ENGINEER MANUAL

EM 1110-3-161
April 1984

ENGINEERING AND DESIGN

WATER SUPPLY, WATER SOURCES

MOBILIZATION CONSTRUCTION

DEPARTMENT OF THE ARMY
CORPS OF ENGINEERS
OFFICE OF THE CHIEF OF ENGINEERS

DEPARTMENT OF THE ARMY
U.S. Army Corps of Engineers
Washington, D.C. 20314

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1. Purpose. This manual provides guidance for developing or investigating water sources at U.S. Army mobilization installations.

2. Applicability. This manual is applicable to all field operating activities having mobilization construction responsibilities.

3. Discussion. Criteria and standards presented herein apply to construction considered crucial to a mobilization effort. These requirements may be altered when necessary to satisfy special conditions on the basis of good engineering practice consistent with the nature of the construction. Design and construction of mobilization facilities must be completed within 180 days from the date notice to proceed is given with the projected life expectancy of five years. Hence, rapid construction of a facility should be reflected in its design. Time-consuming methods and procedures, normally preferred over quicker methods for better quality, should be de-emphasized. Lesser grade materials should be substituted for higher grade materials when the lesser grade materials would provide satisfactory service and when use of higher rade materials would extend construction time. Work items not immediately necessary for the adequate functioning of the facility should be deferred until such time as they can be completed without delaying the mobilization effort.

FOR THE COMMANDER:

PAUL F. KAVANAUGH
Colonel, Corps of Engineers
Chief of Staff

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LIST OF TABLES

CHAPTER 1

WATER SUPPLY SOURCES

1-1. Purpose and scope. This manual prescribes the standards to be used for developing or investigating water sources at Army mobilization facilities.

1-2. Definitions. Definitions for water supply sources will be as presented in EM 1110-3-160.

1-3. General. Water supplies may be obtained from surface or ground sources by expansion of existing systems or by purchase from other systems. The selection of a source of supply will be based on water availability, adequacy, quality, cost of development and operation, and the expected life of the project to be served. In general, all alternative sources of supply should be evaluated to the extent necessary to provide a valid assessment of their value for a specific installation. Alternative sources of supply include purchase of water from U. S. Government owned or other public or private systems, as well as consideration of development or expansion of independent ground and surface sources. A combination of surface and ground water, while not generally employed, may be advantageous under some circumstances and should receive consideration.

1-4. Use of existing systems. If the installation is located near a municipality or other public or private agency operating a water supply system, this system should be investigated to determine its ability to provide reliable water service to the installation at reasonable cost and to determine the possible arrangements that might be made for its use. The investigation must consider near future as well as current needs of the existing system and, in addition, the impact of the Army project on the water supply requirements in the existing water service area. The feasibility of utilizing the existing supply should be compared with the feasibility of reasonable alternatives. Among the important matters that must be considered are: quality of the supply; adequacy of the supply during periods of peak demand; reliability and adequacy of raw water pumping and transmission facilities; treatment plant and equipment; high service pumping; storage and distribution facilities; facilities for transmission from the existing supply system to the Army project; and costs.

1-5. Environmental considerations. For guidance on environmental considerations, EM 1110-3-160 will be consulted.

1-6. Water quality considerations. Guidelines for determining the adequacy of a potential raw water supply for producing an acceptable finished water supply with conventional treatment practices are given in EM 1110-3-162.

a. Hardness. Water hardness classifications are shown in table 1-1.

Table 1-1. Water Hardness Classifications

Total Hardness mg/l as $CaCO_3$	Classification
0 - 100	Very Soft to Soft
100 - 200	Soft to Moderately Hard
200 - 300	Hard to Very Hard
over 300	Extremely Hard

For mobilization work, softening will not be considered unless the hardness exceeds about 400 mg/l as $CaCO_3$ or equipment and processes need low hardness water. In this case the water should be softened at the supply point to the particular equipment or process.

b. Total dissolved solids (TDS). In addition to hardness, the quality of ground water may be judged on the basis of dissolved mineral solids. In general, dissolved solids should not exceed 800 mg/l.

c. Chloride and sulfate. Chloride and sulfate cannot be removed by conventional treatment processes, and their presence in concentrations greater than about 250 mg/l reduces the value of the supply for domestic and industrial use and may justify its rejection if development of an alternative source of better quality is feasible. Saline water conversion systems, such as electrodialysis or reverse osmosis, are required for removal of excessive chloride or sulfate and also certain other dissolved substances, including sodium and nitrate.

d. Other constituents. The presence of certain toxic heavy metals, fluoride, pesticides, and radioactivity in concentrations exceeding U.S. Environmental Protection Agency standards, as determined by the Surgeon General of the Army, will make rejection of the supply mandatory unless unusually sophisticated treatment is provided. For detailed discussion of U.S. Environmental Protection Agency water standards, see 40 CFR - Part 141, AR 420-46, and TB MED 576.

e. Water quality data. Base water quality investigations or analysis of available data at or near the proposed point of diversion should include biological, bacteriological, physical, chemical, and radiological parameters covering several years and reflecting seasonal variations. Sources of water quality data are installation records, U.S. Geological Survey District or Regional offices and Water Quality Laboratories, U.S. Environmental Protection Agency regional offices, state geological surveys, state water resources agencies, state and local health departments, and nearby water utilities, including those serving power and industrial plants, which utilize the proposed source. Careful study of historical water quality data is usually more productive than attempting to assess quality from analysis of a few samples, especially on streams. Only if a thorough search fails to locate existing, reliable water quality data should a sampling program be initiated. If such a program is required, the advice and assistance of an appropriate agency will be obtained. Special precautions are required to obtain representative samples and reliable analytical results. Great caution must be exercised in interpreting any results obtained from analysis of relatively few samples.

1-7. Checklist for existing sources of supply. The following items, as well as others, if circumstances warrant, will be covered in the investigation of existing sources of supply from Government owned or other sources.

- Quality history of the supply; estimates of future quality.
- Description of source.
- Water rights.
- Reliability of supply.
- Quantity now developed.
- Ultimate quantity available.
- Excess supply not already allocated.
- Raw water pumping and transmission facilities.
- Treatment works.
- Treated water storage.
- High service pumping and transmission facilities.
- Rates in gpm at which supply is available.
- Current and estimated future cost per 1,000 gallons.
- Current and estimated future cost per 1,000 gallons of water from alternative sources.
- Distance from Army installation site to existing supply.
- Pressure variations at point of diversion from existing system.
- Ground elevations at points of diversion and use.

- Energy requirements for proposed system.

- Sources of pollution, existing and potential.

- Assessment of adequacy of management, operation, and maintenance.

- Modifications required to meet additional water demands resulting from supplying water to Army installation.

CHAPTER 2

GROUND WATER SUPPLIES

2-1. General. Ground water is water contained in beds of rock, gravel, and sand, termed "aquifers," beneath the land surface. The principal source of ground water is rainfall, and aquifers are replenished, or recharged, by seepage of rainfall into the ground. An aquifer's recharge area may be close to or distant from a well location. Geology controls the abundance of ground water. In general, wells drilled into dense rocks, such as granite, do not yield large quantities of ground water. On the other hand, wells that penetrate unconsolidated formations of loose sand and gravel will often yield large quantities of water, sometimes 1,000 gpm or more per well.

a. Availability. Within a given area, there may be considerable variation from place to place in the yield of aquifers, and a test-drilling program is often required to determine well location and probable productivity. Sources of information regarding well location, depth, and capacity are: existing wells, drilling contractors familiar with the area, state agencies such as state geological surveys and state water resource organizations, and regional or district offices of the U.S. Geological Survey.

b. Quality. Many ground waters have high levels of hardness and may require softening (see para 1-6 for hardness criteria). Iron and manganese are also troublesome constituents of many ground waters; if concentrations in excess of 1.0 mg/l iron and/or .15 mg/l manganese are encountered, treatment will be a requirement for domestic uses and may be required for industrial uses. Other common constituents of ground water are chloride and sulfate. Chloride is objectionable if present in excess of about 400 mg/l and, for sulfate, 500 mg/l. Ground waters contain varying amounts of dissolved carbon dioxide. Minor concentrations are not harmful; excessive amounts can be readily removed by aeration processes. Hydrogen sulfide is a noxious constituent of some ground waters. It has an extremely unpleasant odor, is corrosive, and causes disinfection difficulties. Treatment, usually by some form of aeration, is required for its removal.

c. Economy. Where water requirements are moderate, ground water may prove economical if the supply can be obtained from a few high-capacity wells. However, if the yield of available aquifers is limited, a number of low-capacity wells will be required, resulting in greatly increased capital costs for well construction. System operating and maintenance costs will also be considerably increased. Under such conditions, the economy of a ground water versus surface water supply needs to be carefully examined. The study should include an appraisal of operating and maintenance costs as well as capital costs. No absolute rules can be given for choosing between ground and surface water sources. In general, wells requiring minimum or no treatment or only disinfection will be the preferred supply method when compared with surface sources/filtration plant, due to the economics involved. Each situation must be examined on its merits with due consideration to treatment as well as installation and pumping costs.

2-2. Test drilling. Before an appraisal of the cost of a ground water supply system can be prepared, information is needed regarding well location, depth, productivity, and spacing. Sometimes reliable information can be obtained from a study of existing wells in the same vicinity. Records of local drilling contractors are often of considerable value, as are data available from state geologists and ground water offices of the U.S. Geological Survey. Generally, however, test drilling and test pumping by a competent contractor are required for accurate appraisal of the ground water resources of a locality and such programs are strongly recommended, especially for large water supply projects. A test drilling program will provide reliable information about the following matters, all of critical importance in ground water supply development: location of wells, depth of wells, well spacing, well design, probable productivity of completed wells, probable water quality, materials of well construction, and pumping equipment.

2-3. Water quality considerations. Both well location and construction are of major importance in protecting the quality of water derived from a well.

a. Sanitary survey. Prior to a decision as to well or well field location, a thorough sanitary survey of the area should be undertaken. Such effort will usually provide a good picture of the pollution problems in the area and their possible impact on the ground water as well as an assessment of the probable quality of the water that will be obtained from new wells in the area. Such a survey will involve interviewing personnel from state and local health departments and other state agencies as well as Federal agencies having knowledge of water quality and water use in the area. Also, data related to the following should be obtained and analyzed.

- Locations and characteristics of sewage and industrial waste disposal.
- Locations of sewers, septic tanks, and cesspools.
- Chemical and bacteriological quality of ground water, especially the quality of water from existing wells.
- Histories of water, oil, or gas wells or test holes in area.
- Industrial and municipal landfills and dumps.
- Direction and rate of travel of usable ground water.

b. Well location. The well or wells should be located on the highest ground practicable, certainly on ground higher than nearby potential sources of pollution. The well casing should be carried at least 12 inches above the elevation of the ground surface at the site and the surface near the site built up, by fill if necessary, so that surface drainage will be away from the well in all directions. Where flooding is a problem, special well design will be necessary to insure protection of wells and pumping equipment from contamination and damage during flood periods and to facilitate operation during a flood.

c. Minimum distance from pollution sources. Minimum distances from known potential sources of pollution should be carefully considered in deciding upon well location. Recommended minimum distances for well sites, under favorable geological conditions, from commonly encountered potential sources of pollution are as shown in table 2-1. It is emphasized that these are minimum distances which can serve as rough guides to good practice when geological conditions are favorable. Conditions are considered favorable when the earth materials between the well location and the pollution source have the filtering ability of fine sand. Where the terrain consists of coarse gravel, limestone, or disintegrated rock near the surface, the distance guides given above are insufficient, and greater distances will be required to provide safety. Because of the wide geological variations that may be encountered, it is impossible to specify the distance needed under all circumstances. Consultation with local authorities will aid in establishing safe distances consistent with the terrain.

Table 2-1. Minimum Distances from Pollution Sources

Source	Minimum Horizontal Distance
Building Sewer	50 feet
Septic Tank	50 feet
Disposal Field	100 feet
Seepage Pit	100 feet
Dry Well	50 feet
Cesspool	150 feet

d. Chemical pollution. Chemical pollution may present a serious problem. Sedimentation and filtration in the finest soil-sand materials will not filter chemical contaminants involving substances such as brines, acids, certain metals, and stable organics in solution. These chemicals can reach an aquifer from landfills and leaking waste disposal ponds and will travel long distances through it. Inasmuch as most of these substances are not biodegradable, time of flow is not a factor of importance. Pollutant concentration reductions are usually obtained only as a result of dilution with unpolluted ground water. Once an aquifer is badly polluted with chemical wastes, it is essentially destroyed as a useful water resource.

e. Waste disposal wells. Water supply wells are particularly vulnerable to all forms of pollution from shallow wells used, illegally, for waste disposal. The use of shallow wells for waste disposal is an absolutely unacceptable waste disposal practice. Water supply wells will not be located where disposal well pollution could contaminate the water supply.

2-4. Water samples. Appropriate sampling and testing should be accomplished by the designer to permit determinations of required treatments and the process design (reference to chapter 3 in TB MED 576).

a. Iron and manganese. Aeration causes oxidation of iron and manganese and their subsequent precipitation in the sample bottle and should be avoided, during sampling, insofar as possible. On the results of laboratory analyses may hinge the decision as to whether or not to build a treatment plant for iron and manganese removal, a major item of construction cost.

b. Carbon dioxide and pH. Carbon dioxide (CO_2), a water soluble gas, is a constituent of nearly all ground waters. Its concentration may vary from a few to more than 100 mg/l. CO_2 affects the pH value of the water significantly. Data on CO_2 concentration and pH value are best obtained by simple field tests conducted on carefully collected samples. Aeration should be avoided during sample collection.

c. Hydrogen sulfide. Hydrogen sulfide (H_2S) is a volatile substance occasionally found in ground water. Its presence can easily be detected because of its potent, rotten-egg odor. If an accurate quantitative analysis is needed, the test must be performed in the field, immediately after sampling. Any attempt to perform an accurate test on a shipped sample will give a result far below the true value.

d. Chemical analyses. It is mandatory to review the stipulations contained in the current U.S. Environmental Protection Agency's drinking water standards as interpreted by the Surgeon General of the Army, TB MED 576, and to collect samples as required for the determination of all constituents named in the drinking water standards. The maximum chemical concentrations mandated in the drinking water standards are given in EM 1110-3-162. These limits are not comprehensive and are subject to change.

e. Bacteriological analyses. Collection of samples for bacteriological analysis is useless unless the test well has been thoroughly disinfected in accordance with the procedure for completed wells outlined in paragraph 2-8. If it is desired to obtain such samples, the test well should be disinfected and pumped until all traces of chlorine have disappeared. A bacteriological sample may then be carefully collected in a specially sterilized bottle provided by the health department or other laboratory conducting the examination.

2-5. Water supply wells. A well is a hydraulic structure that permits the withdrawal of water from the interstices of a water bearing formation. A water supply well can be considered to consist of two basic components: (1) a conduit section that houses pumping equipment and provides piping for upward flow of water to the ground surface, (2) the intake section equipped to promote free entry of water from the aquifer into the well. In rock formations, the conduit portion is usually cased from the surface to the top of the aquifer. The remainder, or intake portion, of the well is uncased. In sand-gravel aquifers, the conduit section is cased and the intake portion consists of a screen or a screen plus a gravel pack. The function of the screen and gravel pack is to prevent fine aquifer material, such as sand, from entering the well while permitting the inflow of water. Those responsible for planning and designing water supply wells should recognize the following principles:

a. Location. Consider potential sources of pollution, such as flood waters, sewers, abandoned wells, and landfill areas.

b. Design. Seal off water-bearing formations that are, or are likely to be, contaminated or formations that have undesirable water quality characteristics; e.g., high saline content.

c. Sealing. No opening will be formed between the ground surface and the water-bearing formation other than that through which the water is produced. The annular space around the conduit must be grouted.

d. Materials. Match with prevailing local conditions to insure optimum durability.

2-6. Well design and construction. Wells are constructed as dug wells, driven wells, jetted wells, bored wells, drilled wells, or collector wells. There is no single correct method of well construction. The choice depends on size, depth, formations encountered, and experience of local well contractors. Detailed guidance on water supply well design and construction is contained in AWWA A100 and in EPA-570/9-75-001. These documents should be utilized in connection with the design of water supply wells. Both contain detailed information on drilling-contract documents, types of wells, well casings and screens, testing for yield and drawdown, grouting and sealing, plumbness and alinement, disinfection, samples and records, protection of water quality, shooting or blasting, and sealing of abandoned wells.

a. Rock wells. Wells drilled into consolidated formations such as limestone or dolomite are commonly termed "rock" wells. These wells should be avoided since rock, in general, provides for poor aquifers.

b. Sand-gravel wells. Sand-gravel wells are wells driven in unconsolidated formations of sand, gravel, or mixtures of sand and gravel. Gradation may vary from extremely fine sand through very coarse gravel. An important design consideration for a well that taps a sand or gravel aquifer is matching the intake section of the well to the aquifer. Unless this is carefully considered and properly designed, problems of low specific capacity or sand pumping are likely to be encountered.

c. Well diameter. The diameter of a well has a significant effect on the well's cost. The diameter need not be uniform from top to bottom. Construction may be initiated with a certain size casing, but drilling conditions may make it desirable to reduce the casing size at some depth. However, the diameter must be large enough to accommodate the pump and the diameter of the intake section must be consistent with hydraulic efficiency. The factors that control diameter are (1) yield of the well, (2) intake entrance velocity, and (3) construction method. The pump size, which is related to yield, usually dominates. Approximate well diameters are shown in table 2-2.

Table 2-2. Approximate Well Diameters

Anticipated Well Yield (gpm)	Nominal Size of Pump Bowls (inches)	Optimum Size Well Casing (inches)	Smallest Size Well Casing (inches)
<100	4	6 ID	5 ID
75-175	5	8 ID	6 ID
150-400	6	10 ID	8 ID
350-650	8	12 ID	10 ID
600-900	10	14 OD	12 ID
850-1,300	12	16 OD	14 OD
1,200-1,800	14	20 OD	16 OD
1,600-3,000	16	24 OD	20 OD

Well diameter affects well yield but not to a major degree. Doubling the diameter of the well will substantially increase its cost, but the larger well may produce only about 10 to 15 percent more water. Approximate well diameter versus yield ratio data for nonartesian wells are shown in table 2-3.

Table 2-3. Well Diameter-Yield Ratios

Original Well Diameter	New Well Diameter 6"	12"	18"	24"	30"	36"	48"
6"	100%	110%	117%	122%	127%	131%	137%
12"	90	100	106	111	116	119	125
18"	84	93	100	104	108	112	117
24"	79	88	95	100	104	107	112
30"	76	85	91	96	100	103	108
36"	73	82	88	92	96	100	105
48"	69	77	82	87	91	94	100

Note: The above gives the theoretical increase in yield that results from changing the original well diameter to the new well diameter. For example, if a 12-inch well is enlarged to a 36-inch well, the yield will be increased by 19 percent. The values in the above table are valid only for wells in unconfined aquifers.

For artesian wells, the yield increase resulting from diameter doubling is generally less than 10 percent. Well diameter exerts a major influence on well cost. The diameter should not be increased arbitrarily, but there may be circumstances where doubling or tripling the diameter of a well to obtain 10 to 20 percent more water is justified.

d. Well depth. Depth of a well is usually determined from the logs of test holes or from logs of other nearby wells that utilize the same aquifer. Wells are typically completed to the bottom of the aquifer whenever this is practicable. This practice is desirable because it insures high specific capacity and yield, but it is not always possible. The volume of water produced and keeping the velocities sufficiently low to prevent sand pumping are two important well construction considerations. Construction should seal off water bearing formations that are or may be polluted or of poor mineral quality. A sealed, grouted casing will extend to a depth of at least 20 feet from the ground surface. A depth greater than 20 feet is desirable. Use caution in deep drilling. Sometimes deep formations contain water of undesirable mineral content, e.g., extreme hardness or salinity. Where the depth of water of poor quality is known, terminate the well above the zone of poor quality water.

e. Well screens. Wells completed in sand and gravel with open-end casings, not equipped with a screen on the bottom, usually have curtailed capacity and sand pumping. Screens must be used for sand-gravel wells.

(1) Screen aperture size. A properly designed well screen allows water to enter the well freely at low velocity, prevents sand from entering with the water, and serves as a retainer for

the loose aquifer material. Well screen aperture size should be 45 for mobilization work. The well screen aperture size is defined as the percent of aquifer sample larger than aperture size.

(2) Screen length. Screen length depends on aquifer characteristics, thickness, and available drawdown. For a homogeneous, confined, artesian aquifer, at least 80 percent of the aquifer should be screened and the maximum drawdown should not exceed the distance from the static water level to the top of the aquifer. For a nonhomogeneous, artesian aquifer, it is usually best to screen the most permeable strata. Homogeneous, unconfined (water-table) aquifers are commonly equipped with screen covering between the lower one-third and one-half of the aquifer. A water-table is usually operated so that the pumping water level is slightly above the top of the screen. For a screen length of one-third the aquifer depth, the permissible drawdown will be nearly two-thirds of the maximum possible drawdown. This drawdown corresponds to nearly 90 percent of the maximum yield. Screens for nonhomogeneous water-table aquifers are positioned in the lower portions of the most permeable strata in order to permit maximum available drawdown.

(3) Screen diameter. Screen diameter is a parameter that can be varied after screen length and slot openings have been determined. Screen diameter is selected to satisfy the basic principle that enough screen opening area must be available so that the entrance velocity of the water will not exceed 0.1 fps. The entrance velocity is calculated by dividing the well yield in cfs by the total area of the screen openings in square feet. If the entrance velocity is greater than 0.1 fps, the screen diameter should be increased.

f. Gravel packing. Gravel packing is the process by which selected, clean, disinfected gravel is placed between the outside of the well screen and the face of the undisturbed aquifer. Gravel-pack material must be clean and fairly uniform with smooth, well-rounded grains. The preferred material is siliceous rather than calcareous. The upper limit of calcareous material is 5 percent by weight. The specific gravity of the gravel should average not less than 2.5 with not more than 1 percent by weight having a specific gravity of 2.25 or less. The gravel should contain not more than 2 percent by weight of thin, flat, or elongated pieces (large dimension: 3x small dimension) and be virtually free of shale, mica, clay, sand, dirt, loam, and organic impurities. The gravel must not contain iron or manganese in a form or quantity that would adversely affect the quality of water flowing through it, as visually evidenced by characteristic rust-colored (iron) or black (manganese) deposits.

(1) Gravel size. Gravel size is based on information obtained by sieve analyses of the material in the aquifer. The gravel will be selected so that between 85 and 100 percent of the gravel is larger than the screen openings. The uniformity coefficient of the gravel as defined in EM 1110-3-160 will be 2.5 or less.

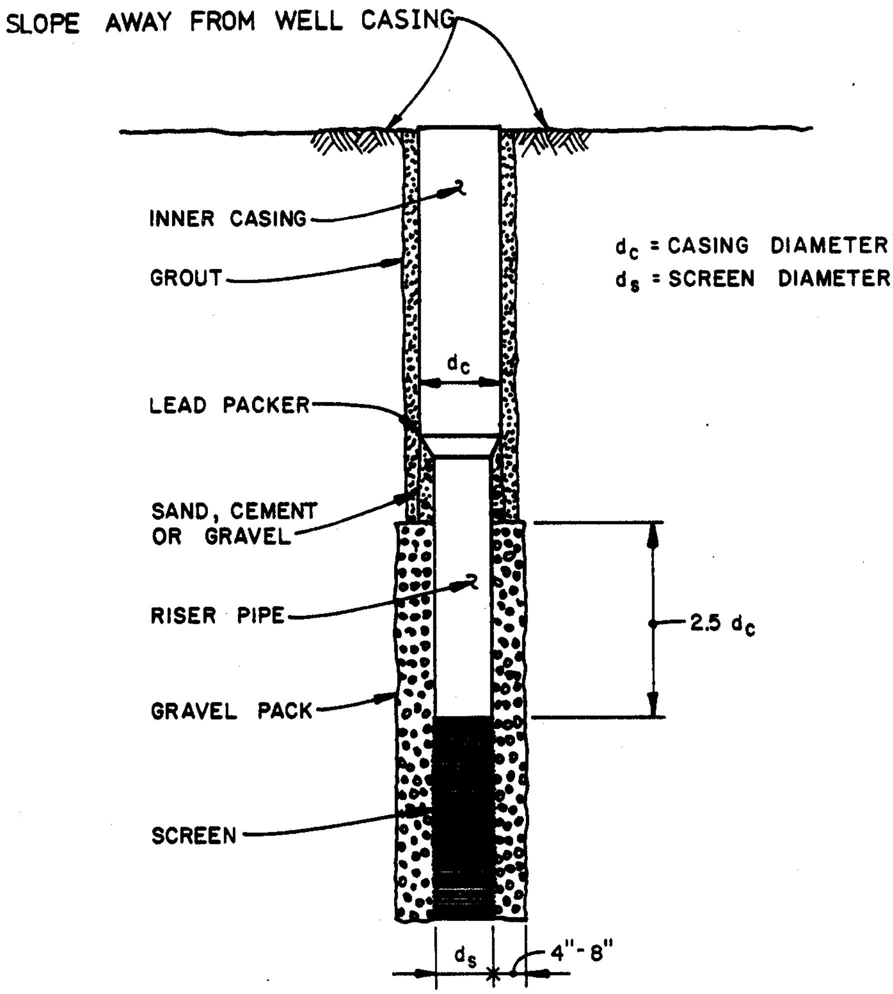
(2) Gravel thickness. The thickness of the gravel pack will range from a minimum of 4 inches to approximately 8 inches. A gravel envelope thicker than about 8 inches will not greatly improve yield and can adversely affect removal of fines, at the aquifer-gravel interface, during well development.

(3) Gravel pack length. As a minimum, the gravel pack will extend the length of the screen plus a distance equal to 2.5 times the largest diameter of the well above the top of the screen. Sand, cement, or additional filter material will be placed between the top of the pack and the lower limit of the sanitary seal. If sand is used, its size must be such that it will not infiltrate into the gravel pack. A gravel-pack well is shown schematically in figure 2-1.

(4) Gravel disinfection. It is important that the gravel used for packing be clean and that it also be disinfected by immersion in strong chlorine solution (200 mg/l or greater available chlorine concentration, prepared by dissolving fresh chlorinated lime or other chlorine compound in water) just prior to or during placement. A suitable mix is 7 pounds of chlorinated lime (25 percent available chlorine) or 2.5 pounds of high test hypochlorite (70 percent available chlorine) dispersed in 1,000 gallons of water. Failure to disinfect the gravel-pack can result in poor bacteriological quality of the water from the completed well. Once it is in place at the bottom of the well, disinfection of the gravel is difficult. Attempting to substitute chlorine disinfection for gravel cleanliness is unacceptable practice. Dirt in the gravel will greatly reduce the effectiveness of the chlorine. Dirty gravel must be thoroughly washed with clean water prior to disinfection and then handled in a manner that will maintain it in as clean a state as possible.

g. Grouting and sealing. Grouting and sealing of wells are necessary to protect the water supply from pollution, to seal out water of unsatisfactory chemical quality, to protect the casing from exterior corrosion, and to stabilize soil, sand, or rock formations which tend to cave. When a well is constructed there is normally produced an annular space between the drill hole and the casing, which, unless sealed by grouting or other acceptable packing material, provides a potential pollution channel.

(1) Prevention of contamination from surface. The well casing and the grout seal should extend from the surface to the depth necessary to prevent surface contamination via channels through soil and rock strata. The depth required is dependent on the character of the formations involved and the proximity of sources of pollution, such as sink holes and sewage disposal systems, but should not be less than 20 feet. The grout seal around the casing should have a thickness of at least 1.5 inches and a greater thickness is recommended where severe corrosive conditions are known to exist. Materials for sealing and grouting should be durable and readily placed. Normally, portland



U. S. Army Corps of Engineers

FIGURE 2-1. SCHEMATIC OF GRAVEL-PACKED WELL cement grout will meet these requirements. Grout is customarily specified as a neat cement mixture having a water-cement ratio of not over 6 gallons per 94-pound sack of cement. Small amounts of bentonite clay may be used to improve fluidity and reduce shrinkage. Grout can be placed by various methods, but to insure a satisfactory seal, it is essential that grouting (1) be done as one continuous operation, (2) be completely placed before the initial set occurs, and (3) be introduced at the bottom of the space to be grouted. Establishment of good circulation of water through the annular space to be grouted is a highly desirable initial step toward a good grouting job. This assures that the space is open and provides for the removal of foreign material.

(2) Prevention of subsurface contamination. Formations containing water of poor quality and located above or below the desired water formation must be sealed to prevent upward or downward migration of inferior quality water into the well. Sealing of formations above or below the aquifer to be utilized can be accomplished by grouting the annular space between drill hole and casing for the entire length of the casing or by grouting this annular space only through formations containing water of poor quality. If only the formations containing poor quality water are to be grouted, the sections of the annular space not filled with grout must be filled with sand to prevent caving of the surrounding strata and to support the grout before the grout has set. To provide a satisfactory seal, the grout must extend at least 10 feet above and 10 feet below the formation producing the mineralized water and must be a minimum of 1.0 inch thick in all locations.

h. Well development. The objective of development is removal of fine sand and other fines from the aquifer with resultant enlargement of passages in the portion of the aquifer near the well. Many wells will be "sand pumpers" or low in productivity unless they are adequately developed. Successful methods of development include mechanical surging, air surging, overpumping, backwashing, and high velocity jetting.

i. Accessibility. All wells eventually require some maintenance and the location should be such that the well will be readily accessible for pump repair, cleaning, disinfection, testing and inspection. The top of the well should never be completed below surface grade or in an inaccessible location. Also, the well should not be located immediately adjacent to a building. There should be at least 2 feet of clearance beyond any building projection such as eaves. Otherwise pump removal for maintenance or repair will be difficult.

j. Design and construction details relating to water quality. Grouting is required for all water supply system projects. Additional features that are related to water quality protection are:

(1) Surface grading. The ground surface in the vicinity of the well will be graded to provide good surface drainage away from the well in all directions. If necessary to achieve this, compacted earth fill will be employed.

(2) Surface slab. The well casing will be surrounded at the surface by a concrete slab having a minimum thickness of 4 inches and extending outward from the casing a minimum of 2 feet in all directions. The slab should be finished a little above ground level and should slope slightly to provide drainage away from the casing in all directions.

(3) Casing. The well casing will extend at least 12 inches above the level of the concrete surface slab in order to provide ample space for a tight surface seal at the top of the casing. The type of seal to be employed depends on the pumping equipment specified.

(4) Well house. While not universally required, it is usually advisable to construct a permanent well house, the floor of which can be an enlarged version of the surface slab. The floor of the well house will slope away from the casing toward a floor drain at the rate of about 1/8 inch per foot. Floor drains will discharge through carefully jointed 4 inch pipe or equally durable watertight material to the ground surface 20 feet or more from the well. The end of the drain will be fitted with a coarse screen. Well house floor drains must not, under any circumstances, be connected to storm or sanitary sewers. The well house will have a large entry door that opens outward. The door will be equipped with a good quality lock. The well house design will be such that the well pump, motor, and drop-pipe can be removed readily. The well house protects valves and pumping equipment and also provides some freeze protection for the pump discharge piping beyond the check valve. Where freezing is a problem, the well house will be insulated and a heating unit installed. Pit construction of any kind is not acceptable. The well house will be of fireproof construction. The well house also protects other essential items. These include:

- Flow Meter
- Depth Gage
- Pressure Gage
- Screened Casing Vent
- Sampling Tap
- Water Treatment Equipment (if required)
- Well Operating Records

If climatic or other conditions are such that a well house is not necessary, then the well will be protected from vandals or unauthorized use by a security fence having a lockable gate.

2-7. Well spacing. To insure reliability of the supply, two or more wells will be provided, and more wells may be required for major systems. Due to the time restraints imposed, it may be necessary to develop one well first; the backup wells can be constructed as time permits. The grouping of wells must be carefully considered because of mutual interference between wells when their cones of depression overlap. This reduces the yield from the individual wells because the drawdown for a given yield in a well subject to interference is greater than the drawdown of the well operated alone at the same yield. The drawdown increase produced by interference may be large for closely-spaced wells operated simultaneously. Space the wells far enough apart to minimize interference. In general, the radius of influence (R), which is defined as the radius of the cone of depression, may range from under 1,000 feet to several thousand feet. A typical value of "R" for water-table conditions is 400 feet. "R" is considerably larger for artesian wells. However, the slope of the drawdown curve decreases rapidly with distance from the well, and spacing less than 2R is generally permissible without creating undue interference. When an aquifer is recharged in roughly equal amounts from all directions, the cone of depression is nearly symmetrical about the well and "R" is about the same in all directions. If, however, substantially more recharge is obtained from one direction, e.g., a stream, then the surface of the cone of depression is distorted, being considerably higher in the direction of the stream. Conversely, the surface of the cone will be depressed in the direction of an impermeable boundary because little or no recharge is obtained from the direction of the impermeable boundary. Where a source of recharge, such as a stream, exists near the proposed well field, the best location for the wells is spaced out along a line as close as practicable to and roughly parallel to the stream. On the other hand, water supply wells should be located parallel to and as far as possible from an impermeable boundary. Where the field is located over a buried valley, the wells should be located along and as close to the valley's center as possible.

2-8. Disinfection of completed well. When the construction is complete and the well is ready for final testing for yield, a necessary final step is disinfection. The disinfection procedures described herein are applicable to "water table" and "nonflowing artesian" wells. Disinfection is needed because invariably some contamination is introduced in the construction process. Periodic chlorination during construction is good practice, but cannot substitute for the final disinfection step. Disinfection is principally dependent upon control of two factors: chlorine concentration and contact time. A chlorine solution prepared from a hypochlorite compound is a safe, convenient, effective disinfection agent. To insure adequate strength, chlorine solutions should be freshly prepared just prior to each use.

a. Cleaning. The first requirement for adequate disinfection is thorough cleaning of the well. A major part of this task can be accomplished by pumping to waste, but the casing may require swabbing with a cleansing agent for removal of oil, grease, or joint dope. After a thorough cleaning of the well, as evidenced by clear water in the pump discharge, disinfection with chlorine can proceed.

b. Chlorine concentration and contact time. To achieve disinfection, it is necessary to provide a minimum concentration of chlorine in the well of 50 mg/l or more for a period of at least 24 hours. The water will not be considered acceptable for human consumption until the bacteriological quality has been tested and found to be acceptable.

c. Stock chlorine solution. A stock chlorine solution with a strength of 15,000 mg/l available chlorine can be prepared from fresh chlorinated lime or a high test hypochlorite compound. Fresh chlorinated lime should contain a minimum of 25 percent available chlorine and the high test hypochlorite, a maximum of 70 percent. Sodium hypochlorite is manufactured with 15 percent available chlorine. It has a half-life of about 3 months.

d. Chlorine application. Prepare a standard chlorine solution having a strength of 50 mg/l and a volume twice that of the water in the well. This solution should then be discharged rapidly into the well taking care to flush the casing wall above the water level. The large volume of chlorine solution purges the well screen and the formation with chlorine solution and usually accomplishes the required disinfection within the 24 hour contact period. If disinfection is not accomplished, repeat the process using a 100 mg/l available chlorine solution having a volume equal to twice that of the water in the well and allow a minimum contact period of 4 hours. Table 2-4 indicates water volume per foot for wells of various diameters.

Table 2-4. Diameter-Volume Relationship

Inside Diameter, inches	Gallons per foot	Inside Diameter, inches	Gallons per foot
4	0.65	20	16.32
6	1.47	22	19.75
8	2.61	24	23.50
10	4.08	27	29.74
12	5.88	30	36.72
14	8.00	36	52.88
15	9.18	42	71.97
16	10.44	48	94.00
18	13.22	60	146.87

(1) Example. Assume 26 feet of water in a well having a diameter of 22 inches. Determine the volume of 50 mg/l of chlorine solution required for the previously described disinfection procedure and also the volume of 1.5 percent stock solution needed for its preparation.

(2) Solution. From table find 19.75 gallons/feet for 22 inches diameter well. Volume of water in well = (19.75)(26) = 514 gallons. 2 x volume in well = (2)(514) = 1,028 gallons of 50 mg/l chlorine solution. One gallon of 1.5 percent stock solution will treat 300

gallons of water at 50 mg/l. Gallons of stock solution required = $\frac{(1,028)(1)}{300}$ = 3.4 gallons. If facilities for handling this fairly large volume of 50 mg/l solution are not available, an acceptable alternative procedure is to apply stock chlorine solution to a continuous flow of clean water into the well. The flow rate of the stock solution and water will have to be adjusted in relation to each other to provide 50 mg/l or more of available chlorine in the mixture. Water inflow and chlorine solution feed should be maintained until the total inflow is equal to at least twice the volume of water in the well. Care should be taken to wash down the casing with the mixture. Either of these procedures will prove effective under most circumstances because both provide for forcing chlorinated water through the screen and into the voids of the gravel pack and water bearing formation. If neither of the previously described methods can be applied, the stock solution may be added to the well through a pipe or hose, preferably at different levels, to provide 100 mg/l chlorine concentration in the well. The well is then agitated with whatever equipment is available (bit or bailer) to mix the chlorine solution throughout the water. This method is not as effective as the two methods previously described. If this third method is used, a minimum contact time of 12 hours is recommended after thorough mixing of the chlorine solution and the water in the well.

e. Bacteriological samples. The effectiveness of disinfection procedures can be judged only by laboratory examination of well water samples for organisms of the coliform group.

2-9. Disinfection of flowing artesian wells. Flowing artesian wells often require no disinfection, but if a bacteriological test, following completion of the well, shows contamination, disinfection is required.

2-10. Maintenance of yield. The most common cause of declining capacity is clogging of the well screen and the water-bearing formation near the screen. This "incrustation" can be caused by products of screen corrosion adhering to the screen, but more often by precipitation, in the voids of the formation and gravel packing and in the screen openings, of incrusting chemicals derived from the water. The quality of the water in the aquifer is the key to both incrustation and corrosion.

a. Mineral content. The corrosive tendency of a water may be roughly judged by its mineral content. In general, the greater the mineral content, the more corrosive the water is likely to be. High sulfate and chloride promote corrosion, but high calcium and alkalinity tend to reduce it somewhat. If corrosion waters are suspected, corrosive-resistant materials should be specified.

b. Use of corrosion-resistant materials. Corrosion can be eliminated or minimized by the use of corrosion-resistant materials for parts of the well that come in contact with the water. Corrosion resistant alloys suitable for use in well screens include various stainless steels, silicon bronze, and a copper-silicone-manganese alloy. Desirable characteristics of an alloy, in addition to corrosion resistance, are high strength and weldability. The principal disadvantage of special alloys is their cost. Steel, galvanized steel, and iron are less expensive materials of construction and may be more readily available. Other corrosion-resistant materials such as PVC screens, PVC coated steel screens, and fiberglass slotted pipe may be considered.

2-11. Abandoned wells and test holes. It is essential that wells, test wells, and test holes that have served their purpose and are to be abandoned, be effectively sealed for safety and to prevent pollution of the ground water resources in the area. The well should be checked to insure freedom from obstructions that interfere with sealing. Prior to initiation of sealing operations, a chlorine compound solution will be added to the well. Enough hypochlorite will be used to produce a chlorine concentration of at least 100 mg/l. Acceptable sealing materials are: concrete, cement grout, neat cement, clay, sand, or combinations thereof. Of these, concrete, neat cement, or grout are recommended materials for wells extending into creviced rock formations. In general, the sealing material will be placed from the bottom to avoid segregation and dilution. Wells extending to more than one aquifer and artesian wells pose difficult sealing problems. One objective of sealing is to prevent exchange of water from one aquifer to another. Figures 2-2 and 2-3 illustrate the configuration of a gravel-packed well in operational condition and after sealing.

2-12. Checklist for ground water investigations.

a. Topographic maps of area where wells could be located.

b. Reports on area geology and ground water resources from U.S. Geological Survey, State Geological Survey, and other state and local agencies that have an interest in or have conducted ground water investigations. Records obtained from drilling contractors familiar with the area. Reports of test drilling and pumping.

c. Copies of logs of existing water supply wells, drawdown data, pumpage, and water table elevations. Estimates of safe yield of aquifers.

d. Records of physical, chemical, and bacteriological analyses of water from existing wells.

e. Assessment of probable treatment requirements, such as iron-manganese removal, softening, corrosion control, and sulfide removal.

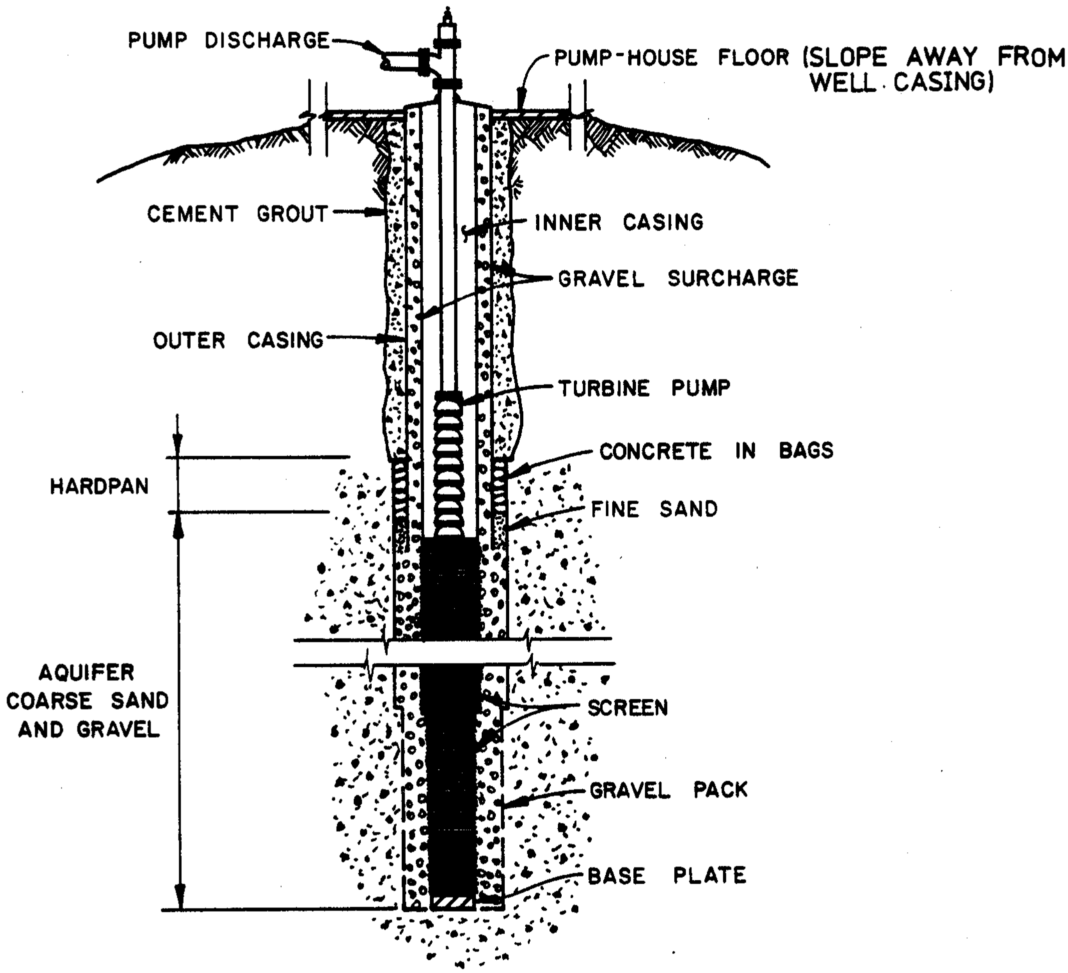
f. Summary of sanitary survey findings, including identification of possible sources of pollution.

g. Probable location, number, type, depth, diameter, and spacing of proposed water supply wells. Significant problems associated with well operation.

h. Energy requirement of proposed system.

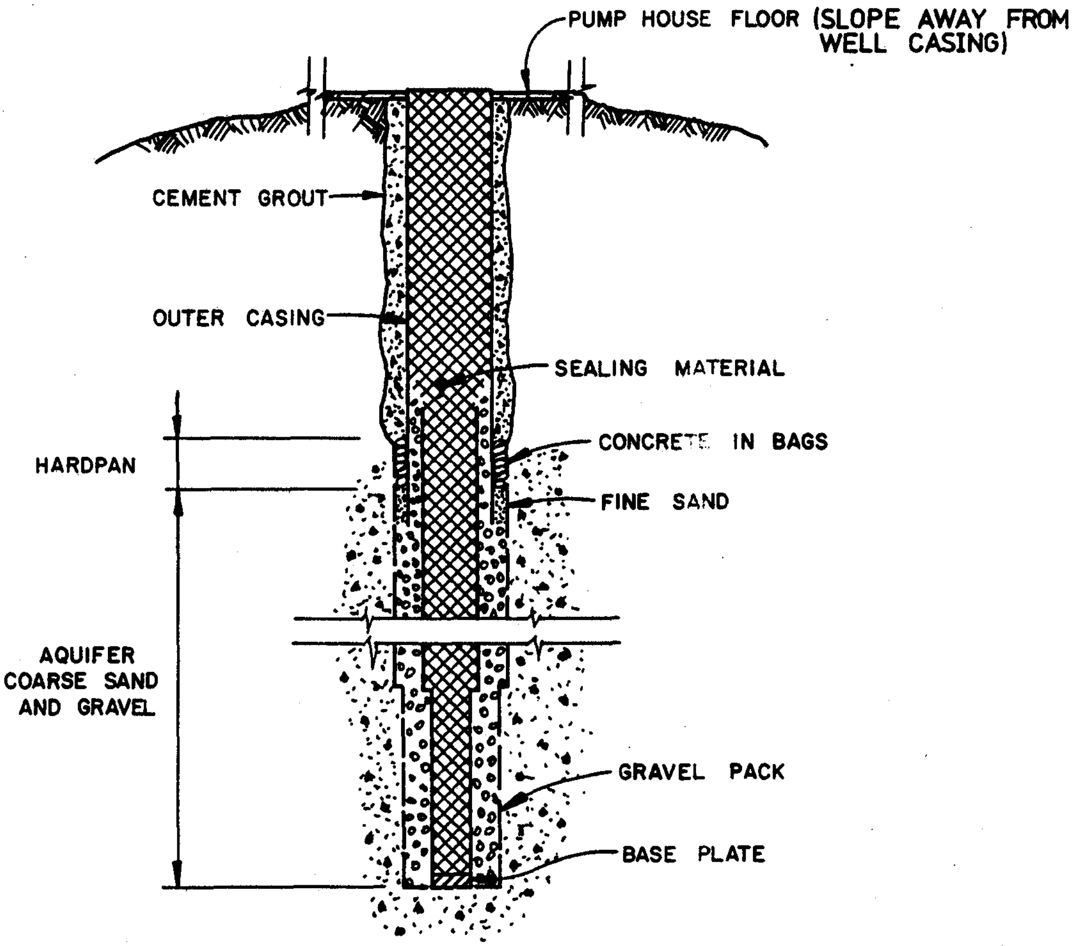
i. Summary of applicable state water laws, rules, regulations, and procedures necessary to establish water use rights.

j. Quality of ground water.



U. S. Army Corps of Engineers

FIGURE 2-2. GRAVEL-PACKED WELL (OPERATIONAL)



U. S. Army Corps of Engineers

FIGURE 2-3. GRAVEL-PACKED WELL (SEALED)

CHAPTER 3

SURFACE WATER SUPPLIES

3-1. Surface water sources. Surface water supply sources include streams, lakes, and impounding reservoirs. Large supplies of surface water are generally available throughout much of the eastern half of the United States where rainfall averages about 35 inches or more annually and is reasonably well distributed through the year. On the other hand, good surface water sources are much more limited in many western regions with the exception of the Pacific Northwest, where surface water is plentiful.

3-2. Water laws. An investigation directed toward development of new or additional sources of supply should be made with consideration of applicable state water laws.

3-3. Watershed control and surveillance. Raw water supplies should be of the best practicable quality even though extensive treatment, including filtration, is provided. Strict watershed control is usually impractical in the case of water supplies obtained from streams. However, some measure of control can be exercised over adverse influences, such as wastewater discharges, in the vicinity of the water supply intake. For supplies derived from impounding reservoirs, it is generally feasible to establish and maintain a control and surveillance program whose objective is protection of the quality of raw water obtained from the reservoir. At reservoirs whose sole purpose is to provide a source of water supply, recreational use of the reservoir and shoreline areas should be rigorously controlled to protect the water supply quality.

3-4. Checklist for surface water investigations. The investigations will cover the following items, as well as others, as circumstances warrant.

a. Topographic maps showing pertinent drainage areas.

b. Hydrologic data, as required for project evaluations, e.g., rainfall, runoff, evaporation, assessment of ground water resources and their potential as the sole source or supplementary source of supply.

c. Sanitary survey findings.

d. Intake location.

e. Water quality data at or near proposed intake site.

f. Feasibility of developing supply without reservoir construction.

g. Reservoir location if reservoir is required.

h. Plans for other reservoirs on watershed.

i. Pertinent geological data that may affect dam foundation or ability of reservoir to hold water.

j. Locations for pump stations, supply lines, treatment plant.

k. Energy requirements for proposed system.

l. State water laws, rules and regulations, procedure for obtaining right to use water, impact of proposed use on rights of other users.

m. Disposition of sludge from water treatment plant.

CHAPTER 4

INTAKES

4-1. General. The intake is an important feature of surface-water collection works. For fairly deep streams, whose flow always exceeds water demands, the raw water collection facilities generally consist of an intake structure located in or near the stream, an intake conduit, and a raw water pump station. Often the intake and pump station are combined in a single structure. On smaller, shallow streams, a channel dam may be required to provide adequate intake submergence and ice protection. Inlet cribs of heavy-timber construction, surrounding multiple-inlet conduits, are frequently employed in large natural lakes. For impounding reservoirs, multiple-inlet towers, which permit varying the depth of withdrawal, are commonly used. Hydraulically or mechanically-cleaned coarse screens are usually provided to protect pumping equipment from debris. If the stream is used for navigation, the intake design should include consideration of navigation use and of impact from boats or barges out of control.

4-2. Capacity and reliability. The intake system must have sufficient capacity to meet the maximum anticipated demand for water under all conditions during the period of its useful life. Also, it should be capable of supplying water of the best quality economically available from the source. Reliability is of major importance in intake design because functional failure of the intake means failure of the water system. Intakes are subject to numerous hazards such as navigation or flood damage, clogging with fish, sand, gravel, silt, ice, or debris, extreme low water not contemplated during design, and structural failure of major components. Many streams carry heavy suspended silt loads. In addition to suspended silt, there is also a movement of heavier material along the bed of the stream. The intake must be designed so that openings and conduits will not be clogged by bed-load deposits. An additional problem, caused by suspended silt and sand, is serious abrasion of pumps and other mechanical equipment. Excessive silt and sand may also cause severe problems at treatment plants. Liberal margins of safety must be provided against flood hazards and also against low-water conditions. A depression dredged in the stream bed to provide submergence is not a solution to the low-water problem because it will be filled by bed-load movement. A self-scouring channel dam may be the only means of assuring adequate water depth. As an alternative to unusually difficult intake construction, gravel-packed wells and horizontal collector infiltration systems located in the alluvium near the river are often worthy of investigation. Water obtained from such systems will usually be a mixture of ground water and induced flow from the stream.

4-3. Ice problems. In northern lakes, frazil ice (a slushy accumulation of ice crystals in moving water) and anchor ice (ice formed beneath the water surface and attached to submerged objects) are significant hazards, while on large rivers, floating ice has caused damage. Intake design must include ample allowances for avoiding or coping with these hazards. The intake location and inlet size are important aspects of design. Excessive inlet water velocities have been responsible for major clogging problems caused by both sand and ice. Inlet velocities in the range of 0.25 to 0.5 fps are desirable for avoiding ice clogging of intakes. Where ice is a problem, river intakes must have the structural stability to resist the thrust of ice jams, and the openings must be deep enough to avoid slush ice which has been reported as deep as 6 to 8 feet. Frazil and anchor ice can also cause difficulties, but on rivers, floating ice is usually the greater hazard. Steam heating has been employed to cope with ice problems at some northern lake intakes. Nonferrous materials are preferred for cold-climate inlet construction because their lower heat conductivity discourages ice formation.

4-4. Intake location. Meandering streams in deep alluviums pose especially difficult intake problems. Here, dikes, jetties, and channel protection may be required to prevent the river channel from moving away from the intake or cutting behind it. On such streams, careful consideration must be given to intake location. Generally, the intake site should be on the outside bank of a well established bend where the flow is usually swiftest and deepest. If the outside bend site includes a rock bank, a reliable intake probably can be placed there. Inside bends are to be avoided because of shallow water and sand bars. Sufficient depth at extreme low stage must also be a consideration. In addition to structural and hydraulic considerations, water quality is of major importance in connection with intake design and location, and the water quality aspects of a proposed location should be carefully examined. The location study should include a sanitary survey whose objective is evaluation of the effects of existing and potential sources of pollution on water quality at the intake site. The survey should include a summary of historical water quality data at the site plus an assessment of the probable impact of all wastewater discharges likely to influence present or future quality.

CHAPTER 5

RAW WATER PUMPING FACILITIES

5-1. Surface water sources.

a. Pump station arrangement. The location and arrangement of raw water pump stations will depend upon the requirements of the local situation and only general comments can be given. Raw water pump stations and intakes are often combined in a single structure, but this is not mandatory. The depth of the structure is a function of the type and arrangement of the pumps used. Horizontal centrifugal pumps are often employed and will give satisfactory performance and good operating economy. However, if the supply is from a variable stream and the pump suctions are to be under positive pressure under all operating conditions, a station of considerable depth probably will be required. Deep stations of the dry-pit type commonly used for horizontal centrifugal pumps should be compartmented so that rupture of pump discharge piping within the station will not flood all other pumps and motors. The depth may be reduced, with some loss in reliability, by installing the pumps at an elevation such that suction lift prevails under some operating conditions. Equipment for priming is a requirement when suction lift is employed. Use of vertical type wet-pit pumps, which requires less space in plan, permits a somewhat shallower station, and does not require priming, may prove an economical alternative. Among other pumping arrangements that could be used are: vertical-type pumps or end-or side-suction centrifugals, with their shafts in a vertical position, located on a submerged suction header. The latter permits location of the pump drive units at an elevation where they are protected from flooding and readily accessible.

b. Pump protection. Pumps, particularly those located on streams, must have protection against debris. In order to prevent or at least minimize screen clogging, the size of the screen openings should be consistent with the capacity of the pump to pass solids. The pump manufacturer can supply information on the largest sphere that the pump will pass. Plants with flows of 1 mgd or larger and obtaining their water from streams should use hydraulically cleaned traveling screens. For smaller installations or those not obtaining water from streams, a fixed bar screen or strainers can be used. For such arrangements, provisions must be made for cleaning. This can be accomplished by backflushing. In general, screening should be held to the minimum required for protection of the pumps. Excessively fine screens, strainers, or bar racks are sometimes subject to rapid clogging and will require frequent cleaning. Debris removed by mechanically cleaned screens must be collected and hauled to a landfill or other acceptable disposal site. Screenings may be stored temporarily at the station in dump carts from which they are discharged to a truck for transport to a disposal site.

c. Structural considerations. Substructures and superstructures will usually be of incombustible materials such as reinforced concrete, brick or other masonry. If these materials are not available, other materials will be evaluated. Structural design should include consideration of requirements for pump and motor servicing and removal for major repairs.

d. Ventilation. Where a gravity ventilation system is deemed inadequate to supply fresh air and remove fumes and heated air from the pump station, a forced ventilation system should be provided. The ventilation system should be capable of removing waste heat from the motors such that no more than a 10 degrees F. rise above ambient temperature of the air in the pump station is permitted. For occupied areas, the ventilation system will have a capacity of about six air changes per hour. If dust-producing chemicals are to be handled at the station, special dust exhaust systems will also be provided. Where chemicals are used in the pump station, precautions should be taken to insure that the exhaust from the ventilation system complies with air pollution prevention requirements.

e. Pumping equipment. In general, pumping equipment should be sized to conform to the rated capacity of the water treatment plant and will include a minimum of three electric motor-driven pumps. With the largest of the three pumps out of service, the remaining two pumps will be capable of supplying raw water at a rate equal to the rated capacity of the plant. To insure water service in the event of a major power outage, a sufficient number of pumps must be equipped for operation when normal electric power is not available. These pumps will be capable of supplying at least 50 percent of the rated capacity of the treatment plant, except where greater capacity is essential. Standby power for emergency operation can be provided by gas-turbine or diesel engine generators or by engines arranged to provide for pump operation by direct engine drives during the emergency.

5-2. Ground water sources. For most applications, either vertical line shaft turbine pumps or submersible turbine pumps will be used. For small-capacity or low-head applications, rotary or reciprocating (piston) pumps may be more appropriate. Factors influencing the selection of pumping equipment include well size, maximum pumping rate, range in pumping rate, maximum total head requirements, range in total head requirements, and type of power available. If all pumps use electric power as the primary energy source, a sufficient number of the pumps must be equipped for emergency operation when normal electric power is not available. Emergency power can be provided by gas-turbine or diesel engine generators or by engines arranged to provide for pump operation by direct engine drives during the emergency. These standby-powered pumps will be capable of supplying at least 50 percent of the required daily demand, except where greater capacity is essential.

5-3. Electric power. If dual electric power feeders, breakers, transformers, and switchgear can be provided, they will increase the station's reliability but may add appreciably to its cost. If a high degree of reliability is deemed necessary, the station should be served by independent transmission lines that are connected to independent power sources or have automatic switchover to direct drive engines.

5-4. Control of pumping facilities. Supervisory or remote control of electric motor-driven pumping units will be provided if such control will substantially reduce operator time at the facilities.

APPENDIX A

REFERENCES

Government Publications.

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40 CFR - 141	National Interim Primary Drinking Water Regulations, as amended.

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A100-66	Standard for Deep Wells.