act

In the Federal government, professional architectural, engineering, planning, and related surveying services must be procured under the Brooks Architect-Engineer Act, Public Law 92-582 (10 U.S. Code 541-544). The Brooks A-E Act requires the public announcement of requirements for surveying services, and selection of the most highly qualified firms based on demonstrated competence and professional qualifications. Cost or pricing is not considered during the selection process. After selection, negotiation of a fair and reasonable price for the work is conducted with the highest qualified firm. Hydrographic surveying supporting the Corps' research, planning, development, design, construction, or alteration of real property is considered to be a related or supporting architectural or engineering service, and must therefore be procured using Brooks A-E Act qualifications-based selection, not by bid price competition. In each year, the Corps procures about $750 million in professional services using the Brooks A-E Act. The Corps typically awards over 500 A-E contracts each year, and under these contracts, some 5,000 separate projects (i.e., task orders) are negotiated and performed. About 500-750 of these orders are for surveying and mapping services. A significant amount of additional surveying work is normally included by subcontract under architectural and engineering task orders for the design of specific projects. In addition, each of some 250 dredging contracts awarded annually contains requirements for the construction contractor to perform various hydrographic surveying services during the construction execution. These services are not obtained using Brooks A-E Act procedures but are normally included in the construction unit price. Occasionally, construction hydrographic surveying services are bid as separate line items.

22-4. Types of Contracted Hydrographic Survey Projects

a. Navigation project condition surveys. Project condition surveys are by far the most prevalent hydrographic operation performed by contract. Condition surveys are performed to assess the status of the Corps 12,000 miles of maintained navigation channels and some 926 harbors. These surveys are performed at least annually over these projects, or more frequently in high shoaling navigation channels. (In Southwest Pass, LA, condition surveys are performed daily to support almost continuous dredging). Condition survey data is transferred to NOAA charts of coastal areas and Corps charts of the inland navigation system. Contractors now perform a significant amount of these condition surveys since Corps in-house survey forces are primarily dedicated to performing dredging measurement and payment surveys.

b. Dredge measurement and payment surveys. Due to declining in-house survey capacity, contractors are increasingly being called upon to perform contract payment surveys for dredging operations. Given the potential for conflicts of interest, and commonly occurring disputes over payment survey adequacy or accuracy, use of contracted forces for official Government payment surveys requires increased surveillance. This process is discussed in more detail in a later section.

c. Water control sections. The Corps flood control and water control responsibilities along most of the nation's river systems entails extensive hydrographic, overbank, and flood plain surveys. Much of this work is accomplished through contract. Contractors are required to develop hydrographic river sections at locations consistent with hydraulic prediction model requirements--e.g., HEC. Often this hydrographic data is merged with upland (overbank) surveys atop levees and topographic/photogrammetric surveys out into the flood plain for inundation studies. Usually the contractor is required to obtain numerous other field data for use in hydraulic and economic damage models (e.g., sediment, land cover/use, and first-floor elevations).

d. Beach renourishment/hurricane protection surveys. Most Corps beach surveys (for renourishment and/or hurricane protection purposes) are performed by contractors. These surveys involve both hydrographic and topographic sections of the beach--before, during, and post construction--and the offshore borrow area.

e. Levee/revetment construction. Contracted hydrographic surveyors are frequently assigned to support on-going marine construction work. A contract survey crew is assigned to provide full-time support to a Corps field area/project office during construction. Typical projects where hydrographic support is needed throughout construction includes levee, jetty, breakwater, dike, weir, or bulkhead construction. For example, along the lower Mississippi River, contracted survey forces are assigned full-time to position Corps-owned sinking plant used to place articulated concrete mats along the revetments. (Note: Support services during construction used to be called "Title II Services" but are now called "Construction Phase Services.")

f. Structural investigation. Detailed hydrographic surveys are often required to assess the underwater condition of bridge piers, navigation locks and dams, hydroelectric plants, etc. Contractors are required to maintain state-of-the-art hydrographic survey equipment to support this work. This may include multibeam systems, diving capabilities, underwater photography, etc.

g. Archeological and environmental surveys. Magnetometer and related geophysical surveys are often required to ensure that underwater artifacts are located prior to construction. Environmental impact studies and surveys often require extensive hydrographic survey support. The Corps contracts most of this work.

22-5. Contracting Processes and Procedures

Corps procedures for obtaining A-E services are based on a variety of Federal and DOD acquisition regulations. The following paragraphs synopsize the overall A-E process used in the Corps.

a. Types of contracts. Two types of A-E contracts are principally used for hydrographic surveying services: Firm-Fixed-Price (FFP) contracts and Indefinite Delivery contracts (IDC). FFP contracts are used for moderate to large mapping projects (e.g., > $1 million) where the scope of work is known prior to advertisement and can be accurately defined during negotiations--typically for a large new project site. Due to variable channel shoaling and changing engineering and construction schedules (and funding), most mapping work in the Corps cannot be accurately defined in advance; thus, these fixed-scope FFP contracts are rarely used, and well over 95% of surveying services are procured using IDC.

b. Announcements for hydrographic surveying services. Requirements for surveying services are publicly announced and firms are given at least 30 days to respond to the announcement. The public announcement contains a brief description of the project, the scope of the required services, the selection criteria in order of importance, submission instructions, and a point-of-contact. This public announcement is not a request for price proposals and firms are directed not to submit any price-related information.

c. Selection criteria. Federal and DOD regulations set the criteria for evaluating prospective surveying contractors as listed below. These criteria are listed in the public announcement in their order of importance and the selection process assigns descending weights to each item in that order. (The order listed below may be modified based on specific project requirements.)

(1) Professional qualifications necessary for satisfactory performance.

(2) Specialized experience and technical competence in the type of work required.

(3) Past performance on contracts with Government agencies and private industry in terms of cost control, quality of work, and compliance with performance schedules.

(4) Capacity to perform the work in the required time.

(5) Location in the general geographical area of the project and knowledge of the locality of the project.

(6) Volume of work awarded by the Department of Defense in the past 12 months.

(7) Superior performance evaluations on recently awarded DOD contracts.

(8) Utilization of small or disadvantaged businesses.

d. Selection process. The evaluation of firms is conducted by a formally constituted Selection Board in the Corps district seeking the services. This board is made up of highly qualified professional employees having experience in architecture, engineering, surveying, etc. A majority of the board members for surveying services must have specific technical expertise in that area. At least one member must be a licensed surveyor. The board evaluates each of the firm's qualifications based on the advertised selection criteria and develops a list of at least three most highly qualified firms. As part of the evaluation process, the board conducts interviews with these top firms prior to ranking them. The firms are asked questions about their experience, capabilities, organization, equipment, quality management procedures, and approach to the project. These interviews are normally conducted by telephone. The top three (or more) firms are ranked and the selection is approved by the designated selection authority--typically the District Commander. The top ranked firms are notified they are under consideration for the contract. Unsuccessful firms are also notified, and are afforded a debriefing as to why they were not selected, if they so request.

e. Negotiations and award. The highest qualified firm ranked by the selection board is provided with a detailed scope of work for the project, project information, and other related technical criteria, and is requested to submit a detailed price proposal for performing the work. In the case of IDC, price proposals consist simply of unit rates for various disciplines, services, and equipment. This list becomes the contract "Schedule B" of prices, and typically each line item of services contains all overheads, profits, and incidental supplies. Once a fair and reasonable price (to the government) is negotiated, the contract is awarded. The Government Contracting Officer is obligated to strive to obtain a negotiated price that is "fair and reasonable" to both the Government and the contractor.

22-6. Indefinite Delivery Order Contracts

The vast majority of the Corps hydrographic surveying services are procured using IDCs. These IDCs are procured using the selection and negotiation process described above. IDC (once termed "Open-End" or “Delivery Order” contracts) have only a general scope of work--e.g., "Hydrographic surveying services in Southeastern United States." When work arises during the term of the contract, task orders are written for performing that specific work. In the Corps, IDCs are typically issued for $1 million with two additional $1 million option term (not year) extensions -- for a total award of $3 million. Task orders may be issued up to $1 million each. Larger IDC awards are often made, both in overall award size and task order limit. Task orders are negotiated using the unit rate "Schedule B" developed for the main contract. Thus, negotiations are focused on the level of effort and performance period. Task orders typically have short scopes of work--a few pages. The scope is sent to a contractor who responds with a time and cost estimate, from which negotiations are initiated. Under emergency conditions (e.g., flood fights, hurricanes) contractors can be issued task orders verbally by the Contracting Officer, with the scope of work simply defined as a limiting number of days for the hydrographic survey crew at the contract schedule rate. The entire process--from survey need to task order award--should routinely take only 2 to 4 weeks. From the IDC Schedule B, a hydrographic survey crew and equipment is pieced together using the various line items--adding or deducting personnel or equipment as needed for a particular project.

22-7. Contracted Construction Measurement and Payment Surveys

a. Fixed-price construction contracts containing unit pricing of items are usually paid based on quantity surveys of material placed or removed. These construction contracts require full-time hydrographic survey support, using either in-house or contracted survey crews (A-E or construction contractor). Typical projects include navigation project dredging, beach renourishment, rock/stone placement, canal/levee construction, revetment construction, etc. On most projects, these quantity survey measurements are performed by in-house Corps forces; however, over the past 15 years, there has been an increasing trend to contract out these payment surveys. Often there are insufficient Corps survey personnel to cover surveying requirements for many on-going construction and dredging contracts. Many contracts (e.g., beach renourishment and revetment construction) require full-time survey capability throughout the construction season; thus, it is usually more efficient to contract this effort.

b. When necessary, either independent A-E contractors or construction contractor survey forces may be used in lieu of Corps surveyors. When contracting dredge payment surveys, the following Corps policy is prescribed by Engineer Regulation 1130-2-520, (Navigation and Dredging Operations and Maintenance Policies):

> "Hydrographic Surveys (For Dredging Projects) ... It is the general policy of the Corps of Engineers that hydrographic surveys for payment purposes be performed by Government equipment and personnel. The method of performance of hydrographic quantity surveys (in descending order) are as follows:
>
> > (1) The Government will perform quantity surveys by using qualified in-house survey crews, if available;
> >
> > (2) The Government will provide quantity surveys by contracting directly with a qualified, independent hydrographic survey contractor;
> >
> > (3) The Government will permit, only in exceptional circumstances, the use of the dredging Contractor's surveys if the [Government] Contracting Officer determines that such surveys are adequate and reasonable for payment purposes."

c. The above policy outlines a preference for performing surveys with Corps forces. This policy is justified in that payment and project clearance/acceptance is based on these surveys, and any disputes (between the Corps and construction contractor) over survey adequacy or accuracy become difficult to resolve unless the contract agent is fully responsible for the survey data. Reduced manpower is making this ideal situation less common; thus, more reliance is being made on A-E firms and construction contractors.

d. The use of construction contractors performing their own payment surveys represents a special case, given the need for quality assurance oversight that must be performed by the Corps when such surveys are performed. Corps policy outlines steps that must be taken when a district elects to use construction contractor forces for hydrographic payment/acceptance surveys:

> "Before approving use of [dredge contractor's surveys] ... [Division] commanders should require District commands to provide rationale and justification for proposing to use [dredge contractor's surveys] and to document their [unsuccessful] efforts to obtain contracts with qualified independent [A-E] hydrographic survey firms."

"[When dredge contractors perform their own payment/acceptance surveys, quality assurance] verification shall be accomplished by stationing a qualified Government representative familiar with the hydrographic surveying equipment on board the Contractor's vessel during all surveying operations for payment purposes. The Government representative shall verify that all survey equipment is properly calibrated at all times and that surveying techniques and equipment conform to the contract specifications."

e. The above "verification" clause is difficult for the Corps to adhere to--especially finding a "qualified" Corps representative to monitor the surveys in progress. The dredge contractor's surveying personnel are recommended to have the following minimum technical qualifications:

"Qualifications. 33 U.S.C. 2292 requires surveying and mapping services for water resources projects to be procured in accordance with Title IX of the Federal Property and Administrative Service Act of 1949 (The Brooks A-E Act, 40 U.S.C. 541). The subject title requires negotiations of contracts on the basis of demonstrated competence and qualifications for the type of professional services required. This is interpreted as requiring that the Contractor must document at least three years of experience in hydrographic surveying of navigable channels and have either a current land surveyor's or professional engineer's license in the state(s) where the surveys will be performed; or an American Congress on Surveying and Mapping (ACSM) certification as an 'Inshore Certified Hydrographic Surveyor.' The Contractor must provide documentation indicating that modern electronic horizontal positioning and depth finding equipment are available and will be used ... the Contractor must provide ... a safe and suitable vessel meeting U.S. Coast Guard requirements ... and that qualified, experienced staff are available and will be used for the operation of the vessel as well as the electronic positioning and depth finding equipment."

f. Few dredge contractors have had any trouble conforming to the above criteria. In most instances, dredge contractors normally have survey forces on the project to perform progress payment surveys, and these same forces can be used for payment and acceptance surveys as well. In some instances, dredge contractors will subcontract their hydrographic survey work. Overall, the vast majority of districts still conduct payment and contract acceptance surveys with their own in-house forces. With declining manpower allocations, there is a definite trend towards contracting an increasing amount of these services. These trends are most noticeable in Alaska and California, and in some districts in the Southeast and Gulf Coasts.

22-8. Contract Specifications and Accuracy Standards

a. Contract specifications and standards for Corps hydrographic surveying work should make maximum reference to existing standards, publications, and other references. The primary reference standard is this manual. Drafting and CADD/GIS standards are contained in various (Tri-Service) CADD/GIS Technology Center publications. Corps headquarters does not specify standard hardware or software for its districts--each district may establish their own standards based on their unique requirements. U.S. Government policy prescribes maximum use of industry standards and consensus standards established by private voluntary standards bodies, in lieu of government-developed standards. This policy is further outlined in EM 1110-1-2909, as follows:

"Voluntary industry standards shall be given preference over non-mandatory Government standards. When industry standards are non-existent, inappropriate, or do not meet a project's functional requirement, ...[other] standards may be specified as criteria sources. Specifications for surveying and mapping shall use industry consensus standards established by national professional organizations, such as the American Society for Photogrammetry and Remote Sensing (ASPRS), the American Society of Civil Engineers (ASCE), the American Congress on Surveying and Mapping (ACSM), or the American Land Title Association (ALTA). Technical standards established by state boards of registration, especially on projects requiring licensed surveyors or mappers, shall be followed when legally applicable. Commands shall not develop or specify local surveying and mapping standards where industry consensus standards or Army standards exist."

b. According to Corps policy outlined in EM 1110-1-2909, technical specifications for obtaining hydrographic survey data shall be "performance-based" and not overly prescriptive or process oriented. Performance-based specifications shall be derived from the functional project requirements and use recognized industry standards where available. Performance-oriented (i.e., outcome based) specifications set forth the end results to be achieved (i.e., final drawing/chart format or accuracy standard) and not the means, or technical procedures, used to achieve those results. A performance-oriented specification provides the most flexibility and allows the most economical and efficient methods to achieve the desired end product. Performance specifications should succinctly define the basic mapping limits, feature location and attribute requirements, scale, contour interval, map format, sheet layout, and final data transmittal, archiving or storage requirements, the required accuracy criteria standards for hydrographic and planimetric features that are to be depicted, and describe quality assurance procedures that will be used to verify conformance with the specified criteria. Performance-oriented specifications should be free from unnecessary equipment, personnel, instrumentation, procedural, or material limitations; except as needed to establish comparative cost estimates for negotiated services. This would include any in-progress reviews or approvals during various phases of the project.

c. EM 1110-1-2909 also states that use of prescriptive (i.e., procedural) specifications shall be kept to a minimum, and called for only on highly specialized or critical projects where only one prescribed technical method, in the opinion of the Government, is appropriate or practical to perform the work. Overly prescriptive specifications typically require specific field instrumentation (e.g., brand name specific multibeam system), boat sizes, personnel, office technical production procedures (e.g., product-specific software or output format), or rigid project phasing with on-going design or construction. Prescriptive specifications reduce flexibility, efficiency, and risk, and can adversely impact project costs if antiquated survey methods or instrumentation are required.

22-9. Contract Statements of Work

Technical specifications for hydrographic surveying which are specific to the project (including items such as the scope of work, procedural requirements, and accuracy requirements) are inserted in the appropriate section of the contract (e.g., Statement of Work--Section C). Procedural and accuracy requirements are referred to this Engineer Manual, as are any quality control criteria for the total (field-to-finish) execution of a hydrographic survey. This manual should be attached to and made part of any A-E service or construction contract requiring hydrographic surveying. References to USACE survey classifications (and related criteria tables) may also be made if required. References to this manual will normally suffice for most USACE hydrographic survey specifications; however, areas where deviations from (or additions to) this manual must be considered in developing the Statement of Work. Following is a guide for a Statement of Work that may be adopted to either a Firm Fixed Price or IDC contract.

Guide Specification for Hydrographic Surveying Services

STATEMENT OF WORK SECTION C

C.1 GENERAL. THE CONTRACTOR, OPERATING AS AN INDEPENDENT CONTRACTOR AND NOT AN AGENT OF THE GOVERNMENT, SHALL PROVIDE ALL LABOR, MATERIAL, AND EQUIPMENT NECESSARY TO PERFORM THE PROFESSIONAL HYDROGRAPHIC SURVEYING *[AND MAPPING WORK] *[FROM TIME TO TIME] DURING THE PERIOD OF SERVICE AS STATED IN SECTION D, IN CONNECTION WITH PERFORMANCE OF *[_______________] SURVEYS *[AND THE PREPARATION OF SUCH MAPS] AS MAY BE REQUIRED FOR *[ADVANCE PLANNING,] [DESIGN,] [MAINTENANCE DREDGING,] [DETERMINING PROJECT CONDITION,] [AND CONSTRUCTION] [or other function] [ON VARIOUS PROJECTS] {specify project(s) if applicable}. THE CONTRACTOR SHALL FURNISH THE REQUIRED PERSONNEL, EQUIPMENT, INSTRUMENTS, AND TRANSPORTATION, AS NECESSARY TO ACCOMPLISH THE REQUIRED SERVICES AND FURNISH TO THE GOVERNMENT REPORTS AND OTHER DATA TOGETHER WITH SUPPORTING MATERIAL DEVELOPED DURING THE FIELD DATA ACQUISITION PROCESS. DURING THE PROSECUTION OF THE WORK, THE CONTRACTOR SHALL PROVIDE ADEQUATE PROFESSIONAL SUPERVISION AND QUALITY CONTROL TO ASSURE THE ACCURACY, QUALITY, COMPLETENESS, AND PROGRESS OF THE WORK.

****

The above clause is for use on an IDC contract for hydrographic surveying services. It may be used for a fixed-price service contract by deleting appropriate IDC language and adding the specific project survey required. This clause is not repeated on individual Task Orders.

****

C.2 LOCATION OF WORK.

A *[PROJECT CONDITION] [PLANS AND SPECIFICATIONS] [PREDREDGE] [_______] {specify type}HYDROGRAPHIC SURVEY IS REQUIRED AT [________] {list project area or areas required}. * [A GENERAL LOCATION MAP OF THE PROJECT AREA IS AT SECTION G OF THIS CONTRACT.]

****

Above location clause is used for Fixed-Price contracts or on IDC Task Orders. Use the following alternate clause when specifying an IDC for hydrographic surveying.

****

HYDROGRAPHIC SURVEYING SERVICES WILL BE PERFORMED IN CONNECTION WITH PROJECTS *[LOCATED IN] [ASSIGNED TO] THE [_______________] DISTRICT. *[THE _________________ DISTRICT INCLUDES THE GEOGRAPHICAL REGIONS WITHIN *[AND COASTAL WATERS] [AND RIVER SYSTEMS] ADJACENT TO:]

*________________________________
{list states, regions, etc.}

C.3 TECHNICAL CRITERIA AND REFERENCE STANDARDS.

(1) U.S. ARMY CORPS OF ENGINEERS ENGINEER MANUAL EM 1110-2-1003, HYDROGRAPHIC SURVEYING. THIS REFERENCE IS ATTACHED TO AND MADE PART OF THIS CONTRACT. (SEE CONTRACT SECTION G).

(**) {List other applicable reference standards which may be applicable to the project--e.g., (Tri-Service) CADD/GIS Standards}.

****

C.4 WORK TO BE PERFORMED

SPECIFIC PROCEDURAL, TECHNICAL, AND QUALITY CONTROL REQUIREMENTS FOR HYDROGRAPHIC SURVEYING *[AND MAPPING SERVICES] TO BE PERFORMED UNDER THIS CONTRACT ARE LISTED IN THE PARAGRAPHS BELOW. UNLESS OTHERWISE INDICATED IN THIS CONTRACT *[OR IN INDIVIDUAL TASK ORDERS THERETO], EACH REQUIRED SERVICE SHALL INCLUDE FIELD-TO-FINISH EFFORT PERFORMED IN ACCORDANCE WITH THE STANDARDS AND SPECIFICATIONS IN EM 1110-2-1003.

****

The following technical clauses are added as necessary in either fixed-price contracts, IDC contracts, or included in individual Task Orders under an IDC.

Fixed-Price contracts: Detail specific hydrographic surveying and mapping technical work requirements and performance criteria which are necessary to accomplish the work.

IDC and Task Orders: Since specific project scopes are indefinite at the time a basic IDC contract is prepared, only general technical criteria and standards can be outlined. Project or site-specific criteria will be contained in each Task Order, along with any deviations from technical standards identified in the basic IDC contract.
****

C.4.1. GENERAL HYDROGRAPHIC SURVEY REQUIREMENTS.

****
For fixed-scope contracts and/or task orders, use the following types of clauses to detail the general work specifications. Terminology would be appropriately modified to cover beach surveys, river sections, disposal area surveys, etc. A general description of the project and any unique purpose of the survey may also be added.
****

a. A HYDROGRAPHIC SURVEY OF THE PROJECT INDICATED IN PARAGRAPH C.2 SHALL BE PERFORMED AND PLOTTED AT A *[PLAN] [SECTION] [PROFILE] SCALE OF 1 INCH = [_______] *(HORIZONTAL) [AND 1 INCH = [_____] FEET (VERTICAL)]. SURVEY PROCEDURES, DATA COLLECTION EQUIPMENT, METHODS AND DENSITIES, AND EQUIPMENT CALIBRATION FOR THIS WORK SHALL FOLLOW THE CRITERIA GIVEN IN EM 1110-2-1003 FOR THIS CLASS OF SURVEY. *[A MAP DETAILING THE WORK SITE IS ATTACHED AT SECTION G OF THIS CONTRACT.] [DREDGING CONSTRUCTION CONTRACT DRAWINGS DEPICTING SECTIONS LIMITS ARE ATTACHED.] * A TOTAL OF [________] CROSS SECTIONS IS REQUIRED.

(1) SURVEY LINE SPACING SHALL NOT EXCEED * [THE LIMITS GIVEN IN EM 1110-2-1003 FOR THE GIVEN CLASS OF SURVEY] [_______ FEET][FULL COVERAGE].

(2) SURVEY LINES SHALL BE REFERENCED TO THE * [CENTERLINE] [___________] OF THE PROJECT AND SHALL BE RUN PERPENDICULAR TO THAT ALIGNMENT. * CROSS SECTIONS SHALL BE RUN * [ON EVEN STATIONS] [AS SHOWN ON THE ATTACHED DRAWING] [BEGINNING AT STATION_____+___]. [SURVEY LINES SHALL DUPLICATE THOSE SHOWN IN THE ATTACHED CONSTRUCTION DRAWINGS.]

****
Add sufficient information to describe the required survey alignment, orientation, and origin, particularly if sections are to duplicate prior surveys.
****

(3) CROSS SECTIONS SHALL BE RUN AT ___ FEET CENTER TO CENTER C/C AND SHALL EXTEND [____] FEET PAST THE SLOPE-GRADE INTERSECT POINT.

(4) * LONGITUDINAL LINES [MAY] [MAY NOT] BE RUN IN LIEU OF CROSS SECTIONS FOR CLASS 1 PAYMENT SURVEYS. * LONGITUDINAL LINE SPACING SHALL FOLLOW THE SPACING GUIDELINES IN EM 1110-2-1003 WITHIN CHANNEL TOES AND ON SIDE SLOPES. * LONGITUDINAL LINES WILL BE USED TO COMPUTE SECTIONAL END AREAS SPACED AT _______-FEET C/C.

(5) * PROJECT CONDITION SURVEY LONGITUDINAL LINE SPACING SHALL NOT EXCEED THE LIMITS GIVEN IN * [OR [_____] FEET]. * CHANNEL * [TOES], QUARTER POINTS AND CENTERLINE SHALL BE RUN. * LONGITUDINAL SIDE SLOPE COVERAGE FOR CLASS 2 SURVEYS * [IS] [IS NOT] REQUIRED [AT A SPACING NOT GREATER THAN [____] FEET].

(6) DEPTH ELEVATION MEASUREMENTS SHALL BE OBTAINED AT * [THE DENSITY GIVEN IN OF EM 1110-2-1003] [______]. DEPTHS SHALL BE PLOTTED ON THE FINAL DRAWINGS AT THE DENSITY SHOWN IN EM 1110-2-1003.

****
Use the following type of clause for basic IDC contracts}
****

b. THE CONTRACTOR MAY BE REQUIRED TO PERFORM HYDROGRAPHIC SURVEYS DURING THE TERM OF THIS CONTRACT. SURVEY PROCEDURES, DATA COLLECTION EQUIPMENT, METHODS AND DENSITIES, AND EQUIPMENT CALIBRATION FOR THIS WORK SHALL FOLLOW THE CRITERIA GIVEN IN EM 1110-2-1003 FOR CLASS OF SURVEY SPECIFIED IN TASK ORDERS TO THIS BASIC CONTRACT. TASK ORDER INSTRUCTIONS WILL CONTAIN SPECIFIC SURVEY LIMITS AND ANY MODIFICATIONS TO EM 1110-2-1003 FOR THE PARTICULAR PROJECT. NORMALLY, MARKED-UP PROJECT MAPS OR CONSTRUCTION DRAWINGS WILL BE PROVIDED TO DELINEATE WORK AREAS.

C.4.2. HORIZONTAL POSITIONING PROCEDURES AND ACCURACIES.

a. VESSEL POSITIONING SYSTEMS AND/OR MODES UTILIZED ON THIS CONTRACT SHALL CONFORM WITH ALLOWABLE HORIZONTAL POSITIONING CRITERIA IN EM 1110-2-1003, BASED ON THE CLASS OF SURVEY REQUIRED. THE CONTRACTOR MAY BE REQUIRED TO DEMONSTRATE TO THE GOVERNMENT THAT HIS POSITIONING SYSTEM, MODE, AND/OR PROCEDURES ARE CAPABLE OF MEETING THE ACCURACY REQUIREMENTS IN EM 1110-2-1003.

d. * THE CONTRACTOR SHALL HAVE A COMPLETE MANUAL TAG LINE SURVEY CAPABILITY AS SPECIFIED IN EM 1110-2-1003. THE TAG LINE SHALL BE CONSTRUCTED TO SURVEY LINES NOT EXCEEDING [_____] FEET FROM THE

BASELINE. TAG LINE PROCEDURES, LIMITATIONS, ALIGNMENT METHODS, AND CALIBRATIONS SHALL CONFORM WITH EM 1110-2-1003.

****

Specify any other unique positioning requirements not covered in the above clauses but which will be required during the contract. This may include visual positioning, sextant control, azimuth intersection positioning, differential GPS, RTK, etc. Reference the appropriate section of EM 1110-2-1003 if such systems are employed.

****

C.4.3. REFERENCE HORIZONTAL CONTROL DATA. UNLESS OTHERWISE INDICATED, THE GOVERNMENT WILL PROVIDE SUFFICIENT EXISTING PROJECT CONTROL FROM WHICH HYDROGRAPHIC SURVEYS MAY BE EXTENDED. THIS CONTROL SHALL BE PRESUMED TO MEET THE ACCURACY REQUIREMENTS IN EM 1110-2-1003. WHEN HYDROGRAPHIC SURVEYS ARE REQUIRED TO BE CONTROLLED FROM PARTICULAR EXISTING MONUMENTS, THIS WILL BE NOTED IN THE * [INSTRUCTIONS] [DRAWINGS FURNISHED].

a. ALL HORIZONTAL AND VERTICAL MONUMENTS ARE KNOWN TO BE IN-PLACE AS OF *[date]. DESCRIPTIONS FOR EACH POINT *[WILL BE PROVIDED PRIOR TO CONTRACT AWARD] *[ARE ATTACHED AT CONTRACT SECTION G] [WILL BE PROVIDED WITH EACH TASK ORDER]. *[THE CONTRACTOR'S FIELD REPRESENTATIVE SHALL IMMEDIATELY NOTIFY THE GOVERNMENT'S CONTRACTING OFFICER REPRESENTATIVE IF EXISTING CONTROL POINTS HAVE BEEN DISTURBED.]

b. NEW STATION MONUMENTATION, MARKING, AND OTHER CONTROL REQUIREMENTS. WHEN EXISTING CONTROL IS FOUND TO BE DESTROYED OR DISTURBED, OR WHEN ADDITIONAL CONTROL SURVEYS ARE REQUIRED, SUCH CONTROL WORK SHALL BE ESTIMATED AND PAID FOR AT THE RATES ESTABLISHED IN SECTION B OF THIS CONTRACT.

C.4.4. DEPTH MEASUREMENT PROCEDURES AND CALIBRATION.

a. GENERAL. THE CONTRACTOR'S FIELD SURVEY FORCES SHALL HAVE THE CAPABILITY TO OBTAIN MANUAL (LEAD LINE AND SOUNDING POLE) AND SINGLE-BEAM [MULTIBEAM] ACOUSTIC DEPTH MEASUREMENTS DURING THIS CONTRACT. ALL DEPTH MEASUREMENT EQUIPMENT, PROCEDURES, AND QUALITY CONTROL SHALL STRICTLY CONFORM WITH THE MINIMUM CRITERIA STANDARDS IN EM 1110-2-1003. THE GOVERNMENT RESERVES THE RIGHT TO INSPECT ANY DEPTH MEASUREMENT EQUIPMENT EMPLOYED DURING THIS CONTRACT.

b. DEPTH MEASUREMENT PRECISION/ACCURACY. DEPTH MEASUREMENTS INCLUDING DEPTH OBSERVATION PRECISION AND RESOLUTION SHALL MEET THE VERTICAL ACCURACY STANDARDS PRESCRIBED IN EM 1110-2-1003.

c. MANUAL DEPTH MEASUREMENTS. LEAD LINE AND SOUNDING POLE INSTRUMENTS SHALL HAVE THE WEIGHT AND DIMENSIONS GIVEN IN EM 1110-2-1003. {Note any variations from these standards due to unique project conditions, such as suspended sediment.} LEAD LINES AND SOUNDING POLES SHALL BE MARKED, READ, AND CALIBRATED IN ACCORDANCE WITH THE CRITERIA IN EM 1110-2-1003. LINE/POLE CALIBRATIONS SHALL BE RECORDED * [IN STANDARD FIELD SURVEY BOOKS] [ON FORMS/WORKSHEETS]. THESE CALIBRATION RECORDS SHALL BE RETAINED FOR INSPECTION IF NECESSARY.

d. ACOUSTIC DEPTH MEASUREMENT. A SURVEY QUALITY [SINGLE BEAM][MULTIBEAM] ECHO SOUNDER SHALL BE USED FOR WORK PERFORMED ON THIS CONTRACT. THE DEVICE MUST BE CAPABLE OF PROVIDING THE REQUIRED VERTICAL ACCURACIES. THE ECHO SOUNDING RECORDER SHALL BE IN GOOD CONDITION AND FREE FROM INDEX ERRORS, FREQUENCY INSTABILITY, OR OTHER RECORDING INSTABILITIES WHICH MAY AFFECT THE QUALITY OF THE DATA.

g. ACOUSTIC CALIBRATION REQUIREMENTS. ACOUSTIC DEPTH SOUNDERS SHALL BE CALIBRATED IN STRICT CONFORMANCE WITH THE ALLOWABLE METHODS, TOLERANCES, AND OTHER CRITERIA GIVEN IN EM 1110-2-1003. ANY DEVIATION FROM THESE CRITERIA MUST BE APPROVED BY THE CONTRACTING OFFICER. DEPTH SOUNDING EQUIPMENT SHALL BE CALIBRATED SUCH THAT THE TOLERANCES GIVEN IN EM 1110-2-1003 ARE ACHIEVED. BAR CHECK, VELOCITY CHECKS,PATCH TEST, PERFORMANCE TESTS, AND/OR BALL CHECKS MUST BE RECORDED * [IN A STANDARD FIELD SURVEY BOOK] [ON FORM _____] [ON WORKSHEET ________] AND ON THE ANALOG GRAPHICAL RECORDING. FAILURE TO PERFORM AND SUBMIT EVIDENCE OF CALIBRATION FOR EACH DAY'S WORK WILL RESULT IN THE WORK BEING DEEMED UNSATISFACTORY AND REQUIRING CORRECTION AT THE CONTRACTOR'S EXPENSE. EXTERNAL CHECKS OF THE CALIBRATION EQUIPMENT OR VESSEL DRAFT/SQUAT SHALL ALSO BE PERFORMED AS REQUIRED IN EM 1110-2-1003. THESE PERIODIC CHECKS SHALL BE RECORDED IN A STANDARD BOUND SURVEY BOOK AND RETAINED ABOARD THE VESSEL FOR REVIEW BY GOVERNMENT OR CONTRACTED CONSTRUCTION INSPECTORS.

C.4.5. VERTICAL REFERENCE DATUMS. DEPTH MEASUREMENTS SHALL BE REDUCED TO THE SPECIFIED DATUM USING CONCURRENT STAFF/GAGE READINGS AT * [____________] [A FIXED REFERENCE POINT], AS DESCRIBED IN EM 1110-2-1003. RIVER GAGES OR TIDE STAFFS/GAGES SHALL BE CONSTRUCTED, REFERENCED, MAINTAINED, STILLED, AND READ IN ACCORDANCE WITH THE CRITERIA IN EM 1110-2-1003. THE * [REFERENCE] [CONSTRUCTION] DATUM FOR THE WORK IS ________________, UNLESS OTHERWISE NOTED.

****

Specify any unique river stage or tidal modeling requirements (eg, RTK DGPS) of the contract or task order thereto, such as types of gages, recording intervals, comparative gage readings, water transfers, and benchmarks which must reference the gage. Specify any unusual differential leveling requirements not covered in EM 1110-2-1003.
****

C.4.6. FIELD DATA RECORDING, REDUCTION, ARCHIVING, AND PLOTTING REQUIREMENTS.

C.4.7. * VOLUME COMPUTATIONS. THE CONTRACTOR SHALL HAVE THE CAPABILITY TO COMPUTE EXCAVATION AND PLACEMENT QUANTITIES FROM WORK PERFORMED UNDER THIS CONTRACT. THE GOVERNMENT WILL FURNISH CONSTRUCTION TEMPLATES AND LIMITS FROM WHICH VOLUMES ARE TO BE COMPUTED FROM PROJECTED SECTIONAL END AREAS USING ANY OF THE TECHNIQUES GIVEN IN EM 1110-2-1003.

C.4.8. MISCELLANEOUS QUALITY CONTROL PROCEDURES. [add as required]

C.4.9. * SPECIAL PURPOSE SURVEYS. THE CONTRACTOR SHALL HAVE PLANT, EQUIPMENT, AND PERSONNEL CAPABLE OF EXECUTING THE FOLLOWING TYPES OF SURVEYS AT THE RATES SPECIFIED IN SCHEDULE B:

****
For each special purpose survey required on the contract, add sufficient procedural and technical detail necessary to describe the work. Equipment and instrumentation requirements should be identified. These special survey requirements must be separate (negotiated) line items on Schedule B, since equipment and personnel requirements may differ substantially from basic hydrographic work. Do not simply list these items on a basic IDC contract to cover unforeseen requirements.
****

a. CHANNEL SWEEP SURVEYS.
b. SIDE SCAN SONAR SURVEYS.
c. SUB-BOTTOM PROFILING.
d. SUB-BOTTOM PROBING.
e. MAGNETOMETER SURVEYS.
f. ENVIRONMENTAL MONITORING SURVEYS/STUDIES.
g. WRECK/UNDERWATER OBSTRUCTION INVESTIGATIONS.
h. BEACH PROFILING SURVEYS.
i. JETTY/GROIN SURVEYS.
k. RIVER SECTIONS.
l. HYDROLOGICAL/HYDRAULIC SURVEYS/STUDIES.
m. DREDGE DISPOSAL MONITORING CONTROL.
n. {other hydrographic-related surveys/studies}

C.4.10. * PROJECT REPORT. A PROJECT REPORT SHALL BE SUBMITTED FOR EACH SURVEY. *[___}COPIES OF THE REPORT SHALL BE INCLUDED. THE REPORT SHALL INCLUDE ITEMS SUCH AS: SCOPE OF WORK, CONTRACTOR PERSONNEL AND EQUIPMENT UTILIZED, WEATHER CONDITIONS, TIDAL DATA, GENERAL SITE PLAN MAP, LINE DESIGNATION MAP, CALIBRATION PROCEDURES USED, HORIZONTAL AND VERTICAL ACCURACIES, AND ANY OTHER PERTINENT INFORMATION TO DESCRIBE THE PURPOSE, METHODS, AND RESULTS OBTAINED.

C.5. SUBMITTAL REQUIREMENTS.

C.5.1. SUBMITTAL SCHEDULE: THE COMPLETED SURVEY DRAWINGS AND/OR DATA FILES, ALONG WITH SUPPORTING DATA, SHALL BE DELIVERED WITHIN *[___ DAYS AFTER NOTICE TO PROCEED IS ISSUED] *[BY {calendar date}] [UPON COMPLETION OF FIELD ACTIVITIES]. * IF FOR ANY REASON THE COMPLETION DATE CANNOT BE MET THE CONTRACTOR WILL ADVISE THE CONTRACTING OFFICER, OR HIS DESIGNATED REPRESENTATIVE, BY TELEPHONE AND CONFIRM BY LETTER THE REASON FOR THE DELAY. * THIS NOTIFICATION ACTION MUST BE SUBMITTED WITHIN [___] DAYS PRIOR TO THE NEGOTIATED COMPLETION DATE OF THE PROJECT. * A COPY OF THIS LETTER MUST ALSO BE ATTACHED TO ENG FORM 93, FINAL PAYMENT.

****
Include a more detailed submittal schedule breakdown if applicable to project. If on-site data processing and reduction are required, so indicate.
****

C.5.2. PACKAGING AND MARKING: PACKAGING OF COMPLETED WORK SHALL BE ACCOMPLISHED SUCH THAT THE MATERIALS WILL BE PROTECTED FROM HANDLING DAMAGE. EACH PACKAGE SHALL CONTAIN A TRANSMITTAL LETTER OR SHIPPING FORM, IN DUPLICATE, LISTING THE MATERIALS BEING TRANSMITTED, BEING PROPERLY NUMBERED, DATED AND SIGNED. SHIPPING LABELS SHALL BE MARKED AS FOLLOWS:

U.S. ARMY ENGINEER DISTRICT, ________________
ATTN: _________________________________
{include office symbol and name}
CONTRACT NO. __________________________
*[TASK ORDER NO. ___________________]
[STREET/PO BOX] ________________________
{complete local mailing address}

*HAND CARRIED SUBMISSIONS SHALL BE PACKAGED AND MARKED AS ABOVE, AND DELIVERED TO THE FOLLOWING OFFICE ADDRESS:

____
{insert office/room number as required}

C.6 PROGRESS SCHEDULES AND WRITTEN REPORTS.

****
Detail any requirements for a prework conference after contract award, including requirements for preparing written reports for such conferences.
****

22-10. IDC Task Order Requests For Proposals and Specifications

IDC Task Orders are issued for specific projects that arise during the course of a contract--normally during a three-year period. The contractor is requested to submit a proposal for time and cost to perform the work, using the previously negotiated unit prices in the IDC schedule. The request for proposal letter will contain supplemental standards and specifications specific to the particular project, along with maps, drawings, guidance documents, etc. The following examples illustrate a typical Task Order letter Request for Proposal along with supplemental specifications for specific task orders representative of coastal and inland hydrographic survey projects.

SAMPLE REQUEST FOR PROPOSAL

Engineering Division
Design Branch

Subject: Contract No. DACW17-96-D-0017

EMC Inc.
101 West Market Street
Greenwood, Mississippi 38930-4431

Gentlemen:

Enclosed are marked drawings depicting the scope of work for the following project:

Canaveral Sand Bypass Phase II
Pre and Post Construction Survey
Canaveral, Florida (Survey No. 97-096)

General Scope. Furnish all personnel, plant, equipment, transportation, and materials necessary to perform and deliver the survey data required hereinafter in accordance with the instructions and conditions set forth in Contract No. DACW17-96-D-0017. Services not specifically described herein are nevertheless a firm requirement if they can be identified as an item, or items, commonly a part of professional grade work of a comparative nature. All work shall be accomplished in accordance with the manuals and TM's specified in your contract.

- Your attention is directed to the Site Investigation and Conditions Affecting the Work clause of your contract. After we have reached agreement on a price and time for performance of this work, neither the negotiated price nor the time for performance will be changed as a consequence of conditions at the site except in accordance with the clause. Costs associated with the site investigation are considered overhead costs which are reimbursed in the overhead rates included in your contract. Additional reimbursement will not be made.

a. Field Survey. Pre and After construction hydrographic and topographic beach survey data shall be collected for the borrow area and beach fill area. Enclosure 1 is the contract plans. Enclosure 2 is the control monument descriptions. Enclosure 3 is the technical requirements for the surveys.

- The Contractor shall furnish one 4-Man hydrographic survey party. The task order shall be issued based on the estimated-not fixed-number of field crew days, project manager, CADD days, and computation days. When the assignment is completed the task order shall be adjusted to reflect the total cost. To certify the hours worked and progress, a daily report shall be furnished to Design Branch from the field party employed. Weekly submittal is acceptable. The Contractor's work hours and days may have to be adjusted to coincide with the Corps of Engineers request. The Contractor shall indicate on the daily report the survey party hours worked on that day. The Contractor shall be notified 24 hours in advance of any work assignment.

- The points of contact are, Mr. Hank Rimmer, at 904-232-1606, and Mr. James Lanier at 407-783-8407. Any instruction given to the survey crew by the Atlantic Coast Area Office shall be coordinated with Mr. Rimmer before commencing.

b. Data processing. The Contractor shall make the necessary computations to verify the accuracy of all measurements and apply the proper theory of location in accordance with the law or precedent and publish the results of the survey.

c. CADD. The hydrographic and topographic features shall be translated or digital capture into Intergraph IGDS 3D design files according to the specifications furnished. The survey data (cover and section view sheets) shall be provided in Intergraph Microstation (PC or 32) Version 4.0 or higher, AT&T System V Unix, CLIX R3.1 Vr. 6.3.2 format as shown in the letter dated 30 September 1992.

Surveying shall be in strict compliance with the Technical Requirements for Surveying Mapping and Photogrammetric services manual and the Minimum Technical Standards set by the Florida Board of Land Surveyors and Mappers.

The completion date for this assignment is 90 days after the Notice to Proceed is signed by the Contracting Officer.

All material shall be returned to Design Branch upon completion of this assignment.

You must notify the Contracting Officer immediately when the work effort is 85% of the not to exceed amount. Contact Design Branch at 904-232-1613 for questions or assistance with your proposal.

You are required to review these instructions and make an estimate in writing of the cost and number of days to complete the work. Please mark your estimate to the attention of Chief, Survey Section.

This is not an order to proceed with the work. The Contracting Officer will issue this at a later date.

Sincerely,

Walter Clay Sanders, P.E.
Assistant Chief, Engineering Division

Enclosures (withdrawn from example)

Example Task Order Scope of Work--Sand Bypass Project

CANAVERAL SAND BYPASS PHASE II PROJECT
PRE AND POST HYDROGRAPHIC AND TOPOGRAPHIC
BEACH CONSTRUCTION SURVEY
CANAVERAL, FLORIDA
SURVEY No.97-096

1. LOCATION OF WORK: The project is located at Canaveral, Florida.

2. SCOPE OF WORK:

2a. The services to be rendered by the Contractor include obtaining topographic and hydrographic beach survey data (x, y, z) for the borrow area from CCAFS-38 TO CCAFS-29, for the beach fill area from R-7-T to R-14 and CADD files as shown on Enclosure 1, contract plans and specifications.

2b. The services to be rendered by the contractor include all the work described below. Details not specifically described in these instructions are nevertheless a firm requirement if they can be identified as an item, or items, commonly a part of professional grade work of a comparative nature.

2c. The contractor shall furnish all necessary materials, labor, supervision, equipment, and transportation necessary to execute and complete all work required by these specifications.

2d. The Corps of Engineers, Design Branch shall be contacted the same day that the Contractor plans to commence the work. The points of contact are, Mr. Hank Rimmer, (CORPS OF ENGINEERS DISTRICT OFFICE) at 904-232-1606, and Mr. James Lanier (ATLANTIC COAST AREA OFFICE) at 407-783-8407. Any instruction given to the survey crew by the Atlantic Coast Area Office shall be coordinated with the Mr. Rimmer before commencing. A meeting with the Atlantic Coast Area Office, Mr. Lanier shall be arrange before commencing the surveys to establish the priority for the surveys.

2e. Rights-of-Entry must be obtained verbally and recorded in the field book before entering on the private property. Enter in the field book the name and address of the property owner contacted for rights-of-entry.

2f. COMPLIANCE: Surveying shall be in strict compliance with Engineering and Design Standards and Specifications for Surveys, Maps, Engineering Drawings, and Related Spatial Data Products and the Minimum Technical Standards set by the Florida Board of Professional Surveyors and Mappers.

2g. All digital data shall be submitted on CD ROM's.

3. FIELD SURVEY EFFORT: Topographic and hydrographic beach survey data shall be obtained for the borrow area from CCAFS-38 TO CCAFS-29, for the beach fill area from R-7-T to R-14 and CADD files as shown on Enclosure 1, contract plans and specifications. Enclosure 2 is the contract plans and specifications. Enclosure 3 is the control monument descriptions. Enclosure 4 is the Technical Requirements.

3a. CONTROL: The Horizontal datum shall be NAD 1927 and the vertical datum shall be N.G.V.D. of 1929. All control surveys shall be Third Order, Class II accuracy.

3a1. The basic control network can be accomplished using precise differential carrier-phase Global Positioning System (GPS). Differential GPS baseline vector observations shall be made in strict accordance with the criteria contained in the engineering manual EM-1110-1-1003 and with the Geometric Geodetic Accuracy Standards And Specifications For Using GPS Relative Positioning Techniques by Federal Geodetic Control Committee, version 5.0.

3a2. Network design, station and baseline occupation requirements, for static and kinematic surveys, satellite observation time per baseline, baseline redundancies, and connection requirements to existing networks, shall follow the criteria given in the above said engineering manual. A field observation log sheet shall be completed at each setup in the field.

3a3. GPS derived elevation data shall be supplied in reference to the above said datum. Existing benchmark data and stations shall be used in tandem in a minimally constrained adjustment program to model the geoid. All supporting data used in vertical adjustment shall be submitted.

3a4. Existing Corps of Engineers project control shall be utilized for establishing horizontal and vertical control. No control monuments shall be utilized that are not included in the control network shown in the contract plans. All established or recovered control shall be fully described and entered in a FIELD BOOK, in accordance with the Technical Requirements of this contract. Recover or establish horizontal and vertical control monuments at each profile line. The designations for new control monuments will be furnished when needed. All horizontal and vertical control shall be verified before using.

3a5. All horizontal and vertical control (double run forward and back) established shall be a closed traverse or level loop no spur lines, with third order accuracy. All horizontal and vertical control along with baseline layouts, sketches, and pertinent data shall be entered in field books.

3a6. All monuments, survey markers, etc., recovered shall be noted on the copies of control descriptions. Control points established or recovered with no description or out-of-date (5 Years old) description shall be described with sketches for future recovery use.

3a7. All original field notes shall be kept in standard pocket size field books and shall become the property of the Government. The first four pages of the field books shall be reserved for indexing and the binding outside edge shall be free of all marking. Design Branch will issue field book numbers upon submittal of field books for checking.

3b. TIDE STAFF: The survey data shall be collect on MLW datum which is 1.9 below N.G.V.D. located in vicinity of "CABLE SOUTH PORT" monument.

3c. BORROW AREA: Collect survey data (X, Y, & Z) for profile lines CCAFS-38 thru CCAFS-29. The profile lines shall start at the monuments (range 0) and extend seaward to range 1600 with data points at 25 foot range intervals and all breaks and 12.5 foot intervals in the water. The profile lines shall be ran on the azimuth shown in Enclosure 1. Establish a survey stake at 3.5 foot MLW elevation on each profile line. The survey stake shall be labeled with 3.5 MLW.

3d. BEACH FILL AREA:

3d1. BASELINE: Establish a baseline landside of the monuments with line of sight from R-7-T to R-14. The baseline shall be establish between elevation 9.5 MLW and the monuments. Establish POT's along the baseline at 100 foot intervals.

3d2. PROFILE LINES: Collect survey data (X, Y, & Z)
on 100 intervals with data points at 25 foot range intervals and all breaks for the land portions and 12.5 for the water portions, from the monuments (range 0) to range 1000 seaward. Establish a survey stake at 9.5 foot MLW elevation for each profile line. The survey stake shall be labeled with 9.5 MLW.

3e. BREAKLINE: Breaklines shall be located for all natural or man-made features as needed. The breaklines shall be located with X, Y, and Z and identified.

3f. DATA COLLECTION (RTK or TOTAL STATION): Data collection will be allowed for data points only, showing all instrument positions, calibration, backsites and closing readings in the field book. If RTK is utilized Q1 and Q2 files shall be furnished. Before using RTK, one session shall be performed around the expected survey area. After observation of the primary control (four monuments; one on each corner of the work area) the geoid model shall be prepared utilizing the four occupied monuments data.

4. DATA PROCESSING: The Contractor shall make the necessary computations to verify the accuracy of all measurements and apply the proper theory of location in accordance with the law or precedent and publish the results of the survey. Compute and tabulate the horizontal and vertical positions on all work performed. Review and edit all field data for discrepancies before plotting the final drawings.

4a. Furnish X, Y, Z, and descriptor ASCII file for each profile line and one X, Y, Z, and descriptor ASCII file with all profile lines included for each area.

5. CADD: The topographic and hydrographic features shall be translated or digital capture into Intergraph IGDS 3D design files according to the specifications furnished. The survey data (cover, control, site plan, plan sheets, and section drawings) shall be provided in Intergraph Microstation (PC or 32) Version 4.0 or higher, AT&T System V Unix, CLIX R3.1 Vr. 6.3.2 format as shown in the letter dated 30 September 1992. All CADD files shall be the same as shown in Enclosure 1.

5a. GLOBAL ORIGIN: The IGDS 3-D design file shall be prepared with a global origin of 0, 0, 2147483.65, Design file master units: FT., Sub units: 1,000, and positional units: 1. The file name shall be the survey number prefixed with an "Y", i.e. Y049sh1.DGN. All reference files name shall commence with the Y049**.DGN also.

5b. DIGITAL TERRAIN MODEL (DTM) DATA: The Contractor shall develop and deliver a surface model of each survey area using Intergraph compatible Digital Terrain Modeling software and the model file shall have the .dtm extension. The digital terrain model shall be developed from the collected data. Breaklines should include ridges, drainage, road edges, surface water boundaries, and other linear features implying a change in slope. The surface model shall be of adequate density and quality to produce a one-foot contour interval derived from the original DTM (Digital Terrain Model) file. The contour data shall be incorporated as a reference file into the final data set (DGN file). All data used to develop the DTM shall be delivered in Intergraph 3-D design files.

5b1. CONTOURS: The contours shall be developed in the digital terrain model (DTM). The contours shall be provided in one or more master (scale 1" = 200') DGN files, attached as a reference file to all sheet files utilizing clip bounds methods. Each contour shall be drawn sharp and clear as a continuous solid line, dashed contours are not acceptable. Every index contour shall be accentuated as a heavier line than the intermediate contour line and shall be annotated according to its actual elevation above MLW. Labeling or numbering of contours shall be placed on top of the contour line, so that the elevation is readily discernible, do not break contours. Labeling of intermediate contours may be required in areas of low relief.

5c. MASTER DGN FILES:

5c1. The survey data (DTM data points) points shall be provided in one or more master DGN file (scale 1" = 200'), attached as a reference file to all sheet files utilizing the clip bounds methods.

5c2. The contours shall be provided in one or more master DGN file (scale 1" = 200'), attached as a reference file to all sheet files utilizing the clip bounds methods. "DO NOT PLOT THE CONTOURS".

5c3. The breaklines shall be provided in one or more master DGN file (scale 1" = 200'), attached as a reference file to all sheet files utilizing the clip bounds methods, "DO NOT PLOT THE BREAKLINES".

5c4. The control points shall be provided in one or more master DGN file (scale 1" = 200'), attached as a reference file to all sheet files utilizing the clip bounds methods.

5c5. The baseline shall be provided in one or more master DGN file (scale 1" = 200'), attached as a reference file to all sheet files utilizing the clip bounds methods.

5d. COVER AND CONTROL SHEET: The first sheet shall be a cover sheet showing the control sketch, survey control tabulation, sheet layout or index, legend, project location map, survey notes, north arrow, graphic scale, grid ticks, large signature title block. Tabulate, plot, and list the control used for the survey on the final drawings.

5e. PLAN SHEETS: The plan sheets shall be prepared to a scale of 1" = 200', in the Corps of Engineers format (reference letter and instruction dated September 30, 1992) showing notes, title block, grid, north arrow, graphic scale, legend, sheet index, and D. O. File Number. Sheets shall be oriented with north to the top and designed to utilize the least number of sheets. The extreme right 7 inches of the sheet shall be left blank for notes, legends, etc. The first (cover) sheet shall have large signature block. The second sheet and all sheets following shall be a continuation sheet and shall have a minimum of two notes, note 1: See Drawing number 1 for notes, note 2: Refer to Survey No. 97-096. PAPER PLOTS ONLY".

6. MAP CONTENT:

6a. COORDINATE GRID (NAD 27): Grid ticks (English) of the applicable State Plane Coordinate System shall be properly annotated at the top, bottom and both sides of each sheet. Spacing of the grid ticks shall be five (5) inches apart.

6b. CONTROL: All horizontal and vertical ground control monuments shall be shown on the maps in plan and tabulated.

6c. TOPOGRAPHY: The map shall contain all representable and specified topographic features which are visible or identifiable.

6d. SPOT ELEVATIONS: Spot elevations shall be shown on the maps in proper position. In areas where the contours are more than 3 inches apart at map scale, spot elevations shall be shown. The horizontal distance between the contours and such spot elevations or between the spot elevations shall not exceed two (2) inches at scale of delivered maps.

6e. CONTOURS: The contours shall be developed in the digital terrain model (DTM). Each contour shall be drawn sharp and clear as a continuous solid line, dashed contours are not acceptable. Every index contour shall be accentuated as a heavier line than the intermediate and shall be annotated according to its actual elevation. Whenever index contours are closer than one-quarter (1/4) inch, and the ground slope is uniform, the intermediate shall be omitted. Labeling or numbering of contours shall be placed on top of the contour line, so that the elevation is readily discernible, do not break contours. Labeling of intermediate contours may be required in areas of low relief.

6f. MAP EDIT: All names, labels, notes, and map information shall be checked for accuracy and completeness. All buildings, roads and man made features shall be labeled with the type of construction, purpose and name. All residences shall be labeled with the type of construction.

6g. SHEET INDEX AND LEGEND: On plan drawings a small scale sheet index shall be shown on each sheet of the series; highlighting the sheets in the standard manner. Planimetric and topographic feature legends shall be shown on each sheet. Contractor logo shall be shown on each drawing.

6h. MAP ACCURACY: All mapping shall conform to the national map accuracy standards except that no dashed contours will be accepted.

7. OFFICE REVIEW AND COMPUTATIONS: The Contractor shall make the necessary computations to verify the correctness of all measurements and apply the proper theory of location in accordance with the law or precedent and publish the results of the survey.

8. DELIVERIES: On completion, all data required shall be delivered or mailed to Design Branch, Survey Section at the address shown in contract, and shall be accompanied by a properly numbered, dated and signed letter or shipping form, in duplicate, listing the materials being transmitted. All costs of deliveries shall be borne by the Contractor. Items to be delivered include, but are not limited to the following:

8a. GPS network plan.

8b. GPS raw data along with field observation log sheets filled out in field with all information and sketches.

8c. Computation files with Horizontal and Vertical abstracts along with any Q1 and Q2 files.

8d. Horizontal and Vertical Field Books.

8e. Furnish X, Y, Z, and descriptor ASCII file for each profile line and one merged with all data collected for each area.

8f. DTM File

8g. DGN files to a scale of 1" = 200.

8h. Advance paper plots of all plan sheets, cover sheet and control sheets for approval.

Example Task Order Scope of Work--River Sections

PROPOSED TASK ORDER NO. 26
CONTINENTAL ENGINEERING, INC.
DACW66-97-D-0053

Scope of Work
1999 Mississippi River General Hydro Surveys
7 January 1999

1. General Scope The contractor shall perform General Hydrographic Surveys on the Mississippi River within the reaches described in the enclosures. The surveys shall include the development of digital maps reduced to the low water reference plane, color coded elevations (polyfill shapes vs triangles), checked for correctness, hard copy of each survey including the raster image, and a format developed to be directly inserted into the Regional Engineering Environmental Geographical Information System (REEGIS).

2. Survey Requirements and Specifications.

a. Miscellaneous. See Miscellaneous Survey and Specifications (MSRS), dated 4 March 1993, paragraphs 1 through 8 for A-E responsibilities in regard to Quality Assurance, Submission of Pay Estimates, Safety, Project Progress Reports, Damages, Coordination of Work, Datums, and Survey Field Notes.

b. Right of Entry. Verify right of entry with the QARs. See paragraph 9.b., MSRS dated March 1993.

c. Survey Limits. The limits for the surveys shall be the reaches as described in Encl. 1. The surveys shall extend from bank to bank at 1056-ft intervals unless otherwise required in the limit enclosure. Additional ranges shall be sounded upstream and downstream as near as safety considerations will allow to existing dikes. The ranges obtained near dikes should not be from bank to bank, but should extend a minimum of 200 feet beyond the riverward end of the dike. The data shall be obtained within the reaches described and sheets not split.

d. Existing Horizontal Control. Adequate horizontal control exists within a reasonable distance of the survey limits to perform this project. The control consists of monuments used for all river work within the Memphis District. Horizontal control shall be supplied to the respective hydrographic survey party chiefs at the Memphis District Office prior to the start of the surveys.

e. New Baseline Control. No new baseline control shall be required for this project.

f. Horizontal Computations. All horizontal data developed for this project shall be computed on the North American Datum of 1983 (NAD 83) using Universal Transverse Mercator (UTM) Zone 15 or 16 plane coordinates in U.S. Survey Feet. See MSRS, paragraph 12 for other requirements. Azimuth orientation shall be from zero North.

g. Existing Vertical Control. Adequate vertical control exists within a reasonable distance of the survey limits to perform this project within the accuracy specified. Recovery of existing vertical control shall be documented as described in MSRS paragraphs 13.a., 13.b., 13.c., and 13.d.

g. New Vertical Control. No new vertical control shall be required for this project.

h. Monumentation. No new monumentation is required under this Scope of Work.

i. Digital Map. A digital map in a separate IGDS file for each hydrographic sheet shall be required at a scale of 1:10,000 with a five-foot contour interval. An ASCII file shall be provided that includes all hydrographic data collected and edited for erroneous soundings and positions. Soundings shall be collected at intervals no greater than 50 feet. A second ASCII file shall also be provided which contains an x,y,and z coordinate at least every 100 feet along each range. A Microstation design file (.DGN) of each plotted "z" elevation at the "x" and "y" coordinate for each point found in the second ASCII coordinate file above shall be submitted. Soundings shall be on level 49, color coded elevations and buoys on level 52. The design file shall contain horizontal and vertical control used to develop the survey. An Intergraph digital terrain model (.DTM) file shall also be provided. For all work along the Mississippi River, the 1993 Low Water Reference Plane elevation shall be used as the zero contour. Digital sheets supplied by the Memphis District reflect true elevations but shall be reduced relative to the 1993 LWRP by the contractor. They shall be developed as three-dimensional graphic elements on level 57 to be loaded as breaklines to the .DTM file. Hydrographic survey shall be performed at the locations and intervals described in paragraph 2.c. and as described below:

(1) Ranges. The ranges shall extend from water's edge to water's edge. The coverage shall include all dike fields, chutes, sandbars and islands that can be surveyed hydrographically. In addition, all navigation buoys within the defined area shall be located by an x and y position and plotted on the maps.

(2) Sounding data (rounded to the nearest foot) shall be plotted at intervals of ± 100 feet using a text size of 80 (using Font 10). The contour interval shall be five feet and the contours shall extend from water's edge to waters edge. The zero contour shall be a dashed (---) line. The –10 contour shall be a solid line of heavier weight than the other contours. The hydrographic data may overlap with adjacent sheets. In these cases all hydro data shall be plotted on all overlapping sheets. All hydrographic maps shall be verified for accuracy by the contractor before final submittal to this office. All miscellaneous data (i.e. title blocks, gage data {furnished by Government}, slope diagrams, and data ranges were sounded) on the sheet shall be completed by the contractor.

(3) All hydrographic survey ranges are to be sounded as nearly normal to the channel as possible. Computer generated contours cannot be developed accurately if ranges are at any noticeable angle. Where some angle cannot be avoided, range spacing should be decreased.

(4) Each survey shall follow the REEGIS standards which are in the enclosure. Each survey shall use polyfill shapes for the color-coded contours instead of triangles.

(5) The following files shall be submitted .DGN, .DTM and .XYZ files for the NGVD Elevation **and** for the Low Water Reference Plane.

(6) A hardcopy plot of each completed hydrographic sheet shall be submitted containing the latitudinal and longitudinal grid, soundings, contours, color coded elevations, raster image, and title block.

(7) Level 63 information as contained in Miscellaneous Intergraph Requirements and Specifications, dated 10 September 1992 shall be included in all files.

3. DATA SUBMISSION. The data required by these surveys shall be developed and submitted by 12 February 1999. No formal SER shall be required for this scope of work.

Example Task Order Scope of Work--Revetment Surveys

PROPOSED TASK ORDER NO. 33
EMC, INC.
DACW66-98-D-0007

Scope of Work
Revetment Before Construction Survey at Norfolk-Star, MS
Approximate River Mile 711L AHP

1. General Scope. The contractor shall perform a revetment before construction survey at Norfolk-Star Revetment, MS. The purpose of this survey is to gather information for the possible extension of Norfolk-Star Revetment. The survey will consist of baseline recovery from Norfolk-Star Revetment baseline station 84+00 to station 75+00 and the establishment of 6000 ft of new baseline upstream from station 75+00. Soundings from water's edge to 800 ft. beyond water's edge and bank sections from water's edge to 150 ft. behind top bank will also be required.

2. Survey Requirements and Specifications.

a. Miscellaneous. See Miscellaneous Survey and Specifications (MSRS), dated 4 March 1993, paragraphs 1 through 8 for A-E responsibilities in regard to Quality Assurance, Submission of Pay Estimates, Safety, Project Progress Reports, Damages, Coordination of Work, Datums, and Survey Field Notes

b. Right-of-Entry. Right-of-entry has been obtained by the Memphis District Corps of Engineers.

c. Survey Limits. The limits for baseline recovery shall be from Norfolk-Star Revetment baseline station 84+00 to station 75+00. Section limits shall be from baseline station 84+00 to 6000 ft. upstream of station 75+00. Lateral limits shall be from 150 ft. behind top bank to 800 ft. beyond water's edge. Sections shall be taken at 100-ft. intervals. A Site Map is provided in Encl. 1.

d. Existing Horizontal Control. The Norfolk-Star Revetment baseline shall be re-established from baseline station 75+00 to baseline station 84+00 in accordance with MSRS, paragraph 11.a, 11.b, 11.d, and 11.f. Paragraph 11.b shall be amended to Third Order Class 2. Adequate horizontal control exists as herein furnished within a reasonable distance of the survey limits to perform this survey to the required accuracy specifications. Existing Norfolk-Star Revetment baseline coordinates are provided in Encl. 2. Note that these coordinates are provided in NAD 83 Geographic Coordinates with Corpscon translated coordinates of Norfolk-Star Revetment baseline to NAD 83 UTM Zone 15, U.S. Survey feet.

e. New Horizontal Control. New baseline shall be established in accordance with MSRS, paragraph 11.a, 11.b, 11.d, and 11.f. Paragraph 11.b shall be amended to Third Order Class 2. The new baseline shall stem from existing baseline station 75+00 and run 6000 ft. upstream of station 75+00 along the bar at River Mile 926R AHP, to new baseline station 40+00.

f. Horizontal Computations. Horizontal data shall be computed on the North American Datum of 1983 (NAD 83) using Universal Transverse Mercator (UTM) Zone 15 plane coordinates in U.S. Survey Feet. See MSRS, paragraph 12 for other requirements.

g. Existing Vertical Control. Vertical control information is provided in Encl. 3. See MSRS, paragraph 13.a, 13.b, 13.c, and 13.d for requirements.

g. New Vertical Control. Third order vertical control shall be established on all Type G or Type F monuments and iron pins installed as described in MSRS, paragraphs 13.a and 13.d. All new vertical control documentation shall be submitted as hard copy and in digital form using previously supplied database software.

h. Monumentation. Monumentation shall be as described in MSRS, paragraph 14.a. through 14.g. and as follows:

(1). Each monument or iron pin (baseline) shall be designated by the stationing preceded by the following character:

BASELINE	DESIGNATION	EXAMPLE
Norfolk-Star	NS	NS 75+00

Note: There shall be a space between the prefix and the stationing, not a dash.

A River List monument/marker documentation form shall be completed in accordance with MSRS, paragraph 14.f (1) for each Monument installed. All existing and new horizontal and vertical control marks used to complete this survey shall be included in the final data submittal.

(2). Each iron pin shall be stamped as described in MSRS, paragraph 14.c.

i. Field Book Documentation.

(1). Recover/Re-establish Norfolk-Star Revetment baseline within the survey limits in accordance with MSRS, paragraphs 11.a, 11.b, 11.d, and 11.f.

(2). Establish new baseline from station 75+00 to 6000 ft. upstream of station 75+00 in accordance with MSRS, paragraphs 11.a, 11.b, 11.d, and 11.f.

(2). Obtain bank sections at 100-ft. intervals. Sections shall extend from water's edge to 150 ft. behind top bank.

(3). Obtain soundings at 100-ft. intervals. Soundings shall extend from water's edge to 800 ft. beyond water's edge.

(4). All elevations shall be referenced to National Geodetic Vertical Datum of 1929. All horizontal positions shall be referenced to the North American Datum of 1983, using UTM Zone 15 plane coordinates in U.S. Survey Feet.

(5). The 1993 Low Water Reference Plane shall be used for contouring which equals 168.40 at mile 711L AHP.

j. Digital Map. Digital maps shall be developed and provided in digital format as described in MSRS, paragraph 23.a.

3. DATA SUBMISSION. The delivery date for the final SURVEY ENGINEERING REPORT shall be 1 March 1999. See MSRS, dated 4 March 1993, paragraph 24, for additional requirements.

Example Task Order Scope of Work--Project Condition Survey

TECHNICAL REQUIREMENTS
JACKSONVILLE HARBOR 30, 34, 38, & 42-FOOT PROJECT, PROJECT CONDITION SURVEY, JACKSONVILLE, DUVAL COUNTY, FLORIDA
(Survey No. 99-315)

1. LOCATION OF WORK. The project is located at Jacksonville Harbor, Jacksonville, Duval County, Florida.

2. SCOPE OF WORK.

2a. The service to be rendered by the Contractor includes obtaining hydrographic survey data as shown on Enclosures 1(Plan drawings), and 2. Enclosure 3 is the technical requirements and Enclosure 4 is control monuments descriptions.

2b. The services to be rendered by the Contractor include all the work described in these technical requirements. Details not specifically described in these instructions are nevertheless a firm requirement if they can be identified as an item, or items, commonly a part of professional grade work of a comparative nature.

2c. The Contractor shall furnish all necessary rights-of-entry, materials, labor, supervision, equipment, and transportation necessary to execute and complete all of the work required by these specifications.

2d. The Corps of Engineers, Survey Section shall be contacted the same day that the Contractor plans to commence the work.

2e. Rights-of-Entry must be obtained verbally and recorded in the field book before entering on the private property. Enter in the field book the name and address of the property owner contacted for rights-of-entry.

2f. COMPLIANCE. Surveying and Mapping shall be in strict compliance with EM-1110-1-1000 for Photogrammetric Mapping, EM-1110-1-1002 Survey Markers and Monumentation, EM-1110-1-1003 NAVSTAR Global Positioning System Surveying, EM-1110-1-1004 Deformation Monitoring and Control Surveying, EM-1110-1-1005 Topographic Surveying, EM-1110-2-1003 Hydrographic Surveying, EM-1110-1-2909 Geospatial Data and System, (Tri-Service) A/E/C CADD Standards, (Tri-Service) Spatial Data Standards, Related Spatial Data Products and Chapter 177, Chapter 472, and Chapter 61G17 of the Minimum Technical Standards set by the Florida Board of Professional Surveyors and Mappers.

2f1. STANDARDS FOR DIGITAL GEOSPATIAL METADATA.
Metadata are "data about data". They describe the content, identification, data quality, spatial data organization, spatial reference, entity and attribute information, distribution, metadata reference, and other characteristics of data. Each survey project shall have metadata submitted with the final data submittal. Furnish a digital file using CORPSMET 95 (Metadata Software) with the appropriate data included. Enclosure 5 is an example of the metadata file printed. Point of contact in survey section is Mr. Bill Mihalik at 904-232-1462.

2g. All digital data shall be submitted on CD-ROM's.

3. FIELD SURVEY EFFORT. Obtain the hydrographic survey data for Cuts 3-19, Cuts 39-55, Terminal Channel, Cuts A, F & G as shown on Enclosures 1, and 2. Enclosure 3 is the control monument descriptions, Enclosure 4 is the technical requirements.

3a. CONTROL.

3a1. The Horizontal datum shall be NAD 1927. The vertical datum shall be NGVD 1929. All control monuments shall be verified both horizontally and vertically by a control survey. All control surveys shall be Third Order, Class II accuracy. All Positions will be tied to the state plane coordinate system, zone 0901 Florida East.

3a2. The basic control network shall be accomplished using precise differential carrier-phase Global Positioning System (GPS). Differential GPS baseline vector observations shall be made in strict accordance with the criteria contained in the engineering manual EM-1110-1-1003 and with the Geometric Geodetic Accuracy Standards And Specifications For Using GPS Relative Positioning Techniques by Federal Geodetic Control Committee, version 5.0.

3a3. Network design, station and baseline occupation requirements, for static and kinematic surveys, satellite observation time per baseline, baseline redundancies, and connection requirements to existing networks, shall follow the criteria given in the above said engineering manual. A field observation log shall be completed at each setup in the field.

3a4. GPS derived elevation data shall be supplied in reference to the above said datum. Existing benchmark data and stations shall be used in tandem in a minimally constrained adjustment program to model the geoid. All supporting data used in vertical adjustment shall be submitted.

3a5. Existing Corps of Engineers control data shall be tied into subject survey net. The GPS network shall commence from the control shown on Enclosure 2. All established or recovered control shall be fully described in accordance with the Technical

Requirements of this contract. All control surveys shall be Third Order, Class II accuracy. The Contractor shall submit the field data and abstracts for the control networks to Survey Section for computation before commencing the mapping. The monument designations shall be furnished as requested. All horizontal and vertical control (double run forward and back) established shall be a closed traverse or level loop no spur lines, with third order accuracy. All horizontal and vertical control along with baseline layouts, sketches, and pertinent data shall be entered in field books. All monuments, survey markers, etc., recovered shall be noted on the copies of control descriptions. Control points established or recovered with no description or out-of-date (5 Years old) description shall be described with sketches for future recovery use. All original field notes shall be kept in standard (pocket size) field books and shall become the property of the Government. The first four pages of the field books shall be reserved for indexing and the binding outside edge shall be free of all marking.

3b. TIDE STAFF: Staff shall be located in the immediate vicinity of the work areas. The gauge shall be referenced MLW as shown on Enclosure 2 (Tide staff locations)

3c. The limits of the hydrographic survey are: Jacksonville Harbor, Cut-3 thru Terminal Channel, Cut-A, Cut-F & Cut-G. Take hydrographic cross-sections for the reaches listed below.

Cut	*Beginning Station*	*Ending Station*	*Azimuth*	*Sta. Interval*
3	0+00.00	300+00.00	96-53-41	100 feet
4	0+00.00	15+38.67	86-36-47	100 feet
5	0+00.00	13+58.23	66-17-49	100 feet
6	0+00.00	24+72.08	42-22-17	100 feet
7	0+00.00	28+21.83	21-18-33	100 feet
8	0+00.00	24+66.35	40-38-49	100 feet
9	0+00.00	24+23.63	65-36-03	100 feet
10	0+00.00	7+77.36	86-22-43	100 feet
11	0+00.00	6+08.86	98-23-01	100 feet
12	0+00.00	4+96.23	107-14-12	100 feet
13	0+00.00	18+14.83	116-51-38	100 feet
14/15	0+00.00	47+62.29	129-38-26	100 feet
16	0+00.00	13+31.28	120-17-44	100 feet
17	0+00.00	10+92.08	108-32-47	100 feet
18	0+00.00	8+98.59	91-46-22	100 feet
19	0+00.00	9+27.10	76-50-50	100 feet
39	0+00.00	36+57.85	60-42-50	100 feet
40	0+00.00	19+94.59	87-46-43	100 feet
41	0+00.00	29+54.53	114-28-25	100 feet
42	0+00.00	159+16.21	79-14-02	100 feet
43	0+00.00	21+57.00	112-50-00	100 feet
44	0+00.00	49+31.81	146-25-58	100 feet
45	0+00.00	40+47.22	136-44-10	100 feet
46	0+00.00	20+64.07	127-12-22	100 feet
47	0+00.00	14+95.67	107-30-00	100 feet
48	0+00.00	13+45.42	88-10-39	100 feet
49	0+00.00	20+41.57	68-43-49	100 feet
50	0+00.00	82+30.97	58-32-58	100 feet
51	0+00.00	58+57.42	16-40-20	100 feet
52	0+00.00	15+69.24	08-59-20	100 feet
53	0+00.00	12+92.85	342-49-45	100 feet
54	0+00.00	10+48.52	333-10-31	100 feet
55	0+00.00	40+11.32	309-07-42	100 feet
Term Ch	0+00.00	186+21.19	10-00-41	100 feet
A	0+00.00	53+10.21	161-45-23	100 feet
F	0+00.00	25+48.02	36-37-57	100 feet
G	0+00.00	149+36.21	17-11-17	100 feet

Coverage should extend a minimum of 200-feet outside channel limits, wideners, and turning basins in all directions. Ensure that lines extend sufficient distance to cover Coal Terminal and proposed settling basin (enclosure 2) which are both adjacent to Cut-42. Coverage in proposed settling basin should extend a minimum of 400-feet in all directions as shown on enclosure.

3d. Priorities are given for this project as follows:

1. Terminal Channel, from Sta. 164+56 to southern terminus.
2. Cut-42 to Sta. 164+56 of Terminal Channel.
3. Cut-14/15 to Cut-19.
4. Cuts A, F & G
5. Cut-19 to Cut-42
6. Bar Cut-3 to Cut-14/15.

Once a priority is completed, mapping should be done and submitted as stated above.

3g. NAVAIDS. All Navigation's Aids (NAVAIDS) shall be located with coordinate positions (GPS) in or adjacent project area. Fixed NAVAIDS shall be positioned four to five times and floating NAVAIDS shall be positioned one time, with wind and tide direction recorded. Note type and condition of NAVAIDS within the project limits. Warning signs, lights, and any existing regulatory markers, (information signs) within the project limits shall be positioned four to five times. Locate all NAVAIDS in the entrance channel.

3h. DGPS. The hydrographic positioning system shall be a Differential Global Positioning System utilizing the USCG Nav-beacon system as the reference station. The positioning system shall be checked with two control monuments and recorded along with setup data (input data to the GPS) in the field book. Hydrographic survey log sheets shall be filled out and submitted along with the field book.

3i. SOUNDING POLE 6" DISK. Utilize a 6 inch diameter disk attached to the bottom of the sounding pole or lead line at all times when collecting conventional soundings.

3j. Breakline. Breaklines shall be located for all natural or man-make features as needed. The breaklines shall be located with X, Y and Z and identified.

3k. DATA COLLECTION (TOTAL STATION). Data collection will be allowed for data points only, showing all instrument positions, calibration, backsites and closing readings in the field book.

4. DATA PROCESSING. The Contractor shall make the necessary computations to verify the correctness of all measurements and apply the proper theory of location in accordance with the law or precedent and publish the results of the survey. Compute and tabulate the horizontal and vertical positions on all work performed. Furnish X, Y, and Z points file for each profile line with descriptors shown for all land features located west of and including the monument at point collected, landward side (one file with land, one file with water, one with land and water data merged). Review and edit all field data for discrepancies before plotting the final drawings. Tabulate a list of the tide staff locations and bench mark designations used for the survey. Furnish ASCII X, Y, Z files with negative sign if elevation is negative.

5. CADD. The survey data shall be translated or digital capture into Intergraph IGDS 3D design files according to the specifications furnished. The survey data (cover, control, site plan, plan sheets, and section drawings) shall be provided in Intergraph MicroStation (PC or 32) Version 4.0 or higher, AT&T System V Unix, CLIX R3.1 Ver. 6.3.2 format as shown in the letter dated 30 September 1992.

5a. GLOBAL ORIGIN. The IGDS 3-D design file shall be prepared with a global origin of 0, 0, 2147483.65, Design file master units: FT., Sub units: 1,000, and positional units: 1. The file name shall be the survey number prefixed to an "A," i.e., A315.DGN. All reference file names shall commence with the A315 also.

5b. Digital Terrain Model (DTM) Data. The Contractor shall develop and deliver a surface model of the survey area using Intergraph compatible Digital Terrain Modeling software and the model file shall have the .dtm extension. The digital terrain model shall be developed from cross sections, spot elevations, and breaklines. Breaklines should include ridges, drainage, road edges, surface water boundaries, and other linear features implying a change in slope. The surface model shall be of adequate density and quality to produce a one foot contour interval derived from the original DTM (Digital Terrain Model) file. The contour data shall be incorporated as a reference file into the final data set. All data used to develop the DTM's shall be delivered in Intergraph 3-D design files.

5b1. Contours. The contours shall be developed in the digital terrain model (DTM). The contours shall be provided in one or more master data base DGN files, attached as a reference file to all sheet files utilizing the clip bounds methods. Each contour shall be drawn sharp and clear as a continuous solid line, dashed contours are not acceptable. Every index contour shall be accentuated as a heavier line than the intermediate and shall be annotated according to its actual elevation above NGVD Whenever index contours are closer than one-quarter (1/4) inch, and the ground slope is uniform, the intermediate shall be omitted. Labeling or numbering of contours shall be placed on top of the contour line, so that the elevation is readily discernible, do not break contours. Labeling of intermediate contours may be required in areas of low relief.

5c. MODEL DGN FILES (SCALE 1:1). The overall hydrographic data (collected data points) shall be provided in one or more master DGN file attached as a reference file to all sheet files utilizing the clip bounds methods. The project depth (30, 34, 38, & 42-foot) contours shall be provided in one or more master DGN file attached as a reference file to all sheet files utilizing the clip bounds methods. The control data points shall be provided in one or more master DGN file attached as a reference file to all sheet files utilizing the clip bounds methods.

5d. COVER AND CONTROL SHEET. The first sheet shall be a cover sheet showing the control sketch, survey control tabulation, sheet layout or index, legend, project location map, survey notes, north arrow, graphic scale, grid ticks, and large signature block. Tabulate, plot, and list the horizontal control used for the survey on the final drawings. In addition show a table on this sheet showing the X and Y coordinates, station and elevation for each point and monument.

5e. PLAN SHEETS. The plan sheets shall be prepared to a scale of 1"=100', in the Corps of Engineers format showing notes, title block, grid, north arrow, graphic scale, legend, sheet index, and D. O. File Number. The data shall be plotted at 12.5-foot intervals. The extreme right 7 inches of the sheet shall be left blank for notes, legends, etc. The second sheet and all sheets following shall be a continuation sheet and shall have a minimum of two notes, note 1: See Drawing number 1 for notes, note 2: Refer to Survey No. 99-315.

5f. Section Views. The sections shall be extracted and displayed from the digital terrain model (DTM OR TNT) utilizing INROADS OR INXPRESS. The sections shall be generated or extracted along the same azimuth as the section was collected in the field. The sections shall be displayed at a 10 to 1 vertical exaggeration. The planimetric lines (alignment of extraction), alignment, stations, and cross sections shall be displayed in one DGN file. Paper plots **"NOT REQUIRED".**

6. Map Content.

6a. Coordinate Grid (NAD 83). Grid ticks (English) of the applicable State Plane Coordinate System shall be properly annotated at the top, bottom and both sides of each sheet. Spacing of the grid ticks shall be five (5) inches apart.
6b. Control. All horizontal and vertical ground control monuments shall be shown on the maps in plan and tabulated.
6c. Topography. The map shall contain all representable and specified topographic features, which are visible or identifiable.
6d. Spot Elevations. Spot elevations shall be shown on the maps in the proper position.
6e. Contours. The contours shall be developed in the digital terrain model (DTM). The contours shall be provided in one or more master data base DGN files, attached as a reference file to all sheet files utilizing the clip bounds methods. Each contour shall be drawn sharp and clear as a continuous solid line, dashed contours are not acceptable. Every index contour shall be accentuated as a heavier line than the intermediate and shall be annotated according to its actual elevation above mean sea level. Whenever index contours are closer than one-quarter (1/4) inch, and the ground slope is uniform, the intermediate shall be omitted. Labeling or numbering of contours shall be placed on top of the contour line, so that the elevation is readily discernible, do not break contours. Labeling of intermediate contours may be required in areas of low relief.
6f. Map Edit and Accuracy. All names, labels, notes, and map information shall be checked for accuracy and completeness. All commercial buildings, roads and man made features shall be labeled with the type of construction, purpose and name. All residences shall be labeled with the type of construction. All mapping shall conform to the national map accuracy standards except that no dashed contour line will be accepted.

7. Office Review and Computations: The Contractor shall make the necessary computations to verify the correctness of all measurements and apply the proper theory of location in accordance with the law or precedent and publish the results of the survey. The contractor shall submit the original field notes and horizontal and vertical abstract (computation abstract) to Survey Section for final computation before mapping commences.

8. DELIVERIES: On completion, all data required shall be delivered or mailed to Design Branch, Survey Section at the address shown in contract, and shall be accompanied by a properly numbered, dated and signed letter or shipping form, in duplicate, listing the materials being transmitted. All costs of deliveries shall be borne by the Contractor. Items to be delivered include, but are not limited to the following:

8a. GPS network plan, (before GPS work commences).
8b. GPS raw data along with field observation log sheets filled out in field with all information and sketches.
8c. Computation files with Horizontal and Vertical abstracts along with any Q1 and Q2 files.
8d. Horizontal and Vertical Field Books.
8e. Furnish X, Y, and Z ASCII file for the longitudinal centerline.
8f. DTM Files (one overall and one per cut)
8g. DGN files. (scale 1" = 100')
8h. Plans plots at a scale of 1" = 1'00. 1 copy is requested with a contour shown inside channel at project depth. Project depth is 42-feet from Sta. 0+00 of Bar Cut-3 to Sta. 210+00 of Bar Cut-3, 38-feet from Sta. 210+00 of Bar Cut-3 to Sta. 164+56 of Terminal Channel, 34-feet from Sta. 164+56 of Terminal Channel to terminus of Terminal Channel, and 30-feet in Cut-A, F, G.
8i. Volumes: Perform necessary calculations to compute volume of material above project depth (plus 1 & 2-feet below) over surveyed area. Provide a spreadsheet showing computed results.
8j. Furnish a digital file using CORPSMET 95 (Metadata Software) with the appropriate data included.
8k. Raw HYPACK Log Files.

Enclosures (withdrawn in example)

22-11. FFP and IDC Contract Pricing

A number of methods are used for scheduling hydrographic survey rates in a FFP contracts or IDCs. The three most common methods are (1) daily rate and (2) cost per work unit rate. The daily rate basis is the cost for a complete hydrographic field crew (including all instrumentation, transport, travel, and overhead) over a nominal 8-hr day. (Daily crew rates are derived from hourly labor and equipment rates. Either daily and/or hourly rates may be used in the IDC price schedule). The cost per work unit rate basis is effectively the daily rate divided by an average production rate for a specified item of survey work. Fixed rates can then be established for items such as river sections, overbank sections, 1,000-ft offshore cross sections, linear units (miles) of sounding, square units (square miles) of sounding, per traverse mile, or any other desired unit. Labor rate contracts may be based on either pricing method. Each of these unit pricing methods have advantages and drawbacks which need to be considered prior to determining which method to use.

a. *Daily rate.* This method is used on the vast majority of USACE contracts. It provides the most flexibility for IDC contracts, especially when individual project scopes are expected to vary widely. It is, therefore, considered a more accurate method of determining costs for individual task orders. One disadvantage is that a more detailed independent government estimate (IGE) must be developed for each task order placed against an IDC. The estimator must be thoroughly familiar with the project and survey procedures.

b. *Cost per work unit rate*. This unit price basis is by far the simplest to administer. It is, in effect, like a GSA Schedule catalogue that allows ordering of services based on simply computed quantities. If all task order projects have relatively constant scopes (i.e., project sites, surveying requirements, and access are similar), this method should yield similar costs to those of a daily rate basis. This pricing method assumes that hydrographic surveying productivity is constant (or will average out over the long term), regardless of project site constraints, weather, and other factors. This may or may not be a valid assumption. Unless such variations are accounted for in the price schedule, a modification to the basic contract may be required. Arriving at this rate basis requires an initial computation of the daily rate, then a determination of an average productivity rate for the field crew. Given all the project-dependent variables, development of average productivity rates is difficult and requires considerable expertise on the part of the government estimator. As a result, cost per work unit rate estimates tend to become worst-case costs that can be abnormally high in some instances. Consequently, work unit rates are rarely used in the Corps.

22-12. Preparing Independent Government Estimates for Hydrographic Survey Services

To develop the price schedule for either FFP contracts or IDC contracts, an independent government estimate (IGE) must be prepared for all technical disciplines, equipment, instrumentation, plant, travel, and other items that will be used in the contract. For a FFP contract, the total of all these individual cost items is used to arrive at an overall project (contract) cost, and forms the basis for negotiating with the contractor. For IDC contracts, individual line items on the price schedule are estimated and negotiated with the contractor, and make up the contract schedule of prices. This IDC schedule is then used for Task Order labor and equipment rates. The daily (or hourly) rate for a surveying crew may be estimated using the following outline. Other breakdowns may be employed to arrive at a cost per crew day, per crew hour, or per unit of work. The crew personnel size, floating plant, depth recorders, data processing systems, vehicles, etc., must be explicitly indicated in the draft contract specifications, with differences resolved during negotiations. Options to add additional specialized survey equipment (along with personnel and/or transport) must be accounted for in the estimate and unit price schedule. A contractor's cost proposal should follow the same general format used by the government's IGE, if possible.

I. Direct labor. Labor or salary costs of survey technicians, including applicable overtime or other differentials necessitated by the work schedule.

II. Overhead on direct labor.

III. General and Administrative (G&A) overhead costs.

IV. Material costs. Include drafting supplies, field books, etc.

V. Travel and transportation costs. Crews' travel, per diem, etc., which includes all associated costs of vehicles used to transport personnel and floating plant to/and from the job site.

VI. Other costs. Include floating plant costs and cost of survey equipment and instrumentation, such as hydrographic positioning systems and depth recorders. Instrumentation and equipment costs should be amortized down to a daily rate, based on average utilization rates, expected life, etc. Exclude any instrumentation and plant costs covered under General and Administrative (G&A) accounts--interest, maintenance contracts, etc.

VII. Profit. (For IDC profit is either factored in the unit prices or computed separately for each task order).

22-13. Estimating Daily Unit Cost Rates for Indefinite Delivery Contracts

Most IDC for hydrographic survey services contain price schedules for the major line items that will be used in subsequent task orders. These line items may be broken out by individual labor and equipment and/or combined for a fully equipped survey crew. The method used is dependent on local preference or use. Most USACE commands tend to compute the daily rate for a complete survey crew and make minor adjustments to that rate, depending on the unique task order scope. Plant and equipment rental rates can represent the major cost item on a hydrographic survey team, especially if the automated survey instrumentation is factored into this rate. Often the plant rental costs far exceed survey crew labor costs. Daily costs for a survey vessel in the 40- to 65-ft-long range can run between $1,500 and $5,000 per day (1999 dollars). Smaller launches (18 ft to 26 ft) are far less--typically $300 to $1,000 per day. Labor costs for survey crew personnel usually range between $500 and $2,000 per day, depending on number of party members, complexity of equipment operated, and geographical area. Thus, a fully automated hydrographic survey team can cost between $800 and $7,000 per day to field. In preparing an IGE, unit costs may be determined from a variety of internal or external cost sources--see EP 715-1-7 (Architect-Engineer Contracting).

a. Labor rates. Field crew personnel costs include direct labor, fringe benefits, and G&A overhead costs. Estimates of labor rates may be obtained from a variety of publications that detail rates by geographical area--see EP 715-1-7. Equivalent General Schedule rates may also be used in estimating labor rates if they are representative of the private sector in the locality where the work is performed.

b. Travel costs. Normally, travel costs are computed for each job based on the current Joint Travel Regulation rates. Vehicle costs may be included under this category or computed under “Other Costs.”

c. Other costs.

(1) Floating plant rental rates. The costs of comparable Corps-owned plant may be used in arriving at an IGE for contracted work. Commercial vessel rental rates may also be used. In the Corps, the daily plant rental and survey equipment rental rates are developed at the time of purchase and are periodically updated based on actual utilization rates as charged against projects. Plant rental rates are recomputed at least annually, or more often if utilization changes significantly. Various Plant Replacement and Improvement Program (PRIP) costs make up this expense; however, such accounting methods are not used by private contractors. In addition, vessel operator labor rates are often incorporated into the plant rental rate. Corps field survey crew labor costs are separate expense items that may be used for comparable estimates.

(2) Survey instrumentation and equipment. survey equipment--particularly major items such as multibeam systems, CADD stations, or side scan--are often broken out separately in the contract price schedule. Costs for each equipment item are reduced to a daily rate based on original purchase cost, depreciation, estimated annual utilization, operation and maintenance (O&M), and other factors. Associated costs, such as insurance, maintenance contracts, and interest, are presumed to be indirectly factored into a firm's G&A overhead account. If not, such costs must be directly added to the basic equipment depreciation rates shown. Other equally acceptable methods for developing daily costs of equipment may also be used, such as manufacturer or third-party vendor daily/monthly rental rates. Equipment utilization and life cycle estimates do represent a large variable in an IGE. Typically the IGE is subsequently revised (during negotiations), based on actual rates as determined from the contractor's proposal and from detailed cost analysis and field price support audits.

The following example depicts a unit price IGE computation for a hydrographic survey crew equipped for multibeam and side scan surveys. Either the total (fully equipped) crew day rate or the rates for some selected items may be used for negotiating the final price schedule ("Schedule B") in a hydrographic survey services IDC. Similar computations would be performed for other major line items that would be included in the IDC, e.g., Project Manager, CADD Workstation Operator, Drafter, Hardware/software, etc.

SAMPLE IGE COMPUTATION FOR 3-MAN MULTIBEAM/SIDESCAN SURVEY CREW

LABOR

Supervisory Survey Tech (Party Chief)	$42,776.00/yr (based on GS 11/5)		
Multibeam Operator			
Overhead on Direct Labor (36%)	$15,399.36/yr		
G&A Overhead (115%)	$49,192.40/yr		
Total:	$107,367.76/yr	$411.57/day	
Survey Technician	$35,355/yr (based on GS 9/5)		
@ 151% O/H (36%+115%)	$88,741.05	$340.17/day	
Survey Aid/Boat Operator	$23,332/yr (based on GS 5/5)		
@ 151 % O/H	$58,563.32	$224.49/day	
		Total Labor Cost for 3-Man Multibeam Crew/day:	**$976.23**

TRAVEL

Per Diem (Nominal): 3 @ $ 88/day
(subject to JTR adjustment on task orders)

Total Travel Cost/day: $264.00

PLANT, FLOATING

Survey Vessel 32-foot:			
$100,000 @ 5 yrs @ 100 d/yr	$ 200/day		
Fuel, O&M, etc	$ 25/day		
		Total Plant Cost/day:	**$ 225.00**

SURVEY INSTRUMENTATION & EQUIPMENT

Echo Sounder (DESO) $30,000 @ 5 yrs @ 50 d/yr	$120/day		
DGPS Carrier Phase Positioning Sys $120,000 @ 4 yrs @ 100 d/yr	$300/day		
INS RPH Motion sensor $35,000 @ 5 yrs @ 100 d/yr	$ 70/day		
Multibeam System (complete) $250,000 @ 5 yrs @ 100 d/y	$500/day		
Side Scan Sonar (complete system) $75,000 @ 5 yrs @150 d/yr	$100/day		
Total Station (RTK), rods, etc. $32,000 @ 5 yrs @ 120 d/yr (rental rate: $60/d)	$ 53/day		
Tide Gage, Auto Telemetry (Manufacturer rental rate)	$ 22/day		
Survey Vehicle $40,000 @ 6 yrs @ 225 d/yr plus O&M	$ 40/day		
Misc Materials (field books, survey supplies, etc)	$ 25/day		
		Total Instrumentation & Equipment Cost/day:	**$ 1,230.00**

Subtotal :	**$ 2,695.23**
Profit @ 10.0%	**$ 269.52**
Total Estimated Cost per Day -- 3 man Multibeam/Side Scan Survey Crew	**$ 2,964.75**

22-14. Contract Price Schedule

The various personnel, plant and equipment cost estimates like those shown in the sample IGE above are used as a basis for negotiating fees for individual line items in the basic FFP or IDC contract. During negotiations with the A-E contractor, individual components of the IGE and the contractor's price proposal may be compared and discussed. Differences would be resolved in order to arrive at a fair and reasonable price for each line item. Computations similar to those shown in the above example would be performed for auxiliary home office direct support functions (e.g., drafter, CADD operator, etc.). The contract may also schedule unit prices based on variable crew sizes and/or equipment and may include non-hydrographic survey functions such as control surveys. A typical negotiated IDC price schedule (i.e., Section B - supplies or services and prices/costs) is shown below. This sample contract schedule is representative of those line items that might be used in a IDC covering Florida and the Caribbean area. Each Corps district has its unique requirements and therefore line items used in schedules will vary considerably. The contract specifications would contain the personnel and equipment requirements for each line item.

CONTRACT SCHEDULE B--HYDROGRAPHIC SURVEYING SERVICES
INDEFINITE DELIVERY CONTRACT

ITEM	DESCRIPTION	UNIT OF MEASURE	UNIT PRICE
1001	4-Man Topographic Survey Party	CD	$ 885.00
1002	5-Man Hydro Survey Party w/boat	CD	$1,382.00
1002a	4-Man Hydro Survey Party w/boat	CD	$1,200.00
1002b	3-Man Hydro Survey Party w/boat	CD	$1,000.00
1002c	2-Man Hydro Survey Party w/boat	CD	$ 784.00
1003	Survey Aid	CD	$ 144.00
1004	Per Diem (Florida)	MD	$ 78.00
1005	Project Manager	MD	$ 335.00
1006a	Project Manager (Per Diem-Florida)	MD	$ 78.00
1007	CADD Operator/Draftsman	MD	$ 300.00
1008	Computer (Person)	MD	$ 238.00
1011	Establish Control Monument	EA	$ 25.00
1012b	Extra Vehicle	DY	$ 100.00
1013	Air Boat (Florida w/operator)	DY	$ 130.00
1014	Marsh Buggy (Florida w/operator)	DY	$ 160.00
1016	Side Scan w/Operator	HR	$ 120.00
1018	Multibeam w/Operator	HR	$ 130.00
1019	Magnetometer w/Operator	HR	$ 120.00

NOTES:
Abbreviations: CD = Calendar Day MD = Man Day DY = Day EA = Each HR = Hour
Prices include overhead and profit.

22-15. Task Order Time and Cost Estimates

Once unit prices have been negotiated and established in the basic IDC schedule as illustrated in the above sections, each IDC task order is negotiated primarily for effort, i.e., time. The process for estimating the time to perform any particular survey function in a given project is highly dependent on the knowledge and personal field experience of the government and contractor estimators. The negotiated fee on a task order is then a straight mathematical procedure of multiplying the agreed-upon effort against the established unit prices, plus an allowance for profit if not included in the unit rates. An IGE is required for task orders over $100,000, along with a detailed profit computation, documented records of negotiations, etc. The scope is attached to a DD 1155 order placed against the basic contract. If a preliminary site investigation is scheduled for this project, any such adjustments should be investigated and resolved prior to negotiating subsequent task orders for the various phases of the work, to the maximum extent possible. As such, the negotiated costs for the subsequent work phases would be considered fixed price agreements. Any later adjustments to these agreed to prices would be issued in the form of modifications to task orders (i.e., change orders), and would have to be rigorously defended as significant, unforeseen changes in the scope. The contractor would be expected to immediately notify the contracting officer (KO) or Contracting Officer's Technical Representative (COTR) of the need for cost adjustments.

The example below illustrates a time and cost IGE for a task order under an IDC using the unit prices taken from the sample contract schedule in paragraph 22-14. The contractor's proposal for this work would follow a similar process. Subsequent Task Order negotiations would primarily focus on significant differences in time estimates for the various phases of the work. This assumes the scope of work is clearly defined in the Request for Proposal. Uncertain scopes would have to be resolved during negotiations and the IGE amended accordingly.

Sample Task Order Time and Cost Estimate--Multibeam, Tag Line, and Side Scan Surveys at OCONUS Location--for Dredging Contract Plans & Specifications

Preliminary Site Investigation and Inspection. A separate task order will be issued for the contractor's Project Manager to accompany the government COTR to the project site, to perform a general reconnaissance, recover control, select tide gage location, obtain berthing and fuel access, etc; and refine estimates of the time and cost to perform the subsequent phases of the work. A five-day trip is estimated, including travel time; allowing over 3 days in country.

Project Manager (1005)	$ 355.00/MD	
Per Diem-OCONUS (1006b)	$ 110.00	
Vehicle (1012b)	$ 100.00	
	$ 565.00/MD	
5-days @ $565.00/MD		$2,825.00
R/T Air Fare		$1,200.00
Total Estimated Cost:		$4,025.00

Geodetic Control Surveys. Geodetic control surveys are performed by the 5-man hydrographic survey crew as the initial phase of work after arrival in country. The full hydrographic survey crew rate (computed later) is charged since this equipment is on location. Data are reduced/computed in field by the survey crew.

Time estimates:		
Observe primary baseline & set control point (includes absolute PLGR observations)	0.5 DY	
Observe supplementary control (calibration point tag line control, etc.)	1.0 DY	
Establish tag line baselines along piers	1.5 DY	
	3.0 DY	
3.0 Days @ $3,199/CD		$9,597.00

Vertical Control Surveys and Tidal Gaging. Concurrent with the geodetic control surveys, a tide gage and staff is established the 5-man hydrographic survey crew as the initial phase of work after arrival in country. The full hydrographic survey crew rate is charged since this equipment is on location. The field crew computes preliminary tidal datums.

Time/cost estimates:		
Construct & establish tide gage at CG pier: (set benchmarks, staffs, run levels, etc.)	1.5 DY	
1.5 Days @ $3,199/CD		$4,798.50
Recording tide gage rental rate (project)		$2,000.00
Set horiz/vert monuments 6 @ $25 ea		$ 150.00
Final tidal computations/analysis (office)		
2.0 Days @ 238.00/DY (1008)		$ 476.00
	Total:	$7,424.50

Alternate Option--Combine Site Inspection and Control Surveys. The site inspection and horizontal & vertical control surveys could be performed in advance of and independent from the hydrographic phase, by an advance 3-man topographic team which includes the Project Manager. Total estimated cost for this option is $15,437--a savings of $5,770 over the proposed estimate.

Multibeam and Side Scan Surveys for Charting/Plans & Specifications. This represents the major line item of work. Crew transport and vessel mob/demob to OCONUS are included as fixed line items to this estimate.

(1) Daily Rate Computation. The cost of a multibeam/side scan survey crew is taken directly from the fixed negotiated rates in the IDC contract schedule, and modified as needed for the particular project. The final crew day (CD) rate will be used to estimate all work phases. The field survey crew is comprised of 5 individuals: (1) Boat Operator, (2) Hydrographer/Party Chief, (3) Survey Computer/CADD Operator, (4) Multibeam/Side Scan Operator, and (5) a Survey Helper (shore-based DGPS & tide gage operator).

5-Man Hydro Survey Party (1001)	$1,382.00
- less 2-survey helpers @ $144 ea (1003)	($ 288.00)
- add Multibeam/Side Scan Sys w/oper use higher Multibeam rate (1018) for either system --$130/hr	$ 1,040.00
-add field CADD Oper/Surv Comp (use 1007)	$ 300.00
-add DGPS Sys- 2 units (1015)	$ 205.00
-add Per Diem (OCONUS) 5 persons @ $112 ea	$ 560.00
Total Daily Rate:	$ 3,199.00

(2) Multibeam Coverage Estimate. The estimated amount of lineal multibeam survey coverage was estimated using average depths for various sections of the project area; from which average multibeam line spacings and lineal coverages (in km) were estimated based on maximum allowable multibeam swath coverage limits--see Appendix * to this estimate. An additional 10% was added for turns and other lost time plus 5% for cross-check lines. From Appendix *, estimated lineal multibeam track is:

Area A:	400 Km
Area B:	140 Km
Area C:	75 Km
Total:	615 Km

Estimated time (CD) to perform work:
615 Km @ 8 Km/hr @ 6 hr/DY = 12.8 CD --
Add 2 additional days for contingencies -- Use 15 CD
(6 hr/DY is assumed effective production in a typical 8 to 10 hr day--less calibration, fueling, etc)

Total Estimated Cost for Multibeam Surveys (field ops):15 CD @ $3,199/DY: $47,985.00

(3) Side Scan Sonar Surveys. Based on an effective line spacing of 80 meters, and a speed of 9 Km/hr to obtain 1-meter resolution, the estimated time to obtain 200% side scan coverage of the project area is 10 days--see Appendix * to this estimate for detailed computations.

Estimated Field Cost: 10 DY @ $3,199/CD = $31,990.00

Offshore Navigational Aid Location. Locate approximately 20 offshore floating aids, daymarks, etc.; positioned to hydrographic survey accuracy levels:

1 DY @ $3,199/CD: $3,199.00

h. Geotechnical Investigation, Bottom Samples and/or Probings. Obtain dry probings and samples at approximately 10 locations in proposed navigation channel.

2 DY @ 3,199.00/CD: $6,398.00

i. Port Facility Surveys (Tag Line). Approximately 1,200 meters of baseline needed to cover the two existing piers indicated n the attached drawings (south face of north dock and both sides of southerly pier). Hubs marked at 20 m increments, or approximately 60 tagline points.

Set baselines, mark hubs, topo , etc:	1.5 days
Tagline 10 to 25 meters off bulkhead at 5 m increments:	2 days
Total:	3.5 days

Est Cost: 3.5 days @ $3,199/CD: $11,196.50

Disposal Area Surveys. Assuming single beam coverage at 25 meter spacing (worst case), survey time is estimated at:

1000/25 +1 = 41 lines; 41 lines @ 1200 m ea = 49.2 Km
49.2 + 10% (turns/reruns) = 55 Km
55 Km / 10 Km/hr = 5.5 hr .... use 1 Day

1 DY @ $3,199/CD = $3,199.00

Travel, Mobilization & Demobilization.

Crew Travel: R/T Air Fare CONUS - OCONUS	
5 persons @ $1,200 ea	$ 6,000.00
Survey Vessel Mob/Demob--barge	
shipment from SE CONUS to OCONUS	$20,000.00
Mob/demob crew prep, labor,	
outfitting, etc 5@ $3,199	$15,995.00
Total:	$41,995.00

Office Data Reduction, Processing, Plotting. Includes all phases of work, such as preparing final smooth sheets (2 ea), plans & specifications drawings (7 ea), final track plots (2 ea), swath coverage plots (2 ea), side scan coverage plots (2 ea), digital plot files, final descriptive reports, etc. Note that a significant portion of this work will be performed in the field given a CADD operator is assigned to the crew to perform these activities. USACE data processing requirements represent only 15% of the total costs, given extensive data and report documentation required under the Chart Update phases of the work. Most of this effort is billed at the skilled CADD technician rate ($300/DY).

Survey computer (1008): 10 days @ $238/DY	$ 2,380.00
CADD Operator (1007): 80 days @ $300/DY	$24,000.00
Total:	$26,380.00

Estimated Quantity Computations. Office survey computer time to prepare templates and compute dredged quantity estimates for various channel alignments/depths:

Survey Computer (1008): 5 days @ $238/DY	$ 1,190.00

Project Manager Supervision & Inspection (Office). Licensed Project Manager periodic inspection and review of office data processing, plotting, computations, quantity computations, final reports, submittal activities, etc. Does not include normal supervision which is already in G&A overhead.

Proj Mgr (1005): 20 DY @ $355.00	$ 7,100.00

Topographic Mapping and Shoreline Surveys. Not applicable. DMA/NIMA data added during office CADD processing phase.

Total Cost Summary--Phase I

Prelim Site Invest & Insp	$ 4,025.00
Geodetic Control Survey	$ 9,757.00
Vert Cont & Tide Gaging	$ 7,424.50
Multibeam Surveys	$47,985.00
Side Scan Surveys	$31,990.00
NAVAID location	$ 3,199.00
Geotech Invest	$ 6,398.00
Tagline & Pier Topo Surveys	$11,196.50
Disposal Area Surveys	$ 3,199.00
Mob/Demob/Travel	$41,995.00
Office Data Processing	$26,380.00
Quantity Comps	$ 1,190.00
S & A	$ 7,100.00
Topo Mapping/Shoreline	N/A
Total Estimated Cost:	$201,839.00

22-16. Firm Fixed Price Contract Price Schedule

FFP contracts for hydrographic survey services require similar IGE and A-E contractor time and cost computations as those shown above for IDC task order rates and times. Typically, for a FFP contract, costs are reduced to a daily rate for field survey effort and hourly rates for office supervision and data processing disciplines. Given the estimated/negotiated quantities for each phase of work by line item, the lump sum job cost is arrived at. The following example depicts a final negotiated price schedule for a FFP contract where the unit price contains all overheads and profits.

Sample Firm Fixed Price Contract Schedule -- Dredging Measurement & Payment Support Surveys

Item	Quantity	Unit	Unit Price ($)	Total ($)
Single Beam Surveys:				
Labor	660	CD	3,464.35	2,286,471.00
Survey Vessel	660	Days	761.20	502,392.00
Equipment-Office	660	Days	227.70	150,282.00
Direct Costs	660	Days	132.71	87,588.60
Multibeam Surveys:				
Mobilization	660	Days	20.76	13,701.60
System	660	Days	920.70	607,662.00
Side Scan Sonar:				
900,000 sq m	1	Job	16,025.00	16,025.00
2,500 sq m	4	Job	5,342.00	21,368.00
Aerial Photography				
(Upland Disposal Area)	30	ea	1,661.00	49,830.00
		Total Cost (Project)		**$3,735,320.20**

22-17. Cost Per Work Unit Schedule

If a cost-per-work-unit fee structure is desired on an IDC, the computed daily/hourly crew rates and other applicable cost items can be divided by the estimated daily/hourly productivity in order to schedule work units. Typical work unit measures are cross-section, coverage area, lineal miles of sounding, and deliverable drawing/sheet. Both the estimated crew daily rate and the estimated productivity rates are subject to negotiation. An infinite number of work unit measures could be formed, given the variety in units of measure, survey classifications, expected local conditions, etc. Use of work unit rates is obviously restricted to individual project areas where work is fairly repetitious, e.g., dredging measurement & payment cross sections, beach renourishment sections. The following example illustrates how a cost per unit of work schedule can be developed for a typical dredging survey.

Example Computation of a Cost per Cross-Section Rate

Daily Crew Rate (Labor+O/H+Plant+Equipment)		$2,964.74
Office Data Processing:		
CADD Operator		
2.25 days processing for each survey day		
$485.00/d (labor incl G&A) @ 2.25 d		$1,091.25
Office Equipment (CADD, Printers, Software, etc)		
$59.00/d @ 2.25 d		$ 132.75
Project Management		
$600.00/d (labor & G&A) @ 0.2 d		$ 120.00
	Subtotal:	$4,308.74
	Profit (10%):	$ 430.87
Total Estimated Cost per Day:		$4,739.61
Estimated daily productivity: 35 channel cross sections per day		
Unit Rate per Cross Section: $4,739.61/35 sections	=	**$135.42/Section**

Cross sections would be itemized in the IDC contract schedule at the above rate. A task order for an After Dredge acceptance section of 30 defined cross sections could then simply be issued for $4,066.60 (30 @ $135.42)--eliminating any need for a detailed IGE.

22-18. Labor Hour Contracts for Surveying Services

Fixed-price task orders under IDC are effectively used to provide a substantial amount of surveying and mapping services in USACE. However, fixed-price task orders are not usually appropriate for quality assurance and payment surveys of ongoing dredging and construction projects since the duration of the survey work is not within the control of the survey contractor. The surveyor contractor's progress is dependent on the progress of the dredging or construction contractor, which in turn, depends on weather, equipment malfunctions, unforeseen site conditions, material availability, labor problems, and many other factors. In such cases, a labor-hour task order is a very useful contracting mechanism. Labor-hour contracts (guidance also applicable to task orders) are covered in Federal Acquisition Regulation (FAR) Subpart 16.6. Labor-hour task orders are appropriate when the uncertainties involved in contract performance do not permit costs to be anticipated with sufficient accuracy or confidence to use a fixed-price task order. The contractor is required to apply its best efforts, but is not obligated to complete the assigned work within the contract ceiling price. Hence, a higher level of surveillance is required by the Government to ensure the contractor is performing as efficiently as possible. No special approvals are required to use labor-hour task orders, but the contracting officer must execute a determination and findings for the contract file explaining why a fixed-price order was not suitable. There is no true negotiation, but rather an agreement on a realistic ceiling price considering the most likely conditions. All hourly costs for personnel and equipment (including overhead and profit) are already established in the contract. The Government buys a certain amount of effort and has considerable control over how that effort is expended toward completion of the specified task. The Government can direct the contractor to start, pause and stop work, within reasonable limitations. However, the Government bears the cost for disruptions in work. A labor-hour task order has the flexibility to follow the progress of the dredging or construction, without unfairly holding the survey contractor to a fixed price. The most cost-effective situation is where there is more than one project in the same area that can be surveyed using one task order. If there is a delay on one project, the survey crew can relocate to another project and resume work with minimal lost time. The following is an example of a Labor Hour task order scope:

LABOR HOUR TASK ORDER

Furnish all personnel, plant, equipment, transportation and materials necessary to perform, process and deliver the survey data described herein for dredging payment surveys in the following work areas in accordance with the general instructions and conditions set forth in Contract DACWXX-XX-D-XXXX:

- [List projects or work areas. Attach marked-up maps if needed. Describe work.]

Since it is not possible to accurately estimate the extent or duration of this work, this order will be issued on an estimated, not-to-exceed basis. The estimated quantities and ceiling price in accordance with the established contract rate schedule are as follows:

3-Person survey crew @ $[____]/hour x [___] hours:	$____________
Project manager @ $[___]/hour x [___] hours:	$____________
Ceiling price:	$____________

It is estimated that this work will begin about [__(date)__] and be completed about [__(date)__]. The contracting officer's representative (COR) at the [______] Project Office will advise the contractor at least [___] hours in advance of when work must begin. The contractor may be directed to stop work at any time due to circumstances beyond the Government's control. If work is stopped at a work area, the contractor may be directed to relocate and start (or continue) work at one of the other work areas covered by this order, or to demobilize and return to the contractor's office. The contractor will be compensated at the hourly contract crew rate while stopped, relocating to another work area, demobilizing, or remobilizing (if required). There will be no compensation while the contractor is demobilized. The COR will advise the contractor at least [___] hours in advance of when the contractor must remobilize and resume work.

The contractor will prosecute the work diligently and efficiently under the general direction and oversight of the COR. The contractor will provide a daily report, describing the work performed and hours worked, to the COR for certification. The daily reports will be used by the contractor to prepare monthly payment vouchers. With each monthly payment voucher, the contractor will estimate monthly and total earnings in the succeeding month, expressed both as total dollars and a percentage of the ceiling price.

The contractor will immediately notify the COR in writing when total estimated earnings reach 85 percent of the ceiling price. Also, if at any time the contractor projects that the total estimated earnings to complete the work will exceed the ceiling price, the contractor will promptly notify the COR and give a revised estimated total price with supporting reasons and documentation. The contracting officer will increase the ceiling price in writing if warranted or limit the work so as to remain within the current ceiling price. Exceeding the ceiling price is at the contractor's own risk.

[Insert technical requirements and deliverables.]

22-19. Verification of Contractor Cost or Pricing

Regardless of the contract price method used, it is essential (but not always required) that a cost analysis, price analysis, and field pricing support audit be employed to verify all cost or pricing data submitted by a contractor, particularly major cost items such as equipment and plant. Actual utilization rates and reduced costs per day must be verified. Some operation and maintenance costs may be directly charged, or portions may be indirectly included in a firm's G&A overhead account. In some instances, a firm may lease/rent survey instrumentation (e.g., multibeam systems) or plant equipment in lieu of purchase. Current rental rates average 10 to 15 percent per month of the purchase cost. Rental would be economically justified only on limited-scope projects and if the equipment is deployed on a full-time basis. Whether the equipment is rented or purchased, the primary (and most variable) factor is the equipment's actual utilization rate, or number of actual billing days to clients over a year. Only a detailed audit and cost analysis can establish such rates and justify modifications to the usually rough assumptions used in the IGE. In addition, an audit will establish any nonproductive labor/costs, which are transferred to a contractor's G&A. Given the variable equipment costs and utilization rates in hydrographic surveying, failure to perform a detailed cost analysis and field pricing support audit on contracted hydrographic services will make the IGE difficult to substantiate.

22-20. Contract Quality Control and Quality Assurance

Under the Corps professional contracting system, contractors are responsible for performing all quality control (QC) activities associated with their work. The Corps is responsible for quality assurance (QA) oversight of the contractor's QC actions. Therefore, Corps QA or testing functions should be focused on whether the contractor meets the required performance specification (e.g., depth accuracy), and not the intermediate surveying or compilation steps performed by the contractor. As a result, for surveys procured using the Brooks A-E Act qualifications-based selection method, Corps representatives are not stationed aboard contractor survey vessels to observe work in progress (i.e., perform QC activities)--the contractor was selected as being technically qualified to perform the work; including all QC associated with it. Corps-performed field testing of a contractor's work is an optional QA requirement, and should be performed only when technically and economically justified. Such Corps testing of a contractor's hydrographic survey data submittal rarely occurs in practice.

22-21. Contractor Performance and Responsibility

a. All surveying firms awarded contracts by the Corps are given official performance evaluations at the end of the contract period. These performance evaluations are maintained in a centralized Department of Defense (DOD) data base (at the Corps Portland District) for a period of six years. Performance evaluations contain both overall ratings (exceptional to unsatisfactory) and narrative comments on specific items that reflect on contractor performance. Adverse narrative comments typically focus around late deliveries, although poor quality of work may also be covered. These performance ratings are used by Corps and other Federal agencies when evaluating prospective A-E contractors. An unsatisfactory or marginal rating in this system can often preclude selection on future contracts; thus, an rebuttal process has been established for firms to protest less than satisfactory ratings.

b. A-E contracts contain a standard responsibility clause to cover deficiencies and other like problems. This clause is applicable to hydrographic surveyors and reads in part:

> "Responsibility of the Architect-Engineer Contractor (Federal Acquisition Regulation 52.236-23): The Contractor shall be responsible for the professional quality, technical accuracy, and the coordination of all designs, drawings, specifications, and other services. ... The Contractor shall, without additional compensation, correct or revise any errors or deficiencies in its ... drawings ... and other services. ... Neither the Government's review, approval, or acceptance of, nor payment for, the services under this contract ... shall be construed to operate as a waiver of any rights ... the Contractor shall be and remain liable to the Government ... for all damages to the Government caused by the Contractor's negligent performance of any of the services furnished under the contract."

c. The above "liability" clause clearly provides that a surveyor is responsible for the technical adequacy and accuracy of his work. It also obliges the firm to correct or revise any errors or deficiencies without charge. It also provides that the firm may be liable for all damages caused by negligent performance.

d. The vast majority of errors/omissions are readily corrected by the contractor without invoking this formal clause. This clause is invoked primarily for design defects discovered during construction. Failure to readily correct errors/omissions is usually reflected in an adverse Performance Evaluation, which obviously will impact future selections. Thus the contractor has special incentive to correct any deficiencies as rapidly as possible. This may involve resurveying an entire area.

e. In assessing liability, the key word is "negligent" performance. A hydrographic surveyor (either government employee or contractor) is not considered "negligent" if they performed the work using the ordinary skill, knowledge, and judgment ordinarily possessed by members of the profession; and that reasonable and ordinary care and diligence was used in performing the work. In addition, the level of government supervision, inspection, and review is a factor. Excessive Corps inspection and review will, in effect, transfer risk (liability) from the contractor to the Government. For example: A contractor is directed by the Corps scope of work to run channel cross-sections at a specific 200-foot spacing using a single beam echo-sounder. Should an undetected rock falling between these sections later cause significant damage to a passing vessel and/or the environment, the contractor could not be held negligible for this event (or subsequent damages) if he followed recognized technical standards for this work. Even if a full-bottom multibeam or side scan survey had been performed over this area, and the rock was missed, negligence would still be difficult to substantiate if the contractor performed the work with ordinary and customary skill, diligence, and care--comparable to that of any other government or private surveyor.

f. An A-E firm is liable to correct the work due to an error or omission, and to pay for any additional cost to the government for implementing these corrections. Additional costs are those in excess of what they would have been had the work been performed correctly. For example: A contractor performs a survey that is later used in contract plans and specifications. After the dredging contract is awarded, it is discovered the survey contained a constant 1-foot (0.3 m) error due to incorrect (i.e., "negligent") setting of the tide gage, causing a 30% overage error in the estimated quantities for the project, ultimately causing the dredge contractor to under-bid the job. The dredging contractor files a claim and successfully negotiates a higher unit price due to this quantity error. The original survey contractor could not be held liable for the difference in unit price because had the contract been advertised with the correct (i.e., reduced) estimated quantities, a higher bid rate would have been anticipated. However, the surveyor would be liable for government expenses incurred in negotiating these construction changes. Had a survey error caused over placement of material in a disposal area, and this material had to be later removed, then the survey contractor would be responsible for all this excess effort. In cases such as these, it behooves the A-E contractor to work closely with the construction contractor in order to minimize losses. A-E contractors carry "errors and omissions" insurance to cover these situations--usually with a substantial deductible. Surveying firms usually carry only about $500,000 in coverage--e.g., to cover constructing a house on an incorrectly staked-out lot. Thus, such insurance is meaningless in the case of a $500 million oil spill event. The government, in effect, holds the ultimate liability.

g. Instances of actual A-E liability due to erroneous surveys are rare--especially in offshore construction/dredging work. Errors and omissions are usually caught and corrected well before construction. Most problems of this nature involve topographic site plan drawings for construction, where underground utility features are "missed" by the surveyor. Both Corps crews and contractor survey crews are equally susceptible to errors and omissions.

22-22. Mandatory Requirements

There are no mandatory technical requirements contained in this chapter. Mandatory requirements associated with A-E contracting are contained in applicable procurement regulations.

Appendix A
References

A-1. Referenced Publications

Public Law 92-582
Brooks Architect-Engineer Act, 10 US Code 541-544

Executive Order 12906
Coordinating Geographic Data Acquisition and Access: The National Spatial Data Infrastructure (NSDI)

ER 1110-1-8156
Policies, Guidance, and Requirements for Geospatial Data and Systems

ER 1110-2-1150
Engineering and Design for Civil Works Projects

ER 1110-2-1200
Plans and Specifications for Civil Works Projects

ER 1110-2-1404
Hydraulic Design of Deep-Draft Navigation Projects

ER 1110-2-1458
Hydraulic Design of Shallow Draft Navigation Projects

ER 1130-2-520
Navigation and Dredging Operations and Maintenance Policies

EP 715-1-7
Architect-Engineer Contracting

EP 1130-2-520
Navigation and Dredging Operations and Maintenance Guidance and Procedures

EM 1110-1-1000
Photogrammetric Mapping

EM 1110-1-1002
Survey Markers and Monumentation

EM 1110-1-1003
NAVSTAR Global Positioning System Surveying

EM 1110-1-1004
Deformation Monitoring and Control Surveying

EM 1110-1-1005
Topographic Surveying

EM 1110-1-2909
Geospatial Data and Systems

EM 1110-2-1202
Environmental Engineering for Deep-Draft Navigation Projects

EM 1110-2-1414
Water Levels and Wave Heights for Coastal Engineering and Design

EM 1110-2-1416
River Hydraulics

EM 1110-2-1502
Coastal Littoral Transport

EM 1110-2-1611
Layout and Design of Shallow-Draft Waterways

EM 1110-2-1613
Hydraulic Design of Deep-Draft Navigation Projects

EM 1110-2-1810
Coastal Geology

EM 1110-2-3301
Design of Beach Fills

EM 1110-2-4000
Sedimentation Investigations for Rivers and Reservoirs

EM 1110-2-5025
Dredging and Dredged Material Disposal

Federal Geographic Data Committee
Geospatial Positioning Accuracy Standards
PART 1: Reporting Methodology

Federal Geographic Data Committee
Geospatial Positioning Accuracy Standards
PART 2: Standards for Geodetic Networks

Federal Geographic Data Committee
Geospatial Positioning Accuracy Standards
PART 3: National Standard for Spatial Data Accuracy

Federal Geographic Data Committee
Geospatial Positioning Accuracy Standards
PART 4: Standards for Architecture, Engineering, Construction (A/E/C) and Facility Management (Draft)

Federal Geographic Data Committee
Geospatial Positioning Accuracy Standards
PART 5: Standards for Nautical Charting Hydrographic Surveys (Draft)

NOTE: Some, but not all, of the Corps of Engineers regulations, pamphlets, and manuals listed above may be downloaded at http://www.usace.army.mil/inet/usace-docs/.

A-2. URL Addresses

a. URL addresses for USACE commands frequently referenced in this manual:

Headquarters, US Army Corps of Engineers	http://www.usace.army.mil
HQ Publications: Engineer Manuals, Regulations Pamphlets & Circulars	http://www.usace.army.mil/inet/usace-docs/
CADD/GIS Technology Center	http://tsc.wes.army.mil
Coastal and Hydraulics Laboratory	http://chl.wes.army.mil
Cold Regions Research and Engineering Laboratory	http://www.crrel.usace.army.mil
Hydrologic Engineering Center (HEC)	http://www.wrc-hec.usace.army.mil
Joint Airborne LIDAR Bathymetry Technical Center of Expertise (JALBTCX)	http://shoals.sam.usace.army.mil
Topographic Engineering Center (USATEC)	http://www.tec.army.mil

b. URL addresses for selected governmental agencies; standards organizations; and hydrographic surveying equipment manufacturers, suppliers, and service firms referenced in this manual:

3001, Inc.	http://www.3001data.com
American Congress on Surveying and Mapping	http://www.survmap.org
American Institute of Architects	http://www.aia.org
American National Standards Institute	http://www.ansi.org
ARC Surveying and Mapping, Inc.	http://www.arcsurveyors.com
Ashtech Precision Products	http://www.ashtech.com
Autodesk, Inc. (AutoCAD)	http://www3.autodesk.com
Bentley Systems, Inc. (MicroStation)	http://www.bentley.com
Biosonics, Inc.	http://www.biosonicsinc.com
Canadian Hydrographic Service	http://www.chs-shc.dfo-mpo.gc.ca
Caris Marine	http://www.caris.com
Coastal Oceanographics, Inc.	http://www.coastalo.com
Construction Specifications Institute	http://www.csinet.org
Federal Geographic Data Committee (FGDC)	http://www.fgdc.gov
FGDC Bathymetric Subcommittee	http://www.csc.noaa.gov/fgdc_bsc
FGDC Federal Geodetic Control Subcommittee	http://www.ngs.noaa.gov/FGCS/fgcs.html
General Services Administration	http://www.gsa.gov
Hydrographic Society of America	http://www.thsoa.org
Innerspace Technology, Inc.	http://www.innerspacetechnology.com
International Hydrographic Office	http://www.iho.shom.fr/iho.html
John E. Chance & Assoc., Inc.	http://www.jchance.com
Knudsen Engineering Limited	http://www.knudsenengineering.com
Marimatech	http://www.marimatech.com
Motorola	http://www.motorola.com
National Imagery and Mapping Agency (NIMA)	http://www.nima.mil
National Institute of Building Sciences	http://www.nibs.org
National Institute of Standards and Technology (NIST)	http://www.nist.gov
National Oceanographic and Atmospheric Administration (NOAA)	http://www.noaa.gov
NOAA National Ocean Service (NOS)	http://www.nos.noaa.gov
NOAA Coast Survey	http://chartmaker.ncd.noaa.gov

NOAA National Geodetic Survey (NGS)	http://www.ngs.noaa.gov
Odom Hydrographic Systems, Inc.	http://www.odomhydrographic.com
Raytheon Marine Company	http://www.raymarine.com
Reson Inc.	http://www.reson.com
Ross Laboratories	http://www.rosslaboratories.com
SeaArc Marine	http://www.seaark.com
Trimble Navigation Limited	http://www.trimble.com
Triton Elics Intl	http://www.tritonelics.com
TSS (UK) Ltd.	http://www.tss-realworld.com
TVGA Engineering, Surveying, P.C.	http://www.tvga.com
US Coast Guard Navigation Center (NAVCEN)	http://www.navcen.uscg.mil
US Geological Survey (USGS)	http://www.usgs.gov
US Naval Oceanographic Office (USNAVOCEANO)	http://www.navo.navy.mil
University of New Brunswick (UNB)	http://www.unb.ca
University of New Hampshire-NOAA Joint Hydrographic Center	http://www.ccom-jhc.unh.edu/

Appendix B
FGDC Hydrographic Accuracy Standard

Geospatial Positioning Accuracy Standards
Part 5: Standards for Nautical Charting Hydrographic Surveys - Public Review Draft

Subcommittee on Marine and Coastal Spatial Data
Federal Geographic Data Committee

November 2000

Federal Geographic Data Committee

Established by Office of Management and Budget Circular A-16, the Federal Geographic Data Committee (FGDC) promotes the coordinated development, use, sharing, and dissemination of geographic data.

The FGDC is composed of representatives from the Departments of Agriculture, Commerce, Defense, Energy, Housing and Urban Development, the Interior, State, and Transportation; the Environmental Protection Agency; the Federal Emergency Management Agency; the Library of Congress; the National Aeronautics and Space Administration; the National Archives and Records Administration; and the Tennessee Valley Authority. Additional Federal agencies participate on FGDC subcommittees and working groups. The Department of the Interior chairs the committee.

FGDC subcommittees work on issues related to data categories coordinated under the circular. Subcommittees establish and implement standards for data content, quality, and transfer; encourage the exchange of information and the transfer of data; and organize the collection of geographic data to reduce duplication of effort. Working groups are established for issues that transcend data categories.

For more information about the committee, or to be added to the committee's newsletter mailing list, please contact:

Federal Geographic Data Committee Secretariat
c/o US Geological Survey
590 National Center
Reston, Virginia 22092

Telephone: (703) 648-5514
Facsimile: (703) 648-5755
Internet (electronic mail): gdc@usgs.gov
Anonymous FTP: ftp://fgdc.er.usgs.gov/pub/gdc/
World Wide Web: http://fgdc.er.usgs.gov/fgdc.html

5.1 Introduction

5.1.1 Objective

This document provides minimum standards for the horizontal and vertical accuracy of features associated with hydrographic surveys that support nautical charting. Such features include, but are not limited to, water depths, objects on the seafloor, navigational aids, and shoreline.

5.1.2 Scope

For the purposes of this Standard, hydrographic surveys are defined as those surveys conducted to determine the configuration of the bottom of water bodies and to identify and locate all features, natural and man-made, that may affect navigation. Nautical charts are compilations of data from numerous sources, principally hydrographic surveys, designed specifically to meet the requirements of marine navigation. The scope of these standards includes the coastal waters of the U.S. and its territories.

5.1.3 Applicability

These standards are intended to be used by federal agencies and their contractors for conducting hydrographic surveys that will be used for updating nautical charts. They do not apply to hydrographic surveys for river and harbor navigation projects or surveys for project construction which are covered by Part 4 of the FGDC Geospatial Positioning Accuracy Standards. Local authorities may also prescribe these standards for high quality surveys for other purposes.

5.1.4 Related Standards

These standards may be used in conjunction with, or independent of, other Parts of the overall Geospatial Positioning Accuracy Standard. Part 1 (Reporting Methodology) applies directly to this part with the exception that vertical coordinate values should be referenced to the applicable chart datum and not one of the geodetic vertical datums (NAVD 88 or NGVD 29). See section 5.3.

There may be occasions where geodetic control points need to be established to support hydrographic surveys. In such instances, the specifications in Part 2 (Standards for Geodetic Networks) should be referenced. The accuracy testing described in Part 3 (National Standard for Spatial Data Accuracy) is generally inapplicable to this Part 5 since the referenced features are not repeatedly measured. Part 4 (Standards for Architecture, Engineering, Construction (A/E/C) and Facility Management) provide accuracy standards for other categories of hydrographic surveys (Contract Payment, Project Condition and Reconnaissance) that are not explicitly conducted to support nautical charts.

5.1.5 Standards Development Procedures

This standard was developed by the FGDC Bathymetric Subcommittee during 1998 and generally follows the Standards for Hydrographic Surveys adopted by the International Hydrographic Organization in April 1998.

5.1.6 Maintenance

The U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service, Office of Coast Survey, is responsible for developing and maintaining Standards for Nautical Charting Hydrographic Surveys for the FGDC Bathymetric Subcommittee. Address questions concerning the standards to: Director, Office of Coast Survey, NOAA, N/CS, 1315 East-West Highway, Silver Spring, Maryland 20910.

5.2 Spatial Accuracy

As defined in Part 1, horizontal spatial accuracy is the two-dimensional circular error of a data set's horizontal coordinates at the 95% confidence level. Vertical spatial accuracy is defined by the one-dimensional linear error of depths at the 95% confidence level.

5.3 Reference Datums

The horizontal reference datum should be the North American Datum of 1983 (NAD 83). If other datums or coordinate systems are used, their relationship to NAD 83 should be documented. Vertical coordinate values should be referenced to the applicable chart datum and not one of the geodetic vertical datums (NAVD 88 or NGVD 29). The Mean Lower Low Water (MLLW) datum is used for Atlantic, Pacific and Gulf coast charts. The nautical chart vertical datum for each of the Great Lakes is referenced to the International Great Lakes Datum (1985). Other water level-based datums are used on lakes and rivers.

5.4 Classification of Surveys

To accommodate in a systematic manner different accuracy requirements for areas to be surveyed, four orders of survey are defined. These are described below, with specific details provided in Tables 1 and 2.

5.4.1 Special Order

Special Order hydrographic surveys approach engineering standards and their use is intended to be restricted to specific critical areas with minimum underkeel clearance and where bottom characteristics are potentially hazardous to vessels. These areas must be explicitly designated by the agency responsible for survey quality. Examples of areas that might be so designated are harbors, berthing areas, and associated critical channels. All error sources must be minimized. Special Order requires the use of closely spaced lines in conjunction with side scan sonar, multi-transducer arrays or high resolution multibeam echosounders to obtain 100% bottom search. It must be ensured that cubic features greater than 1 meter can be discerned by the sounding equipment. The use of side scan sonar in conjunction with a multibeam echosounder may be necessary in areas where thin and dangerous obstacles may be encountered. Side scan sonar should not be used for depth determination but to define areas requiring more detailed and accurate investigation.

5.4.2 Order 1

Order 1 hydrographic surveys are intended for harbors, harbor approach channels, recommended tracks, inland navigation channels, and coastal areas of high commercial traffic density where underkeel clearance is less critical and the geophysical properties of the seafloor are less hazardous to vessels (e.g. soft silt or sand bottom). Order 1 surveys should be limited to areas with less than 100 m water depth. Although the requirement for seafloor search is less stringent than for Special Order, full bottom search is required in selected areas where the bottom characteristics and the risk of obstructions are potentially hazardous to vessels. For these areas searched, it must be ensured that cubic features greater than 2 m up to 40 m water depth or greater than 10% of the depth in areas deeper than 40 m can be discerned by the sounding equipment. In some areas the detection of 1-meter cubic features may be specified.

5.4.3 Order 2

Order 2 hydrographic surveys are intended for areas with depths less than 200 m not covered by Special Order and Order 1 and where a general description of the bathymetry is sufficient to ensure there are no obstructions on the seafloor that will endanger the type of vessel expected to transit or work the area. It is the criteria for a variety of maritime uses for which higher order hydrographic surveys cannot be justified. Full bottom search may be required in selected areas where the bottom characteristics and the risk of obstructions may be potentially hazardous to vessels.

5.4.4 Order 3

Order 3 hydrographic surveys are intended for all areas not covered by Special Order, and Orders 1 and 2 in water depths in excess of 200 m.

5.5 Positioning

The horizontal accuracy, as specified in Table 1, is the accuracy of the position of soundings, dangers, and all other significant submerged features with respect to a geodetic reference frame, specifically NAD 83. The exception to this are Order 2 and Order 3 surveys using single-beam echo sounders where it is the positional accuracy of the sounding system sensor. In such cases, the agency responsible for the survey quality should determine the accuracy of the positions of soundings on the seafloor.

If the accuracy of a position is affected by different parameters, the contributions of all parameters to the total position error should be accounted for. A statistical method, combining different error sources, for determining positioning accuracy should be adopted. The position error, at 95% confidence level, should be recorded together with the survey data. Although this should preferably be done for each individual sounding, the error estimate may also be derived for a number of soundings or even for an area, provided differences between error estimates can be safely expected to be negligible.

It is strongly recommended that whenever positions are determined by terrestrial systems, redundant lines of position should be observed. Standard calibration techniques should be completed prior to and after the acquisition of data. Satellite systems should be capable of tracking at least five satellites simultaneously; integrity monitoring for Special Order and Order 1 surveys is recommended.

Primary shore control points should be located by ground survey methods to a relative accuracy of 1 part in 100,000. When geodetic satellite positioning methods are used to establish such points, the error should not exceed 10 cm at 95% confidence level. Secondary stations for local positioning, which will not be used for extending the control, should be located such that the error does not exceed 1 part in 10,000 for ground survey techniques or 50 cm using geodetic satellite positioning.

The horizontal positions of navigation aids and other important features should be determined to the accuracy stated in Table 2, at 95% confidence level.

5.6 Depths

The navigation of commercial vessels requires increasingly accurate and reliable knowledge of the water depth in order to exploit safely the maximum cargo capabilities. It is imperative that depth accuracy standards in critical areas, particularly in areas of marginal underkeel clearance and where the possibility of obstructions exists, be more stringent than those established in the past and that the issue of adequate bottom coverage be addressed.

In determining the depth accuracy of the reduced depths, the sources of individual errors should be quantified and combined to obtain a Total Propagated Error (TPE) at the 95% confidence level. Among others these errors include:

a) measurement system and sound velocity errors
b) tidal measurement and modeling errors, and
c) data processing errors.

A statistical method for determining depth accuracy by combining all known errors should be adopted and checked. Recognizing that there are both constant and depth dependent errors that affect the accuracy of depths, the formula under Table 1 in Chapter 1 is to be used to compute, at 95% confidence level, the allowable depth errors by using for a and b the values from row 3 of Table 1. As an additional check on data quality, an analysis of redundant depths observed at crossline intersections should be made.

For wrecks and obstructions which may have less than 40 m clearance above them and may be dangerous to normal surface navigation, the least depth over them should be determined either by high definition sonar examination or physical examination (diving). Mechanical sweeping may be used when guaranteeing a minimum safe clearance depth.

All anomalous features previously reported in the survey area and those detected during the survey should be examined in greater detail and, if confirmed, their least depth be determined. The agency responsible for survey quality may define a depth limit beyond which a detailed seafloor investigation, and thus an examination of anomalous features, is not required.

Measured depths should be reduced to chart or survey datum, by the application of tidal or water level height. Tidal reductions need not be applied to depths greater than 200 m, except when tides contribute significantly to the TPE.

5.7 Sounding Density

In planning the density of soundings, both the nature of the seabed in the area and the requirements of the users have to be taken into account to ensure adequate bottom coverage. It should be noted that no method, not even 100% search, guarantees by itself the reliability of a survey nor can it disprove with certainty the existence of hazards to navigation, such as isolated natural hazards or man made objects such as wrecks, between survey lines.

Line spacing for the various orders of hydrographic surveys is proposed in Table 1. The results of a survey should be assessed using procedures developed by the agency responsible for the survey quality. Based on these procedures the adequacy of the sounding density should be determined and the line spacing reduced if warranted.

5.8 Bottom Sampling

The nature of the seabed should be determined by sampling or may be inferred from other sensors (e.g. single beam echo sounders, side scan sonar, sub-bottom profiler, video, etc.) up to the depth required by local anchoring or trawling conditions. Under normal circumstances sampling is not required in depths greater than 200 meters. Samples should be spaced according to the seabed geology, but should normally be 10 times that of the main scheme line spacing. In areas intended for anchorages, density of sampling should be increased. Any inference technique should be substantiated by physical sampling.

5.9 Tidal Observations

Tidal height observations should be made throughout the course of a survey for the purpose of providing tidal reductions for soundings, and providing data for tidal analysis and subsequent prediction. Observations should extend over the longest possible period, and if possible, for not less than 29 days. Tidal heights should be observed so that the total measurement error at the tide gauge, including timing error, does not exceed +/- 5 cm at 95% for Special Order surveys. For other surveys +/- 10 cm should not be exceeded.

5.10 Metadata

To allow a comprehensive assessment of the quality of survey data it is necessary to record or document certain information together with the survey data. Such information is important to allow exploitation of survey data by a variety of users with different requirements, especially as requirements may not be known when survey data is collected. The information describing the data is called metadata. Examples of metadata include overall quality, data set title, source, positional accuracy and copyright. Metadata is data implicitly attached to a collection of data.

Metadata should comprise at least the following information:

- the survey in general (e.g. date, area, equipment used, name of survey platform)
- the horizontal and vertical datum
- calibration procedures and results
- sound velocity for corrections to echo soundings
- tidal datum and reduction procedures
- accuracies achieved and the respective confidence levels.

Metadata should preferably be in digital form and an integral part of the survey record. If this is not feasible similar information should be included in the documentation of a survey. It is recommended that agencies responsible for the survey quality systematically develop and document a list of metadata used for their survey data.

It is understood that each sensor (i.e. positioning, depth, heave, pitch, roll, heading, seabed characteristic sensors, water column parameter sensors, tidal reduction sensor, data reduction models etc.) possesses unique error characteristics. Each survey system should be uniquely analyzed to determine appropriate procedure(s) to obtain the required spatial statistics. These analysis procedure(s) should be documented or referenced in the survey record.

5.11 Elimination of Doubtful Data

To improve the safety of navigation it is desirable to eliminate doubtful data, i.e. data which are usually denoted on charts by PA (Position Approximate), PD (Position Doubtful), ED (Existence Doubtful), SD (Sounding Doubtful) or as "reported danger". To confirm or disprove the existence of such data it is necessary to carefully define the area to be searched and subsequently survey that area according to the standards outlined in this publication.

No empirical formula for defining the search area can suit all situations. For this reason, it is recommended that the search radius should be 3 times the estimated position error of the reported hazard at the 95% confidence level as determined by a thorough investigation of the report on the doubtful data by a qualified hydrographic surveyor. If such report is incomplete or does not exist at all, the position error must be estimated by other means as, for example, a more general assessment of positioning and depth measurement errors during the era when the data in question was collected.

The methodology for conducting the search should be based on the area in which the doubtful data is reported and the estimated danger of the hazard to navigation. Once this has been established, the search procedure should be that of conducting a hydrographic survey of the extent defined in the preceding paragraph, to the standards established in this publication. If not detected, the agency responsible for the survey quality shall decide whether to retain the hazard as charted or to expunge it.

5.12 Quality Control

To ensure that the required accuracies are achieved it is necessary to check and monitor performance. Establishing quality control procedures which ensure that data or products meet certain standards and specifications should be a high priority for hydrographic authorities. This section provides guidelines for the implementation of such procedures.

Quality control for positioning ideally involves observing redundant lines of position and/or monitor stations which are then to be analyzed to obtain a position error estimate. If the positioning system offers no redundancy or other means of monitoring system performance, rigorous and frequent calibration is the only means of ensuring quality.

A standard quality control procedure should be to check the validity of soundings by conducting additional depth measurements. Differences should be statistically tested to ensure compliance of the survey with the standards given in Table 1. Anomalous differences should be further examined with a systematic analysis of contributing error sources. All discrepancies should be resolved, either by analysis or re-survey during progression of the survey task.

Crosslines intersecting the principal sounding lines should always be run to confirm the accuracy of positioning, sounding, and tidal reductions. Crosslines should be spaced so that an efficient and comprehensive control of the principal sounding lines can be effected. As a guide it may be assumed that the interval between crosslines should normally be no more than 15 times that of the selected sounding lines.

The proposed line spacing from Table 1 may be altered depending on the configuration of the seafloor and the likelihood of dangers to navigation. In addition, if side scan sonar is used in conjunction with single beam or multibeam sonar systems, the specified line spacing may be increased.

Multibeam sonar systems have great potential for accurate seafloor coverage if used with proper survey and calibration procedures. An appropriate assessment of the accuracy of measurements with each beam is necessary for use in areas surveyed to Special Order and Order 1 standards. If any of the outer beams have unacceptable errors, the related data may be used for reconnaissance but the depths should be otherwise excluded from the final data set. All swaths should be intersected, at least once, by a crossline to confirm the accuracy of positioning, depth measurements and depth reductions.

References

International Hydrographic Organization, April 1998, IHO Standards for Hydrographic Surveys, Special Publication No. 44, 4th Edition, 23p.

TABLE 1
Summary of Minimum Standards for Hydrographic Surveys

ORDER	Special	1	2	3
Examples of Typical Areas	Harbors, berthing areas, and associated critical channels with minimum underkeel clearances	Harbors, harbor approach channels, recommended tracks and some coastal areas with depths up to 100 m	Areas not described in Special Order and Order 1, or areas up to 200 m water depth	Offshore areas not described in Special Order, and Orders 1 and 2
Horizontal Accuracy (95% Confidence Level)	2 m	5 m + 5% of depth	20 m + 5% of depth	150 m + 5% of depth
Depth Accuracy for (1) **Reduced Depths (95% Confidence Level)** (2)	a = 0.25 m b = 0.0075	a = 0.5 m b = 0.013	a = 1.0 m b = 0.023	Same as Order 2
100% Bottom Search (3)	Compulsory	Required in selected areas	May be required in selected areas	Not applicable
System Detection Capability	Cubic features > 1 m	Cubic features > 2 m in depths up to 40 m; 10% of depth beyond 40 m	Same as Order 1	Not applicable
Maximum Line Spacing (4)	Not applicable, as 100% search compulsory	3 x average depth or 25 m, whichever is greater	3-4 x average depth or 200 m, whichever is greater	4 x average depth

(1) To calculate the error limits for depth accuracy the corresponding values of a and b listed in Table 1 should be introduced into:

$$\text{Depth Accuracy} = \pm [a^2 + (b * d)^2]^{1/2}$$

where:
a is a constant depth error, i.e. the sum of all constant errors, b*d is the depth dependent error, i.e. the sum of all depth dependent errors where b is a factor of depth dependent error, and d is depth.

(2) The confidence level percentage is the probability that an error will not exceed the specified maximum value.

(3) A method of exploring the seabed which attempts to provide complete coverage of an area for the purpose of detecting all features addressed in this publication.

(4) The line spacing can be expanded if procedures for ensuring an adequate sounding density are used

The rows of Table 1 are explained as follows:
Row 1 "Examples of Typical Areas" gives examples of areas to which an order of survey might typically be applied.
Row 2 "Horizontal Accuracy" lists positioning accuracies to be achieved to meet each order of survey.
Row 3 "Depth Accuracy" specifies parameters to be used to calculate accuracies of reduced depths to be achieved to meet each order of survey.
Row 4 "100% Bottom Search" specifies occasions when full bottom search should be conducted.
Row 5 "System Detection Capability" specifies the detection capabilities of systems used for bottom search.
Row 6 "Maximum Line Spacing" is to be interpreted as either (1) spacing of sounding lines for single beam sounders or (2) distance between the outer limits of swaths for swath sounding systems.

Table 2

Summary of Minimum Standards for Positioning of Navigation Aids and Important Features

	Special Order surveys	Order 1 surveys	Order 2 and 3 surveys
Fixed aids to navigation and features significant to navigation	2 m	2 m	5 m
Natural Coastline	10 m	20 m	20 m
Mean position of floating aids to navigation	10 m	10 m	20 m
Topographical features	10 m	20 m	20 m

Appendix C
FGDC Hydrographic Data Content Standard

National Hydrography Data Content Standard for Coastal and Inland Waterways – Public Review Draft

Bathymetric Subcommittee
Federal Geographic Data Committee

January 2000

Federal Geographic Data Committee

Established by Office of Management and Budget Circular A-16, the Federal Geographic Data Committee (FGDC) promotes the coordinated development, use, sharing, and dissemination of geographic data.

The FGDC is composed of representatives from the Departments of Agriculture, Commerce, Defense, Energy, Housing and Urban Development, the Interior, State, and Transportation; the Environmental Protection Agency; the Federal Emergency Management Agency; the Library of Congress; the National Aeronautics and Space Administration; the National Archives and Records Administration; and the Tennessee Valley Authority. Additional Federal agencies participate on FGDC subcommittees and working groups. The Department of the Interior chairs the committee.

FGDC subcommittees work on issues related to data categories coordinated under the circular. Subcommittees establish and implement standards for data content, quality, and transfer; encourage the exchange of information and the transfer of data; and organize the collection of geographic data to reduce duplication of effort. Working groups are established for issues that transcend data categories.

For more information about the committee, or to be added to the committee's newsletter mailing list, please contact:

Federal Geographic Data Committee Secretariat
c/o US Geological Survey
590 National Center
Reston, Virginia 22092

Telephone: (703) 648-5514
Facsimile: (703) 648-5755
Internet (electronic mail): gdc@usgs.gov
Anonymous FTP: ftp://fgdc.er.usgs.gov/pub/gdc
World Wide Web: http://fgdc.er.usgs.gov/fgdc.html

1. INTRODUCTION

1.1 OBJECTIVE

Geospatial hydrography data for waterways, shorelines, coastlines, etc. that supports transportation applications has been specified as one of the key framework information layers for the National Spatial Data Infrastructure (NSDI). The objective of this NSDI Hydrography Data Content Standard for Coastal and Inland Waterways (hereafter called the Hydrography Standard) project is to develop a nationally focused hydrographic data content standard for spatial data that supports safety of navigation. When complete, this standard will provide a consistent catalog of terms and definitions (semantics) to ensure uniform interpretation of information across a variety of organizations that develop and use hydrographic feature data and applications. This standard is based upon a well known logical data model for geospatial data of features, attributes, and domain values that is consistent with the Spatial Data Transfer Standard/Federal Information Processing Standard (SDTS/FIPS 173 part 2).

1.2 SCOPE

The scope of this Hydrography Standard project first focused on developing a catalog of hydrographic feature terms and definitions pertaining to navigation of coastal and inland waterways. In that the guidance from the NSDI concentrated on transportation/navigation, the team limited the scope to information relating to charting and electronic chart display applications. This standard will <u>not</u> address data distribution formats, extraction criteria, or accuracy reporting methods beyond inland and coastal waterways. This standard does not currently address hydrographic symbology. However, in future versions/releases of this standard it is planned to add this standard symbology information.

1.3 APPLICABILITY

This Hydrography Standard is applicable to any U.S. organization that generates hydrographic feature information that supports coastal and inland waterways navigation. This standard is also applicable to any U.S. organization that uses hydrographic feature information generated by another organization and must translate its feature schema to a common feature schema based upon a standard hydrographic dictionary.

1.4 JUSTIFICATION/BENEFITS

There has never been a national data content standard for hydrographic data that support navigation applications; yet there has been interest from federal agencies, private industry, and the public for a uniform presentation of this type information for some time. A data content standard that supports navigation applications will ensure effective use and exchange of geospatial data across multiple agencies, organizations, and other users.

Specifically, this Hydrography Standard will facilitate semantic consistency when capturing geospatial hydrographic information for military and commercial navigation and electronic charting databases (in a GIS or CADD) and provide consistent data for applications that query, analyze this information, and interpreted this information for display of electronic charts. This standard will support cost savings associated with reducing the translating geospatial hydrographic information. This standard should also reduce the costs of building navigation applications by eliminating the “multi-fuel” requirement of handling many different type of hydrographic feature information.

1.5 RELATED STANDARDS

This Hydrography Standard closely parallels the hydrographic information contained within the following standards:

International Hydrographic Organization's S57 (IHO S-57) Appendix A, Object Catalog for Digital Hydrographic Data. IHO is an intergovernmental consultative and technical organization working to support the safety of navigation and the protection of the marine environment.

North Atlantic Treaty Organization’s (NATO) Digital Geographic Information Exchange Standard (DIGEST) Part 4, Feature Attribute Coding Catalog (FACC), a comprehensive coding scheme for features, their attributes and attribute. This allows for joint naval operations between sovereign countries and requires naval personnel to have familiarity amongst traditional S-57 and FACC.

(Tri-Service) CADD/GIS Technology Center Spatial Data Standard (TSSDS Release 1.8), which is primarily used for civil and military installation mapping and facility management.

U.S. Army Corps of Engineers (USACE) Regional Engineering and Environmental Geographic Information System (REEGIS) project's data dictionary for inland waterways and primarily used by the USACE for engineering, navigation and flood control structures along the Mississippi River.

Also, this Hydrography Standard contains cross-references to the IHO- S57, NATA FACC, and TSSDS standards.

1.6 STANDARDS DEVELOPMENT PROCESS

This standard was developed under the guidance and procedures specified by the Federal Geographic Data Committee (FGDC) under the authority of the Bathymetric Subcommittee. The FGDC announced the initiation of this Hydrography Standard project in the Federal Register in 1998 and issued a call for any interested party to participate on the project development team. The project team that developed this standard was composed of experts from the National Oceanographic and Atmospheric Administration (NOAA) and National Imagery and Mapping Agency (NIMA), the U.S. Army Corps of Engineers and the U.S. Coast Guard, several pilot associations, and private industry representatives. (These agencies and organizations represented users of various existing Hydrography standards.) In addition to the expertise brought to this project team from the various organizations represented, key documents were used in the development of this standard. These standards are cited as references in the Related Standards section of this document.

The first step after the formation of a Hydrography Standard project team was to agree upon the scope of this Hydrography Standard. The project team then reviewed key documents that consisted of adopted standards and systems that had developed and used hydrographic feature data. The next step for the project team was to develop a master list of candidate features extracted from the related standards documents.

Next, the project team reviewed the master feature list and eliminated those clearly outside of the agreed to scope. A detailed comparison of feature terms and definitions extracted from the aforementioned standards was conducted. From this effort, the team was able to derive a standard feature term and definition for each feature. As a byproduct of this activity, a matrix was developed, which provides a mapping to related terms, or features, contained in each or the source standards. These matrices are included as appendices.

The project team has extracted all the attributes derived from the aforementioned standards and culled this list of attributes down to a subset of core attributes to include in the Hydrography standard. The project team created a domain list for each "category" of feature to facilitate the cross reference. Other attributes have been grouped into logical collections applicable to individual features to ease implementation. Finally, a draft Hydrography Standard document was generated to include the features, attributes, and domain terms and definitions lists, and additional descriptive documentation as specified by the FGDC directives on creating an NSDI standard.

1.7 TARGET AUTHORIZATION BODY

The Bathymetric Subcommittee originally proposed the development of this Hydrography Standard as an FGDC standard. The Bathymetric Subcommittee and the Standards Working Group of the FGDC may pursue a joint FGDC and American National Standards Institute (ANSI) adoption of this standard. To develop this Hydrography Standard through as an ANSI standard will require the development of an ANSI standard proposal and potentially an ANSI public review. The Bathymetric Subcommittee may consider (at a later date) promoting parts of this standard (e.g., inland waterways information) that are not currently part of the S-57 standard to International Hydrographic Organization for inclusion in their standard.

1.8 MAINTENANCE AUTHORITY

The National Oceanographic and Atmospheric Administration (NOAA) is the maintenance organization for the Hydrography Standard for the Federal Geographic Data Committee. All general questions and comments concerning this standard should be addressed to:

Anne Hale Miglarese, *Chair,*

NOAA Coastal Services Center
2234 South Hobson Ave.
Charleston, SC 29404-2413
phone 843-740-1238
fax 803-974-6315
amiglarese@csc.noaa.mil

1.9 PARTS OF THE STANDARD

This Hydrography Standard consists of a detailed main body and four appendices. The main body of the Hydrography Standard defines the purpose of this standard, the process followed during its development, the organization(s) involved in its development and maintenance, the actual Hydrography Standard Data Dictionary (sometimes called the Object Catalog), and its relationship to other standards. Appendices A through D contain matrix cross-references between the respective source data standards and the Hydrography Data Content Standard. Appendices A through D are informative and therefore not mandatory.

2.0 DEFINITIONS

For the purpose of this Hydrography Data Content Standard, the following definitions apply.

2.1 **attribute –** a characteristic of an object (e.g., an attribute of hydrography surface course = degree of permanence of the surface course)

2.2 **attribute value** - a specific quality or quantity assigned to an attribute for a specific feature instance (e.g., electrical cable material = dry).

2.3 **data content standard** - provides the semantic definitions for a set of real world spatial phenomena of significance to a community. Data Content Standards may be organized and presented in a specified logical data model.

2.4 **domain** - a finite list (or range) of permissible values for a specified attribute. Included are tables of: units of measure, types, styles, status, names, methods, materials, dispositions, sources, dimensions, data, classes, etc. (e.g., degree of permanence = dry, intermittent, permanent, etc . . .)

2.5 **feature –** definition and description of a set (class of real world phenomena) into which similar feature instances are classified (e.g., shoreline and isohaline_zone_area).

2.6 **feature instance** - real-world spatial phenomenon about which data is collected, maintained, and disseminated. (e.g., the McMillan Water Reservoir). Feature instances are the geospatial objects that are graphically delineated in a spatial database.

2.7 **geospatial data** - data with implicit or explicit reference to a location relative to the surface of the earth.

2.8 **hydrography -** the science of the physical conditions, boundaries, flow, and related characteristics of earth's waters

2.9 **navigation –** to safely move on or through the water in a vessel.

2.10 **semantic content –** natural language information (e.g. names of features, attributes, and their phenomena on the earth's surface).

3.0 LOGICAL DATA MODEL

Agreement on a common format is not sufficient to ensure that the geospatial information transferred is meaningful to both the sender and the receiver. In order to share spatial data (and as part of a SDTS data transfer process) a common data model must be defined and used. In addition, semantic content of a spatial database (i.e., the entities and associated attribute and attribute value information) must be well defined and agreed upon by an application community and specified in either an off-line document (i.e. data content standard) and/or in the metadata for a given database. Part 2 of the SDTS is a formal attempt to develop a standardized list of entities. Additionally application communities that want to share geospatial information are developing data content standards modeled after the SDTS data model.

This Hydrography Standard data model (figure 1.) is based upon the SDTS geospatial data model as presented in Parts 1 and 2 of that standard as well as the specifications in ISO/IEC 8613-10:1995. The logical data model depicts the real world phenomena represented by features that are characterized by attributes that are assigned attribute values. This Hydrography Standard defines each of the features and their attributes and specifies a domain list for category attributes; e.g. those which further differentiate the individual features. In addition, this standard incorporates the use of a Feature Code, which identifies the feature in cryptic form for implementation of the standard. It also incorporates feature representation information that specifies the allowable graphic representations for each of the features.

Hydrography Data Model

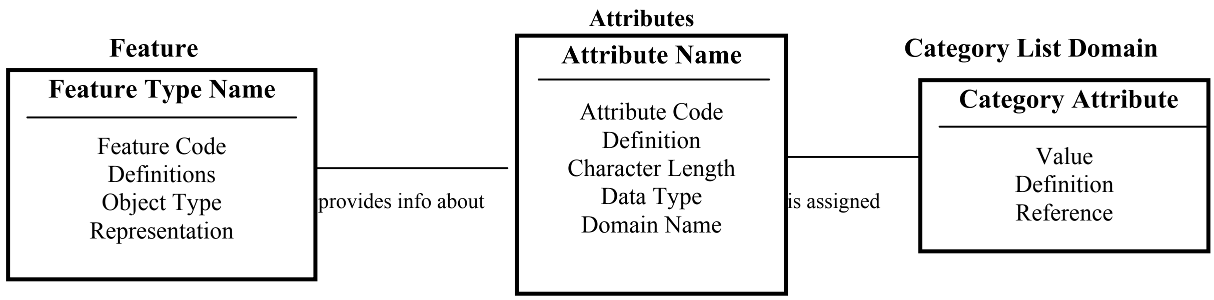


Figure 1

4.0 HYDROGRAPHY STANDARD DATA DICTIONARY/OBJECT CATALOG

CODE FEATURE NAME

HS001 ADMINISTRATION_AREA Land and water under the rights, powers, or authority of various local, state, and national governments.

CATEGORY COMMON_NAME COUNTRY DESCRIPTION FORMAL_NAME HORIZ_ACC RECORD_DATE SOURCE_DATE

HS002 AIRPORT/AIRFIELD An area used for landing, take-off, and movement of aircraft, not including associated buildings, runways, and other facilities, either military or civilian.

COMMON_NAME CONDITION DESCRIPTION FORMAL_NAME RECORD_DATE SOURCE_DATE STATUS

HS003 ANCHOR_BERTH A designated area of water where a single vessel, seaplane, etc. may anchor.

COMMON_NAME DATE_END DATE_START DESCRIPTION FORMAL_NAME RADIUS RECORD_DATE SOURCE_DATE STATUS

HS004 ANCHORAGE_AREA A designated area in which vessels anchor or may anchor.

COMMON_NAME DATE_END DATE_START DESCRIPTION FORMAL_NAME PERMIT RECORD_DATE RESTRICTION SOURCE_DATE STATUS

HS005 AQUATIC_VEGETATION_AREA A discrete area where submerged or partially submerged aquatic flora has been identified.

COMMON_NAME DESCRIPTION FORMAL_NAME RECORD_DATE SOURCE_DATE

HS006 BEACON A fixed object used for navigation, usually consisting of a single pile or lattice structure, which may or may not actually be in the water.

CARDINAL COLOR_PATTERN COMMON_NAME CONDITION CONSTRUCTION DATE_END DATE_START DESCRIPTION ELEVATION FORMAL_NAME HEIGHT LATERAL PRIMARY_COLOR RECORD_DATE SHAPE SOURCE_DATE SPECIAL_PURPOSE STATUS VERT_ACC VERT_DATUM

HS007 BERTH A named or numbered mooring location, normally alongside a pier or wharf.

COMMON_NAME DATE_END DATE_START DEPTH_ACC DEPTH_DATUM DESCRIPTION DESIGNATOR FORMAL_NAME QUALITY RECORD_DATE SOURCE_DATE STATUS

HS008 BOAT_LIFT A mechanical device for lifting vessels between two levels other than a lock.

COMMON_NAME DESCRIPTION FORMAL_NAME RECORD_DATE SOURCE_DATE

HS009 BOAT_RAMP A partially submerged hard surfaced area or fixed (not afloat) structure on a shoreline for launching and retrieving vessels or vehicles.

COLOR_PATTERN COMMON_NAME CONDITION CONSTRUCTION DATE_END DATE_START DESCRIPTION FORMAL_NAME HEIGHT HORIZ_ACC HORIZ_CLEARANCE LENGTH PRIMARY_COLOR RECORD_DATE SOURCE_DATE STATUS VERT_ACC VERT_DATUM VERT_LENGTH WIDTH

HS010 BOTTOM_CHARACTERISTICS Designations used on surveys and charts to indicate the consistency, color and classification of the sea floor, as determined by sampling methods.

COMMON_NAME DESCRIPTION FORMAL_NAME MATERIAL NATURE_BOTTOM PRIMARY_COLOR RECORD_DATE SOURCE_DATE

HS011 BREAKWATER A stone structure which is designed to reduce the action of waves and currents near the entrance to river and ports. Sometimes called a breakwater.

COLOR_PATTERN COMMON_NAME CONDITION CONSTRUCTION DATE_END DATE_START DESCRIPTION FORMAL_NAME HEIGHT HORIZ_ACC HORIZ_CLEARANCE LENGTH PRIMARY_COLOR RECORD_DATE SOURCE_DATE STATUS VERT_ACC VERT_DATUM VERT_LENGTH WIDTH

HS012 BRIDGE A supporting structure used by pedestrians, vehicles, rail traffic, and utility services erected over obstacles such as a river, chasm, mountain, road or railroad. BRIDGE PIERS may support the structure at various locations along its length, or it may completely span the obstacle.

BRIDGE_TYPE CLEARANCE COLOR_PATTERN COMMON_NAME CONDITION CONSTRUCTION DATE_END DATE_START DESCRIPTION DESIGNATOR ELEVATION FORMAL_NAME

HEIGHT HORIZ_ACC HORIZ_CLEARANCE LENGTH MATERIAL
NUM_SPANS PRIMARY_COLOR RECORD_DATE SOURCE_DATE STATUS VERT_ACC
VERT_CLEARANCE VERT_DATUM WIDTH

HS013 BRIDGE_PIER The support(s) below the span of a bridge in the form of pillar(s) or abutment(s) for the spans of a bridge. In general, BRIDGE PIERS are only separately coded if they emerge from the surface of the water such that they may be a hazard to navigation.

COLOR_PATTERN COMMON_NAME CONDITION CONSTRUCTION DATE_END DATE_START
DESCRIPTION FORMAL_NAME HEIGHT PRIMARY_COLOR RECORD_DATE SOURCE_DATE
VERT_ACC VERT_DATUM VERT_LENGTH WIDTH

HS014 BRIDGE_TOWER A tower or pylon extending above the surface of the bridge. In general, BRIDGE TOWERS are only separately coded if they may be conveniently used as an aide to navigation.

COLOR_PATTERN COMMON_NAME CONDITION CONSTRUCTION DATE_END DATE_START
DESCRIPTION DESIGNATOR FORMAL_NAME HEIGHT HORIZ_ACC PRIMARY_COLOR
RECORD_DATE SOURCE_DATE VERT_ACC VERT_DATUM VERT_LENGTH WIDTH

HS015 BUILDING A relatively permanent structure, roofed and usually walled and designed for some particular use.

COLOR_PATTERN COMMON_NAME CONDITION CONSTRUCTION DESCRIPTION DESIGNATOR
ELEVATION FORMAL_NAME FUNCTION HEIGHT HORIZ_ACC LENGTH
NO_FLOORS PRIMARY_COLOR RECORD_DATE SHAPE SOURCE_DATE STATUS
VERT_ACC VERT_DATUM WIDTH

HS016 BUILT-UP_AREA An area containing a concentration of buildings and the supporting road or rail network.

COMMON_NAME CONDITION DESCRIPTION FACC_CAT FORMAL_NAME HEIGHT
MATERIAL RECORD_DATE S_57_CAT SOURCE_DATE VERT_ACC VERT_DATUM
WIDTH

HS017 BUOY A floating object moored to the bottom in a particular place, as an aid to navigation or for other specific purposes.

CHARACTER COLOR_PATTERN COMMON_NAME CONSTRUCTION DATE_END DATE_START
DESCRIPTION FACC_CAT FORMAL_NAME HEIGHT LATERALPERIOD PRIMARY_COLOR
RADAR_REFLECTOR RECORD_DATE S_57_CAT SHAPE SOURCE_DATE
SPECIAL_PURPOSE STATUS TOP_MARK VERT_ACC

HS018 CANAL An excavated shallow- or deep draft watercourse designed for navigation, usually artificially cut through land area to bypass rock outcrops and rapids, or through shallow intracoastal areas where an adequate depth cannot be maintained at low water periods. Canal edges or borders usually extend above the water surface with visible banks and important ship and bank interaction effects.

COMMON_NAME CONDITION DATE_END DATE_START DEPTH DESCRIPTION
FORMAL_NAME HORIZ_ACC HORIZ_CLEARANCE LENGTH RECORD_DATE
RESTRICTION S_57_CAT SOURCE_DATE STATUS WATER_VELOCITY WIDTH

HS019 CARGO_TRANSHIPMENT_AREA An area designated for the transfer of cargo from one vessel to another.

COMMON_NAME DATE_END DATE_START DESCRIPTION FORMAL_NAME RECORD_DATE
SOURCE_DATE STATUS WIDTH

HS020 CAUSEWAY A raised roadway of solid structure built primarily to provide a route across wet ground or intertidal area.(Alt)A raised area across low or wet ground used for transportation of pedestrians or vehicles.

CLEARANCE COMMON_NAME CONDITION CONSTRUCTION DESCRIPTION FORMAL_NAME
HEIGHT LENGTH RECORD_DATE SOURCE_DATE STATUS WIDTH

HS021 CAUTION_AREA Generally, an area where the mariner has to be made aware of circumstances influencing the safety of navigation.

COMMON_NAME DATE_END DATE_START DESCRIPTION RECORD_DATE SOURCE_DATE
STATUS WIDTH

HS022 CHANNEL_RIVER_SYSTEM(SHALLOW) An inland waterway system used by shallow-draft (15 feet or less) commercial towing and recreational vessels. Includes open river navigation systems (Mississippi River below St. Louis, Missouri River, Columbia River below Bonneville Dam) and canalized streams with locks and dams (e.g. Ohio River, Mississippi River above St. Louis, MO

COMMON_NAME DATE_END DATE_START DEPTH_ACC DESCRIPTION FORMAL_NAME
RECORD_DATE SOURCE_DATE STATUS VERT_DATUM

HS023 CHANNEL_MAINTAINED(DEEP_DRAFT) Type of navigation channel provided for the movement of vessels with drafts of 15 feet or more designed for open-water navigation including seagoing and intracoastal vessels operating in the Great Lakes. Deep-draft channels are usually marked and designated on the appropriate navigation charts with known/fixed depth and width parameters. May be formed and maintained totally, or in part, through excavation,

COMMON_NAME DATE_END DATE_START DEPTH_ACC DESCRIPTION FORMAL_NAME
RECORD_DATE SOURCE_DATE STATUS VERT_DATUM

HS024 CHECKPOINT An official place to register, declare or check goods and people.

COMMON_NAME DEPTH

HS025 COAST_GUARD_STATION Watch keeping station at which a watch is kept either continuously, or at certain times.

COMMON_NAME DATE_END DATE_START DESCRIPTION FORMAL_NAME RECORD_DATE
S_57_CAT SOURCE_DATE STATUS

HS026 CONTIGUOUS_ZONE A zone contiguous to a coastal State's territorial sea, which may not extend beyond 24 nautical miles from the baselines from which the breadth of the territorial sea is measured. The coastal state may exercise certain control in this zone subject to the provisions of Internationa Law. (IHO Dictionary, S-32, 5th Edition, 993)

COMMON_NAME COUNTRY DATE_END DATE_START DESCRIPTION RECORD_DATE
SOURCE_DATE STATUS

HS027 CONTINENTAL_SHELF_AREA The seabed and subsoil of the submarine areas that extend beyond its territorial sea throughout the natural prolongation of its land territory to the outer edge of the continental margin.

COMMON_NAME COUNTRY DESCRIPTION FORMAL_NAME RECORD_DATE SOURCE_DATE

HS028 CONTROL_POINT A permanently monumented survey control point constructed with an original purpose of establishing spatial location in one or more dimensions from a known reference or datum.

COMMON_NAME DATE_END DATE_START DESCRIPTION ELEVATION FORMAL_NAME
RECORD_DATE SOURCE_DATE VERT_ACC VERT_DATUM

HS029 CONVEYOR A mechanical apparatus for moving bulk material or people from place to place (as by a moving belt or chain of receptacles).

COLOR_PATTERN COMMON_NAME CONDITION DATE_END DATE_START DESCRIPTION
DESIGNATOR FORMAL_NAME HEIGHT HORIZ_ACC LENGTH PRIMARY_COLOR
RECORD_DATE SOURCE_DATE STATUS VERT_ACC VERT_CLEARANCE
VERT_DATUM WIDTH

HS030 CRANE A machine for lifting, shifting and lowering objects or materials by means of a swinging boom or with a lifting apparatus supported on an overhead track.

COLOR_PATTERN COMMON_NAME CONDITION DESCRIPTION FORMAL_NAME HEIGHT
HORIZ_ACC LENGTH MATERIAL PRIMARY_COLOR RECORD_DATE SHAPE
SOURCE_DATE STATUS ERT_ACC VERT_CLEARANCEVERT_DATUM WIDTH

HS031 CURRENT Currents (non-gravitational) include either singly or in combination: ocean currents, inter-oceanic equalizing currents, currents of navigable rivers, river outflow effects offshore and other non-tidal flows.

COMMON_NAME DATE_END DATE_START FORMAL_NAME ORIENTATION RECORD_DATE
SOURCE_DATE VELOCITY

HS032 **CUSTOM_ZONE** The area within which national customs regulations are in force.

COUNTRY DESCRIPTION RECORD_DATE SOURCE_DATE STATUS WIDTH

HS033 **DAM** A barrier constructed to hold back water and raise its level to form a reservoir or to prevent flooding.

COLOR_PATTERN COMMON_NAME CONDITION CONSTRUCTION DATE_END DATE_START DESCRIPTION FORMAL_NAME HEIGHT LENGTH PRIMARY_COLOR RECORD_DATE SOURCE_DATE VERT_ACC VERT_DATUM WIDTH

HS034 **DAY_MARK** The daytime identifier of an aid to navigation. The daymark conveys to the mariner, during daylight hours, the same significance as does the aid to naviation's light at night.

COLOR_PATTERN COMMON_NAME CONSTRUCTION DATE_END DATE_START DESCRIPTION ELEVATION FORMAL_NAME HEIGHT PRIMARY_COLOR RECORD_DATE S_57_CAT SHAPE SOURCE_DATE STATUS VERT_ACC VERT_DATUM

HS035 **DEEP_WATER_ROUTE** A deep water route in a designated area, within defined limits, which has been accurately surveyed for clearance of sea bottom and submerged obstacles to a minimum indicated depth of water.

COMMON_NAME DATE_END DATE_START DEPTH_ACC DESCRIPTION FORMAL_NAME RECORD_DATE SOURCE_DATE STATUS VERT_DATUM

HS036 **DEPTH_AREA** A depth area is a water area whose depth is within a defined range of values.

DESCRIPTION RECORD_DATE SOURCE_DATE VERT_DATUM

HS037 **DEPTH_CONTOUR**A line connecting points of equal water depth which is sometimes significantly displaced outside of soundings, symbols and other chart detail for clarity as well as generalization.

DEPTH DESCRIPTION RECORD_DATE SOURCE_DATE VERT_DATUM

HS038 **DISTANCE_MARK** A distance mark indicates the distance measured from an origin and consists of either a solid visible structure or a distinct location without special installation.

COMMON_NAME DATE_END DATE_START DESCRIPTION FORMAL_NAME RECORD_DATE RIVER_MILE SOURCE_DATE

HS039 **DOLPHIN**A post or group of posts, which may suport a deck, used for mooring or warping a vessel.

COLOR_PATTERN COMMON_NAME CONDITION CONSTRUCTION DATE_END DATE_START DESCRIPTION FORMAL_NAME HEIGHT PRIMARY_COLOR RECORD_DATE SHAPE SOURCE_DATE STATUS VERT_ACC VERT_DATUM

HS040 **DREDGED_AREA** An area of the bottom of a body of water which has been deepened by dredging.

COMMON_NAME DESCRIPTION FORMAL_NAME LENGTH PERMIT RECORD_DATE RESTRICTION SOURCE_DATE VERT_DATUM

HS041 **DRYDOCK** A structure, providing support for a vessel, which has a means of removing water so that the bottom of the vessel can be exposed.

COMMON_NAME CONDITION DESCRIPTION FORMAL_NAME HORIZ_ACC HORIZ_CLEARANCE LENGTH RECORD_DATE SOURCE_DATE STATUS VERT_DATUM WIDTH

HS042 **DUMPING_GROUND** An area where dredged material or potentially harmful material e.g. explosives chemical waste is deliberately deposited.

COMMON_NAME DESCRIPTION FORMAL_NAME RECORD_DATE S_57_CAT SOURCE_DATE STATUS WIDTH

HS043 **DYKE** A linear stone structure with a peaked or trapezoidal section located in pointway, secondary and main channel area and typically extending channelward from the convex bank to improve channel for navigational and flood control purposes.

COMMON_NAME DESCRIPTION ELEVATION LENGTH RECORD_DATE SOURCE_DATE

HS044 ELEVATION An elevation is the vertical distance of a point or a level, on, or affixed to, the surface of the earth, measured from a specified Geodetic vertical datum.

COMMON_NAME DESCRIPTION DESIGNATOR ELEVATION FORMAL_NAME HORIZ_ACC
MATERIAL RECORD_DATE SOURCE_DATE VERT_ACC VERT_DATUM

HS045 FAIRWAY A navigable pathway in an open and unobstructed waterway, such as a bay, lake, sound, or straight, or open coast, usually leading into a harbor from the open sea outside a buoyed channel, ordinarily used by vessel traffic, and so designated by appropriate authority.

COMMON_NAME CONDITION CONSTRUCTION DESCRIPTION ELEVATION FORMAL_NAME
RECORD_DATE SOURCE_DATE STATUS VERT_ACC VERT_DATUM WIDTH

FENCE/WALL A natural or man-made barrier used as an enclosure or boundary or for protection.

COLOR_PATTERN COMMON_NAME CONDITION CONSTRUCTION DESCRIPTION ELEVATION
FORMAL_NAME HEIGHT PRIMARY_COLOR RECORD_DATE S_57_CAT SOURCE_DATE
STATUS VERT_ACC VERT_DATUM WIDTH

HS047 FENDER A protective structure designed to cushion the impact of a vessel and prevent

COLOR_PATTERN COMMON_NAME CONDITION CONSTRUCTION DATE_END DATE_START
DESCRIPTION FORMAL_NAME HEIGHT HORIZ_ACC HORIZ_CLEARANCE
LENGTH PRIMARY_COLOR RECORD_DATE S_57_CAT SOURCE_DATE STATUS
VERT_ACC VERT_DATUM WIDTH

HS048 FERRY_ROUTE A route in a body of water where a ferry crosses from one shoreline to another.

COMMON_NAME DATE_END DATE_START DESCRIPTION FORMAL_NAME RECORD_DATE
S_57_CAT SOURCE_DATE STATUS TRIP_LENGTH

HS049 FISHERY_ZONE The offshore zone in which exclusive fishing rights and management are held by the coastal nation.

COMMON_NAME COUNTRY DESCRIPTION FORMAL_NAME RECORD_DATE SOURCE_DATE
STATUS

HS050 FISHING_FACILITY A structure in shallow water for fishing purposes which can be an obstruction to ships in general. The position of these structures may vary frequently over time.

COMMON_NAME DESCRIPTION FORMAL_NAME HEIGHT RECORD_DATE S_57_CAT
SOURCE_DATE STATUS VERT_ACC

HS051 FISHING_GROUND A water area in which fishing is frequently carried on.

COMMON_NAME DESCRIPTION FORMAL_NAME RECORD_DATE SOURCE_DATE STATUS

HS052 FISHING_HARBOR A harbour with facilities for fishing boats.

COMMON_NAME CONDITION CONSTRUCTION DATE_END DATE_START DESCRIPTION
FORMAL_NAME RECORD_DATE S_57_CAT SOURCE_DATE STATUS

HS053 FLEETING_AREA Area where barges and tows are assembled into a fleet.

COMMON_NAME DESCRIPTION PERMIT

HS054 FLOATING_DOCK A facility which can be raised or lowered into the water which can serve as a launching place for vessels or as a floating drydock.

COLOR_PATTERN COMMON_NAME CONDITION DATE_END DATE_START DESCRIPTION
FORMAL_NAME HEIGHT HORIZ_ACC HORIZ_CLEARANCE LENGTH
PRIMARY_COLOR RECORD_DATE SOURCE_DATE STATUS VERT_ACC VERT_DATUM
WIDTH

HS055 FLOOD_DIVERSION_AREA An area specifically intended to be covered with water to permit reduction in river/waterbody water levels protecting more critical areas from inundation.

COMMON_NAME DESCRIPTION

HS056 **FLOODWALL** A structure erected to protect an area from high river stages.

COLOR_PATTERN COMMON_NAME CONDITION CONSTRUCTION DATE_END DATE_START
DESCRIPTION ELEVATION FORMAL_NAME HEIGHT HORIZ_ACC
HORIZ_CLEARANCE LENGTH PRIMARY_COLOR RECORD_DATE S_57_CAT
SOURCE_DATE STATUS VERT_ACC VERT_DATUM WIDTH

HS057 **FOG_SIGNAL** A warning signal transmitted by a vessel, or aid to navigation, during periods of low visibility. Also, the device producing such a signal.

COMMON_NAME DATE_END DATE_START DESCRIPTION FORMAL_NAME FREQUENCY
PERIOD RECORD_DATE S_57_CAT SOURCE_DATE STATUS

HS058 **FORTIFIED_STRUCTURE** A structure for the military defence of a site.

COMMON_NAME CONDITION CONSTRUCTION DESCRIPTION FORMAL_NAME HEIGHT
HORIZ_ACC RECORD_DATE S_57_CAT SOURCE_DATE VERT_ACC VERT_DATUM

WIDTH

HS059 **FOUL_GROUND** An area of numerous unidentified dangers to navigation. The area serves as a warning to the mariner that all dangers are not identified individually and that navigation through the area may be hazardous. Commonly used to encode areas behind danger lines on navigation charts. (adapted from IHO Dictionary, S-32, 5th Edition)

COMMON_NAME CONDITION CONSTRUCTION DEPTH DESCRIPTION FORMAL_NAME
HEIGHT RECORD_DATE S_57_CAT SOURCE_DATE STATUS VERT_ACC

VERT_DATUM

HS060 **FREEPORT_AREA** A port where certain import and export duties are waived to facilitate reshipment to other countries.

COMMON_NAME DESCRIPTION FORMAL_NAME RECORD_DATE SOURCE_DATE STATUS WIDTH

HS061 **GATE** A structure that may be swung, drawn, or lowered to block an entrance or

passageway. (United States Geological Survey, Jan.89)

COMMON_NAME CONDITION CONSTRUCTION DESCRIPTION FORMAL_NAME HORIZ_ACC
HORIZ_CLEARANCE RECORD_DATE S_57_CAT SOURCE_DATE STATUS
VERT_ACC VERT_CLEARANCE VERT_DATUM WIDTH

HS062 **GAUGING_STATION** A device which monitors stream flow and water elevation.

COMM_CHANNEL COMMON_NAME DATE_END DATE_START DESCRIPTION FORMAL_NAME
RECORD_DATE S_57_CAT SOURCE_DATE STATUS

HS063 **GRAIN_ELEVATOR/ELEVATOR** A tall structure used to store and distribute grain whose location accuracy is not sufficient for naviation purposes.

COLOR_PATTERN COMMON_NAME CONDITION CONSTRUCTION DESCRIPTION ELEVATION
FORMAL_NAME HEIGHT HORIZ_ACC PRIMARY_COLOR RECORD_DATE S_57_CAT
SHAPE SOURCE_DATE STATUS VERT_ACC VERT_DATUM WIDTH

HS064 **GRIDIRON** A flat frame, usually of parallel timber baulks, erected on the foreshore so that a vessel may dry out on it for painting or repair at low water.

COMMON_NAME CONSTRUCTION DESCRIPTION FORMAL_NAME HEIGHT HORIZ_ACC LENGTH
RECORD_DATE SOURCE_DATE STATUS VERT_ACC WIDTH

HS065 **GUIDE_WALL** The structure used to guide boats or ships into a lock chamber.

COLOR_PATTERN COMMON_NAME CONDITION CONSTRUCTION DATE_END DATE_START
DESCRIPTION FORMAL_NAME HEIGHT HORIZ_ACC HORIZ_CLEARANCE
LENGTH PRIMARY_COLOR RECORD_DATE S_57_CAT SOURCE_DATE STATUS
VERT_ACC VERT_DATUM WIDTH

HS066 **HARBOR** A natural or artificial improved body of water providing protection for vessels and anchorage and docking facilities.

COMMON_NAME DEPTH DESCRIPTION FORMAL_NAME RECORD_DATE SOURCE_DATE
STATUS

HS067 **HARBOR_FACILITY** A harbor installation with a service or commercial operation of public interest.

COMMON_NAME CONDITION CONSTRUCTION DATE_END DATE_START DESCRIPTION
FORMAL_NAME RECORD_DATE S_57_CAT SOURCE_DATE STATUS

HS068 **ICE_AREA** An area which is covered by ice for the entire year.

COMMON_NAME DESCRIPTION ELEVATION FORMAL_NAME HEIGHT RECORD_DATE
S_57_CAT SOURCE_DATE STATUS VERT_ACC VERT_DATUM WIDTH

HS069 ICE_BOOM Floating barriers, anchored to the bottom, used to deflect the path of floating ice in order to prevent the obstruction of locks, intakes etc., and to prevent damage to bridge piers and other structures.

COMMON_NAME CONDITION CONSTRUCTION DEPTH DESCRIPTION FORMAL_NAME
HEIGHT RECORD_DATE S_57_CAT SOURCE_DATE STATUS VERT_ACC

VERT_DATUM

HS070 INCINERATION_AREA An offshore area officially designated as suitable for the burning of chemical waste by specially equipped ships.

COMMON_NAME DEPTH DESCRIPTION FORMAL_NAME RECORD_DATE RESTRICTION
SOURCE_DATE STATUS WIDTH

HS071 INSHORE_TRAFFIC_ZONE A routeing measure comprising a designated area between the landward boundary of a traffic separation scheme and the adjacent coast, to be used in accordance with the provisions of the International Regulations for Preventing Collisions at Sea.

COMMON_NAME DATE_END DATE_START DEPTH DESCRIPTION FACC_CAT
RECORD_DATE RESTRICTION S_57_CAT SOURCE_DATE STATUS WIDTH

HS072 ISLAND An area of land completely surrounded by the waters of an ocean, sea, lake, or stream.

COMMON_NAME CONDITION DESCRIPTION ELEVATION FORMAL_NAME HEIGHT
RECORD_DATE SOURCE_DATE STATUS WIDTH

HS073 ISOGONIC_LINE Lines connecting point of equal magnetic variation.

MAG_VARIATION

HS074 LAKE Any body of water surrounded by land.

COMMON_NAME DESCRIPTION ELEVATION FACC_CAT FORMAL_NAME RECORD_DATE
SOURCE_DATE VERT_ACC

VERT_DATUM WIDTH

HS075 LANDING_PLACE A named place, normally outside a harbor facility, where boats can transfer passengers or cargo. A ferry terminal may be called a landing area.

WIDTH

HS076 LANDMARK Tall structures or objects which are precisely located to serve as an aid to navigation.

COLOR_PATTERN COMMON_NAME CONDITION CONSTRUCTION DESCRIPTION DESIGNATOR
Directivity ELEVATION FORMAL_NAME FUNCTION HEIGHT HORIZ_ACC
HORIZ_DATUM PRIMARY_COLOR RECORD_DATE S_57_CAT SHAPE SOURCE_DATE
STATUS V ERT_ACC VERT_DATUM WIDTH

HS077 LEADING_LINE A track line which passes through one or more (usually two) clearly defined objects, along which a vessel can safely travel.

DATE_END DATE_START DESCRIPTION ORIENTATION RECORD_DATE S_57_CAT
SOURCE_DATE STATUS

HS078 LEVEE An embankment for controlling the waters of the sea, river or other water bodies.

COMMON_NAME DESCRIPTION RECORD_DATE SOURCE_DATE

HS079 LIGHT_VESSEL/LIGHTSHIP A distinctively marked manned vessel anchored or moored at a defined point to serve as an aid to navigation.

CHARACTER COLOR_PATTERN COMMON_NAME CONSTRUCTION DATE_END DATE_START
DESCRIPTION FORMAL_NAME HEIGHT HORIZ_ACC HORIZ_DATUM LENGTH
PERIOD PRIMARY_COLOR RANGE RECORD_DATE SOURCE_DATE STATUS
VERT_ACC VERT_DATUM WIDTH

HS080 LOCK A wet dock in a waterway, permitting a ship to pass from one level to another.

COMMON_NAME DATE_END DATE_START DESCRIPTION DIRECTIVITY ELEVATION
FORMAL_NAME HEIGHT HORIZ_ACC HORIZ_CLEARANCE LENGTH
MATERIAL RECORD_DATE SOURCE_DATE STATUS WIDTH

HS081 LOCK_BASIN/LOCK_CHAMBER A wet dock in a waterway, permitting a ship to pass from one level to another.

COMMON_NAME DATE_END DATE_START DESCRIPTION FORMAL_NAME HORIZ_ACC
HORIZ_CLEARANCE LENGTH RECORD_DATE SOURCE_DATE STATUS WIDTH

HS082 LOG_POND A maritime area enclosed with connected floating timbers used as a staging area for sawn logs.

COMMON_NAME DESCRIPTION FORMAL_NAME LENGTH RECORD_DATE SOURCE_DATE
STATUS WIDTH

HS083 MAGNETIC_DISTURBANCE_AREA A localized anomaly in the earth's magnetic field.

COMMON_NAME DESCRIPTION FORMAL_NAME MAG_ANOMALY RECORD_DATE SOURCE_DATE

HS084 MAGNETIC_VARIATION Lines connecting point of equal magnetic variation.

DATE_END DATE_START DESCRIPTION RECORD_DATE SOURCE_DATE VARIATION

HS085 MAJOR_INFLOW/OUTFLOW_STRUCTUR Major inflow and outflow structures, i.e., the intake structure of an electric generating stations, located in the river that are potential hazards to navigation.

COMMON_NAME CONDITION DATE_END DATE_START DEPTH DESCRIPTION
FORMAL_NAME HEIGHT RECORD_DATE RESTRICTION S_57_CAT SOURCE_DATE
STATUS VERT_ACC VERT_DATUM

HS086 MARINE_FARM An assemblage of cages, nets, rafts and floats or posts where fish, including shellfish are artificially cultivated.

COMMON_NAME DATE_END DATE_START DEPTH DESCRIPTION FORMAL_NAME
HEIGHT RECORD_DATE RESTRICTION S_57_CAT SOURCE_DATE STATUS
VERT_ACC VERT_DATUM WIDTH

HS087 MAT_CASTING_FIELD A site where concrete blocks are cast for ACM revetment.

COMMON_NAME DATE_END DATE_START DESCRIPTION FORMAL_NAME RECORD_DATE
SOURCE_DATE STATUS

HS088 MEASURED_DISTANCE_LINE A course whose length has been accurately measured and is used in conjunction with ranges ashore. It is used by vessels to calibrate logs, engine revolution counters, etc., and determine speed.

COMMON_NAME DATE_END DATE_START DESCRIPTION FORMAL_NAME LENGTH
ORIENTATION RECORD_DATE S_57_CAT SOURCE_DATE STATUS VERT_DATUM

HS089 MILITARY_PRACTICE_AREA An area within which naval, military or aerial exercises are carried out. Also called an exercise area.

COMMON_NAME DATE_END DATE_START DESCRIPTION FORMAL_NAME RECORD_DATE
RESTRICTION S_57_CAT SOURCE_DATE STATUS WIDTH

HS090 MINE-NAVAL An explosive device used in naval warfare located on or below the sea.

DEPTH DESIGNATOR HORIZ_ACC IDENTIFIER STATUS

HS091 MOORED_VESSEL A semi-permanently moored ship.

COLOR_PATTERN COMMON_NAME CONDITION DESCRIPTION FORMAL_NAME HEIGHT
HORIZ_ACC LENGTH PERMIT PRIMARY_COLOR RECORD_DATE S_57_CAT SOURCE_DATE
VERT_ACC WIDTH

HS092 MOORING_FACILITY A structure used for mooring/warping a ship or as a protection for harbor

COLOR_PATTERN COMMON_NAME CONDITION CONSTRUCTION DATE_END DATE_START
DESCRIPTION FORMAL_NAME HEIGHT PRIMARY_COLOR RECORD_DATE S_57_CAT
SHAPE SOURCE_DATE STATUS VERT_ACC VERT_DATUM

HS093 **NAMED_WATER_AREA** An area within a water body which is commonly referenced by a name.

COMMON_NAME DESCRIPTION FORMAL_NAME RECORD_DATE SEA_TYPE SOURCE_DATE

HS094 **NAVIGATION_LIGHT** A luminous or lighted aid to navigation.

CATEGORY COLOR_PATTERN COMMON_NAME DATE_END DATE_START DESCRIPTION
ELEVATION FORMAL_NAME HEIGHT HORIZ_ACC HORIZ_DATUM MATERIAL
ORIENTATION PRIMARY_COLOR RANGE RECORD_DATE SIG_GROUP SIG_PERIOD
SIQ_SEQUENCE SOURCE_DATE STATUS VERT_ACC VERT_DATUM

HS095 **NAVIGATION_LINE** A navigation line is a straight line extending towards and area of navigational interest and generally generated by two navigational aids or one navigational aid and a bearing.

DATE_END DATE_START DESCRIPTION ORIENTATION RECORD_DATE S_57_CAT
SOURCE_DATE STATUS

HS096 **OBSTRUCTION** In marine navigation, anything that hinders or prevents movement, particularly anything that endangers or prevents passage of a vessel. The term is usually used to refer to an isolated danger to navigation…(IHO Dictionary, S-32, 5th Edition, 3503)

COMMON_NAME CONDITION CONSTRUCTION DEPTH DESCRIPTION FORMAL_NAME
HEIGHT RECORD_DATE S_57_CAT SOURCE_DATE STATUS VERT_ACC
VERT_DATUM

HS097 **OFFSHORE_LOADING_FACILITY** A facility located offshore for loading and unloading cargo.

COLOR_PATTERN COMMON_NAME CONSTRUCTION DATE_END DATE_START DESCRIPTION
ELEVATION FORMAL_NAME HEIGHT PRIMARY_COLOR RECORD_DATE S_57_CAT
SHAPE SOURCE_DATE STATUS VERT_ACC VERT_LENGTH WIDTH

HS098 **OFFSHORE_PLATFORM** A permanent offshore structure, either fixed or floating, used in the production of oil or natural gas.

COLOR_PATTERN COMMON_NAME CONDITION CONSTRUCTION DATE_END DATE_START
DESCRIPTION ELEVATION FORMAL_NAME HEIGHT HORIZ_ACC PRIMARY_COLOR
RECORD_DATE S_57_CAT SOURCE_DATE STATUS VERT_ACC VERT_DATUM
WIDTH

HS099 **OFFSHORE_PRODUCTION_AREA** An area at sea within which there are production facilities.

COMMON_NAME CONDITION DATE_END DATE_START DEPTH DESCRIPTION
FORMAL_NAME HEIGHT RECORD_DATE RESTRICTION S_57_CAT SOURCE_DATE
STATUS VERT_ACC VERT_LENGTH WIDTH

HS100 **OIL_BARRIER** A construction to dam oil flow on water.

COMMON_NAME CONDITION DATE_END DATE_START DESCRIPTION FORMAL_NAME
RECORD_DATE S_57_CAT SOURCE_DATE STATUS

HS101 **OVERHEAD_PIPELINE/CABLE** A collection of wires, cables, or pipe either supported or suspended above the waterway.

COMMON_NAME CONDITION DATE_END DATE_START DESCRIPTION DESIGNATOR
ELEVATION FORMAL_NAME HEIGHT HORIZ_ACC LENGTH MATERIAL
RECORD_DATE S_57_CAT SOURCE_DATE STATUS VERT_ACC
VERT_CLEARANCE VERT_DATUM WIDTH

HS102 **PARK** An area set aside and designated for several types of leisure or recreational activities.

COMMON_NAME

HS103 **PARKING_AREA** An area used for parking vehicles not including residential streets and driveways.

COMMON_NAME DESCRIPTION FORMAL_NAME LENGTH RECORD_DATE S_57_CAT
SOURCE_DATE SPACES STATUS WIDTH

HS104 **PIER/WHARF/QUAY** A structure primarily used as berthing places for vessels.

COLOR_PATTERN COMMON_NAME CONDITION CONSTRUCTION DATE_END DATE_START
DESCRIPTION ELEVATION FORMAL_NAME HEIGHT HORIZ_ACC
HORIZ_CLEARANCE LENGTH PRIMARY_COLOR RECORD_DATE S_57_CAT
SOURCE_DATE STATUS VERT_ACC VERT_DATUM WIDTH

HS105 **PILE/POST** A long heavy timber or section of steel, wood, concrete, etc.. forced into the earth which may serve as a support, as for a pier, or a free standing pole within a marine environment.

COLOR_PATTERN COMMON_NAME CONDITION DATE_END DATE_START DESCRIPTION
ELEVATION FORMAL_NAME HEIGHT PRIMARY_COLOR RECORD_DATE S_57_CAT

SOURCE_DATE VERT_ACC VERT_DATUM WIDTH

HS106 **PILOT_BOARDING_PLACE** The meeting place to which a pilot comes out.

COMM_CHANNEL COMMON_NAME DATE_END DATE_START DEPTH DESCRIPTION
FORMAL_NAME RECORD_DATE S_57_CAT SOURCE_DATE STATUS WIDTH

HS107 **PONTOON** A permanently floating structure used as a bridge support or as the head of a pier, dock, or landing.

COMMON_NAME CONDITION CONSTRUCTION DATE_END DATE_START DESCRIPTION
FORMAL_NAME HEIGHT RECORD_DATE SOURCE_DATE STATUS VERT_ACC

HS108 **PORT_AUTHORITY** An area over which a harbour authorty has jurisdiction.

COMMON_NAME CONDITION CONSTRUCTION DATE_END DATE_START DESCRIPTION
FORMAL_NAME RECORD_DATE S_57_CAT SOURCE_DATE STATUS

HS109 **PRECAUTIONARY_AREA** A routing measure comprising an area within defined limits where ships must navigate with particular caution and within which the direction of traffic flow may be recommended.

DATE_END DATE_START DEPTH DESCRIPTION FORMAL_NAME RECORD_DATE
RESTRICTION SOURCE_DATE STATUS WIDTH

HS110 **PRODUCTION_AREA** An existing structure that was created, by man, for occupation, storage, or to facilitate an activity.

COMMON_NAME CONDITION DATE_END DATE_START DESCRIPTION DESIGNATOR
ELEVATION FORMAL_NAME FUNCTION HEIGHT HORIZ_ACC HORIZ_DATUM
MATERIAL PRODUCT RECORD_DATE S_57_CAT SOURCE_DATE STATUS
VERT_ACC VERT_DATUM WIDTH

HS111 **PROMENADE_PIER** A pier used only for recreational purposes. These structures are sometimes the remnants of the approaches to bridges.

COLOR_PATTERN COMMON_NAME CONDITION CONSTRUCTION DATE_END DATE_START
DESCRIPTION ELEVATION FORMAL_NAME HEIGHT HORIZ_ACC HORIZ_CLEARANCE
LENGTH PRIMARY_COLOR RECORD_DATE S_57_CAT SOURCE_DATE STATUS VERT_ACC
VERT_DATUM WIDTH

HS112 **PYLON** A pylon or pole used to support a telephone or telegraph line.

COLOR_PATTERN COMMON_NAME CONDITION CONSTRUCTION DATE_END DATE_START
DESCRIPTION ELEVATION FORMAL_NAME HEIGHT HORIZ_ACC HORIZ_DATUM
PRIMARY_COLOR RECORD_DATE S_57_CAT SOURCE_DATE VERT_ACC VERT_DATUM
WIDTH

HS113 **RADAR_LINE** A track along which ships may be guided by coastal radar stations in the even of bad visibility.

COMMON_NAME DESCRIPTION FORMAL_NAME ORIENTATION RECORD_DATE SOURCE_DATE
STATUS

HS114 RADAR_RANGE Indicates the coverage of a sea area by a radar surveillance station. Inside this area a vessel may request shore based radar assistance, particularly in poor visibility.

COMM_CHANNEL COMMON_NAME DATE_END DATE_START DESCRIPTION FORMAL_NAME RECORD_DATE SOURCE_DATE STATUS

HS115 RADAR_REFLECTOR A device capable of, or intended for, reflecting radar signals.

DESCRIPTION HEIGHT RECORD_DATE SOURCE_DATE STATUS VERT_ACC VERT_DATUM

HS116 RADAR_STATION A station with a transmitter emitting pulses of ultra-high frequency radio waves which are reflected by solid objects and are detected upon their return to the sending station.

COMM_CHANNEL COMMON_NAME DATE_END DATE_START DESCRIPTION FORMAL_NAME HEIGHT LENGTH MAX_RANGE RECORD_DATE S_57_CAT SOURCE_DATE STATUS VERT_ACC VERT_DATUM WIDTH

HS117 RADAR_TRANSPONDER_BEACON A transponder beacon transmitting a coded signal on radar frequency, permitting an interrogating craft to determine the bearing and range of the transponder. Also called recon.

COMMON_NAME DATE_END DATE_START DESCRIPTION ELEVATION FORMAL_NAME HORIZ_ACC MAX_RANGE PRIMARY_COLOR RECORD_DATE S_57_CAT SOURCE_DATE

STATUS

HS118 RADIO_CALLING_IN_POINT A specified point some distance from the harbor at which a vessel's navigator notifies the harbor authority of his ship's position to assist traffic control.

COMM_CHANNEL COMMON_NAME DATE_END DATE_START DESCRIPTION FORMAL_NAME RECORD_DATE SOURCE_DATE STATUS

HS119 RADIO_STATION A place equipped to transmit radio waves. Such a station may be either stationary or mobile, and may also be provided with a radio receiver.

CALL_SIGN COMM_CHANNEL COMMON_NAME DATE_END DATE_START DESCRIPTION DESIGNATOR ELEVATION EST_RANGE FORMAL_NAME FREQUENCY HORIZ_ACC HORIZ_DATUM LENGTH MATERIAL ORIENTATION RECORD_DATE S_57_CAT SOURCE_DATE STATUS VERT_ACC WIDTH

HS120 RAILROAD A rail or set of parallel rails on which a train or tram runs.

COMMON_NAME CONDITION DESCRIPTION FORMAL_NAME HEIGHT RECORD_DATE SOURCE_DATE STATUS VERT_ACC

HS121 RAILROAD_YARD A system of tracks within defined limits, and associated features, provided for loading/unloading and assembling trains.

COMMON_NAME TRACK_LENGTH WIDTH

HS122 RAPIDS Portions of a stream with accelerated current where it descends rapidly but without a break in the slope of the bed sufficient to form a waterfall. Usually used in the plural.

COMMON_NAME DESCRIPTION FORMAL_NAME HEIGHT RECORD_DATE SOURCE_DATE VERT_ACC WIDTH

HS123 RECOMMENDED_TRACK A track recommended to all or only certain vessels.

COMMON_NAME DATE_END DATE_START DEPTH DESCRIPTION FORMAL_NAME RECORD_DATE S_57_CAT SOURCE_DATE STATUS VERT_DATUM

HS124 REEF A rocky or coral elevation at or near enough to the surface of the sea to be a danger to surface navigation.

COMMON_NAME DEPTH DESCRIPTION FORMAL_NAME HORIZ_ACC LENGTH MATERIAL RECORD_DATE S_57_CAT SOURCE_DATE WIDTH

HS125 RESCUE_STATION A place at which life saving equipment is held.

COMMON_NAME DATE_END DATE_START DESCRIPTION DESIGNATOR ELEVATION FORMAL_NAME FUNCTION HEIGHT HORIZ_ACC IDENTIFIER LENGTH MATERIAL RECORD_DATE S_57_CAT SOURCE_DATE STATUS VERT_ACC WIDTH

HS126 RESTRICTED_AREA A specified area designated by an appropriate authority within which navigation is restricted in accordance with certain specified conditions.

COMMON_NAME DATE_END DATE_START DESCRIPTION FORMAL_NAME RECORD_DATE RESTRICTION S_57_CAT SOURCE_DATE STATUS

HS127 RETRO_REFLECTOR A means of distinguishing unlighted marks at night. Retro-reflective material is secured to the mark in a particular pattern to reflect back light.

COLOR_PATTERN DESCRIPTION HEIGHT PRIMARY_COLOR RECORD_DATE SOURCE_DATE
STATUS VERT_ACC VERT_DATUM

HS128 RIVER A natural flowing watercourse.

COMMON_NAME DEPTH DESCRIPTION FORMAL_NAME LENGTH RECORD_DATE
SOURCE_DATE STATUS WIDTH

HS129 RIVER_BANK River edge delineated during general planimetric mapping from aerial photography.

COMMON_NAME CONDITION DESCRIPTION FORMAL_NAME RECORD_DATE SOURCE_DATE

HS130 RIVER_ENGINEERING_STRUCTURE Any man-made object designed to check, control, or direct flow placed in the waterway which may pose a hazard to navigation.

COLOR_PATTERN COMMON_NAME CONDITION CONSTRUCTION DATE_END DATE_START
DESCRIPTION FORMAL_NAME HEIGHT HORIZ_ACC HORIZ_CLEARANCE
LENGTH PRIMARY_COLOR RECORD_DATE S_57_CAT SOURCE_DATE STATUS
VERT_ACC VERT_DATUM WIDTH

HS131 ROAD A road is an open way for the passage of vehicles.

COMMON_NAME CONDITION CONSTRUCTION DESCRIPTION DESIGNATOR FORMAL_NAME
HORIZ_ACC MATERIAL RECORD_DATE S_57_CAT SOURCE_DATE STATUS

SURFACE WIDTH

HS132 RUNWAYA defined area, usually rectangular, used for the conventional landing and take-off of aircraft.

COMMON_NAME CONDITION CONSTRUCTION DESCRIPTION DESIGNATOR ELEVATION
FORMAL_NAME HORIZ_ACC LENGTH RECORD_DATE S_57_CAT SOURCE_DATE

STATUS SURFACE WIDTH

HS133 SAFETY_FAIRWAY An area defined by the code of regulations where construction of temporary or permanent structures is prohibited.

COMMON_NAME DATE_END DATE_START DEPTH DESCRIPTION FORMAL_NAME
RECORD_DATE RESTRICTION SOURCE_DATE STATUS VERT_DATUM

HS134 SAND_WAVES A large mobile wave-like sediment feature in shallow water and composed of sand. The wavelength may reach 1000 meters, the amplitude may be up to 20 meters.

DESCRIPTION HEIGHT RECORD_DATE SOURCE_DATE VERT_ACC

HS135 SANDBAR The boundary or outline of an area where the bottom protrudes above the surface of the water subject to water levels and currents.

DESCRIPTION FORMAL_NAME RECORD_DATE SOURCE_DATE VERT_DATUM

HS136 SEA-PLANE_LANDING_AREA A designated portion of water for the landing and take-off of sea planes.

COMMON_NAME DESCRIPTION ELEVATION FORMAL_NAME LENGTH RECORD_DATE
RESTRICTION SOURCE_DATE STATUS WIDTH

HS137 SEAWALL A structure built to protect the shore from erosion.

COLOR_PATTERN COMMON_NAME CONDITION CONSTRUCTION DATE_END DATE_START
DESCRIPTION FORMAL_NAME HEIGHT HORIZ_ACC HORIZ_CLEARANCE LENGTH
PRIMARY_COLOR RECORD_DATE S_57_CAT SOURCE_DATE STATUS VERT_ACC
VERT_DATUM WIDTH

HS138 SHORELINE The line where a land mass is in contact with a body of water.

COMMON_NAME DESCRIPTION ELEVATION FACC_CAT FORMAL_NAME PRIMARY_COLOR
RECORD_DATE S_57_CAT SOURCE_DATE VERT_ACC VERT_DATUM

HS139 SHORELINE_CONSTRUCTION Any man-made structure immediately adjacent to the water way designed to assist in the management of flow and the deposit of sediment.

COLOR_PATTERN COMMON_NAME CONDITION CONSTRUCTION DATE_END DATE_START
DESCRIPTION ELEVATION FORMAL_NAME HEIGHT HORIZ_ACC
HORIZ_CLEARANCE LENGTH PRIMARY_COLOR RECORD_DATE S_57_CAT
SOURCE_DATE STATUS VERT_ACC VERT_DATUM WIDTH

HS140 SILO/TANK A container used for the storage of liquids or gases.

COLOR_PATTERN COMMON_NAME CONDITION CONSTRUCTION DESCRIPTION DESIGNATOR
ELEVATION FORMAL_NAME HEIGHT HORIZ_ACC HORIZ_DATUM LENGTH
PRIMARY_COLOR PRODUCT RECORD_DATE S_57_CAT SHAPE OURCE_DATE
STATUS VERT_ACC VERT_DATUM WIDTH

HS141 SLIPWAY A prepared slope for launching and recovering vessels.

COLOR_PATTERN COMMON_NAME CONDITION CONSTRUCTION DATE_END DATE_START
DESCRIPTION FORMAL_NAME HEIGHT HORIZ_ACC HORIZ_CLEARANCE LENGTH
PRIMARY_COLOR RECORD_DATE S_57_CAT SOURCE_DATE STATUS VERT_ACC
VERT_DATUM WIDTH

HS142 SLOPE_TOPLINE The upper marking of a slope, e.g. the ridge line or the separation line between two different gradients.

COMMON_NAME CONSTRUCTION DESCRIPTION ELEVATION FORMAL_NAME PRIMARY_COLOR
RECORD_DATE S_57_CAT SOURCE_DATE VERT_ACC VERT_DATUM

HS143 SMALL_CRAFT_FACILITY A place at which a service generally of interest for small crafts or pleasure boats is available.

COMMON_NAME DESCRIPTION FORMAL_NAME RECORD_DATE S_57_CAT SOURCE_DATE
STATUS

HS144 SOUNDING A measured water depth or spot depth which has been reduced to chart datum and includes drying heights.

COMMON_NAME DEPTH DESCRIPTION FORMAL_NAME HORIZ_ACC RECORD_DATE
SOURCE_DATE STATUS VERT_DATUM

HS145 SPRING A natural issue of water or other substances from the earth. One on the bottom of the sea is called a submarine spring.

COMMON_NAME DESCRIPTION FORMAL_NAME RECORD_DATE SOURCE_DATE

HS146 STRAIGHT_TERRITORIAL_BASELINE A baseline is the line from which the outer limits of the territorial sea and certain other outer limits are measured.

COMMON_NAME COUNTRY DESCRIPTION RECORD_DATE SOURCE_DATE

HS147 SUBMARINE_TRANSIT_LANE An area where submarines may navigate under water or at the surface.

COMMON_NAME DESCRIPTION FORMAL_NAME RECORD_DATE RESTRICTION SOURCE_DATE

HS148 SUBMERGED_PIPELINE/CABLE Any pipeline or cable which lying on or under the bottom.

COMMON_NAME CONDITION DATE_END DATE_START DEPTH DESCRIPTION
DESIGNATOR DIAMETER ELEVATION FORMAL_NAME HEIGHT HORIZ_ACC
HORIZ_DATUM MATERIAL PRODUCT RECORD_DATE RESTRICTION S_57_CAT
SOURCE_DATE STATUS VERT_ACC VERT_DATUM WIDTH

HS149 SWAMP/MARSH Those areas that are inundated or saturated by surface or ground water.

COMMON_NAME DESCRIPTION FORMAL_NAME RECORD_DATE S_57_CAT SOURCE_DATE

HS150 SWEPT_AREA An area that has been determined to be clear of navigational dangers to a specified depth.

DEPTH DESCRIPTION RECORD_DATE SOURCE_DATE VERT_DATUM

HS151 TERRITORIAL_SEA_AREA The territorial sea is a belt of water of a defined breadth but not exceeding 12 nautical miles measured seaward from the territorial sea baseline.

COMMON_NAME COUNTRY DESCRIPTION RECORD_DATE RESTRICTION SOURCE_DATE STATUS WIDTH

HS152 TIDAL_STREAM A tidal stream (or tidal current) is a horizontal movement of water associated with the rise and fall of the tide caused by tide-producing forces.

COMMON_NAME DATE_END DATE_START DESCRIPTION FORMAL_NAME MAX_RATE MIN_RATE RECORD_DATE S_57_CAT SOURCE_DATE STATUS VELOCITY

HS153 TIDE_DATA_POINT Tidal heights over time may be approximated by a series of height values given at regular intervals, starting from a specific moment in time.

COMMON_NAME DESCRIPTION FORMAL_NAME RECORD_DATE SOURCE_DATE STATUS TIME_START TIME_END

HS154 TIDEWAY A natural watercourse in intertidal areas where water flows during the ebb or flow.

COMMON_NAME DESCRIPTION FORMAL_NAME RECORD_DATE SOURCE_DATE

HS155 TOP_MARK One of more relatively small objects of characteric shape and color placed on an aid to identify it purpose.

COLOR_PATTERN DESCRIPTION HEIGHT PRIMARY_COLOR RECORD_DATE SHAPE SOURCE_DATE STATUS V ERT_ACC VERT_DATUM

HS156 TRAFFIC_SEPARATION_SCHEME A traffic separation scheme is a scheme which aims to reduce the risk of collision in congested and/or converging areas by separating traffic moving in opposite, or nearly opposite, directions.

DATE_END DATE_START DESCRIPTION FORMAL_NAME RECORD_DATE RESTRICTION S_57_CAT SOURCE_DATE STATUS

HS157 TUNNEL A passage that is open at both ends, buried under the sea bed or laid over the sea floor or bored under the ground or through mountains. (based on ISO S-57)

COMMON_NAME CONDITION DESCRIPTION FORMAL_NAME HORIZ_ACC HORIZ_CLEARANCE LENGTH RECORD_DATE SOURCE_DATE STATUS VERT_ACC VERT_CLEARANCE WIDTH

HS158 TURNING_BASIN A maintained area for vessels to turn.

COMMON_NAME DESCRIPTION FORMAL_NAME LENGTH RECORD_DATE RESTRICTION SOURCE_DATE VERT_DATUM WIDTH

HS159 TWO_WAY_ROUTE A two-way route is a route within defined limits inside which two-way traffic is established, aimed at providing safe passage of ships through waters where navigation is difficult or dangerous.(IHO Dictionary, S-32, 5th Edition, 5712)

COMMON_NAME DATE_END DATE_START DEPTH DESCRIPTION RECORD_DATE S_57_CAT SOURCE_DATE STATUS VERT_DATUM

HS160 UNDERWATER_ROCK A concrete mass of stony material or coral which dries, is awash, or is below the water surface.

COMMON_NAME DEPTH DESCRIPTION FORMAL_NAME RECORD_DATE SOURCE_DATE STATUS VERT_DATUM

HS161 UNSURVEYED_AREA An area for which no bathymetric survey information is available.

COMMON_NAME DESCRIPTION RECORD_DATE SOURCE_DATE WIDTH

HS162 VEGETATION Collections or individual plants.

COMMON_NAME DESCRIPTION ELEVATION FORMAL_NAME HEIGHT RECORD_DATE S_57_CAT SOURCE_DATE VERT_ACC

HS163 VISUAL_SIGNAL_STATION A place on shore from which signals are made to ships at sea.

COMM_CHANNEL COMMON_NAME DATE_END DATE_START DESCRIPTION FORMAL_NAME RECORD_DATE S_57_CAT SOURCE_DATE STATUS

HS164 WAITING_AREA/LOCK_ARRIVAL_POINT A designated location where boats or tows wait to receive clearance to enter a lock chamber or basin.

HS165 WATER_TOWER An elevated container and its supporting structure used to hold water.

COLOR_PATTERN	COMMON_NAME	CONDITION	CONSTRUCTION	DESCRIPTION	DESIGNATOR
ELEVATION	FORMAL_NAME	HEIGHT	HORIZ_ACC	HORIZ_DATUM	LENGTH
PRIMARY_COLOR	PRODUCT	RECORD_DATE	S_57_CAT	SHAPE	SOURCE_DATE
STATUS	VERT_ACC	VERT_DATUM	WIDTH		

HS166 WATER_TURBULENCE The disturbance of water caused by the interaction of any combination of waves, currents, tidal streams, wind, shoal patches and obstructions.

COMMON_NAME	DESCRIPTION	FORMAL_NAME	RECORD_DATE	S_57_CAT	SOURCE_DATE

HS167 WATERFALL A sudden descent of water over a step in the bed of a river or the sea bottom caused by tidal flows. In place names commonly shortened to fall or falls, e.g. Niagara Falls.

COMMON_NAME	DESCRIPTION	ELEVATION	FORMAL_NAME	HEIGHT	LENGTH
RECORD_DATE	SOURCE_DATE	VERT_ACC	WIDTH		

HS168 WILDLIFE_MANAGEMENT_AREA An area set aside for the investigation, maintenance, or management of plants and/or animals.

COMMON_NAME	DATE_END	DATE_START	DEPTH	DESCRIPTION	FORMAL_NAME
RECORD_DATE	RESTRICTION	S_57_CAT	SOURCE_DATE	STATUS	WIDTH

HS169 WRECK The ruined remains of a stranded or sunken vessel which has been rendered useless.

COMMON_NAME	DATE_START	DEPTH	DESCRIPTION	ELEVATION	FORMAL_NAME
HEIGHT	HORIZ_ACC	LENGTH	RECORD_DATE	S_57_CAT	SOURCE_DATE
STATUS	TONNAGE	VERT_ACC	VERT_DATUM	WIDTH	

5.0 HYDROGRAPHY STANDARD ATTRIBUTE DEFINITIONS

Attribute Name	Attribute Definition	Data Type
BRIDGE_TYPE	The various types of bridges.	Text (30)
CALL_SIGN	The designated call-sign of a radio station.	Text (30)
CARDINAL	The four quadrants (north, east, south and west) are bounded by the true bearings NW-NE, NE-SE, SE-SW, and SW-NW taken from the point of interest. A cardinal mark is named after the quadrant in which it is placed.	Text (35)
CATEGORY	The attribute which differentiates the "types" or "kinds" of like features which may be separately identified in the standard. The specific values (or domain) associated with the standard is a function of the individual feature type.	Text (35)
CHARACTER	Any identifier comprised of the class, number and color(s) of flashes or occultations, of a light or lights at one geographic position [i.e. Q(6)+LF1, VQ G, L F1 (3+2)WR].	Text (30)
CLEARANCE	The vertical clearance of an object in closed condition (e.g. a closed lifting bridge) measured from the plane towards the object overhead.	Text (30)
COLOR_PATTERN	The various colour patterns of a navigational mark.	Text (30)
COMM_CHANNEL	A channel number assigned to a specific radio frequency, frequencies or frequency band.	Text (30)
COMMON_NAME	A unofficial, slang, or other common or textual designation of the feature.	Text (55)
CONDITION	A domain value indicating the physical situation or condition of the feature.	Text (35)
CONSTRUCTION	A domain indicating the technique or primary method used in building or constructing the feature.	Text (35)
COUNTRY	The attribute indicates the nationality of the specific object or feature.	Text (30)
DATE_END	The date the feature will, or is expected to, cease to exist, if known. May also indicate the latest date on which the feature may reasonably be expected to be present in this location. This date will almost always be in the future.	Numeric
DATE_START	The date the existence of the feature began, if known. May also indicate the earliest date on which the feature may reasonably be expected to be present in this location.	Numeric
DEPTH	The numeric distance from the surface of the earth to the deepest point of the feature.	Numeric
DEPTH_ACC	The best estimate of the accuracy of the sounding data	Text (30)
DEPTH_DATUM	The name of the datum which determines the reference for the numeric attribute Depth.	Text (30)
DESCRIPTION	A user defined description of the feature.	Text (255)
DESIGNATOR	Any identifying number which differentiates the feature from any other similar features.	Numeric
DIAMETER	Pipe diameter in inches	Numeric
DIRECTIVITY	The side or sides of a feature which produces the greatest reflectivity potential.	Text (30)
ELEVATION	The altitude of the ground level of an object, measured from a	Text (30)

specified vertical datum.

EST_RANGE The estimated range of a non-optical electromagnetic transmission. Text (30)

FACC_CAT The differentiation attribute which exists within the Feature and Attribute Coding Catalog Standard. Text (30)

FORMAL_NAME A official name or textual designation of the feature. Text (55)

FREQUENCY The frequency of a signal. Text (30)

FUNCTION The function, or purpose of various buildings. Text (30)

HEIGHT The numeric height of the feature as measured from the lowest point to the highest point. Numeric

HORIZ_ACC The best estimate of the horizontal accuracy of horizontal clearance and distances. Numeric

HORIZ_CLEARANCE The numeric horizontal distance through an opening in the feature. Numeric

HORIZ_DATUM Horizontal datum. The name of the reference used for measurements in the horizontal direction. Text (30)

IDENTIFIER A unique number which identifies the feature as opposed to all other features of the same type. Text (30)

LATERAL There are two international buoyage regions, A and B, between which lateral marks differ. The buoyage region is encoded using the separate attribute MARSYS. When top-marks, retro reflectors and/or lights are fitted to these marks, they are encoded as separate objects. Text (30)

LENGTH A measurement of the longer of two linear axis. Numeric

MAG_ANOMALY The value of the deviation from the normal magnetic variation. Numeric

MAG_VARIATION Horizontal angle between true north and magnetic north measured East (positive value) or West (negative value) according to whether magnetic north lies east or west of true north. Numeric

MATERIAL A domain specifying the primary material used on the construction of the feature. Text (35)

MAX_RANGE The extreme distance at which an object can be seen or a signal detected in nautical miles Numeric

MAX_RATE Maximum speed of current. Numeric

MIN_RATE Minimum speed of current. Numeric

NATURE_BOTTOM The attribute ‘nature of surface’ encodes the general nature of the material of which the land surface or the sea bed is composed. Text (30)

NO_FLOORS The number of floors or levels within a structure. Numeric

NUM_SPANS Number of spans in a bridge or aqueduct. Numeric

ORIENTATION The angular distance measured from true north to the major axis of the object. Numeric

PERIOD	The time occupied by an entire cycle of intervals of light and eclipse.	Text (30)
PERMIT	Any permit required for the vessel.	Text (30)
PRIMARY_COLOR	The Primary or most frequently occurring color of the feature.	Text (12)
PRODUCT	The various substances which are transported, stored or exploited.	Text (30)
QUALITY	The reliability of the value of sounding.	Text (30)
RADAR_REFLECTOR	Indicates whether or not a radar reflector is attached to, or connected with, a feature.	Text (30)
RADIUS	The vector extending from the centre to the periphery of a circular or spherical object.	Text (30)
RANGE	The nominal range at which an object can be seen or a signal detected in nautical miles.	Numeric
RECORD_DATE	The date when the specific feature was captured, edited, or deleted.	Numeric
RESTRICTION	A domain value indicating any limitations or other conditions imposed on the use or function of the feature.	Text (35)
RIVER_MILE	The most currently used river mile designation for a given river system.	Text (30)
S_57_CAT	The differentiation attribute which exists within the IHO S-57 Standard.	Text (30)
SEA_TYPE	The various types of sea areas.	Text (30)
SHAPE	The various types or shapes of the daymarkers used on beacons or buoys.	Text (30)
SIG_GROUP	The number of signals, the combination of signals or the morse character(s) within one period of full sequence.	Numeric
SIG_PERIOD	The time occupied by an entire cycle of intervals of light and eclipse.	Text (30)
SIQ_SEQUENCE	The sequence of times occupied by intervals of light and eclipse for all ‘light characteristics’ except for occulting where the sequence of times is occupied by intervals of eclipse and light.	Text (30)
SOURCE_DATE	The production date of the source; e.g. the date of measurement.	Numeric
SPACES	The total parking spaces available in the area including handicapped or reserved spaces.	Numeric
SPECIAL_PURPOSE	A mark may be a beacon, a buoy, a signpost or may take another form.	Text (30)
STATUS	A domain value indicating the current status of the feature.	Text (35)
SURFACE	The physical surface composition of a road.	Text (30)
TIME_END	The end of a active period.	Numeric
TIME_START	The start of an active period.	Numeric
TONNAGE	Tonnage of a sunken or stranded wreck.	Numeric
TOP_MARK	The characteristic shape secured at the top of a buoy or beacon to aid identification.	Text (30)

TRACK_LENGTH Total cumulative length of track contained within confines of the feature, exclusive of the branch or main trunk lines running into and/or out of the feature. Numeric

TRIP_LENGTH Length of crossing between shore points. Numeric

VARIATION A positive value, i.e. unsigned indicates variation in an Easterly direction while a negative value indicates variation in a westerly direction. Numeric

VELOCITY The speed of the current in knots. The rate of travel of a current. Numeric

VERT_ACC The best estimate of the vertical accuracy of heights, vertical distances, and vertical clearances, excluding sounding measurements. Numeric

VERT_CLEARANCE The numeric distance from the surface of the earth to the lowest point associated with the feature. Numeric

VERT_DATUM This attribute is used to specify the datum to which both heights and soundings are referred. Text (30)

VERT_LENGTH The total vertical length of an object. Numeric

WATER_VELOCITY Range of water velocity, estimated in meters/second within delineation of feature exclusive of high water due to runoff or low water due to drought. Numeric

WIDTH The numeric width of the feature as measured across its widest dimension. Numeric

6.0 IMPLEMENTATION

This Hydrography Standard has not yet been implemented in any significant way. Its organization, however, is designed to permit easy implementation on a number of existing GIS and/or A-E-C/CADD platforms. The conversion of the Hydrography Standard Logical Model to a physical implementation is accomplished by specifying several naming conventions associated with the standard. These conventions and the physical implementation, while compatible with most major database management systems, are provided for information only and are not intended to mandate or recommend any vendors software. In addition, the implementation strategy provided is only one of several acceptable strategies and is included for information only. The revised organization of the Hydrography Standard and its naming conventions are represented in Figure 2.

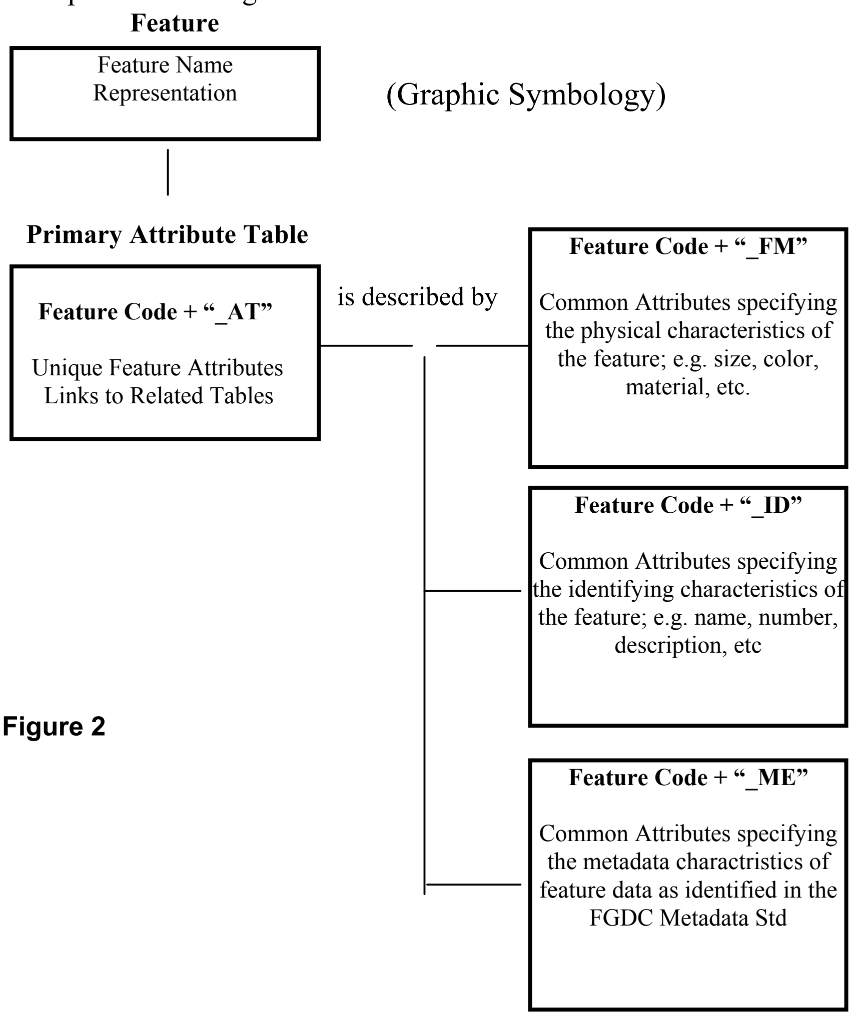


Figure 2

The codes of the features and the names of the attributes are designed to meet the naming restrictions associated with the major Relational Data Base Management Systems in use in the GIS field. And, by defining standard "groupings" of attributes which apply to the features, it is possible to identify separate "tables" of these attributes associated with each of the features, further simplifying implementation. The attribute groupings defined include **IDENTIFICATION** – which specifies numbers, names, and descriptions of the feature, **FORM** – which specifies physical characteristics of the features, and **METADATA**.

7.0 REFERENCES

International Hydrographic Organization, S57 Appendix A, Object Catalog for Digital Hydrographic Data, 1997.

National Institute of Standards and Technology, Federal Information Processing Standard Publication 173 (Spatial Data Transfer Standards), U. S. Department of Commerce, 1992.

North Atlantic Treaty Organization (NATO), Digital Geographic Information Exchange Standard (DIGEST) Part 4, Feature Attribute Coding Catalog (FACC), 1998.

(Tri-Service) CADD/GIS Technology Center, (Tri-Service) Spatial Data Standard (TSSDS), version 1.8, 1998.

U.S. Army Corps of Engineers (USACE), Regional Engineering and Environmental Geographic Information System (REEGIS), Project's Data Dictionary For Inland Waterways Information, 1997.

Glossary

1. Abbreviations and Acronyms

1DRMS:	One deviation (sigma) Root Mean Square
2DRMS:	Two deviations (sigma) Root Mean Square
2-D:	Two dimensional
3-D:	Three dimensional
A-E:	Architect-Engineer
AEA:	Average end area
AD:	After-dredging survey
BD:	Before-dredging survey
BM:	Benchmark
bps:	Bits per second
CADD:	Computer Aided Design and Drafting
CERC:	Coastal Engineering Research Center (Coastal & Hydraulics Laboratory)
CHS:	Canadian Hydrographic Service
CONUS:	Continental United States
COR:	Contracting Officer's Representative
CPE:	Circular probable error
CRREL:	Cold Regions Research and Engineering Laboratory
CSE:	Circular standard error
CW:	Civil Works
cf:	Cubic foot
cy:	Cubic yard
dB:	Decibel
deg:	Degrees
DEM:	Digital elevation model
DTM:	Digital terrain model
DFARS:	Defense Federal Acquisition Regulation Supplement
Diam:	Diameter
DOP:	Dilution of precision
DTM:	Digital terrain model
DGPS:	Differential global positioning system
EDM:	Electronic distance measurement
EFARS:	Engineer Federal Acquisition Regulation Supplement
EM:	Engineer Manual
EP:	Engineer Pamphlet
EPS:	Electronic positioning system
ERDC:	Engineer Research and Development Center
ETS:	Electronic tracking system
ER:	Engineer Regulation
FAR:	Federal Acquisition Regulation
FGDC:	Federal Geographic Data Committee
FOA:	Field Operating Activity
fps:	Feet per second
ft:	Feet
FTE:	Full-time equivalent
GDOP:	Geometric dilution of precision
GIS:	Geographic information system
GPS:	Global positioning system
GRS 80:	Geodetic Reference System of 1980

HDOP:	Horizontal dilution of precision
HEC:	Hydrologic Engineering Center
HEC-RAS:	HEC-River Analysis System
HPR:	Heave pitch roll
HTRW:	Hazardous toxic & radioactive waste
HQUSACE:	Headquarters US Army Corps of Engineers
Hz:	Hertz
IGLD:	International Great Lakes Datum
IHO:	International Hydrographic Organization
JALBTCX:	Joint Airborne LIDAR Bathymetry Technical Center of Expertise
kHz:	Kilohertz
kts:	Knots
lb	Pound
LIDAR:	Light detection and ranging
LWRP:	Low water reference plane
m:	Meter
MCY:	Million cubic yards
mi:	Mile
MLLW:	Mean lower low water
MLW:	Mean low water
MSE:	Mean square error
MSL:	Mean sea level
MTL:	Mean tide level
NAD 27:	North American Datum of 1927
NAD 83:	North American Datum of 1983
NAVAID:	Navigational aid
NAVCEN:	Navigation Center (US Coast Guard)
NAVD 88:	North American Vertical Datum of 1988
NAVOCEANO:	US Navy Oceanographic Office
NGRS:	National Geodetic Reference System
NGS:	National Geodetic Survey
NGVD 29:	National Geodetic Vertical Datum of 1929
NIMA:	National Imagery and Mapping Agency
nm:	Nanometer
NOAA:	National Oceanic and Atmospheric Administration
NOS:	National Ocean Survey
NSRS:	National Spatial Reference System
NTE:	Not to exceed
O&M:	Operations & Maintenance
OTF:	On-The-Fly GPS (real time kinematic carrier)
P&S:	Plans & Specifications
PI:	Point of intersection
ppm:	Parts per million
PPS:	Precise positioning service
ppt:	Parts per thousand
PRIP:	Plant Replacement and Improvement Program
QA:	Quality assurance
QC:	Quality control
RMS:	Root mean square
RMSE:	Root mean square error
RPM:	Rounds per minute
RTK:	Real time kinematic
SA:	Selective availability
SAR:	Synthetic aperture radar

SDS:	Spatial Data Standard
sf:	Square feet
SHOALS:	Scanning Hydrographic Operational Airborne LIDAR Survey
SPCS:	State plane coordinate system
SPS:	Standard positioning service
sq ft:	Square foot
sqrt:	Square root
STA:	Station
TBM:	Temporary benchmark
TEC:	Topographic Engineering Center
TIN:	Triangulated irregular network
U/M:	Unit of measure
U/P:	Unit price
UNB:	University of New Brunswick
URL:	Universal Resource Locator
US (U.S.):	United States
USACE:	US Army Corps of Engineers
USATEC:	US Army Topographic Engineering Center (ERDC)
USC&GS:	US Coast & Geodetic Survey
USCG:	US Coast Guard
USGS:	US Geological Survey
UTM:	Universal Transverse Mercator
VDC:	Volts Direct Current
VDOP:	Vertical dilution of precision
WES:	Waterways Experiment Station
WGS 84:	World Geodetic System of 1984
WRDA:	Water Resources Development Act

2. Glossary of Terms

Acceptance Section: A portion of an overall dredging contract over which payment is computed, based on estimated progress per payment period. A contract may have any number of acceptance sections.

Acceptance Survey: see Contract Acceptance Survey.

Accuracy: The degree of closeness of a variable to its true value.

Advance Maintenance Dredging: The additional depth and/or width specified to be dredged beyond the project channel dimensions for the purpose of reducing overall maintenance costs by decreasing the frequency of dredging. Advance maintenance must always be authorized.

After-Dredging Survey: Hydrographic survey(s) performed after dredging of a required section(s) has been completed. This survey is used for clearance, payment, and acceptance purposes.

After-Construction Survey: Any survey performed upon completion of construction, usually for payment or quality control purposes.

Allowable Overdepth: See *Overdepth*.

Analog Depth Recorder: A graphical recording echo sounder showing profile view of channel section..

Archeological Survey: Survey conducted to locate and/or investigate surface/subsurface archeological ruins. Typically, magnetometers and side-scan sonars are used for offshore archeological investigations.

Architect-Engineer (A-E) Contract: The type of contract prescribed for procuring hydrographic surveys in accordance with FAR Part 36.

Authorized Dimensions (Project): Length, width, and depth dimensions of a navigation channel as specified in the congressional authorizing document for the navigation project.

Automated Hydrographic Survey Processing System: A computer system which combines positional and depth measurements into a single database, including associated guidance, tracking, editing, plotting, and quantity take-offs.

Bar Check (Calibration): Method by which echo sounders are independently calibrated with a doubly suspended reference bar.

Baseline: The primary reference line defining a construction coordinate system.

Baseline Boat: An anchored boat used to extend an offshore baseline for tag line surveys.

Bathymetry (bathymetric): The measurement of ocean depths to determine sea floor topography.

Beach Renourishment Surveys: Surveys of coastal erosion control projects that involve combined topographic and hydrographic surveying procedures.

Before-Dredging Survey: Survey performed immediately in advance of a dredging operation for initial payment reference grade.

Bend: A channel turn that is designed as a continuous curve with a given radius; usually provided for large channel changes (or turn angles) in direction.

Bendway: Channels in curved reaches, extending along one bank, usually with usually with limited width restrictions and increased flows.

Bid Documents: Contract plan and specification documents from which bids were estimated and tendered.

Bin Measurement: A method of estimating work accomplished where the measurement of material in a hopper or scow is used for payment purposes.

Box Cut: Dredging a slope steeper than the required slope, including partial payment allowance therefor. Material removed from the box cut is payable up to that amount of material above the side slope line.

Brackish: Moderately saline water.

Bulkhead: A protective structure used to maintain stable shorelines in ports and waterways.

Canal: An excavated shallow- or deep-draft watercourse designed for navigation, usually artificially cut through land area to bypass rock outcrops and rapids, or through shallow intracoastal areas where an adequate depth cannot be maintained at low water periods. When connected to an existing stream or other body of water, locks may be required to offset steep gradients causing velocities too high for navigation. Canal edges or borders usually extend above the water surface with visible banks and important ship and bank interaction effects. The East and Gulf Coast intracoastal waterway systems are considered canals under this definition.

Center-line Survey: Surveying only the center line of a project alignment, or profile survey.

Chainage: see Stationing and Station-Offset.

Channel (Bar): Type of entrance channel, usually passing over a shallow offshore bar.

Channel (Cutoff): Channels cut through a bendway; constructed to eliminate sharp bends, eliminate troublesome reaches, reduce the length of a navigation channel, or increase the flood-carrying capacity of the stream.

Channel (Deep-Draft): Type of navigation channel providing for the movement of vessels with drafts of 15 feet or more, and designed for open-water navigation including seagoing and intracoastal vessels and vessels operating in the Great Lakes. Deep-draft channels are usually marked and designated on the appropriate navigation charts with known/fixed depth and width parameters. May be formed and maintained totally, or in part, through excavation, such as dredging.

Channel (Divided): Bifurcated channels or divided flow found in alluvial inland navigation streams, in addition to those formed by cutoffs.

Channel (Downbound): For waterways with a current, downbound means in the direction of the current. For slack water this characterizes traffic that moves in a southerly or westerly direction.

Channel (Entrance): The main access channel into a bay, harbor, or port.

Channel (Fairway): A navigable pathway in an open and unobstructed waterway, such as a bay, lake, sound, or straight, or open coast, usually leading into a harbor from the open sea; outside a buoyed channel, ordinarily used by vessel traffic, and so designated by appropriate authority.

Channel (Inbound): This characterizes traffic moving from one waterway into another where the destination in on the subject waterway.

Channel (Inland River Navigation System): An inland waterway system typically used by shallow-draft (15 feet or less) commercial towing and recreational vessels. Includes open river navigation systems (Mississippi River below St. Louis, Missouri River, and Columbia River below Bonneville Dam) and canalized streams with locks and dams (e.g., Ohio River, Mississippi River above St. Louis, Arkansas River). Minimum width of inland waterway channels is dependent on the type and size of vessels, alignment, current velocities, traffic patterns and clearances, and many other factors.

Channel (Interior): Connects the entrance (inlet) channel to port facilities. Usually semiprotected in a bay, estuary, or river.

Channel (Meandering): Natural inland streams having erodible bed and banks; developing a sinuous course consisting of a series of alternate bends and crossings with some relatively straight reaches.

Channel (Navigation): A project feature with authorized project limits/dimensions, which is designed, constructed, and maintained for use by commercial and/or recreational navigation traffic. Includes appropriate harbors, canals, turning basins, anchorage/mooring areas, and/or waterways.

Channel (Outbound): Characterizes traffic moving from one waterway into another where the origin in on the subject waterway.

Channel (Privately Maintained): Non-Federal channels and berthing areas maintained by states, regional authorities, local governments, or private interests.

Channel (Shallow Draft): Type of navigation channel providing for the movement of small commercial and recreational vessels with drafts less than 15 feet. Shallow-draft channels are usually marked and designated on the appropriate navigation charts with known/fixed depth and width parameters. May be formed and maintained totally, or in part, through excavation, such as dredging.

Channel (Side): Channels adjacent to the navigable channel created by divided flows in and around islands or other obstructions.

Channel (Spur): Similar to terminal or interior channels.

Channel (Straight): Channels in long straight reaches or in long flat bends in inland navigation systems. Straight reach banks are often unstable and tend to be difficult to maintain in sediment carrying streams.

Channel (Terminal): Interior channel leading from main ship channel to a commodity or fuel terminal.

Channel (Upbound): For waterways with a current, upbound means against the current. For slack water, this characterizes traffic that moves in a northerly or easterly direction.

Channel Condition Survey/Report: Tabular or graphical report of channel conditions (e.g., minimum clearances) based on most recent hydrographic survey.

Channel Depth: Depth of a navigation project as defined or refined below:

> *Authorized depth (Authorized project depth)*: Depth of a waterway authorized in the enabling legislation for a river and harbor navigation project. Authorized depth is generally the actual dredging limit and not the draft limit of vessels to be accommodated. Channel depth based on draft of loaded design vessel, plus squat, sinkage in fresh water, effect of trim and wave action, safety and efficiency clearances.
>
> *Design depth*: Channel depth based on draft of loaded design vessel, plus squat, sinkage in fresh water, effect of trim and wave action, safety and efficiency clearances, advance maintenance, and dredging tolerances. Termed "required depth" in dredging projects.
>
> *Allowable overdepth (dredging tolerance)*: Additional depth below the required depth specified in a dredging contract; a dredging pay item (typically 1 to 3 feet below the required depth) to account for inability to dredge at a uniform depth with a fluctuating water surface.
>
> *Controlling depth*: Actual effective depth based on current hydrographic surveys (i.e., Channel Condition Surveys/Reports) of a navigation project. Due to shoaling and maintenance dredging schedules, controlling depths may be less than the authorized project depth.
>
> *Advance maintenance depth*: Depth to which a channel is dredged deeper than the authorized depth to provide for the accumulation and storage of sediment.
>
> *Nominal project depth*: The depth which must be maintained in order to ensure the safe passage of any vessel operating within the authorized project dimensions at mean low tide (typically mean lower low water).
>
> *Safety clearance*: Designed clearance between bottom of vessel in motion and channel bottom; to avoid damage to ship's propellers from sunken timbers and debris, reduce displacement of bottom material, and avoid fouling pump and condensers by bottom material.
>
> *Efficiency clearance*: Clearance in addition to that required for safety based on design vessel efficiency, resistance, etc.

Channel Dimensions: Geographic location and physical dimensions of a maintained or natural navigation channel; and as further defined below:

> *Channel alignment*: Fixed design alignment of a channel, or series of channel reaches; based on the centerline of the channel in straight reaches, or on fixed baselines for irregular sections, such as basins, bends, and widener sections. Historical centerline of a river channel which provides safe navigation through a waterway.

Authorized Dimensions: Physical dimensions of a waterway channel authorized in the enabling legislation for a river and harbor navigation project

Channel width: Maintained width of a channel measured at the bottom of the slope at the design depth. Design channel width accumulates width of maneuvering lane(s), clearances between vessels when passing, and bank clearances in restricted channels.

Constructed dimensions: Channel dimensions which have been provided by initial or new work dredging, which may be equal to or less than the authorized project dimensions.

Maintained dimensions: Navigation channel dimensions (length, width, and depth) that are determined by using traffic, or other restrictions, which are less than or equal to the authorized dimensions, or the constructed dimensions if less than the authorized dimensions.

Bank clearance: Horizontal distance between the adjacent maneuvering lane edge and the bottom of the side slope.

Channel ship clearance: Clearance lane or distance between maneuvering lanes to allow for two-way traffic; typically 80% of the beam of the design vessel.

Maneuvering lane(s): Portion of channel width within which a ship may deviate from a mean line while transiting through the channel and maintain safe bank clearances or safe from an approaching vessel.

Points of intersection (PI): Fixed intersection points of two consecutive straight channel reaches, usually designated by Geographic or State Plane Coordinate System (SPCS) grid values and/or station-offset coordinate systems. Channel stationing usually commences at the outermost offshore PI and increases/accumulates shoreward (inbound or upbound) through successive PIs.

Toe limits: The fixed geographic (SPCS) location of the authorized channel limits (or perimeter boundaries of irregular basins), as designated on the project design documents and depicted on navigation charts. Toe perimeters are usually based parallel to and relative to the channel centerline and the authorized width.

Widener section limits: The fixed geographic (SPCS) location of the limits (or perimeters) of widening sections situated at the inside bend of two intersecting channels; as designated on the project design documents and depicted on navigation charts. Stationing may be set relative to the adjacent PI station or by independent baseline formed by intersection of the widener with the main channel toes.

Channel Reach: Linear length or section of navigable channel with defined markings and limits; usually referred to by local name.

Channel Sweep Survey: A full-coverage survey/sweep of an excavated project using rigid bars, side-scan sonar, multiple transducer, or multibeam echo sounding to determine the locations of shoals, obstructions, or hard materials.

Clark Spheroid 1866 (Clark 1866): A rotational ellipsoid having the following dimensions: semi-major axis, 6,378,274 m; semi-minor axis, 6,356,650 m; flattening (derived), 1/294.978. This ellipsoid reference model was used for the NAD 27 horizontal datum adjustment.

Comparison of Simultaneous Observations: A reduction process in which a short series of tide or tidal current observations at any place is compared with simultaneous observations at a control station where tidal constants have previously been determined.

Condition Survey: see Project Condition Survey.

Constructed Dimensions: Channel dimensions which have been provided by initial or new work dredging. These dimensions are equal to or less than the authorized dimensions.

Contract Acceptance Survey: A final survey performed over a construction area or dredging acceptance section to determine quality and/or quantity of construction; typically over a specified portion of a channel to determine if it has been dredged clear to the required grade and can be contractually accepted by the government.

Contract Payment Survey: Any survey intended to measure the amount of contract payment or performance.

Contract Survey: Any survey associated with contracted construction activities.

Control Structure: See flood control structure.

Controlling Depth: Actual minimum depth of a waterway at its shallowest point.

Course Indicator: See *Left-Right (Helmsman's) Track Indicator*.

Cross Section: A survey line run normal to the alignment of a project, channel, or structure.

Crossing: Channel alignment which crosses the waterway from one bank to the adjacent bank; or straight reaches between alternate bends, common on meandering rivers.

Deep-Draft Navigation Project: A project designed and constructed for vessels with drafts exceeding 15 ft.

Deepening Project: Authorized construction for deepening an existing project.

Depth: The distance between a reference surface datum and grade below water.

Depth Digitizer: Electronic device which measures the elapsed times of acoustical pulses and converts these times to depth.

Differential Leveling Surveys: Conventional terrestrial leveling using spirit bubble or self-compensating instruments.

Digital Elevation/Terrain Model: A topographic/geospatial data set of a project area. The DEM is usually a gridded model at constant post spacing. A DTM typically contains terrain breaklines.

Disposal Area Survey: A survey of a dredge disposal area (emergent, submergent, or combined).

Disposal Monitoring. The monitoring of dredges, barges, scows, etc., to and from a disposal area, usually for misplaced dumping purposes.

Disposal Monitoring Surveys: Surveys performed over offshore submergent disposal areas for quality control and environmental purposes, typically to monitor minimum placement grade restrictions, misplaced materials, etc.

Draft (Draft Correction/Variation): Distance from the reference water surface to a point on the hull of a vessel and correction/variation thereof.

Dredge Control and Positioning Systems: Electronic positioning systems used to monitor and control various aspects of the dredging process. These systems primarily include visual analog and digital displays of a dredge's current location/status.

Dredging (Dredging Process): The practice of removing material from underwater locations, including the process of transportation and disposal of material for the purpose of constructing new waterways, maintaining existing waterway dimensions, obtaining fill for land reclamation, beach nourishment, constructing dikes and levees, creating wetlands and marshes, obtaining materials from borrow areas, or other beneficial uses.

During Dredging Survey: A survey performed during dredging operations, usually to monitor daily/weekly/monthly progress and to estimate partial progress payments.

Eccentricity: An offset between measurement reference points.

Electronic Distance Measurement (EDM): Pulsing or phase comparison determination of a distance.

Electronic Positioning System (EPS): A system which receives two or more EDMs to obtain a position.

Emergent Disposal Area: A dredge disposal area constructed in open water with a finish grade above datum.

Epoch: As used in tidal datum determinations, a 19-year metonic cycle over which tidal height observations are meaned to establish a reference datum.

Examination Survey: Another term used in Corps for Project Condition Survey.

Fathometer: Raytheon trade name for an echo sounder.

Feasibility Study Survey. Survey performed in support of feasibility studies in advance of detailed engineering design.

Fix: The instant at which the position of a vessel is observed.

Flat Pool Level. Vertical reference datum used above Lock and Dam 26 on the Upper Mississippi River.

Floating Plant: Dredges, survey boats, barges, tugs, etc. owned by USACE. (From programming category in PRIP).

Flood Control Project: A project involved with the control of flooding due to surface runoff.

Flood Control Structure: A structure used to control or regulate surface water runoff. The structure includes locks, dams, spillways, floodwalls, levees, revetments, dikes, etc.

Fluff: See *Suspended Sediment*.

Geodetic Coordinates: Angular latitudinal and longitudinal coordinates, usually referenced to some defined ellipsoid of revolution (also, geographical coordinates).

Geodetic Reference System (GRS 80): A rotational ellipsoid using parameters of semi-major axis, geopotential number, angular earth rotation rate, and a coefficient from a second-degree Legendre function of the gradational potential. These parameters are also used to compute the WGS 84 ellipsoid.

Geographical Coordinates: See *Geodetic Coordinates.*

Geometric Dilution of Precision (GDOP): A statistic used to measure the geometrical effects on the accuracy of a coordinated point from the intersection of lines, circles, spheres, hyperbolas, etc.

Geotechnical Investigations: Subsurface investigation of soils, rock, and other strata for the purposes of engineering design.

Horizontal Dilution of Precision (HDOP): Horizontal component of GDOP.

Impoundment Basin (Settlement Basin): See *Sediment Basin*.

Indefinite Delivery Contract (IDC): Form of A-E service contract for procuring recurring services, such as hydrographic surveys.

Independent Government Estimate (IGE): The government's estimate used as the basis for comparing and negotiating contracted services.

In-Place Quantity Measurements/Surveys: Process by which the amount of work accomplished (i.e., material excavated or placed) is determined by measuring the in-place conditions, utilizing before- and after-dredge surveys.

Interim (Contract) Survey: A survey performed during construction to monitor progress or placement, often for interim progress payment purposes.

International Great Lakes Datum of 1955 or 1985 (IGLD 55 or 85): Vertical reference datums (and epoch of reference) used in the Great Lakes and their connecting waterways.

Investigation Survey: A survey used for general investigative purposes, usually well in advance of detailed engineering and design.

Kinematic Positioning: A position determined while a vessel is in motion (used synonymously with dynamic positioning).

Left-Right (Helmsman's) Track Indicator: A digital or analog device on a survey boat or dredge which guides the helmsman in steering a prescribed channel alignment or cut area.

Levee: A flood control structure along a waterway, often protected with revetments.

Line of Position: Angular or distance measurement used to determine a position when combined with lines of position from other systems.

Line Spacing: Spacing between successive survey lines of a project area.

Local Project Datum: Any horizontal or vertical construction datum which may or may not be referenced to a regional datum.

Logging (Data logging): Recording of observed survey data.

Longitudinal Surveys (Alignment): Surveys run parallel to a project (channel) alignment--opposite of Cross-Section Surveys.

Low Water Pool. Hydraulically based lower surface reference plane in a controlled/regulated body of water.

Low Water Reference Plane. A hydraulic reference plane based on a particular stage-duration profile (e.g., 1974 Low Water Reference Plane on the Lower Mississippi River).

Lump Sum Construction Dredging Contract: Procurement method by which the contractor is paid a single lump sum price for dredging of material. Mobilization and demobilization are generally a separate bid item.

Maintained Channel Dimensions: Navigation channel dimensions (length, width, and depth), determined by user traffic, which are less than or equal to the authorized dimensions, or the constructed dimensions if less than the authorized dimensions.

Maintenance Dredging: Dredging performed over a constructed project to remove recurring sediment (shoal) buildup.

Maximum Pool Elevation. Maximum pool height in a controlled system.

Mean High Water (MHW): Identical to MLW except using high water heights.

Mean Low Water (MLW): A tidal datum in which the means of the low water heights are observed over a specific 19-year period.

Mean Lower Low Water (MLLW): Tidal datum defined by the mean of the lower low water heights, observed over a specific 19-year period.

Mean Range of Tide: The difference between MHW and MLW.

Mean Sea Level (MSL): A tidal datum which is the mean of hourly water elevations observed over a specific 19-year metonic cycle (the National Tidal Datum Epoch).

Mean Sea Level Datum of 1929: Identical to NGVD 29 (discontinued terminology).

Mean Tide Level (MTL) or Half Tide Level: A tidal datum midway between MHW and MLW.

Measurement and Payment Survey: Surveys performed for contracted construction payment purposes.

Metonic Cycle: A period of 19 years or 235 lunations (1 lunation or synodical month = 29.530588 days).

Minimum crossing distance: Length of straight reach that should be provided between alternate bends in a river channel.

Minimum Pool Elevation. Vertical reference elevation in a controlled surface.

Multibeam System: Channel sweep systems employing a single transducer.

Multiple Ranging: Three or more distances used to trilaterate a position.

Multiple Transducer System: Channel sweep system using multiple vertically mounted transducers.

National Geodetic Vertical Datum of 1929 (NGVD 29): A fixed reference adopted as a standard geodetic datum for heights, based on an adjustment holding 26 primary tide stations in North America fixed. The latest general adjustment is the NGVD 29. Portions of the upper Mississippi River are referenced to the previous (1912) general adjustment. A new readjustment is currently in progress, and will be termed the North American Vertical Datum of 1988 (NAVD 88) when completed. The NGVD is not the same as mean sea level (MSL).

Navigation Aid (NAVAID): An object used for vessel navigation purposes (e.g., buoys, lights, daymarks, beacons, ranges, etc.).

Navigation Channel: A project feature with authorized project limits/dimensions, which is designed, constructed, and maintained for use by commercial and/or recreational navigation traffic. A navigation channel includes harbors, canals, turning basins, anchorage/mooring areas, and/or waterways.

Nominal Project Depth: The depth which must be maintained in order to ensure safe passage at mean low tide.

Navigation Project Dimensions: Depth, width, and lengths of channels, harbor maneuvering areas and anchorages, sidings, bends, turning places, lock sizes, horizontal and vertical bridge clearances and lengths of breakwaters; as authorized in the enabling legislation for a river and harbor navigation project.

Normal Pool Level: Vertical reference datum for canalized river systems.

Offset (Coordinate): Distance parallel to the baseline on a station-offset system.

Offset (Instrument): Distances between sensors, echo sounder, and positioning antennas on a boat.

On-Site Calibration: Calibrating a system at the project site.

Overbank Survey (Sections): Surveys run up river embankments.

Overdepth: Additional depth below the required section (or template) specified in a dredging contract. This additional depth is permitted (but not required) because of inaccuracies in the dredging process.

Pay Grade (Pay Template): The design and/or specified excavation grade to which payment is measured.

Payment Survey: See *Contract Payment Survey*.

Plans and Specifications (Survey): Surveys intended for use in project design, quantity/cost estimating, and contract specifications/plans for bidding purposes.

Pool Elevation. The surface elevation of a controlled body of water.

Prebid Survey: See *Plans and Specifications (Survey)*.

Precision: The amount by which a measurement deviates from its mean.

Preconstruction Survey: Survey performed in advance of construction placement/excavation, usually for monitoring initial in-place condition for subsequent payment reference.

Predredge Survey: Before-dredge survey.

Primary Control Tide Station: A tide station at which continuous observations have been made over a minimum of a 19-year metonic cycle. This station serves as the primary control for transferring control to subordinate tide stations through the method of comparison of simultaneous observations.

Probings: Manual or mechanically/hydraulically assisted investigation of subsurface soils to determine the elevation or existence of rock.

Progress Payment Survey: Survey used to measure the progress of construction at any point for payment purposes (usually performed monthly or in sequence with authorized submittal of construction progress payment estimates).

Project Condition Survey: Survey designed to measure the current condition of a constructed project to determine requirements for maintenance or repair. Performed periodically on authorized navigation projects.

Quality Assurance (QA): Construction procedure by which quality control procedures are monitored. Also, procedures for assessing quality of observed hydrographic depth data.

Quality Control (QC): Construction process by which quality of work and materials is measured and controlled, including surveys performed during that process. Also, procedures and criteria for maintaining adequacy/quality of hydrographic survey equipment.

Quantity Take-Offs: Process of estimating material volume computations--for dredging or other construction.

Range (coordinate): A project offset coordinate, usually relative to the center-line alignment (i.e., sailing range).

Range (distance): An offshore distance measured by an electronic positioning system.

Real-Time Survey/Plot: The processing and/or plotting of survey data during the actual survey.

Reconnaissance Survey: A general minimum-effort survey performed to determine the approximate conditions of a project site.

Remote Station/Transmitter: Term usually identifying hydrographic positioning shore stations.

Required Section/Depth: Excavation section/depth which must be dredged to clear grade.

Revetment: A facing built on an embankment (e.g., levee) to prevent scour by weather or water.

Revetment Surveys: Surveys performed on revetments for condition and/or construction purposes.

Sailing Line: Recommended navigation channel in an inland waterway system. Recommended sailing lines may vary seasonally.

Scale Factor (Grid/Correction): A factor used to correct for differences between grid and geodetic distances.

Sea Level Datum (SLD): This term should not be used due to the confusion over differences between NGVD 29 and mean sea level.

Secondary Control Tide Station: A tide station at which continuous observations have been made over a minimum period of 1 year but less than a 19-year metonic cycle.

Sediment Basin: A basin constructed to trap sediment eroded from a slope or being transported by a river.

Shallow Draft Project: A navigation project with a project depth less than 15 feet.

Shoaling (shoal): The reduction of water depth due to sediment deposition.

Side Slope (Channel). The designed/constructed cut on the side banks of a navigation channel, normally referred to by the gradient ratio.

Sounding: A subsurface depth measured by an acoustic device or echo sounder. This term is generalized to include any depth regardless of how it was measured (lead line, sounding pole, etc.).

Stage: The elevation of a river or confined water area, usually referred to a low water datum plane.

Start/Stop Points: The end points of an arbitrary baseline used to reference surveys performed with an automated hydrographic survey system and from which survey line offsets are run. The baseline is normally aligned to the project stationing.

State Plane Coordinate System (SPCS): A reference coordinate system used by the various states of the United States of America.

Station (Stationing): Measure of distance along a project's alignment, typically in 100-ft increments.

Station-Offset Coordinate System: A construction coordinate system referenced to a local baseline which is usually aligned with the center line of the project.

Stilling Well: Mechanism or structure for stilling wave action in a tide or water level stage gage.

Strike: Object or shoal lying above grade in a channel.

Submergent Disposal Area: A dredge disposal area where the top of grade is below the water surface by some specified amount (offshore disposal area).

Subsurface Elevation: An absolute elevation of a point below water, usually referenced to an established vertical datum--as opposed to reference to a water level plane/datum.

Subsurface Investigations: Engineering investigations of subsurface materials or structures.

Survey Alignment: The direction of survey lines relative to the project alignment (e.g., cross sections, profiles, laterals, etc.).

Suspended Sediment (Fluff): Lightweight particles in suspension.

Sweep Rafts: Large rafts or barges (up to 100 ft long) used to suspend heavy channel sweeping bars for clearing projects at authorized grade.

Sweep Survey: Channel sweep survey.

Take-off: See *Quantity Take-Offs*.

Task Order: Separate work item under an Indefinite Delivery Contract for surveying services. Previously termed Delivery Order or Work Order.

Template: Design, required, or overdepth prisms.

Tertiary Tide Station: A tide station at which continuous observations have been made over a minimum period of 30 days but less than 1 year.

Tidal Datum: A construction/excavation datum based on a tidal phase reference, usually mean lower low water.

Tide: The periodic rise and fall of water resulting from gravitational interactions between the sun, moon, and earth.

Tide Station: The geographic location at which tidal observations are conducted. Also, the facilities used to make tidal observations (tide staff, tide gage, tide house, tidal benchmarks, etc.).

Total Station: An electronic surveying instrument which digitally measures and displays angular, distance, and/or x-y-z coordinate data to a stationary remote point. A fully automated self-tracking total station will automatically track a moving target.

Track Plotter: A digital hard-copy plotter once used on a dredge or survey boat to record the line track of the vessel to monitor dredging or survey alignment, coverage, progress, etc.

Transformation (of coordinates): Conversion of coordinates from one coordinate system (or datum) to another.

Transponder: A remote EPS station which receives and reprocesses a signal from an offshore vessel. (Also, Motorola, Inc., EPS.)

Triangulated Irregular Network (TIN): A linked network of x-y-z data points in a digital terrain model (DTM) from which volumes can be computed using the triangular prismoidal elements.

Triangulation Intersection (Vessel Positioning): Determining the position of an offshore point by measuring two or more angles (directions or azimuths).

Trilateration Positioning: Method of position determination using the intersection of two or more distances to a point.

Trisponder: Trade name for Del Norte, Inc., electronic positioning equipment.

Turning Basin: An open area along the end of a waterway or harbor to allow vessels to turn around or moor. In restricted interior channels, a basin enabling a vessel to reverse direction and leave the harbor or make a substantial change in direction.

Uncontrolled Centerline Survey: A reconnaissance survey of the approximate center-line alignment of a navigation project, usually with minimal (visual) positioning methods.

Uncontrolled Survey: Any hydrographic survey performed with minimal horizontal control.

Underwater Obstruction Surveys: Surveys of navigation hazards for salvage or debris removal.

Unit Price Dredging Construction Contract: Procurement of dredging services in which payment is based on an applicable unit price from a specified section, typically measured in volume (cubic yards), area (per station or per square yard), or time (per hour or fraction thereof).

Universal Transverse Mercator (UTM) Coordinate System: A worldwide metric military coordinate system rarely used for civil works applications.

Upland Disposal Area: A dredging disposal area located adjacent to or upland from the navigation project.

Widener Section: An enlarged section at the intersection of two channels.

World Geodetic System 1984 (WGS 84): A rotational ellipsoid having the following dimensions: semi-major axis, 6,378,137 m; semi-minor axis (derived), 6,356,752 m; flattening (derived), 1/298.257224. This ellipsoid reference model/datum is the surface from which GPS coordinates are computed. The WGS 84 and the GRS 80 use the same earth center, which makes the NAD 83 adjustment coordinates compatible for practical engineering applications using differential GPS measurements to obtain geodetic positions relative to the reference station.

Zero Tolerance: Dredging payment method under which no allowable overdepth allowance is authorized.