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	Engineering and Design OPERATION AND MAINTENANCE OF EXTRACTION AND INJECTION WELLS AT HTRW SITES	
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CEMP-RA

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

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Pamphlet
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Engineering and Design
OPERATION AND MAINTENANCE OF EXTRACTION AND INJECTION WELLS AT HTRW SITES

1. Purpose. This engineer pamphlet transmits a document which describes requirements for carrying out Operations & Maintenance (O&M) for extraction and injection wells at HTRW sites. Appendix D of this document contains logs and checklists to be used during O&M of extraction or injection wells, or to review O&M plans submitted by contractors.

2. Applicability. This pamphlet applies to HQUSACE elements, and all USACE commands, having responsibility for preparing or reviewing O&M plans for extraction and injection wells at HTRW sites.

3. Distribution Statement. Approved for public release, distribution is unlimited.

4. References. Required and related publications are listed in Appendix A.

5. Explanation of Abbreviations and Terms. Special terms used in this pamphlet are explained in Appendix B.

FOR THE COMMANDER:

4 Appendices
(See Table of Contents)

RUSSELL L. FUHRMAN
Major General, USA
Chief of Staff

CEMP-RA

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Table of Contents

Chapter 1
Introduction

1-1. Purpose

a. This engineer pamphlet (EP) provides geotechnical, chemical, microbial, and operational guidance for U.S. Army Corps of Engineers (USACE) elements in identifying aspects of groundwater extraction and injection wells and systems that have led to failures of either the extraction and injection wells or related piping and treatment systems at hazardous, toxic, and/or radioactive waste (HTRW) sites. These guidelines are a compilation of specific problems that have been identified in each of several categories, along with a technical discussion of their diagnoses and solutions.

b. This EP provides the multidisciplinary guidance needed to:

(1) Sustain the performance of ground water extraction and injection systems so that site mission (ground water cleanup) failure does not occur.

(2) Delay substantial, radical rehabilitation of these systems as long as possible.

c. This EP will provide:

(1) Background and rationale for well maintenance problems.

(2) Demonstrated prevention and remedial methods for wells.

(3) Specific guidance in applying solutions.

d. This background and associated recommendations will be based on experience and applied research by USACE, its contractors, and other experienced parties.

e. The USACE and the programs it oversees in HTRW ground water remediation have the responsibility to ensure that the projects fulfill their mission of cleaning up ground Water to the extent necessary (defined by risk analysis or legal maximum contaminant levels (MCLs)) to protect human health and the environment where technically feasible. Pumping and injection well systems are integral parts of these efforts on many sites. It is the management's responsibility to ensure that well systems installed continue to function at the optimal level.

1-2. Applicability

This EP applies to all USACE Commands having Civil Works and/or Military Programs HTRW project responsibilities.

1-3. References

Required and related publications are listed in Appendix A.

1-4. Distribution Statement

Approved for public release; distribution is unlimited.

1-5. Safety

Personal safety is the top priority in any operations on HTRW sites. The guidance in this EP is provided with safety in mind. However, users of this pamphlet are responsible for following the requirements of EM 385-1-1 and ER 385-1-92.

1-6. Scope and Application

a. Scope. This EP is concerned with the operation and maintenance (O&M) of ground water injection and extraction systems on HTRW sites; however, it does not address the rehabilitation of these systems (that is, the actions taken to restore a well after substantial loss of performance), although maintenance operations will have some similarities with rehabilitation. The scope also excludes the O&M of the water treatment plant facility. Other pumping or injection wells besides those at HTRW sites (for example, ground water monitoring wells or water supply and injection wells for purposes other than HTRW cleanup) have performance and water quality problems associated with well deterioration. Also, monitoring wells (for either HTRW or preventive monitoring) may become clogged and no longer provide reliable samples for water quality analysis. While not specifically addressed to these applications, many features of the diagnosis and maintenance treatments will also apply to these other wells.

(1) Performance. This EP will emphasize the role of preventive design and construction (based on good quality data and practice) in preventing or delaying problems. It is assumed that wells on HTRW sites will

- operate under conditions that often promote rapid well performance deterioration.
- need to be designed and operated in such a way that unavoidably promotes well performance problems.

(2) Effects of past design and maintenance. The EP also addresses situations where installation operators are required to maintain well systems that were not optimally designed in the first place. In studying the operating challenges of such systems, it has become apparent that some O&M practices for HTRW site well systems are ineffective, and obsolete processes are being followed that do not reflect modern understanding of microbial and geochemical processes. This EP is intended to provide guidance to update O&M processes, taking into consideration modern understandings to improve O&M effectiveness.

b. Application. The specific application of and adherence to these guidelines must be tailored to each project function, the contaminants of concern, the adopted treatment solution, local geohydrologic properties, geotechnical judgment, available resources, applicable regulatory requirements, policy and guidance, public concerns, and remediation goals.

1-7. Terminology

Communication between regulatory, oversight, owner, and contractor personnel involved in the remediation of an HTRW site is important both before and during remediation of the site. Communication is complicated by the involvement of numerous technical disciplines and regulatory agencies, and it is imperative that the descriptive language used during discussions be compatible. Likewise, the practices of well design, construction, and maintenance and rehabilitation also have specific terminology and usages. This EP promotes an interdisciplinary approach to well-system design and O&M that works to enhance system performance. The reader is assumed to be a technically competent person who may not be familiar with all specific terminology usages, but has a general but not thorough knowledge of ground water and well-system construction. Therefore, a wide range of definitions will be supplied to promote clarity.

a. Definitions.

(1) EM 1110-1-4000 provides definitions for terms in the following topical areas:

- Drilling and well installation plan/drilling plan.
- Field activity (FA).
- Field drilling organization (FDO).
- Geotechnical data quality management.
- Hazardous and/or toxic waste.
- Well redevelopment/rehabilitation.
- Screened interval.
- Site Safety and Health Plan (SSHP).
- Well development.

(2) Additional industry (e.g., National Groundwater Association, American Water Works Association (AWWA) Research Foundation, American Society for Testing and Materials (ASTM)) and international sources of definitions were used in preparation of this pamphlet. Several relevant documents provide lists of definitions specific to the O&M of wells, particularly Borch, Smith, and Noble (1993), Cullimore (1993), Driscoll (1986), Helweg, Scott, and Scalmanini (1983), Smith (1992), and Alford and Cullimore (1999). ASTM Standard Guides cited herein (e.g., D 5978, Standard Guide for Maintenance and Rehabilitation of Ground-Water Monitoring Wells) also provide definitions of specific terms used.

(3) Some technical terms have come to be commonly used in specific ways in well maintenance activities and are frequently used in this pamphlet. Most of these relate to causes of problems. Others are used in specific ways in this pamphlet and are defined in Appendix B.

1-8. Basis

The basis for the information and recommendations contained in this pamphlet is experience in actual operations. Relevant case history information is published in Leach et al. (1991); Smith (1995); and Alford and Cullimore (1999).

Chapter 2
Suggested Minimum Baseline Data for Each Well

2-1. Causes of Well Problems

a. Cause summary. HTRW well-system problems have a number of identified causes (Driscoll 1986; Borch, Smith, and Noble 1993; Smith 1995; Alford and Cullimore 1999) that often work together to produce conditions encountered on the well site. Table 2-1 summarizes problems with wells.

b. Symptom determination. In many cases, symptoms of well deterioration may not be apparent until well performance is severely impaired, unless the results of system water and quality and performance monitoring are compared over time to establish trends. Such problems can be prevented and mitigated by effective O&M, but to do so requires valid information on the environment, hydrology, and material performance of the well system produced by information collection in the process known as "maintenance monitoring."

c. Purpose of maintenance monitoring. Maintenance monitoring is one aspect of well problem prevention, and includes maintenance and rehabilitation that is employed to provide early detection of deterioration of wells. The ideal situation is to detect deteriorating effects in time to prevent problems or allow the easiest possible treatment. Table 2-2 summarizes useful well information to collect for troubleshooting and predicting problems.

d. Minimum analysis goals. At a minimum, a preventive maintenance (PM) monitoring program should provide regular analyses to determine:

- Whether a deteriorating condition may be occurring.
- The reasons for changes in well and pump performance and water quality as soon as the changes can be detected.

e. PM monitoring information use. In order for O&M to make use of such information over time:

- A maintenance system must have organized and accessible records.
- Information collection should begin with the project design phase and continue throughout the working life of the extraction and injection system.
- Records must be regularly reviewed by qualified personnel.

f. Adjusting maintenance monitoring protocols. In general maintenance monitoring approaches should be tried and reviewed over a period of time and adjusted based on experience. They must be implemented as part of a systematic maintenance program involving:

- Institutional commitment.
- A goal of deterioration prevention.
- Systematic monitoring as part of site maintenance procedures.
- A method evaluation of information to determine what maintenance actions are necessary.

In any case, it has to be recognized that monitoring approaches and responses will be site specific, and likely will require adjustment during implementation.

Table 2-1. Definitions of Poor Well Performance and Causes

Problems	Causes
Sand/Silt Pumping: Pump and equipment wear and plugging.	Inadequate screen and filter-pack selection or installation, incomplete development, screen corrosion, collapse of filter pack due to washout resulting from excessive vertical velocity in the filter pack, presence of sand or silt in fractures intercepted by a well completed "open-hole," incomplete casing bottom seat (casing-screen break) or casing-screen break due to settlement, ground movement, or poor installation. Pumping in excess of gravel pack and system capacity (oversized pump, pipe breakage lowering pumping head, etc.).
Silt/Clay Infiltration: Filter clogging, sample turbidity.	Inadequate well casing seals, infiltration through filter pack, or "mud seams" in rock, inadequate development, or casing-screen break due to settlement, ground movement, or poor installation. Formation material may be so fine that engineered solutions are inadequate.
Pumping Water Level Decline: Reduced yields, increased oxidation, well interference, impaired pump performance.	Area or regional water-level declines, pumping in excess of sustainable well capacity, well interference, or well plugging or encrustation. Sometimes a regional decline will be exaggerated at a well due to plugging.
Injection water level rise and reduced acceptance rate or increased injection system head.	Area or regional water-level rise; injection in excess of sustainable well capacity; well plugging or encrustation; encrustation, plugging, or corrosion and perforation of discharge lines; increased TDH in water delivery system.
Lower (or Insufficient) Yield: Unsatisfactory system performance.	Dewatering or caving in of a major water-bearing zone, pump wear or malfunction, encrustation, plugging, or corrosion and perforation of discharge lines, increased total dynamic head (TDH) in water delivery or treatment system.
Complete Loss of Production: Failure of system.	Most typically pump failure. Also loss of well production due to dewatering, plugging, or collapse.
Chemical Encrustation: Increased drawdown, reduced output or reduced injection acceptance rate.	Deposition of saturated dissolved solids, usually high Ca, Mg carbonate, and sulfate salts or iron oxides, or FeII sulfides. May occur at chemical feed points, e.g., feeding caustic soda to raise pH into a Ca-rich water.
Biofouling Plugging: Increased drawdown, reduced output or reduced injection acceptance rate, alteration of samples, clogging of filters and lines.	Microbial oxidation and precipitation of Fe, Mn, and S (sometimes other redox-changing metals that are low solubility when oxidized) with associated growth and slime production. Often associated with simultaneous chemical encrustation and corrosion. Associated problem: well "filter effect": samples and pumped water are not necessarily representative of the aquifer. Often works simultaneously with other problems such as silting.
Pump/Well Corrosion: Loss of performance, sanding, or turbidity.	Natural aggressive water quality, including H_2S, NaCl-type waters, biofouling and electrolysis due to stray currents. Aggravated by poor engineered material selection.
Well Structural Failure: Well loss and abandonment.	Tectonic ground shifting, ground subsidence, failure of unsupported casing in caves or unstable rock due to poor grout support, casing or screen corrosion and collapse, casing insufficient, local site operations.

Table 2-2. Parameters Useful in Well Maintenance Monitoring

Type Tests	Parameters Obtained
Hydraulic testing	Flow and drawdown for specific capacity (water level rise in injection wells).
	Total amount of pumping time and quantity pumped per year.
	Periodic step-tests for well and pump efficiency.
	Power and fuel consumption for pump efficiency.
Physicochemical parameters (for changes due to deterioration)	Total and ferric iron, and total manganese (and other metals as indicated).
	Important anions as identified, including sulfides, sulfates, carbonates, and bicarbonates.
	pH, conductivity, and redox potential (Eh) where possible (instrument readings may be replaced by checking ratios of Fe (total) to Fe^{2+} (soluble)).
	Turbidity or total suspended solids calculation of product water.
	Calculation of corrosion/encrustation potential using a consistent method.
Microbial	Total Fe/Mn-related bacteria (IRB), sulfur-reducing bacteria (SRB), slime-forming and other microbial types of maintenance concern as indicated.
Visual/physical	Pump and other equipment inspection for deterioration
	Borehole TV for casing and screen deterioration.

g. Incorporating PM data collection into the site data collection effort. Too often the significance and central importance of data are overlooked in the context of the scope of the whole project. What may seem to be minor clerical details to those responsible for a project's overall management can be important later in site operations. The quality and completeness of boring logs, well completion diagrams, and well testing, etc., are often left to contractors who do not appreciate the value of the data, or left to inexperienced, overworked, or unsupervised junior technical staff. Omissions in the data are often apparent only when it is too late to correct the deficiency.

(1) Data are easiest to obtain and more accurate if data collection is incorporated into the project plan at the onset. There is a tendency to omit maintenance planning, data gathering, and repair costs when bids are higher than budgeted, or to inadequately fund these tasks as costs are adjusted to available funds during project management. Budgets to fund remediation activities themselves can be unrealistic in this regard in not adequately considering the real costs of maintenance.

(2) Compiling data at a later stage of a project's operation is generally difficult and less successful. The following sections describe the types of testing and information recommended, and how the information should be collected, recorded, and managed, along with useful references and standards in practical use. A minimum of baseline data on each well is needed to assess and interpret the well's performance through time. Specifications should assure that there are specific requirements for data collection and analysis for O&M purposes.

2-2. Well Tests: Purpose and Description

a. General. Reliable, valid tests are critical to well assessment and management. Such assessment and management is enhanced by a history of valid well data over time, back to installation if possible (Chapter 3). Valid results depend on their reliable, valid, and reproducible test design, performance, reporting, and interpretation. In practice, performance and proper reporting of results lag behind performance standards. This pamphlet briefly reviews pumping test types and how they are used to assess pump, well, and pumped-formation (aquifer) parameters. It describes minimum valid baseline data to be reported, including

- Minimum data standards for tests.
- Minimum data for individual water level measurements (not just final levels), pumping rates, sand (particulate) or colloidal content, and information on conditions that would affect results.
- How to determine adequate testing intervals.

b. Data collection.

(1) Accurate discharge flow data are needed for any pumping test. All devices should be calibrated prior to installation, and at regular intervals to ensure proper operation. Flow measurement devices suitable for pumping tests include:

- Orifice weirs: Driscoll (1986) provides a detailed description of the necessary elements of the construction and use of an orifice weir.
- Mechanical flow meters which may also be used.
- Sonic-based flow meters available that are accurate and well adapted to this application.

(2) Equally important are time and water level measurements throughout the test. The times of measurements must be accurately reported and the water levels themselves reported accurately in decimal units (for analysis input). If there is the potential for water cascading in the well during the test, fit the well with a drawdown (stilling) tube to shield the water level probe from the cascading water and ensure accurate water level measurements. Finally, the data must be recorded on a sheet specifically structured to record and organize pumping test data (an example is supplied in Appendix D). Directly measuring system gauge pressure is essential in evaluating pump performance and useful in making field decisions on tests of relatively unknown wells or pumps.

c. Step-drawdown tests. Step-drawdown tests are probably the most valuable hydraulic testing tool available for assessing well performance in the context of maintenance and rehabilitation. When properly conducted and analyzed, they provide data on specific capacity and well and aquifer losses. Additionally, from the analysis, well efficiency and drawdown and specific capacity at a given discharge rate can be estimated.

(1) Conducting and analyzing step-drawdown tests are treated in detail in Kruseman and de Ridder (1994). For porous medium aquifers, the Hantush-Bierschenk method of analysis is employed, which is relatively straightforward. For fractured rock aquifers, Rorabaugh's method may be required, which is less straight forward. A computer application to solve Rorabaugh's method, such as FASTEP (Labadie and Helweg 1975), may be useful. Plate D-2 is an example step drawdown plot. Plates D-3 and D-4 provide an analysis of the step-drawdown test charted in Plate D-2 to determine well and aquifer loss. Plates are provided in Appendix D.

(2) The utility of data derived from the step-drawdown test is in the ability to:

- Determine characteristics about both the well and the aquifer simultaneously (aquifer and well loss).
- Extrapolate or interpolate the performance of the well at various discharge rates, using measured data points as a reference.
- Determine the operating characteristics of the well pump used.

(3) If performed immediately after a well is constructed, the step-drawdown test provides an estimate of the efficiency of the well and effectiveness of the well development phase of the well construction, and the baseline well and pump performance for comparison in the future. First checks of a well design's criteria or assumptions can also be made and adjusted as needed. It is highly recommended that all of these wells be pre-developed immediately after the well screen and filter pack are installed. This procedure gives a far greater chance of removing both drilling fluid solids and natural fines, and of replacing any of the filter pack that subsides due to consolidation, etc.

(4) Note that well loss does not increase linearly to the discharge rate; therefore, well efficiency and specific capacity are not constant and decline with increasing discharge rate. This relationship makes comparing well performance data through time and various discharge rates difficult without normalizing the data to the same discharge rate. The equation describing well and aquifer loss to interpolate or extrapolate pumping water levels should be used as needed. The equation can also be used to estimate specific capacity and efficiency at the intended discharge rate. Changes in well performance will then be apparent.

(5) For step-test data to be useful in calculating well, pump, and aquifer performance parameters:

- Data must be accurately gathered, with data collected at standard intervals of decreasing frequency as recommended (Helweg, Scott, and Noble (1983), and Driscoll, 1986).
- Each step must be of a sufficient length of time for either the water level decline to stabilize or the decline trend to be established on a semi-log plot of drawdown versus time (but does not have to be long).
- The effects of interference (such as other wells turning on and off) must be factored into the analysis.

(6) HTRW sites may impose restrictions on optimal step testing methodology. For example, a five-step test with pressure measurement is recommended to determine pump wear. However, pumping contaminated ground water requires collection of the fluid. Perfecting the gathering of pump wear data from a three-step test, and learning to extrapolate from short steps may be a necessary compromise in methodology.

d. Constant rate and slug tests. Constant rate pumping tests and slug tests (in which an instantaneous charge of water or a solid object is introduced into a well) are employed predominantly to determine aquifer characteristics, that is, transmissivity, hydraulic conductivity, and storage coefficient. Their utility in well maintenance and rehabilitation is less direct than with step-drawdown tests, but data derived from these tests can be used in preliminary calculations of expected well hydraulic parameters.

(1) Constant-rate pumping tests.

(a) With knowledge of aquifer characteristics, the theoretical drawdown in the aquifer at the well screen for a given discharge rate can be calculated and compared with the observed drawdown at the same rate, yielding the well efficiency at that rate. As a constant rate test approaches steady-state, the final specific capacity at the discharge rate can be calculated. Neither the constant-rate or the slug test can provide the means for predicting the well loss and the well efficiency that occurs over a range of discharge rates. A step-drawdown test is needed.

(b) The constant rate test is conducted similarly to the step-drawdown test. As with the step-drawdown test, accurate discharge, water level, and time measurements are essential. Again, Kruseman and de Ridder (1994) provide an in-depth discussion of conducting and analyzing these tests. Computer applications are available to aid in the analysis of constant rate tests. Boulding (1995) provides a useful conceptual review of pumping test software which can be updated by research into current products.

(2) Slug tests. A slug test is also used to determine aquifer characteristics, not well performance, and involves a different procedure and methods of analysis.

(a) Descriptions of procedures and methods of analysis are provided in Kruseman and de Ridder (1994), Bouwer and Rice (1976), Hvorslev (1951), and ASTM D 4044, D 4050, and D 4104. The computer applications available to aid in the analysis of constant rate tests, such as AQUITEST (Walton 1996), also provide analysis of slug tests. Because of the small volumes of water involved and the short (or long) time span over which the test occurs, pressure transducers and digital data logging are generally employed. Pressure tranducers are submerged in the well and register the pressure of the column of water overlying them. Water-level changes are detected as changes in pressure as the height of the overlying water column either increases or decreases. The data logger can be programmed to sample and record data from the transducer at required time intervals. This feature of digital data logging is most useful when conducting slug tests in high-permeability sediments where many water level measurements will be required over a span of seconds as the water level rapidly recovers.

(b) As with constant rate pumping test data, calculations of aquifer characteristics based on slug test data can be used for estimation of theoretical well mounding in injection wells.

2-3. Specific Capacity Data

a. Definitions. Specific capacity is a term used to express the productivity of a well, and is defined as Q/s, where Q is the discharge rate and s is the drawdown in the well (Driscoll 1986). The observed drawdown in the well is a function of aquifer and well loss; therefore, Q/s is a term incorporating both aquifer and well performance. Step-drawdown tests described in Section 2-2 provide a means of separating the aquifer and well loss components.

b. Use of Q/s calculations. Q/s calculations, using water-level change and well pumping data, are used to assess pumping well performance and results of development and redevelopment (Helweg, Scott, and Scalmanini 1983; Driscoll 1986; Borch, Smith, and Noble 1993). The data that need to be collected (Q and s in pumping wells) are simple to obtain and the calculations simple to make. Specific capacity and specific acceptance are relatively sensitive indicators of hydraulic performance change in wells. Making valid calculations in turn depends on reliable data collection. Appropriate actions in response to changing values depend on setting action levels that permit a response before performance is seriously impaired.

c. Minimum data needed and standards for data gathering, reporting, and assessment. To determine Q/s for a well, accurate static water-level, pumping water-level, and discharge rate data are needed. Since the water table or potentiometric surface varies seasonally and with outside stresses, a deeper pumping water level for a given discharge rate may not reflect a change in the well performance. Therefore, some means will be required to determine the variation in the static water level, e.g., an observation well outside the influence of the pumping well or static water levels obtained when the well is not pumped.

d. Effects on Q/s calculations. Static and pumping water levels can be affected by oscillations caused by the pump, cascading water, the water level probe becoming entangled in wiring and pump column, and operator error.

(1) Many problems can be avoided by installing a stilling (drawdown) tube in the well. Also, clearly establishing the "measuring point" (MP) of the well from which all measurement are taken and informing all personnel who will be collecting data of the MP will avoid many problems. The discharge rate can vary in response to system back-pressure and changes in pump performance, and therefore cannot be assumed to be constant. It should be measured along with water levels when determining Q/s. The flow meter used to measure the discharge rate is also subject to error as it wears or clogs.

(2) It is desirable that a baseline Q/s be determined at the intended discharge rate when a well is constructed (assuming the efficiency of the well is acceptable). Subsequent measurements of the drawdown in the well and discharge rate and recalculation of Q/s will provide an indication of the ongoing performance of the well (Borch , Smith, and Noble, 1993; Howsam, P., Misstears, B., and Jones, C. 1995). See Chapters 4 and 5.

2-4. Development Data

a. Purposes of development. In well construction, development has three purposes:

- Repair damage done to the aquifer during drilling.
- Set the filter pack.
- Increase the permeability of the aquifer in the vicinity of the well.

b. Redevelopment. Later, development activities may be a component of a maintenance program to further the original development effort, or applied as a component of a maintenance program to maintain or restore a well's performance. In this use, the processes are termed “redevelopment.”

c. Development process description and importance. Detailed descriptions of development and redevelopment processes can be found in Australian Drilling Industry Training Committee Limited (ADITC) (1997), Driscoll (1986), NGWA (1998), and ASTM D 5521 (in the context of monitoring wells).

(1) Drilling method influence. The drilling method will, to some degree, modify or damage the aquifer material in the process of drilling the hole. One must know what damage or modifications are likely to have occurred in the aquifer material to judge the applicability or effectiveness of the development effort. This information is usually recorded on the drilling field log maintained by qualified oversight personnel. Each lithologic material will be uniquely vulnerable to the drilling process and may require specific development methods. Also, future performance problems may be related to aquifer lithology. Different well construction methods will require different methods of development and the construction of the well will determine what methods are applied in future activities. Additionally, the type of drilling method used tends to influence the method of development (if cable tool: surge blocks and bailers, if rotary: air compressors and pumps).

(2) Development methods. Well development includes as components many tools and methods and the development data should include descriptions of the tools and methods utilized. For example:

(a) If air lifting was applied, what was the size and capacity of the air compressor, at what depth was the airline set?

(b) If surging was applied, what was the configuration of the surge block assembly, does the diameter of the assembly match the casing and screen, through what intervals was it applied, and what was the length and speed of the stroke?

(c) If jetting was applied, what was the configuration of the jetting tool, through what intervals was is applied, etc. (nozzle velocity and distance from screen)?

(d) Other pertinent information, e.g., how much time was spent on each interval in cleaning.

(e) What predevelopment planning and decisions were made that would make development more or less likely to be successful?

d. Development data gathering. Valid and complete development information is necessary to assess results and to provide benchmarks for future development efforts. This information is recorded in a well development log and collected with drilling and well construction log information (see example forms in Appendix D). Minimum development information necessary includes:

(1) Drilling method description -- it affects development methods chosen and how field data are reported.

(2) Description of development procedures used -- air lifting, jetting, surge blocking, etc., including descriptions of equipment and capacities (e.g., air compressor cubic feet per minute (cfm) capacity).

(3) Time for each segment.

(4) Description of material drawn into well -- amount and type to determine its origin (need to know if it is aquifer or well pack), standards of development and how measured.

e. Integration of development data with other data. Development information is merged with step-drawdown data, well construction data, and lithologic data to provide insight into how the aquifer material has been modified or is behaving through time in the vicinity of the well. This insight is crucial for assessing changes in well performance and the appropriateness and effectiveness of maintenance and rehabilitation efforts.

f. Development data gathered and significance.

(1) Development time. The effectiveness of even an appropriate development method is related to the amount of time it is applied, and it must be determined if the time of application was sufficient for the method to be effective. Development data should include the amount of time devoted to each of the tools and methods mentioned above. The construction log may provide the amount of time devoted to development, or the work crews' time sheets or daily log may also provide the time devoted.

(2) Development results. The data should include some form of documentation of the progress of the development. Some drillers estimate changes in the discharge from the well during air lifting or surging to indicate the progression of development. The driller may record a qualitative description of the sediment and material removed from the well. A semi-quantitative record of the sediment concentration

may be had from allowing samples to settle in a bucket, and a quantitative record may be available if water samples were collected using an Imhoff cone or Rossum sampler. These and other methods are discussed in Driscoll (1986).

(3) Well acceptance tests. Finally, data from well acceptance tests, usually a step-drawdown test (Section 2-2), is helpful to document the effectiveness of the development. (As described in the discussion on step-drawdown testing, the resulting efficiency of the well can be estimated from the analysis of the test.)

2-5. Well Construction Diagram

"As constructed" well construction records are used in well maintenance to provide a basis for comparison of past and present conditions, and for use in other calculations. At a minimum, diagrams shall contain an accurate geographic location and precise designation used by the project, accurate depth, diameter (including different components), casing and screen material type, screen slot size and screen length, filter pack type, particle size and dimension, grout type and dimensions, and well equipment descriptions and dates drilled and developed. ER 1110-345-700 provides general guidance for plan components. EM 1110-1-4000 provides general guidance on well construction documentation. Plate 2-3 is an example well construction diagram.

2-6. Construction Boring Log

Boring logs include precise geographic location and boring identification (with cross reference to subsequent well designations), accurate formation descriptions (including sediment and rock descriptions provided according to uniform accepted standards with accurate depths), and particle size descriptions of water-producing/accepting zones.

a. Lithologic log. The lithologic log is a record of the character, depths, and thickness of geologic materials encountered by the drill as the borehole is advanced, with emphasis given to hydraulic properties of the materials. Lithologic logs should be recorded and maintained by qualified oversight personnel, using standard engineering or geologic terminology. EM 1110-1-4000 provides guidance on sample logging, the data to be recorded, and examples of forms used to record the data.

(1) The lithologic/boring log should contain as a minimum.

(a) The depth at which geologic changes occur and at which samples are collected and described.

(b) A description of cutting samples collected at every change of geologic materials and at 1- to 1½ -m (3.28- to 5-ft) intervals, and 100 percent logging for the screened interval in either the pilot or the final boring.

(c) Changes in drilling action, that is, penetration rate, fluid loss, drilling noise, etc.

(2) Descriptions of unconsolidated sediments should note dominant grain size, sorting, and estimates of relative percentages of sizes according to the Unified Soil Classification System (USCS) procedures and those described in ASTM 421 and 422. Grain shape and rounding are useful for estimating hydraulic properties. Color related to degree of weathering and oxidation-reduction is useful in determining degree of saturation. Descriptions of consolidated bedrock should note degree of cementation, induration, and fracturing. The depth at which saturated conditions occur should be noted. Changes in drilling fluid properties (gains or losses of fluids, changing specific gravity, etc.) should be noted, as they provide information on water-bearing zones.

b. Borehole camera survey. High-resolution borehole camera (still or video) surveys provide a means of recording lithology and fracture features in open boreholes, in addition to construction features. The camera provides depth-specific images for interpretation of lithologic features; for example, noticeable changes in formation color and texture, water cascading into the hole through fractures, and fracture orientations.

2-7 Pump, Flow Meter, Pressure, Electrical, and other Monitoring

a. Equipment and material choice importance in data gathering.

(1) Purpose. Meeting data-gathering goals requires apparatus that will provide the most accurate possible measurements. The equipment should be reliable and not distort measurements. To achieve these goals, the equipment should be well matched to the data-gathering needs and well operational environment.

(2) Material choices. The choice of materials to be used in devices for pumping and injection well performance is important to well system life and quality of service. For example, in most situations, where metals are specified, they should be stainless steel or other materials resistant to corrosion in the water being extracted. Materials should be specified based on analysis and experience under the environmental conditions to be found in the system. This requires analysis of the geochemistry of the fluid (Section 2-8) and comparison to the reactivity of materials proposed for use. This analysis should consider biological fouling and corrosion predictions (Section 2-9) because biofouling routinely introduces clogging and corrosive conditions where they might not occur in sterile fluids. Discussions of the material choice decision-making process are provided in numerous references (e.g., EM 1110-2-1914, EM 1110-1-4000, EM 1110-1-4008, and Powers, 1992; Borch, Smith, and Noble 1993; Smith 1995; and McLaughlan 1996 in the open literature specific to well maintenance).

(3) System component capacity. Pumps should be sized to closely match the well capacity and match the flow requirements and pressure head conditions in the system being supplied.

(a) Poor sizing affects performance adversely. Pumping well capacity can be established by step testing (Section 2-2). Flow and head conditions may be calculated, allowing for any likely fluctuations. Should as-built conditions differ from design conditions, pump selection should be reviewed to ensure that it matches the as-built hydraulics.

(b) EM 1110-1-4008 provides guidance in pump discharge head calculations. Pump sizing then can commence using standard ground water industry well pump sizing procedures. TI 814-1 provides sizing calculation procedures for submersible and vertical turbine pumps typical of remediation extraction wells. Powers (1992) provides design sizing methods for vacuum and ejector pump systems often employed.

(c) Once hydraulic head and flow conditions are used to design an ideal pump, comparisons can be made to pump capacity charts or pump curves generated by manufacturers and provided in the Contract Submittals (TM 5 813-9). See also discussion in Chapter 9 concerning material choices.

(d) An important feature is the location of the low water-level (lwl) shut-off, as specified by CEGS 11212. Manual override of the pump controls should not bypass the lwl shut-off.

b. Monitoring measurement systems. To obtain necessary baseline data, reliable methods of monitoring system parameters are needed.

(1) Water-level measurement recommendations include:

- Water-level data may be collected manually or the process automated.
- For relatively small numbers of wells and conditions where personnel are not at health risk when water columns are exposed, electric water-level probe and manual data entry may be used.
- For larger numbers of wells where personnel time would be inordinately devoted to water-level measurements, instrumented airline or automated water level recording via transducers is recommended.

For conditions where exposure to vapors off-gassing from well fluids poses an inhalation hazard, instrumented airline or automated water-level recording via transducers is recommended. Several approaches to water-level measurement are possible, each with its advantages and disadvantages. Table 2-3 summarizes these features.

(2) For flow measurements, each pumping well and receiving well or discharge should be metered. Total system pumping production should match total discharge. Imbalances may indicate leaks or metering inaccuracies.

(a) Flow meters should be sized to the expected flow. Instantaneous and totalized flow readings in commonly used volume-rate units (cubic meters/hour, gal/min, etc.) are necessary.

(b) Flow measurement method selections should take into consideration the quality of the fluid to be measured. High-solids, biofouling, or scaling water streams may foul turbine flow meters (TM 5-813-5, TI 814-3). Acoustic devices may have better service lives under some circumstances. Systems standard to industrial waste water treatment applications should suffice.

(c) At a minimum, measurements should be taken manually daily to weekly, depending upon fluctuation.

(d) Wherever possible, flow meters should have automatic readouts, either to a central SCADA system or readout device. Systems standard to industrial water supply should suffice. Calibrate the equipment at the frequency recommended by the manufacturer.

(3) For pressure measurement, either manually read or digital read-out meters may be used. With both, plugging of sensor orifices is to be expected. To detect pressure changes in the conveyance system, pressure should be measured as near as possible to the wellhead (immediately downstream of the pump discharge check valve). Measurements should be taken daily to weekly. Automation facilitates data collection.

(4) For electrical (power), measure changes in pump motor amperage (A) draw, circuit voltage (V), and resistance ohms (Ω) to detect problems in the electrical system. Portable equipment should be available for testing purposes.

(a) Voltage should be within +10 percent of the motor nameplate voltage when the motor is under load (running). Larger voltage variations may cause winding damage. These variations should be corrected in the power supply or the motor replaced to match the supplied voltage characteristics if the voltage remains constantly high or low.

Table 2-3. Features of Water-Level Measurement Methods

Type of water-level measurement	Advantages	Disadvantages
Electric sounder	Commonly available, reliable when maintained, accurate under most water-only conditions (+0.02 in.), not highly subject to downhole fouling. One sounder can be used on multiple wells.	Requires wellhead access and unobstructed water surface access, probe will foul in floating material on water surface, mechanical aging of conductor wire must be considered, cross-contamination is possible, requires personnel to take levels and manually enter data.
Airline (gauge measurement) or instrument measurement)	Inexpensive, no need for direct access to water level surface, each well has a dedicated airline.	Relatively inaccurate (+1 in. or more), subject to fouling, requires personnel for taking levels and manual entry of data.
Airline (instrument measurement)	Inexpensive, no need for direct access to water level surface, each well has a dedicated airline. With instrument, improves accuracy to electric water-level sounder range. Data recording possible.	Subject to fouling, requires personnel for taking levels.
Water level transducers	Relatively accurate when properly selected and maintained, permits automatic data querying in SCADA* system, dedicated to well, no personnel exposure to water, no direct water access needed.	Relatively expensive per unit, requires regular maintenance to deter fouling. If maintenance not performed, automatic systems may record inaccurate (useless) data.

* Supervisory, control, and data acquisition. Note that all these water level monitoring methods provide data that can be manually entered into SCADA databases. Note that all conventional water level measurement systems are fouled by non-aqueous-phase liquids and will yield inaccurate results.

(b) Increases in amperage on start or run cycles over listed service factor amps indicate

- Loose terminals in the control box or possible cable defect.
- Too high or low service voltage.
- Motor windings are shorted.
- Mechanical resistance such as sand in bearings.

(c) A drop in typical “run” amperage indicates a loss of mechanical resistance against motor operation. This datum, in combination with reduced flow and/or pressure data, can be used to confirm that a problem has developed in pump output, such as if a hole has developed in the pump discharge pipe.

(d) Deviations in circuit ohms indicate wiring problems. Low values on one or more line legs indicates a potential motor short. Greater-than-normal values indicate poor cable connections or joints, or windings or cables may be open. If some values are higher than normal and others lower than normal, drop leads may be mixed.

(e) Megaohm detections outside the circuit indicate ground faults. For a motor installed in a well, if resistance between any wire lead and true ground is $<0.5\ M\Omega$, motor damage is likely to have occurred.

(f) Voltage imbalance in three-phase (3-ϕ) systems causes excessive motor aging and poor performance, and should also be checked routinely.

(g) Total kilowatt-hour (kWh) use can be used to calculate changes in motor and system efficiency.

(h) Electrical monitoring should be automatic if at all possible or, if manual, checked weekly. CEGS 13405 provides guidance in specifying apparatus for monitoring pump motor operation as well as the flow, temperature, pressure, and chemical-physical properties of the discharge. Particular attention should be paid to regularly monitoring wellhead voltage, amperage, Ω, and ϕ balance conditions of individual wells. Grounding should also be checked on a routine O&M schedule.

(5) For water sampling, strategically placed water sampling ports permit analysis of maintenance-related water quality parameters. A monthly to quarterly schedule is recommended (Section 5-1 to 5-3). Noncorrodible taps placed to permit sampling fluid at well discharge and other strategic points are necessary to detect indicators of chemical and biological clogging and corroding conditions. Where corrosion and biofouling are sampled directly using coupons (Smith 1992; McLaughlan 1996; Little, Wagner and Mansfield 1997), provision must be made for attachment of the necessary sampling devices and discharge of flow-through fluids. (Note: After any manual measurement or sampling, the location of the automatic lwl shut-off should be checked to verify that it was not adversely affected.)

(6) Measuring systems should be automated as much as possible. Measuring system maintenance must be integral with the well maintenance plan (Chapter 5).

2-8. Ground Water Geochemistry: Hazardous and Nonhazardous

a. Physicochemical data purpose. Physicochemical parameters are necessary to specify well materials, predict clogging and corrosive conditions, and plot environmental change. These parameters should be collected in the planning phase and during operation.

b. Physicochemical data analyses to be conducted.

(1) The basic, nonhazardous water chemistry data should begin with a standard set of constituents known as the “routine analysis for water quality” (Domenico and Schwartz 1990). This set of constituents is generally used for assessing the suitability of a water for human consumption and agricultural and industrial uses. The routine analysis includes the majority of the mass dissolved in the sample and that which remains unidentified is negligible. The routine analysis will also include other items, for example, pH, Eh (ORP or redox potential), and total dissolved solids (TDS). This analysis should enable one to identify the major ion species present, and the potential for deposition of solids.

(2) The routine analysis contains most of the major and minor ionic constituents, as well as a few of the minor constituents, if needed.

(3) Computer applications are available for organizing and plotting ionic constituent data that would facilitate tracking spatial or temporal variations in water quality (for example, HydroChem available from RockWare). Analyzing the chemistry data can be facilitated by utilizing programs such as WATEQ (Truesdell and Jones 1974), BALANCE (Parkhurst et al., 1982), and MINTEQ (U.S. EPA).

(4) Table 2-4 summarizes the purposes of specific physicochemical analyses recommended for use in identifying the mechanisms at work in ground water within the influence of the sampled wells. Analysis of geochemical mechanisms at work is crucial information in "triage" (Chapter 5) in which a determination is made of the appropriate levels of maintenance monitoring should be made. As specific redox-sensitive pairs important to a system are identified, these pairs can be monitored for change over time.

Table 2-4. Summary of Physicochemical Methods Relevant to Well Maintenance

Constituent Analysis	Purpose of Analysis
Fe (total, Fe^{2+}/Fe^{3+}, Fe minerals and complexes)	Indications of clogging potential, presence of biofouling, Eh shifts. Fe transformations are the most common among redox-sensitive metals in the environment.
Mn (total, Mn^{4+}/Mn^{2+}, minerals and complexes)	Indications of clogging potential, presence of biofouling, Eh shifts. Less common but locally important in some wellfields.
S (total, $S^{2-}/S^{0}/SO_4^{2-}$, S minerals and complexes)	Indications of corrosion and clogging potential, presence of biofouling, Eh shifts.
Eh (redox potential)	Direct indication of probable metallic ion states, microbial activity. Usually bulk Eh, which is a composite of microenvironments.
PH	Indication of acidity/basicity and likelihood of corrosion and/or mineral encrustation. Combined with Eh to determine likely metallic mineral states present.
Conductivity	Indication of TDS content and a component of corrosivity assessment.
Major ions	Carbonate minerals, F, Ca, Mg, Na, Cl determine the types of encrusting minerals that may be present and are used in saturation indices. One surrogate for many cations is total hardness.
Turbidity	Indication of suspended particles content, suitable for assessment of relative changes indicating changes in particle pumping or biofouling.
Sand/silt content (v/v, w/v)	Indication of success of development/redevelopment, potential for abrasion and clogging.
Note: Generally, the Fe^{2+}/Fe^{3+} ratio (easily measured using conventional field analysis instruments) is the most useful. In some settings, Mn oxidation (resulting in more difficult-to-remove minerals) and the sulfur system may be dominant.	

c. Hazardous physical/chemical parameters. Personnel safety (Chapter 7) dictates that physical (primarily radiological) and chemical conditions that will affect how maintenance can be performed should be known. For the most part, data collected for the purpose of regulatory monitoring (and its toxicological interpretation) should cover hazards of exposure to pumped fluids. Additional factors may include:

- Radon emission (hazard of exposure during long-term monitoring).
- Carbon dioxide, volatile organic gases, and hydrogen sulfide (hazard during confined space entry or long-term exposure).

d. Compatibility with well cleaning chemicals.

(1) Chemicals that may be used in maintenance treatment of wells (Chapter 6) may react unfavorably with pumped fluids to produce

- A hazardous personnel condition.
- Unexpected system damage.

(2) Potential reactions should determined prior to chemical application. Table 2-5 provides representative incompatibility relationships with compounds used in well treatment.

Table 2-5. Well Treatment Chemical Incompatibility

Chemical	Chemical Incompatibility
Acetic acid	Chromic acid, ethylene glycol, nitric acid, hydroxyl compounds, perchloric acid, peroxides, permanganates, and other strong oxidizers.
Acids (in general)	Sulfides, cyanide compounds, chlorates and perchlorates, ammonium nitrate, azides, alkali and alkaline earth metals, organic peroxides.
Carbon dioxide	Dusts of aluminum, manganese, titanium, chromium, and maganese suspended in carbon dioxide streams.
Chlorine	Anhydrous ammonia, ammonia, acetylene, butadiene, hydrocarbons, hydrogen, sodium carbide, turpentine, benzene, finely divided metals, activated carbon, any strong reducing compounds.
Chlorine dioxide	Organic materials, ammonia, methane, phosphine, hydrogen sulfide.
Halogens in general: (Strong oxidants)	Fuels, any flammable liquid, or other organic compounds.
Hydrofluoric acid	Aqueous or anhydrous ammonia, intensely corrosive to organics.
Hydrogen peroxide (Strong oxidant)	Copper, chromium, iron, most metals or their salts, alcohols, aniline, acetone, organic materials in general.
Hypochlorites	Acids (specifically HCl), activated carbon, other concentrated organic compounds, anhydrous ammonia.
Nitric acid (conc.)	Acetic acid, acetone, aniline, chromic acid, hydrocyanic acid, hydrogen sulfide, flammable liquids, flammable gases
Organic acids	Aluminum, arsenic compounds, strong reducing compounds.
Oxalic acid	Silver, mercury (forms low-solubility minerals in presence of calcium).
Potassium permanganate (Strong oxidant)	(Strong oxidant) glycerin, ethylene glycol, benzaldehyde, sulfuric acid, fuels, other organic compounds, flammable and explosive compounds.

(2) Persons designing any treatment involving fluids that contain strongly reactive, oxidative, reductive, explosive, or volatile compounds should specifically review chemical reactivity databases for conflicts. EM 385-1-1 provides guidance in health and safety physical/chemical reporting needs for health and safety.

2-9. Biological Assay

a. Purpose. Biofouling is historically a major or dominant component of corrosion and clogging impacts on ground water remediation systems (Leach et al. 1991; Smith 1995; Alford and Cullimore 1999). Section 4-6 reviews potential effects of system biological activity.

(1) From a maintenance standpoint, it is well recognized that early detection is crucial to the management of biofouling problems. However, it has always been difficult to correlate the results of testing for biofouling components and the degree of deterioration of components of wells. For example, samples that do not contain biofilm particulate matter and microorganisms do not necessarily indicate an absence of this material. Cultivating media may not support microorganisms that contribute to fouling, and sampling may not collect samples representative of the formation's and well system's microbial ecology.

(2) Smith (1992), Cullimore (1993), Smith (1996), and Alford and Cullimore (1999) discuss and provide guidance on biofouling assay methods and their utility in maintenance monitoring to provide useful information. With such information, the following questions can be readily answered:

- Is biofouling present?
- What types of biofouling organisms are present?
- Is the well more or less biofouled than before? The answer to this last question requires monitoring over time.

b. Mission of biological tests. Biological assay plans have differing strategies depending on the purpose of the study. Biological assays for maintenance monitoring have goals different from those for general aquifer ecology or bioremediation planning. Maintenance monitoring methods chosen should be task-oriented to detect those biological indicators or conditions that lead to reduced well system performance. For this reason, methods that provide rapid, general insight into biofouling and biocorrosive conditions are preferred over methods that characterize genetic makeup or metabolic capabilities.

c. Types of biological analyses employed in PM monitoring.

(1) Examination by light microscopy. This has traditionally been the method of choice for confirming and identifying "iron bacteria" (APHA, AWWA, and WEF, 1998, Section 9240). However, in many instances, biofouling as a cause of well problems may be difficult to diagnose via microscopy alone, even with very good tools and skills (Smith, 1996).

(2) Cultural enrichment.

(a) Culturing can provide a means to detect nonfilamentous, metabolically active biofouling microflora, and also to profile the ecological physiology niches occupied by microorganisms. Currently, the most promising cultural approach, from a practical application standpoint in the United.States., for routine maintenance monitoring purposes available in North America is the Biological Activity Reaction Test (BART) method (Cullimore 1993). This method was found by Smith (1992) in field trials to provide useful qualitative information in well biofouling events and is increasingly accepted as a standard biofouling monitoring method (Smith 1996).

(b) The BART method tubes come with a variety of media mixtures. The IRB-BART^{TM}0 , for example, is designed to recover anaerobic (sulfur- and nitrate-reducing) and microaerophilic heterotrophic Fe- and Mn-precipitating microorganisms (iron-related bacteria, IRB). Cullimore (1993), Smith (1992, 1996), and Alford and Cullimore (1999) provide guidance in BART method use. Smith (1996) is a proposed standard method, incorporating BART-type methods to replace the current (Section 9240 and ASTM D 932) standard methods that rely on microscopy alone. MAG tests (MAG Ltda., La Plata, Argentina) are a commercial alternative to some versions of BART (Gariboglio and Smith 1993; Smith 1996). In addition, bench-formulated liquid media may be used if preferred and facilities are available. Kissane and Leach (1993) (Appendix C) and Smith (1992) provide guidance in the context of well biofouling analysis. The commercial products eliminate the need to determine specific nutritional requirements and the facilities typically needed for environmental microbiology, and thus are more likely to be practical in maintenance monitoring use.

(3) Sampling issues.

(a) Cullimore (1993) describes a time-series pumped-sampling program that attempts to overcome the uncertainties of collecting particulates (biofilm components) by grab sampling. Cullimore's procedures involve taking advantage of the phenomenon that biofilm detachment occurs preferentially on start-up after a period of rest, in which the pump is allowed to shut down for a period of time from 2 hr to several days. This approach, which includes taking replicates of samples at each sample event, helps to overcome the statistical limitations of pumped grab sampling for cultural analysis.

(b) Grab samples remain unreliable for microscopic analysis (Smith 1992; Tuhela, Smith, Tuovinen 1993). For this purpose, some method is needed to provide enough sample to view or otherwise analyze mineralogically or chemically. Methods for collection of biofilm on immersed surfaces can provide essentially intact biofilms for analysis. These methods are also adaptable for collection of samples of inorganic encrustations and evaluating MIC effects (McLaughlan 1996; Little, Wagner, and Mansfield 1997). The flow cell system in Smith (1992) has been successful in practical use for such biofilm collecting. Sample collection using this method will be described in the Standard Methods 20th-Edition Supplement, Section 9240. Coupon sampling apparatus developed for MIC evaluation may also be used.

d. Minimum biological testing elements. At a minimum, a maintenance monitoring program for HTRW pumping and injection wells should include the use of tests kits (BART) and other self-monitoring systems (biofilm collection and visual inspection of components) on site, and visual inspection of equipment, at the least in a troubleshooting or baseline-monitoring role. Sample collection should follow the procedures of Cullimore (1993) for BART grab sample collection. Biofilm collection (either as a specific task or part of equipment inspection) can follow the protocol outlined in Smith (1996). BART testing and biofilm collecting can be conducted in a baseline troubleshooting role and then annually or at observed changes. Baseline-scheduled BART and other biofouling analyses are a useful part of “triage” (Chapter 5) for establishing maintenance protocols for new systems and documenting changes during operation when samples are collected regularly. Some sites may exhibit little or no change in biofouling analysis results once well systems are established and other sites may provide chronically aggressive results, so that BART analyses can be discontinued once the condition is documented. In these sites, biofouling analysis can be minimized.

2-10. Field Data Reporting and File Documentation

a. Purpose. The primary purpose for collecting, analyzing, and tracking trends in collected data is that there are many reasons why a well may experience diminished performance, and collected data are crucial for identifying causes. Also, once a pattern of well performance decline is established, collected data will enable the operators to plan maintenance and rehabilitation activities before a well is beyond recall.

b. Well data file features. Each well requires a comprehensive file of all data pertaining to its ongoing maintenance and performance history as well as the initial data pertaining to its construction, well performance, pump performance, water chemistry, and biological environment described above. Establishing this record system for each well should be done at the onset of the project. Since such data will periodically be manipulated and analyzed, a format for the records should be established that is compatible with the methods used for analysis. Consistency will save time and frustration, and improve accuracy.

c. File records purpose and format issues. Correct and relevant field data recording is essential for data to be of any value. How this is done can be project specific. HTRW projects, which are under regulatory supervision, by nature have in place systems to acquire, store, manage and report data sets. The data management system in place for the project in question can be adapted to provide the same activities for maintenance planning. Format issues include:

- Successful maintenance monitoring programs have been run using entirely physical paper files in the water supply field.
- Spreadsheet organization of data provides a tabular display of various data, permits plugging data into formulas to perform routine calculations such as those for specific capacity and motor efficiency, and permits rapid charting of data trends.
- Database systems permit cross-comparison of parameters to ascertain cause-effect relationships (e.g., changes in hydrocarbon concentration vs. head loss in pumping systems).

Storage and availability issues include:

- Copies of the spreadsheets should be kept on-site at the well field in individual log books for each well.
- Essential well data (depth, diameter, pump type, and identification) should be marked at the well.
- Accessible inventories of physical file components such as video tapes should be maintained so that people reviewing files may know what data are available. Chapter 8 provides checklists, and other chapter topics indicate data needs. These should be reviewed.

d. Types of records needed. Essential information includes:

(1) Physical locations and as-built descriptions of the wells and their equipment. The physical geographic location of each well should include reference to fixed landmarks as well as precise geographical coordinates such as provided by a geographical positioning system (GPS) for use in plotting using geographical information systems (GIS).

(2) As-built diagram of the well's construction, with any modifications over time.

(3) Lithologic log of the well as constructed, well drilling and construction logs, and any other logging data (caliper, gamma-gamma, etc.). Logs must be completely labeled with dates, depths, and borehole site identification. Copies of interpretation reports should be included in the file.

(4) Records of pumping tests and geophysical structure, borehole flow meter, etc., tests of the completed well over time.

(5) Pump performance data from pumping tests as applicable by date, including analysis and recommendations of pump performance reports.

(6) Pumping and static water levels by date and time of day.

(7) Dates of replacement of components, manufacturer and type of component, if known, and length of service, if known. Itemized invoices with costs should be included. Photos or video tapes should be made of deteriorated components for future reference, including descriptions. Copies of product owner operation and service literature should be included along with documentation of any contractor service personnel.

(8) Electrical, power and pump mechanical information.

(9) Water quality data from wellhead samples, plus biofilm collector results, listed by date. Labs and costs should be tracked, and should include reports analyzing water quality data.

(10) Electrical, power and pump mechanical (submittal literature, shop drawings, and nameplate) information.

(11) Details of well rehabilitation activities, including dates, diagnosis, if any, treatment methods, results, time involved, and costs.

(12) Color borehole TV survey videotapes. These should be taken at any zero point such as at well construction and at intrusive service intervals such as well rehabilitation to record visual changes in well conditions. Tapes may be consolidated as summary tapes of important well features over the years. Tapes should be labeled by well identification and date and stored properly in an accessible location.

Chapter 3
Historical Data: Influence on Pumping/Injection and Drawdown Results

3-1. General

a. Purpose. The primary purpose of routine maintenance monitoring data acquisition is to provide information to chart trends in historical well and system performance. These changes over time indicate performance change, and trends are used to schedule maintenance activities. A checklist is provided in Chapter 8 for use in assessing the adequacy of well maintenance actions.

b. Key factors. The key factors in maintenance monitoring analyses are not the absolute numerical values (e.g., total Fe = 2.6), but the changes over time (total Fe was 2.6, 6 months later it was 0.6). A significant change in parameters indicates that the well may be in need of attention**,** or indicates biogeochemical changes of interest as microorganisms extract Fe, PO_4, etc., which may eventually lead to well performance changes. In any system or activity, data may be collected to fulfill some past directive, but the purpose for the activity may be lost over time as personnel change. Personnel involved in well maintenance should be conversant with all of the following sections.

3-2. Pumping Rates

The typical pumps used on HTRW projects are the widespread centrifugal pump designs adapted for well applications. In centrifugal pumps, output flow is in a dynamic relationship with system head: as system head is raised and lowered (e.g., due to clogging or other system hydraulic fluctuations), flow lowers or rises in inverse proportion. Changes in pumping rates over time will result due to changes in pumping head.

a. Internal pump changes. Clogging (increased resistance) and wear (reduced pressure) both result in lowered pump output, usually as a gradual declining trend. In submersible or lineshaft turbine well pumps, an abrupt loss of output usually is due to a hole developing in discharge piping. Another cause may be an inadvertent valve closing or other obstruction.

b. External head changes. If regional or pumping/injection head changes, this change will affect the pump output of an otherwise properly functioning pump. While direct measurement of water level (Section 3-4) is a more sensitive parameter, increased drawdown may be reflected in reduced flow. The size of this effect is specific to the pump.

c. System demand changes. Operational changes may affect the flow and efficiency of a pump. Restricting flow (e.g., for plume management) may be reflected in a pump operating inefficiently and having a shortened operating life.

3-3. Wellhead Pressure

Wellhead (system) pressure in the pump discharge significantly affects pump output flow (Section 3-2) and likewise affects injection acceptance. If system head increases, a centrifugal pump cannot produce as much output. Reduced flow then also may be a reflection of increased system head. This in turn is most typically a result of clogging activity. However, other causes, such as inadvertent valve closing or insufficient power, should also be investigated.

3-4. Water-Level Data

a. General use of water-level data. Water-level data, combined with flow data, can be used to chart changes in well specific capacity (and aquifer and well loss) over time. The longer and more representative the water-level history, the more reliable the trends that can be drawn from the data.

b. Internal pumping/recharge well levels. Except when static, these levels only reliably reflect the dynamics inside the well itself. Pumping output flow divided by the pumping (or injection) dynamic level provides specific capacity (Section 2-2). This calculation should also be made over time. As with the source data, the longer and more representative (seasonal, site pumping pattern) the specific capacity history, the more likely that valid trends can be drawn.

c. Comparisons of water levels. Pumping/injection water levels in wells typically differ (sometimes dramatically) from levels outside the casing. For direct comparison with aquifer loss and well loss calculations (Section 2-2) and routine monitoring, these differences can be used to narrow down

- Whether a change in pumping water level reflects a "regional" (site) trend.
- Where clogs are occurring.

(1) Pumping or injection dynamic level to filter pack piezometer comparisons are used to determine whether or not clogging is in the screen and filter pack. Installation of in-screen and satellite rehabilitation wells facilitates this monitoring (Section 5.4 and Alford and Cullimore 1999).

(2) Pumping or injection dynamic level to area monitoring well comparisons are used to determine if clogging is occurring in the screen and filter pack vicinity, or whether a change in pumping water reflects change at the "regional" scale.

(3) Unit-specific piezometer levels are used to determine what changes are occurring in the contributions by multiple units to a well.

3-5. Piezometric Data

Piezometric data provide water levels outside the immediate casing and pumping influence of a well. Piezometers (water-level monitoring wells) offer information on the response of a producing or accepting unit to change induced by site activities in addition to larger scale effects (e.g., changes in water table). As with pumping and recharge wells, the reliability of water-level response in monitoring wells depends on the wells' original design, development, and maintenance. A Standard Guide to procedures for this purpose has been published by ASTM (D 5978).

3-6. Electrical (Power) Data

Power component (V, A, ϕ) data (Section 2-7) charted over time provide a history of motor and power system changes. Historically, power problems may be the most common source of well problems. Power supply consistency is sometimes suspect, especially with ϕ imbalance. A history of ϕ imbalance data can provide the evidence needed to take well system power source problems to the power supply for correction.

a. Off-grid power quality. On generator- or solar-run systems, V and A changes reflect variability of the quality of power supplied and can provide ideas on what changes may be necessary.

b. Use of power data. Within a pump circuit, changes in amperage draw can be used to spot worn motors, or pumping system problems such as a clogged or perforated discharge line. As with the hydrologic data, the longer and more complete the records, the more likely that valid trends can be charted.

3-7. Video for Historical Comparison

When properly used, downhole video provides a direct view of conditions within wells. Video documents the as-built condition and timing of subsequent well damage and deterioration. Types of clogging conditions can be identified visually with some background. A progression of videos in any particular well, especially from the original construction condition, provides a direct way to watch changing conditions in the well (e.g., progressing screen corrosion or biofouling development). A video can also be used for comparison to file records where file records are suspect or incomplete.

3-8. Piezometric Maps

Existing interpretation aids available on typical HTRW projects can be used to assist in performance analysis. Piezometric or water table maps provide information on "regional" head data that influence specific capacity, and help to illustrate anomalies around pumping wells. Depths of water-bearing formation exposure and evidence of pumping centers can also provide insight into well-clogging oxidation occurrence in a well field.

3-9. Geologic Regime

a. Information on geologic maps. Geologic maps and cross-sections provide information on the influence of stratification and particle and geochemical types on well performance and degradation, and how effective original well designs were. Trouble-causing situations such as long, large-particle-size filter packs in variable stratified aquifers can be identified. Expected well treatment problems such as overdeveloping clay lenses can be predicted. Good geology and geophysical data relevant to the well's location are essential for proper well design.

b. Problems with too little geologic information. Well systems are often designed based on too little geologic site information. Problems that crop up often have a basis in a well being designed for a generic site condition, sometimes based on single borings, instead of well-site specific data. Files reveal when this is the case when multiple wells on a site will have identical depths, screen slot sizes, and filter packs. Results include screens and filter packs that are too fine or too coarse for the formation material and generally poor hydraulic efficiency.

c. Preserving original information. Because interpretations of geologic data over time may be distorted or simplified, it is recommended that original field notes be preserved for reference. Good data collection and analysis save operational money in the long term by aiding good well design that improves the capability of facility operators to maintain well systems. It is important that facilities maintain an archive that remains available and accessible despite management changes for use by future technical oversight or advising personnel (Section 4-3).

3-10. Maintenance Logs for Individual Wells

a. File elements. Section 2-10 reviews major file elements for well system maintenance. While general site information such as piezometric maps can be held centrally, files should be kept for individual wells to record their specific O&M histories.

b. Information recorded at well site. As an onsite backup, brief basic information on the well should be kept within the casing or casing protection sleeve or structure. This information should include:

- Dimensions of the entire well (depth), casing (length) and screen (length, location, type, and slot sizes), and filter pack (length, thickness, and particle sieve sizes).
- Material construction of each.
- Pump and power information.
- Information on any inserts downhole.
- Last service date and information on how to obtain more detailed records.

c. *Offsite backup information*. Files and video tapes kept at the project site should be duplicated at an offsite location that will continue to be available to site O&M personnel perpetually, regardless of changes in project management or service provider firms.

3-11. Downtime History

a. Information from well files. Well files should include a brief comment section on history of the total (project site) system for use in pinpointing causes and effects. Service intervals, costs, details of persons and companies involved, and analyses of results (what works, what doesn't, specific capacity changes) should be included for a history analysis, and for the sake of the next person (perhaps years in the future and unacquainted with the last service action).

b. Out-of-operation information. It is sometimes most useful to know why and how long a well was out of operation. For example:

(1) It is commonly the case on HTRW remediation sites to construct wells and then to leave them sitting idle for long periods during project development. It is widely observed that this practice results in wells that must be rehabilitated before they can be used (Borch, Smith, and Noble 1993; Smith 1995; NGWA 1998).

(2) Sites and individual wells may experience periods of hiatus in operations for various reasons. Again, equipped, developed wells, perhaps already with developing degrading conditions, sit idle.

(3) Such information can help personnel in troubleshooting problems down the line to make sense of the condition they find. Checklists for site well array O&M planning are provided in Chapter 8.

Chapter 4
Data Evaluations and Troubleshooting in Well System Maintenance

Making and refining maintenance decisions and evaluating the degree of maintenance action success requires a systematic and effective data evaluation and troubleshooting process. Organizing such a process requires both institutional and technical planning.

4-1. Institutional and Funding Issues in Maintenance Planning, Analysis and Execution

a. Historic lack of well O&M planning. Successful O&M of any mechanical system such as a pumping well array requires an institutional structure and indoctrination that preventive maintenance is valuable and indeed essential in preventing future problems. This is well demonstrated for wells in a variety of operating settings (including water supply, dewatering, and hydraulic relief) and particularly well demonstrated in HTRW remediation. Despite the well-known vulnerability of monitoring and remediation wells to performance degradation, provisions for preventive design and maintenance are routinely shortchanged in practice (e.g., Smith 1995; Alford and Cullimore 1999).

b. Institutional and contractual barriers to well O&M implementation. A persistent problem in encouraging rational well maintenance planning and execution is the array of roadblocks that discourage the implementation of these logical behaviors in the HTRW remediation field. In the project development-contract administration process, USACE internal professionals or a contracted architectural-engineering (AE) firm develops a scope of work (SOW), specifications, and design. Once a contract is let, the work is administered by Construction teams. It is imperative that well system O&M be explicitly incorporated into the SOW and specifications, and included as an issue in design (designing for ease of maintenance). Likewise, contract administration needs to enforce the well system O&M imperatives of the SOW.

(1) History and experience (e.g., Smith 1995; Alford and Cullimore 1999) demonstrate the necessity of planning and adequately funding well system O&M oversight and professional review. Such funding and O&M planning (with professional review):

- Should be an integral part of Title II HTRW remediation planning and funding activities at the outset of project development, and should be included in any specifications or SOWs involving the monitoring and pumping of ground water.
- Should be part of the USACE review checklist.
- Should include maintenance monitoring data management as an integral part of site data management.
- Should ensure that, once constructed and active, HTRW remediation projects have the funding budgeted and available to perform adequate routine well system maintenance monitoring, repair, replacement, and cleaning as part of the overall site and system O&M contract.
- Should be protected to the extent possible contractually from transfer to other purposes.

(2) Checklists for well system O&M maintenance planning are addressed in Chapter 8 and examples provided in Appendix D.

c. Expected outcomes of a lack of maintenance planning. The logical necessity of such planning takes the form of a typically remorseless "pay me now or pay me later" scenario:

(1) Filter and other water treatment clogging occur due to constituents pumped from wells that supply the treatment plants. Some of this is unavoidable, but others, such as biofouling buildup, can be minimized by preventive maintenance actions at the well source.

(2) Hydraulic losses due to clogging occur that can be prevented and mitigated in the same way by maintenance activities at the well source and preventive engineering design that reduces choke points and permits line service.

(3) Perhaps most costly of all is a situation where the project's objectives (ground water cleanup) are not achieved or delayed due to preventable well field problems.

d. The extent of O&M monitoring must be determined. Chapter 2 reviews testing recommended and minimum data elements needed to define conditions that could cause well system clogging and corrosion. Chapter 3 defines the historical background needed to establish trends. Once a baseline of information on site hydrogeology, biogeochemistry, and operations is established, and trends become apparent through scheduled monitoring (Chapter 5), the level of effort appropriate to detect deteriorating conditions can be established.

4-2. Quarterly Review of Site Performance Data

a. Schedule of performance review. At a minimum, projects should review performance and other maintenance monitoring data (Chapter 2) regularly. Doing so quarterly is a common recommendation and fits into typical project review schedules. At this time project's operational team reviews data and operational information to answer the questions: "Where do we stand now?" and "What do we expect to happen?"

b. Personnel versatility. A review of the range of information required for baseline well field maintenance monitoring (Chapter 2) shows that it is multidisciplinary. It is highly recommended that the project involve personnel experienced in well field maintenance information review and interpretation. Such persons (or a team of persons) should be conversant with all of the following sections. Desirable qualifications of personnel should be incorporated in bid specifications if O&M contractors are to be expected to comply with them.

4-3. Baseline and Historical Data for Wells/Site

a. Background. Chapters 2 and 3 outline necessary baseline and historical well and site information and how it should be managed to facilitate O&M planning. A crucial element is the availability of historical information and the means to interpret that information. If possible, information should be available extending back to site characterization studies and forward to the present to aid in evaluation of processes and activities affecting the maintenance of the well system. O&M personnel can predict trends based on data gathered during troubleshooting, but uncertainty is higher than with actual historical data.

b. Historical data management. An essential element in this process is a data management system that permits the detailed tabulation, plotting, cross-reference, and statistical analysis of a broad range of information as described in Section 2-10. A system that stores and permits the easy retrieval and cross-referencing of a variety of information without artificial topical boundaries helps human troubleshooters and planners to see patterns that may not be immediately obvious. This archive may be physical and the retrieval system a knowledgeable human, or on a computer. Project data systems should permit:

- Charting of information (e.g., pumping water levels) back to the site's characterization and development at flexible scales.
- Cross-referencing of various data to look for trends (e.g., specific capacity vs. lithology or biofouling indicators).
- Data access by (or to be maintained by) the department or firm responsible for O&M if these tasks are split from regulatory oversight.

c. *Human operational experience and its preservation and transfer*. As useful as data and other information are, they are most valuable when filtered through human operational experience. All systems have quirks or features that defy the kind of quantification possible in a computer database file.

(1) Filing systems are imperfect and incomplete. Human experience provides the kind of anecdotal background that is often most useful in troubleshooting. For example, noting that problems began when there was a change in pumps.

(2) HTRW remediation site maintenance planning should make provision for:

- Regular recording of maintenance actions and observations by operating personnel.
- Minimizing personnel changes to preserve memories.
- Ensuring that key operating personnel are well-informed and trained in their tasks.
- Outside expert assistance on an as-needed basis.

4-4. Operator/Working Crew Leader Qualifications and Training

Well-trained and motivated onsite operating personnel are crucial in successful O&M management. Frequent turnover, poor training, and lack of positive motivation will defeat even the most well-crafted O&M plan. While requirements may vary, the following are essential:

a. Institutional continuity and "ownership" of the O&M plan and its execution are crucial in fulfilling any plans to properly maintain well arrays. Experience shows that if maintenance is the personal crusade of one person, but not adopted by the entire site operator crew and management, that crusade ends if the original enthusiast leaves.

b. The operators on site must understand the O&M plan, the purpose of its activities, and why they are important to the operation of the remediation system. At a minimum, the operations supervisor should understand and be able to verify field data collection, manage and participate with field personnel in daily maintenance actions, and enforce common sense issues during daily operation.

c. For these reasons, training is essential. All personnel responsible for well array O&M should be formally trained in the O&M plan, its components that pertain to the well system, and essential tasks (Chapters 2 and 3).

4-5. Determination of Operational Maintenance Responsibilities

An important consideration in well system O&M is defining the roles of plant management and operational personnel in scheduling, analyzing, reviewing, and revising various O&M activities. These can be divided into two primary levels.

a. Plant manager -- project level. This person or team operates at the level of the HTRW remediation project's management level and integrates O&M activities into the overall project goals and structure. Primary tasks related to well system O&M:

- Sets up maintenance action schedules
- Follows up to ensure actions are accomplished
- Is responsible for data collection and evaluation
- Prepares status report of evaluations
- Seeks and works with outside expert help as needed.

b. Designated oversight personnel -- operations level. This person or group operates at the HTRW remediation site level. If a separate O&M Company oversees the regular function of the site's physical plant, then this group may consist of both the O&M company's management and onsite personnel. Their work scopes involve:

- Assisting in maintenance schedules and making recommendations for modifications based on site-level experience with individual wells.
- Conducting necessary training of pertinent personnel (as necessary with outside expert assistance).
- Being responsible for enforcing maintenance actions and reporting to the plant manager.

4-6. Biological Activity Implications

a. Biological activity importance to O&M. Section 2-9 reviews biological maintenance monitoring needs. However, HTRW remediation projects are typically designed by personnel (environmental engineers and hydrogeologists) who typically have a limited background in microbiology. It is important to understand the purposes for the emphasis on bioassay in maintenance monitoring for it to be properly implemented.

(1) Production and hydraulic efficiency loss. Historically, the primary factor in well system production loss on HTRW projects is biological activity (e.g., Leach et al. 1991; Smith 1995; Alford and Cullimore 1999; ASTM D 5978). Biofouling has been identified as a primary cause of well performance problems in "clean" water supply for many years (e.g., Borch, Smith, and Noble 1993; Cullimore 1993), For ground water contaminant plumes, unless the predominant contaminant is biologically recalcitrant (such as TCE, for example), microbial activity is greatly accelerated and increases the rate of biological corrosion and clogging.

(2) Effects of "representativeness" of monitoring samples. Biofilms, which serve protection and scavenging functions for microorganisms that form them, naturally have the effect of attaching and holding organic molecules and some metals. Consequently, it has been recognized that monitoring well samples may not always be representative of bulk-formation ground water quality (unpredictable accuracy). Smith (1995;1996) reviews the limited literature on this subject relevant to monitoring. This effect and its implications are recognized in ASTM D 5978.

(3) "Unexpected" geochemical changes. Biological activity has the tendency to induce or accelerate processes that may be unlikely or much slower in an abiotic environment. For example, biological corrosion occurs in environments considered "encrusting" in Langelier, Ryznar, or similar indices (Borch, Smith, and Noble 1993). Iron and occasionally manganese clogging accelerates where metal-precipitating bacteria flourish. Iron, manganese, and sulfur ($S^0$0 or SO_4^{2-}) reduction processes (all entirely microbial) mobilize large amounts of iron, manganese or sulfide (S^{2-}) into solution. The S^{2-}

readily combines with dissolved iron (Fe^{2+}) to form encrusting iron sulfide minerals. Iron oxidation is also driven anaerobically by denitrification. The CO_2 generated by microbial respiration drives carbonate equilibrium toward bicarbonate saturation. These and other microbial effects tend to complicate geochemical estimating.

b. The importance of biological assays in maintenance monitoring. These assays provide:

- An "early warning" method of predicting biological effects on geochemical transformations such as predicting ferrous sulfide mineral formation in a 12.9^{o} C (55^{o} F) alkaline carbonate ground water when SRB are detected.
- Means of evaluating changes in biological activity over time. In this, the historic record is essential.

c. Interpretation. At the present time, the interpretation of biological assay information is not always straightforward. Because the existing assay tools are inexact, proper interpretation is critical (but becoming easier). Because interpretation is somewhat subjective and changing over time (e.g., compare Smith 1992; Cullimore 1993; and Smith 1996), it is useful to involve personnel experienced with this type of testing in planning an O&M program and in forming the O&M management team (Section 4.5). The references to literature and web site resources provided (Appendix A) offer a background in the types of effects to expect.

4-7. Impacts on Plant

The scope of this document does not extend to treatment plant O&M; however, it has become evident that bio-physical-chemical activity in wells (pumping and injection) has a direct influence on plant and project mission performance. In addition to the routine effects of pumped water quality on the plant, the consequences of changes induced by well treatments should also be considered. Treatment effects may include extended periods of sloughing from the well as damaged clog components are dislodged and pumped out. In general, treatment plant effects expected should include direct adverse effects on treatment plant performance, input and output effects, and institutional loss of confidence.

a. Direct adverse effects on treatment plant performance. These effects include:

- Excessive organic loading ((biological oxygen demand (BOD), chemical oxygen demand (COD), etc.)) of the plant.
- Acid solution pH shock, which may be particularly disruptive for activated carbon or biological digestion systems (relying on attached microflora). These should be neutralized to within stated plant tolerance.
- Process disruption due to increased BOD, COD, etc., of the development solution and subsequent pumpage from wells re-establishing the biogeochemical status prior to the treatment event.
- Low contaminant concentration due to plume disruption.
- Sediment production and geochemical alteration of constituents so that they are not as well addressed by the treatment system. Clogging slugs of biofilm and solids (sand, silt, clay) developed out of wells may be particularly destructive to membrane and resin bed treatment systems.
- Fouling of piping, sensors, air strippers, granular activated carbon columns, ultraviolet emission lamps, etc.
- Alteration of geochemistry. Rapid flip-flopping of pH can be expected during treatments. Plants adapted to established reductive water may have to transiently adapt to a more

oxidative Eh. Erratic detections or spikes of compounds whose solubility is redox- or pH-sensitive may occur.

- Metal oxide breakthrough from filters into the rest of the treatment train. Acidic waters may flush attached iron and other metal oxides from filter particle surfaces, and breakthrough may occur, resulting in coating of downstream media and membranes.
- Enhanced cost of operation due to lowered efficiencies and frequent cleaning, backwashing, or replacement of media.

b. Input and output effects. The effects include:

- Pumping well and system clogging, which restricts flow so that cleanup of calculated plume volume is slowed or stopped, or contaminated ground water bypasses the installed system while wells are replaced or rehabilitated.
- Altered aquifer hydraulic conductivity so that the plume bypasses the pumping well array, favoring higher-hydraulic conductivity channels less affected by biofouling.
- If injection wells cannot take enough water, the plant has to cut back or shut down.

c. Institutional loss of confidence in pump-and-treat strategies. This effect is already apparent in the literature and discussion groups when “pump and treat” is discussed. Arguably, a contributing factor in poor performance in these systems is performance deterioration due to environmental factors such as biofouling that can be addressed through well system PM (Smith 1995; Alford and Cullimore 1999).

Chapter 5
Schedule of Maintenance Actions for Wells

5-1. Well and Plant Maintenance Schedule Overview

a. General. Chapter 9 provides a recommended maintenance program. This pamphlet provides recommendations and decision trees for a variety of operational settings. It is emphasized that this is a guide that should be adapted to local needs and should be revised as experience dictates.

b. Pre-selection of maintenance testing intervals and methods. There is considerable debate concerning appropriate monitoring and inspection intervals for maintenance of pumping and injection wells for HTRW sites. The purpose of such monitoring is to

Detect deterioration symptoms in time to permit the most cost-effective repair or replacement.
Define the condition sufficiently so that correct rehabilitation diagnosis and treatment are possible.

The ideal situation from an operational standpoint is to achieve these objectives with the minimum possible intrusion, time, and material costs. Some biogeochemical environments and hydrologic conditions result in a reduced likelihood of well clogging and corrosion than others. Among those conditions so recognized are high-specific-capacity aquifer settings under nitrate-reducing conditions with modest total organic carbon. Clogging potential is greater at both higher and lower redox potentials (e.g., sulfate-reducing and iron-oxidizing). Field work on domestic water supply wells in a region with well clogging and water quality concerns documented in Cullimore and Legault (1997) showed that, if there is a background of data on well-deteriorating causes and effects, monitoring can be limited to one or a few biological parameters. These parameters can be supported by the hydrologic measurements previously identified in Chapter 2. However, defining deteriorating conditions is necessary during site development for monitoring to be safely minimized and can only be reasonably accomplished using existing wells in the area that have had time for biofouling to develop.

5-2. Minimum and Optimal Regular Schedule for First Year

This section and Sections 5-3 and 5-4 offer maintenance schedule recommendations based on the principle of establishing a data baseline and then settling into less frequent (or more intense) preventive maintenance (PM) activity if conditions warrant. Table 5-1 is a summary minimum recommendation for first-year maintenance activity frequency for an HTRW well array. It is an appropriate monitoring level-of-effort for a new (or newly started) facility if

- There is sufficient background information on the biogeochemical and hydrologic environment to make good estimates of the types and rates of deterioration to be expected.
- The well construction and system equipment are well documented (as in a new system) and not one taken over from another responsible party or O&M service provider).

a. Choosing level of effort. “Sufficient” information may include experience with other facilities with similar geochemistry and contaminants and hydrogeology or detailed site characterization including geochemical information from samples of existing (e.g., domestic water) wells from which conclusions about biological mechanisms can be made. Table 5-2 lists the type of data that should be available to permit a minimized first-year maintenance testing schedule (Table 5-1).

Table 5-1. Minimal First-Year PM Schedule

Maintenance Test	Testing Regime	Time Interval
Physical inspection	Borehole color video	On new wells, then at pump service intervals
	Surface facility inspection. Inspect and clean as needed at sampling points	Monthly or whenever visited
	Examination of pulled components	As needed, when pulled.
Hydraulic performance	Well discharge or acceptance (volume rate and pressure)	Weekly (recommend installation of automated data collection in accordance with CEGS 13405)*
	Drawdown or head change	Weekly (recommend installation of automated data collection)
	Graphical analysis	Quarterly
	Specific capacity test (well hydraulic performance) on selected representative wells.	Annually on selected trouble or recommended wells or at recommended shorter intervals
	Pump performance. Conduct step “pump” test (Section 2.1) of centrifugal pumps and similar wear analysis of positive displacement pumps, compare to “nominal” data.	At least annually or at recommended shorter intervals if pump service is severe (Q/s and pump test can be a single operation). Alternative: In maintenance system, include triggers for out-of-nomimal power readings.
Electrical (power)	System and motor V, A, ϕ, Ω	When visited for service (Recommend installation of current monitors with alarms)
Physicochemistry	PH, mV, and temperature	At well start up and quarterly using project onsite instruments (calibrated) or routine (laboratory)*
	Suspended particulate matter (sand, silt, clay)	At well testing then at pump test intervals
Biofouling microbial component	BART analyses. After clog-typing, pick suitable test type (IRB, SRB, or SLYM) and monitor for change.	At well start up for baseline, then quarterly on selected representative wells.
Treatments and service	Well hydraulic improvement and pumping systems	As testing indicates Q/s or injection rate drops below 90% or pumping system degrades
	Instrumentation calibration	In accordance with CEGS 13405
* CEGS 13405 specifies continuous metering, monitoring, and recording equipment for parameters such as flow, temperature, pressure, and physical-chemical properties of discharged fluids. It does not include methods for cleaning or other O&M issues.		

Table 5-2 Troubleshooting New Site Data Needs

Parameter	Potential Problems
Fe and Mn (total, Fe^{2+}/Fe^{3+}, Fe minerals, Mn^{4+}/Mn^{2+}, Mn minerals and complexes) sometimes other metals such as Al. Select based on presumed geochemistry.	Indications of clogging potential, presence of biofouling, Eh shifts. Fe transformations are the most common among redox-sensitive metals in the environment. Mn is less common but locally important.
S (total, S^{2-}/SO_4^{2-}, S minerals and complexes) as suspected due to site geochemistry.	Indications of corrosion and clogging potential, presence of biofouling, Eh shifts.
pH.	Indication of acidity/basicity and likelihood of corrosion and/or mineral encrustation. Combined with Eh to determine likely metallic mineral states present.
Conductivity.	Indication of TDS content and a component of corrosivity assessment.
Major ions.	Carbonate minerals, F, Ca, Mg, Na, Cl determine the types of encrusting minerals that may be present and are used in saturation indices. One surrogate for many cations is total hardness.
Sand/silt content (v/v, w/v).	Indication of success of development/redevelopment, potential for abrasion and clogging.
Biofouling parameters.	See Chapter 2 Section 9: Select appropriate methods to permit a complete but convenient assessment of biofouling mechanisms present.

b. Note on monitoring levels of effort. Choices should be made on the basis of long-term site life-cycle cost-effectiveness. The cost comparison should be between the cost to perform the appropriate maintenance vs. the cost of having the well system or the remediation project to fail to function properly with possible replacement of numerous wells. If specific experience with particular contaminant or site conditions permit a much reduced level of effort without impairing performance, this is acceptable. However, history indicates that

- Maintenance monitoring is cost-effective compared to the alternatives.
- Decisions made to minimize prevention and maintenance monitoring based on short-term experience may be regretted later as deteriorating phenomena result in performance degradation.

(1) It may actually reduce operational problems if certain monitoring is intensified, at least on certain critical wells. For example:

- Test pumps at least annually.
- Conduct graphical analyses of pumping tests monthly, instead of quarterly, for wells in which rapid decline or fluctuation of specific capacity is noted.
- Conduct physicochemical analyses at least monthly on wells which exhibit highly variable water quality.
- Add turbidity or (better yet) particle counting, using automated, in-stream sensors, to detect upswings in particulate sloughing that often accompanies enhanced biofouling.
- Add microscopy of samples from biofilm flow cells (Smith, 1992) to visually observe

changes in biofilm consistency, and analyze collected samples for changes in elemental analysis and crystalline structure of encrusting compounds. This information is useful in adjusting treatment programs.

(2) Rather than reducing monitoring, cost and labor savings can be realized by using automated sampling and data reporting and computerized maintenance management software to minimize human time investment. Automated systems should be evaluated periodically and verified manually.

5-3. Schedule for Reducing Maintenance After First Year

Maintenance (including monitoring) intervals can be reduced as trends are established. (Exception: troublesome wells that may be on annual or more-frequent treatment schedules based on first-year experience.) Typically, on wells performing adequately, the frequency of physicochemical and biofouling parameter testing can drop to quarterly if little change in conditions is noticeable after one year. Table 5-3 summarizes a post-first-year PM schedule.

5-4. Schedule for Intensive Maintenance for Critical Wells

a. Long-term intensive maintenance. As site experience develops (1 to 5 years), certain wells will be identified that will require intensive maintenance to continue useful operation. Intensive maintenance will include the following (detailed in Appendix C):

- Premaintenance testing of performance components.
- Removal of pump and inspection of components, repair and refurbish as needed.
- Chemical treatment (primary well and satellite wells).
- Mechanical development.
- Re-installation of well components.
- Testing (pre- and post-repair testing and PM testing, which includes parameters listed in Tables 5-1 and 5-2).

b. Schedule. A typical schedule is 3 to 6 months for injection wells and 6 months to annually for pumping wells. Where pump removal is determined not to be cost effective, or is especially difficult, pump testing to determine its status on the above schedule is a second option.

c. Well system modifications for treatment.

(1) In situations where pump removal is expensive and difficult (and this situation cannot be modified readily), some wells may respond well to in-well recirculating cleaning systems properly installed and operated. Such systems involve installing a return-flow pipe string to the open zone below the well pump, connected to the well pump discharge. An electronically actuated valve is controlled by a timer or other control device that flushes the sump or screen to remove built-up slime, oxides and sediment. Chemical feeds can be added to effect more aggressive cleaning.

(2) Additional wells should be installed at these locations to permit alternating wells in operation. Wells should be sufficiently far away from their alternating partners to be outside the likely clogging zones (if possible), but situated to maintain hydraulic control of the plume at this location.

(3) Satellite wells are recommended for introduction of cleaning solutions. Three to five wells may be installed at regular intervals around the pumping well at a distance of 2 to 7 m (6.6 to 23 ft). The distance depends on local hydraulic conductivity and the perceived degree of existing clogging).

Table 5-3. Long-Term PM Schedule

Maintenance Test	Testing Regime	Time Interval
Physical inspection	Borehole color video	At each major rehabilitation (before and after) or five years (whichever is sooner). Concentrate on screen and other stress points
	Surface facility inspection. Inspect and clean as needed at sampling points	Quarterly or each visit
	Examination of pulled components	As needed (at least test pump if not pulling it annually). Wells should be equipped for easy pulling if at all possible.
Hydraulic performance	Well discharge or acceptance (flow rate and pressure)	Weekly (recommend installation of automated data collection in accordance with CEGS 13405*)
	Drawdown	Weekly to biweekly. (recommend installation of automated data collection)
	Graphical analysis	Quarterly
	Specific capacity test (well hydraulic performance)	Annually or at recommended shorter intervals for specific representative or trouble wells.
	Pump performance. Conduct step “pump” test (Section 2-2) of centrifugal pumps and similar wear analysis of positive displacement pumps, compare to “nominal” data	At least annually or at recommended shorter intervals if pump service is severe (Q/s and pump test can be a single operation). Severe: This is subjective. One useful criterion: Pump replacement in 3 yr or less.
Electrical (power)	System and motor V, A, ϕ, Ω	Weekly (Recommend installation of current monitors with alarms)
Physicochemistry	Inorganic parameters	At least quarterly using project onsite instruments (calibrated) or routine monitoring (laboratory)*
	Suspended particulate matter (sand, silt, clay)	Manually at well testing then quarterly
	Turbidity (adds colloidal)	In-line monitors (continuous)*
Biofouling Microbial Component	BART analyses. Pick one indicator type based on past performance (IRB, SRB, SLYM, DN) and use for a marker.	Quarterly. Watch others (IRB, SRB, SLYM) at least annually. May be discontinued if results vary little over time.
	Biofilm flow cell for microscopy	Annually on selected wells
Treatments and Service	Well hydraulic improvement and pumping systems	As testing indicates Q/s drops below 90% or pumping system degrades
	Instrumentation calibration	In accordance with CEGS 13405.
* CEGS 13405 specifies continuous metering, monitoring, and recording of parameters such as flow, temperature, pressure, and physical-chemical properties of discharged fluids.		

(4) Chemical feeds (pellet or solution) are sometimes prescribed for well maintenance cleaning. Operators should resist any temptation to rely on chemical feed systems themselves to maintain wells. The feed suggested in item (1) would inject a cleaning solution along with flushing. Chemical choices recommended may be found in Section 6-1.

Chapter 6
Chemical Dosage for Wells

Chemical treatment in a preventive mode is a major aspect of maintenance of well and fluid system performance. ASTM D 5978, which addresses the maintenance of monitoring wells, does not recommend the use of chemicals, but redevelopment only. This restrictive guidance is not extended to pumping and injecting wells on HTRW sites, for which the responsible use of chemicals in PM redevelopment is usually needed to improve the well's effectiveness. Experience shows that chemical choices in well treatment are often made based on incomplete information or vendor sales literature. And while information should not be dismissed if it comes from a commercial source (as vendors frequently seek to educate), it is crucial that personnel engaged in the planning of well system O&M seek expert advice and review publications specifically written for these types of sites to become well acquainted with the features of chemical choices, both for effectiveness and safety.

6-1 Lists of Chemicals to be Used

a. Issues in chemical choices. The listings of chemicals in this section include brief summaries of the chemicals' uses. Detailed information is provided in Borch, Smith, and Noble (1993), ADITC (1997), and Smith (1995).

(1) Reactivity with constituents of contaminated ground water is an issue in HTRW remediation and monitoring well maintenance. Table 2-4 provides a summary of common reactions.

(2) Cost is frequently cited as an issue in choices made as to whether to use chemicals and electing which ones and how much to use.

(a) Three factors affect the market price of chemical products used in well cleaning:

- Actual process and shipping costs.
- Premiums for purity and standard certification.
- Degree of commercial exclusivity (particularly with proprietary products).

(b) In terms of effectiveness, a more expensive chemical may be a better choice and therefore cost-effective. Among the acids, for example, organic-based and more concentrated products are more expensive than inorganic acids, primarily due to process costs. However, their effectiveness against biofouling and relative handling safety may outweigh the actual material cost differential.

(c) The USACE directs that HTRW site project and O&M management take a "long-view" approach to O&M cost-effectiveness calculations, i.e., to consider cost-effectiveness on a life-cycle cost basis. Available research (Sutherland, Howsam, and Morris 1994) in water supply applications indicates that even aggressive PM is cost-effective compared to losses in efficiency, equipment repair, and well failure. HTRW ground water plume management adds the factor of the project mission, i.e., the cost of failure to control contaminated ground water.

(d) Warning. The chemicals used in O&M are all reactive and pose risks to skin, mucous membranes, and other soft tissues of humans, and are potentially harmful to the environment if handled improperly. They should only be used by trained personnel familiar with their safe use, and who are equipped with proper respiratory and skin protection. Material Safety Data Sheets (MSDS) and other safety information must be reviewed by all personnel involved (mandatory). No HTRW remediation

project should employ personnel or contractors to perform well cleaning who cannot clearly demonstrate competence in use of, and a thorough understanding of the potential reactivity between well cleaning chemicals, contaminants of concern and other chemicals present on the site.

b. Chemical classes and properties. The following paragraphs summarize chemical purposes and effects, safety, handling, and effectiveness features.

(1) Acids. Acids are used to dissolve hard encrusting materials, including Fe and Mn oxides and carbonate deposits. Tables 6-1 and 6-2 list acids most commonly used in well rehabilitation. Table 6-1 lists recommended compounds. Table 6-2 lists commonly used well cleaning compounds not recommended by the USACE for HTRW well PM treatment.

Table 6-1. Recommended Acid Compounds

Acid	Descriptors	Safety & Handling
Acetic acid	Excellent biocide and biofilm dispersing acid. Relatively safe to handle. Often a major component of biofouling “enhancers” and brand-name mixtures specified for biofouling. Acidizing to pH < 2 with sulfamic acid recommended (rapidly loses acid power without). Should use food or good industrial grade > 85 % acid. (variation: glycolic or hydroxy-acetic acid).	Safety: Use gloves, splash protection, and respirator at barrel end*. Does not require placarding for shipment. Handling: These solutions freeze at working ambient temperatures: glacial at 10^o to 12.8^o C (50^o - 55^o F), 84% at 4.4^o C (40^o F), 15% (working solution) ~ 0^o C (32^o F). Make the dilution at an ambient above the stock solution freezing point.
Sulfamic acid	Relatively effective against carbonate scales, and as an acid enhancer for acetic acid. Not effective alone against biofouling or metal oxides.	Safety: Relatively safe to transport and handle (solid, dust inhalation should be avoided). Handling: Solid, less aggressive than HCl (Table 6-2). Use gloves, dust mask and goggles. Provide proper ventilation. Circulate during mixing.
Other organic acids	For example, oxalic and citric acids. Useful as chelating agents. Oxalic acid is also effective as a primary acidizer in low-Ca water. Often form insoluble precipitates in high-Ca waters.	Safety: Safe to transport. Handling depends on form (typically granular solids). Use gloves, dust mask, and goggles. Provide proper ventilation. Circulate during mixing.
* Refer to Chapter 7 and health and safety references.		

(2) Biocides. These agents are used in the attempt to reduce bacterial populations. As in water supply well cleaning (Borch, Smith, and Noble 1993), in HTRW well cleaning (maintenance or rehabilitation), reducing bacterial numbers is typically impractical and no longer considered a primary objective (Smith 1995; Alford and Cullimore 1999). The reduction of hydraulic impact and other symptoms for the longest time possible is the primary objective.

(a) Chlorine (typically sodium or calcium hypochlorite (AWWA Standard B300)). Sodium hypochlorite is liquid and more likely to retain solubility in high total dissolved solids solutions. One procedure used to limit and remove biological encrustation is termed a "shock" chlorine treatment. Standard ANSI/AWWA C654-97 covers the procedures for shock chlorination and bacteriological testing for the disinfection of wells for potable water service. Well cleaning maintenance and rehabilitation are not standardized but methods are available (Borch, Smith, and Noble 1993). Concentrations as high as 500 to 2,000 mg/L of chlorine are usually desirable for this. This is NOT RECOMMENDED for HTRW maintenance treatment applications. Chlorine is a powerful oxidant that reacts with organic compounds, causing chemical alteration of the compounds to more difficult-to-treat forms or to potentially explosive situations with eruption of chemicals at the surface. This latter reactivity, particularly in light of the carcinogenic properties of some chlorinated organic compounds, is the basis for increasing regulatory scrutiny of the use of chlorine for purposes other than maintaining potability of water.

Table 6-2. Common Well Cleaning Chemicals in Use -- Not Recommended

Acids	Safety Concerns*	Effectiveness
Muriatic acid (HCl)	WARNING: Extremely hazardous to handle. Volatile liquid: Requires respiratory and splash protection.	Powerful for removing mineral and inorganic metal oxide scale. Relatively ineffective against biofouling and deleterious to stainless steel (CEGS 13405).
	DO NOT mix with chlorine reaction in well can lead to surface eruption of chemicals and Cl gas; use inhibitors for metal well screens but note that some industrial inhibitors should not be used in potentially potable ground water (toxicity), and gelatin (safe) provides nutrient and inoculum for regrowth.	Steel industry pickling liquor by-product. Quality is a problem, with cadmium and other impurities often present in industrial grades, although NSF 61** certified solutions are available. NOT RECOMMENDED for maintenance treatments.
Phosphoric acid	WARNING: Extremely hazardous to handle. A strong food grade quality acid, readily available, 75%, in 208 liter (55 gal) drums and 45.4 – 56.8 liter (12-15 gal) containers.	Effective against metal and mineral hydroxides. Somewhat effective against biofouling, but no more so than some other mixtures.
	Quite hazardous to handle. Full breathing mask and splash protection required. Adequate ventilation a must.	Leaves phosphate residue behind for bacteria. NOT RECOMMENDED for maintenance treatments.
* Refer to Chapter 7 and health and safety references. ** NSF International Standard 61 covers the safety of chemicals for human contact.		

(b) Ozone. Ozone (O_3) is formed by exposure of oxygen O_2 to strong electrical charges. Ozone has to be generated at the point of application due to its instability, which precludes storage under pressure or transport, making it largely impractical for rehabilitation. Ozone does not have a recognized practical application in well maintenance treatment, although it may be used in piping system treatment to repress biological activity (CEGS 13405 and EM 1110-1-4008).

(c) Hydrogen peroxide. Like ozone, aqueous hydrogen peroxide is a powerful disinfectant and oxidant. It has been used with some effectiveness in removing well biofouling in both water supply and environmental wells. There are a variety of sources of "generic" 50% peroxide mixtures available commercially. It should also be noted that H_2O_2 is aggressively attacked by bacterial enzymes. It breaks down to form H_2O and O_2, and the resultant oxygenation can actually enhance microbial growth away from the well and the lethal oxidant zone. It may be used in piping system treatment to repress biological activity. (CEGS 13405 and EM 1110-1-1008).

(d) Potassium permanganate. Potassium permanganate (AWWA B303), another powerful oxidant used in maintaining industrial process systems and in water treatment (CEGS 13405) for relatively uncontaminated water, is not used as a primary oxidant in well treatments. Dissolution of metals and biofilms is more effectively accomplished using acids (Section 6-1c(1)).

(e) Use of heat. In some cases, water heated to 54° C and recirculated over several days is sufficient without chemicals at least in the short term. Note: Heat propagates from the application source, but typically accumulates in the well structure due to the poor thermal conductivity of soil materials. Heat can actually enhance growth away from the thermal shock zone, as well as cause drying and shrinking clays such as bentonite grout. Using heat alone is also very inefficient in terms of fuel or power to generate thermal energy. The best approach to using heat is in a process such as the blended chemical heat treatment method described below (6-1.c) with a prudent selection of chemicals (Alford and Cullimore, 1999).

(3) Sequestration. In well treatment, these compounds are most properly used in low concentrations in chemical blends as aids in acidizing mixtures to retain biofilm and metal oxide components in solution for removal, once they are dissolved and dispersed in the water column. Examples are various polyphosphates, pyrophosphates, and polyacrylamide-based compounds. In addition, acetic acid and citric acid (Section 6-1c(1)), and some proprietary acid formulations also have related chelating properties.

(a) Phosphate-containing compounds are NOT RECOMMENDED for maintenance well treatment. Residuals of the compounds themselves (higher molecular weight (MW) polymers) and breakdown products (low-MW pyrophosphate and orthophosphate or phosphate) remain behind in the formation (attached to clays). The presence of an enhanced phosphate resource induces enhanced biofilm development, often at the edge of development influence.

(b) Polyacrylamide and similar polyelectrolyte wetting agents provide the desired effects of dispersing clogging deposits and clay/silt buildup without being phosphate sources. These compounds are not readily attacked by microorganisms. They should be handled, used, and ultimately disposed of according to manufacturer/supplier and MSDS instructions.

(4) Reactivity. Consult reactivity tables (e.g., Table 2-4) for problems with ground water constituents. EM 1110-1-1008 provides guidance in system material reactivity.

c. Blended method treatments. Typically, no one chemical type will address all encrustation and biofouling removal, suspension, dispersal, and repression needs. Blending approaches can permit more effective removal of multiple problems, or treat a single difficult problem more effectively (Smith, 1995; Alford and Cullimore, 1999). Appendix C includes one scenario. The exact blend of chemicals for a particular well field situation is determined based on an analysis of the needs for cleaning the clogging materials present and ground water quality.

d. Role of development. It should be emphasized that all chemical mixtures are far more effective with adequate mechanical mixing and development, and should be specified based on an adequate analysis of the problem.

e. Purge water handling. Any purge water should be disposed of properly in wastewater treatment or surface spreading on soil. The definition of “properly” will depend on the chemical mixtures, their chemical properties (e.g., pH), and the sensitivity of the treatment or land system. Discharge to any surface waters must be avoided. Phosphate-loaded water discharged to surface waters can cause algal blooms and oxygen depletion, resulting in suffocation of aquatic animals. Additionally, pH shock is toxic to aquatic life, and turbidity can suffocate.

6-2 Use and Interpretation of MSDS

a. Requirement. Having MSDS on hand is a requirement of governing agencies (including USACE) and a central feature in safety plans involving chemical safety. The Occupational Safety and Health Administration (OSHA) requires the MSDS to accompany each container of reactive chemical from point of origin to point of consumption or final disposal. Each person handling each chemical must verify that he/she has read the MSDS, or has had it read to him/her and that he/she understands the precautions necessary.

b. Use. MSDS must be on hand to provide guidance in personnel exposure problems, reactivity concerns, and neutralization recommendations, and to provide information on basic physical properties (e.g., the relatively high freezing temperature of organic acids). The MSDS of proprietary chemical blends also permits interpretation of their contents and modes of operation in treatment.

6-3 Calculation Work Sheets

This pamphlet provides calculations for well volume dosages, and includes well volume/foot tables for common well diameters. These are found in Appendix D. Appendix C offers recipes for commonly used mixtures.

Chapter 7
Health and Safety Concerns

HTRW well system O&M has a number of critical health and safety issues related to general well and pump mechanical and electrical operation and control, as well as specific concerns of handling potentially hazardous formation and treatment fluids, and related issues such as confined space operation.

7-1 Health and Safety Plan

O&M safety must be a component of overall site safety. The development and implementation of a specific but flexible plan is needed, including personnel expertise and compliance, and training to make personnel thoroughly familiar with chemical and mechanical activities. Depending on the specific nature of the well system and the nature of the contaminants and treatment chemicals, O&M activities will require worker hazard analyses and compliance with any applicable OSHA standard found in 29 CFR 1910 and/or 29 CFR 1926, in addition to any applicable requirements of EM 385-1-1. In all cases, the O&M safety and health managers will be required to comply with 29 CFR 1910.132 through the performance of a site-specific hazard analysis, the selection of personal protective equipment (PPE) appropriate to protect workers from the hazards identified, a written hazard assessment certification, and worker training in the hazards and PPE to be used. The following guidance will assist in that effort.

7-2 Level of Protection for Mixing and Well Application

Well maintenance treatments involve the use of reactive chemicals (Sections 6-1 and 6-2). Once a chemical regime is selected, the appropriate use of chemical-resistant gloves, boots, and apparel, full-face splash shields, and other specific protection such as for handling hot and supercold solutions should be specified. See Section 6-1 and other references. An excellent strategic policy for safety is to, as a rule, employ treatment mixtures that minimize hazard and the likelihood of personal injury due to error, while still being effective. The mixture in Appendix C is one such treatment.

7-3 Chemical Handling Hazards

a. *Transferring chemical solutions*. Typically, the major exposure injury risk point during PM treatment is at drums containing concentrated acid, caustic, or oxidizing agent solutions. Spilling or transfer hose troubles may result in skin exposure. Vapors may cause mucous membrane and eye tissue irritation or damage. Persons handling concentrated chemicals should wear full-face splash guards and respirators and chemical resistant clothing and gloves. Persons handling dilute solutions may work with care in OSHA Level D gear (29 CFR 1910).

7-4 Mixing Chemicals

a. Mixing hazards. Mixing of concentrated reactive solutions can result in personal hazards. For example, neutralization of acids poses a potential hazard if basic compounds are added too rapidly to strongly acid solutions (pH <5). Significant foaming may occur.

b. Hazard review. Personnel should review how to handle specific chemical source stock and solutions. MSDS provide general guidance but should not be relied upon for complete instructions, which should be in the site-specific O&M Site Safety and Health Plan (Section 7-1). General chemical mixing safety requirements are listed below:

- Personnel should always add acid to water and not vice versa.
- Strong oxidants should never be used where hydrocarbon concentrations are high in well water solutions, as ignition is a low-but-not-zero probability.
- Alkaline and caustic compounds should be added slowly to acidic compounds when neutralization is required, and never added to wells when acid solutions are still in the well.
- Hoses, valves, and connections should be secured and not leaking. Spraying acid or oxidant chemicals can result in dermal burns and clothing damage.
- All work should be conducted in unobstructed and well-ventilated areas.
- Personnel must routinely review MSDS and company recipe sheets before each treatment event and work at a deliberate pace, avoiding rush.
- Extra lime or soda ash should be kept on hand to treat spills, and eyewash packages and abundant clean water should be kept close at hand for dilution when personnel are splashed.

Chapter 8
Checklists

Checklists facilitate the implementation of the site well array O&M plan by providing site personnel with concrete tasks and schedules. Checklists for the following may be found in Appendix D.

8-1 Type and Frequency of Data to be Collected

Checklists should include daily and totalized flows, pressure per well, and other data (pH, drawdown). Consult Chapter 5 for frequencies.

8-2 Well Maintenance Log

Table 8-1 lists the recommended information to be logged during a PM treatment event.

Table 8-1. PM Treatment Log Items

Data types	Description
Physical properties	Well identification and diameter, depth to screen, screen interval, total depth
Remediation measures	Type and amount of chemical used, surging method and times
Related measurements	Periodically and before and after remediation -- Amount and identification of sedimentation Flow Well drawdown Piezometer drawdowns
	Power data and notations on instrumentation
Notes on repairs and replacements	Modifications to the well structure and all equipment data
Related comments	All potentially pertinent information (weather, delays, equipment problems, discussions over methods, change orders)
Itemization of costs	For budgeting and future reference.

8-3 O&M Calculation Work Sheet

Specific formula calculation sheets should be provided, specific to the wells to be treated. See Section 6-1 and Appendix C for chemical and treatment choice information.

8-4 Other Records

a. Field data sheets. As discussed in Chapter 2, drawdown and flow sheets should be developed for routine field data collection and should include all relevant data columns. A variety of examples exist from text, government, and commercial sources.

b. Cost-effectiveness calculation spreadsheets. Sutherland, Howsam, and Morris (1994) provides cost-effectiveness work sheets and spreadsheets adaptable for HTRW site use.

c. Work orders. Most organized sites generate work orders for activities such as PM well treatment or equipment repair. These may be paper forms or generated in software maintenance management systems.

Chapter 9
Suggested Maintenance (Minimum and Optimum)

The following paragraphs list recommended maintenance practices, intervals, and evaluation processes. They are adapted from more in-depth discussions elsewhere (e.g., Borch, Smith, and Noble 1993; Howsam, Misstears, and Jones 1995; Powers 1992; Smith 1995; ADITC 1997; NGWA 1998) and project experience.

9-1 Design Aspects

A variety of design considerations can serve to prevent or slow well system deterioration, and facilitate maintenance and rehabilitation in the future. In many cases, the improvements cost little or no more than inferior designs and materials initially, and save money in life-cycle costs.

a. Improved materials. Corrosion- and deterioration-resistant materials slow the deterioration of well components and limit recurrence of preventable problems, making the success of maintenance actions more likely. EM 1110-1-4008 provides information on material compatibility. Specific to well equipment, polyvinyl chloride (PVC) casing, for example, is corrosion-resistant and suitable for most HTRW applications. Alternative metal casings are available where plastic or fiberglass casings are not suitable (Smith 1995; NGWA 1998). Notable product developments (approaching 20 years in service) include the widespread availability of all-stainless-steel and stainless-and-plastic pumps, high-quality rigid plastic pump discharge (drop) pipe with twist-on-twist-off connections, and flexible discharge hose (specifically designed for well pump use) composed of reliable, high-strength, corrosion-resistant material that permits easy pump service. Relatively smooth pump interior surfaces and corrosion resistance are showing increasing intervals between pump service events.

b. Other pump selection considerations. Pump motor and discharge-end product lines can seem to have a remarkable sameness in a competitive market. On the other hand, pumps may be marketed for "environmental duty" which may not be superior to other products for aggressive ground water pumping applications. Some considerations:

(1) Pump end material selection.

(a) A material designation of "stainless steel" includes a range of corrosion-resisting alloys. Some do well in anaerobic environments typical of high-organic-carbon water (e.g., Type 316 and better), and some do not (Type 304). The alloy should be selected to be compatible with the service environment.

(b) Welding and stamping alter the corrosion-resisting characteristics of stainless steel alloys so that the manufactured product may not match the resistance of the unaltered alloy. In some cases, a cast stainless bowl selection may be superior.

(c) While versatile, stainless steel may not suit every situation. In some high-chloride, bio-corrosive environments, only high-silicon bronze or plastics may provide suitable service life. At high temperature or high radiological activity , some plastics degrade at unacceptable rates. In addition to bowl and impeller materials, selections of bearing materials and designs are factors in selection.

(2) Pump end hydraulic efficiency. Higher efficiency pump ends are recommended. Pump impeller-bowl designs and numbers of stages should be matched to the operating head conditions.

(3) Submersible vs. lineshaft installations. In general, submersible models are more versatile but characteristically provide less wire-to-water efficiency than many lineshaft turbine models. Lineshaft installations offer the advantage of having the motor at the surface, where it is accessible, heavy motors for very large pumps are not suspended downhole, and motors are less expensive to repair. Disadvantages of lineshaft installations include:

- The need for a lineshaft and its associated bearings which require lubrication and are vulnerable to wear, especially in aggressive, biofouling water.
- The need to use steel column pipe, which is subject to rapid corrosion.
- Restricted access at the surface for drawdown measurement and other access to the well casing.
- Greater skill is needed in lineshaft pump repair, and wells must be very straight and plumb.
- Surface-mounted motors must be protected from weather and heated or cooled as needed.

(4) Achieving a balance of equipment features. As exact matches to conditions and ideals may not be possible, pump choice may be a balance of features. In general, the highest efficiency pump models should be used. Exceptions occur where service is so severe that short operating lifespans can make more expensive, tunable pumps not cost-effective to operate. In these cases (particularly where efficiency differences are minor), low-priced but serviceable pumps that can be discarded and replaced or cleaned may be the better option.

c. Computers and controllers. Automated water-level and flow information facilitates data analysis and planning. Devices exist to provide "real time" water-level and flow measurements without personnel being onsite. SCADA systems originally developed for process treatment can be adapted for well fields, permitting rapid, easy, and continuous monitoring of well and pump hydraulic performance, and even physical-chemical changes. Pump controllers help to maintain regular current flow of the proper characteristics and phase to pump motors, thereby prolonging motor life and shielding motors from line surges. All pump motors should be equipped with automatic controllers.

d. Suction flow control. One technology that has developed in recent years is the refinement of the controlled-inflow pump tailpipe referred to as a suction flow control device (SFCD). These simple devices are perforated pump intake pipes. The perforations are made in a pattern that forces flow to enter the well in a more cylindrical fashion (Nuzman 1989 and Ehrhardt and Pelzer 1992), instead of

- An upward-faced cone pattern typical of pumped screened wells in which almost all flow enters through the top 10 to 15% of the screen when the pump is above the screen.
- Preferentially at the point where the pump is located within the screen, typical of many HTRW pumping wells.

Unfortunately, practical commercial access to the best quality devices is at present still limited to Europe and the Mediterranean, and inclusion in U.S. site planning has to await commercial availability in this country.

e. Well and water system modifications to facilitate maintenance. A maintenance-friendly wellhead setup is important to minimize the difficulty of performing maintenance. Issues include meeting limits to avoid confined space designation, making the well seal secure but removable, and discharge head and instrument connections easy to detach. Table 9-1 provides recommendations for wellhead features to facilitate maintenance.

f. Wellhead chemical treatment.

(1) A hydrant should be installed between the well pitless discharge and the well house flow meter-valve assembly for discharge to waste during treatment. Several suitable self-draining hydrant styles approved for potable water distribution are available on the market (ANSI/AWWA C503 and CEGS 02510). During the well treatment process, a hose may be run from the blowoff hydrant to containment and treatment.

(2) Chemical feed pumps can be used to meter chemical mixtures into wells (CEGS 11242). The manufacturer should also be consulted about the chemical compatibility of diaphragm and housing of the liquid end. Also, the suitability of hose installed for short term, periodic service feeding pH 2 solutions should be double-checked.

Table 9-1. Design and Equipment for Wellheads to Facilitate Maintenance

Recommended Features	Feature Application
Room exists for personnel to operate and manipulate equipment around the wellhead, reasonably accessible, dry and stable wellhead area, elimination of confined-space-entry conditions.	Improves accuracy and reduces the potential for accidental injury or equipment damage or loss. Minimizes personnel needs for routine tasks; reduces time and equipment required for maintenance events.
Locks, caps, or security apparatus are corrosion- and weather-resistant	Personnel do not waste time and risk injury or equipment damage attempting to perform maintenance. Instrumentation is not easily damaged by heat, cold, or vandalism.
Water-level measurement access and flow readings are easily obtained	Personnel can perform these tasks efficiently and willingly.
Wellhead structures and fittings permit easy removal of pumps and downhole equipment.	Pumps can be removed quickly, saving money.
Piping and valving is designed to limit pressure drops, and permit convenient flow diversion and pipe maintenance.	Clogging is minimized, and maintenance flushing and pigging can be accomplished. See paragraphs 9-1f and 9-1g.
Water quality taps are accessible and protected from weather and corrosion.	Samples can be readily obtained and taps maintained.

(3) Systems have been developed to systematically redevelop with the pump in place, and designed to provide treatment chemicals to the screen where past pump-in-place designs were not effective. An example is a system in which a valved return flow pipe is installed to permit periodic or demand flushing of the well water column. These should be considered as maintenance treatment options.

g. Distribution pipeline maintenance. Distribution lines from wells may also develop deposits of iron oxides and biofilm. If oxidation and fouling in wells are kept to a minimum, lines are likely to remain relatively clean. However, line clogging is a very common problem in systems pumping contaminated ground water to treatment.

(1) If the system head shows signs of increasing, a program of pigging and flushing can be instituted. Pigging is the process of running a soft plug with a rough, abrasive outside surface through the lines to remove deposits. (The procedure is described in Deb et al. (1990)). Some system modification

will be needed to accommodate the procedure, and it is recommended that planning for this option be part of well system design. Pigging requires:

- An upstream entry point for the pig (for example at a well house).

- A means of providing water pressure to propel the pig (water pressure from a potable water system fire hydrant would suffice).

- An outlet collection point for wastewater and pig.

(2) Alternatives such as electrostatic dispersion of colloidal fouling components have also been suggested, and possibly have application.

h. Well array design recommendations. These design recommendations are detailed below.

(1) Have enough wells installed in a pumping or injection array to permit continued operation and plume control while wells are out of service (being treated or pumps replaced).

(2) Install a ring of treatment wells around pumping or injection wells subject to clogging (Section 5-4). These can greatly improve treatment success in the near-well formation by providing a way to force treatment chemicals toward the pumping well screen from the outside and also to provide more access for agitation of the near-well formation.

(3) On sites with very deep wells, options (1) and (2) may be quite expensive. In these cases, where both replacement and rehabilitation may be very expensive and difficult, designing and planning for a rigorous maintenance defense of the existing pumping wells are especially important.

9-2 Chemical Addition

a. Methods of addition. Chemicals may be introduced into wells by gravity (tremie), pumping in against water column pressure, and high-pressure jetting. A feature of each is that chemical solutions are directed to the screen region and not simply poured into the well. For maintenance treatments, simple pouring and pumping (versus jetting or pressurizing) is usually sufficient. Jetting may be used for more completely developed clogging situations. Note that both redevelopment methods and chemicals used in maintenance (as well as rehabilitation) treatments can be hazardous to personnel and possibly damaging to well structures.

b. Professionalism. Any treatment program must be initiated by professional contractors highly familiar with these treatments. Site personnel can be trained in the safe use and evaluation of the effectiveness of these methods by the contractor.

9-3 Mechanical Agitation

Chemicals introduced should be mixed through the screen column, either through surging (see Section 9-5) or recirculation pumping. As it is mixed and pumped in, and later during development, the solution should be checked and adjusted to maintain pH <2. Current research under way at the Canadian Federal Government's Praire Farm Rehabilitation Administration's geotechnical laboratory suggests that most chemicals should have a maximum in-well contact time of less than 10 hr where clay swelling is a possibility.

9-4 Chemical Recovery

Chemical solutions containing biofilm, metal oxides, and other solid debris must be removed from the well column. It is essential to note that neutralization should never be conducted in the well column itself, because

- Clogging material will drop out of suspension or solution.
- Explosive effervescence is possible when caustic solutions are introduced into solids-laden acid solutions.

a. Containment. Containment and treatment such as neutralization are then necessary before release into the environment. Options include:

(1) Pump into holding tanks. Development slurries are typically best pumped to pretreatment tanks for settling and acid neutralization. Such tanks should be sufficiently large to hold three to six times the borehole volume so that development (Section 9-5) does not have to stop. Other options include neutralization "on the fly" in smaller tanks using a calculated feed rate of neutralizing chemical solution.

(2) Divert to existing lagoons. On occasion, slurries may be diverted to surface containment and permitted to lose acid or oxidant power. Solids may settle in place.

(3) Divert to treatment plant. Typically on HTRW remediation sites, water treatment is available, and development slurries must pass through them prior to release. Typically pretreatment is necessary. The tolerances and requirements of the treatment process should be known and not exceeded.

b. Regulatory aspects. Environmental regulations and standards that apply to such impoundments apply. Project agreements with regulators and local regulations may need to be checked before discharging to existing treatment plants or lagoons if they were not originally intended to accept such waste. Ultimately solids must go to secure disposal per regulatory requirement.

9-5 Well Development

Practically all methods of drilling cause compaction of unconsolidated materials of variable thickness in an annulus around a drill hole. In addition, fines are driven into the wall of the hole, drilling mud invasion may occur to a greater or less extent, and a mud cake (if used) may form on the wall of the hole. These effects are well described in standard well construction references such as ADITC (1997) and Driscoll (1986).

a. Defining well development and redevelopment. Well development is the final well construction step that

- Removes formation damage caused by the borehole drilling process.
- Establishes the optimal hydraulic contact possible between the well and the aquifer formation supplying fluids to (or accepting fluids from) the well.

Redevelopment is the process of using development methods to remove accumulating clogging material from around an installed well.

b. Well development and redevelopment effects. The importance of proper initial well development and redevelopment in well maintenance is difficult to emphasize enough. Proper well development breaks down the compacted borehole wall, liquefies gelled mud, and moves both mud and formation fines into the well, from which they are removed by bailing or pumping. This action creates a more permeable and stable zone about the screen or intake bore. The stabilization of the formation adjacent to the well intake that is achieved by development can practically eliminate sand pumping, and contributes to a more efficient well, longer well life, and reduced operation and maintenance costs. EM 1110-2-1914 and TM 5-813-1 provide general guidance on well development. Numerous detailed references on development methods are available, including ADITC (1997), Driscoll (1986), and Roscoe Moss Company (1992). Borch, Smith, and Noble (1993) provide information and guidance from a redevelopment perspective. NGWA (1998) provides specific pumping well methods description and guidance.

c. Well development and redevelopment methods.

(1) Overpumping. The development process consists of continuous or intermittent pumping at pumping rates up to 1-1/2 times the design capacity. Overpumping lacks the necessary in-and-out action of optimal development action but can be conducted with available well pumps.

(2) Surging and bailing (utilizing surge block). The development process is carried out by surging and bailing the well. The surging is done by a single or double solid (or valved) surge block with development water and sediment removed typically by airlift pumping. Surging should be conducted with tools capable of a 0.3- to 0.6-m/sec (1- to 2-ft/sec). stroke and capable of working the screen in 0.6- to 1.5-m (2- to 5-ft) sections, concentrating on known trouble spots. One variation is swabbing (e.g., Roscoe Moss Co., 1992).

(3) Surging and pumping. Where there is insufficient submergence for airlift pumping to work properly, development can proceed using surging and pumping with a well pump. Pumping is conducted through the surge block which incorporates a piece of the suction pipe in the fabrication of the block, at rates up to one half of the design capacity. Upon completion of the development work, the well is cleaned to the bottom. A variation of surging and pumping and overpumping, especially useful in tight wells, employs a well pump moved up and down with a reversible pump puller. Pumps especially equipped for this purpose with attached surge block collar, etc., are available. Care must be taken to ensure that air does not enter the formation, but is only used to move fluid, which carries the kinetic development force (see paragraph 9-5e).

(4) Hydraulic jetting. Development is accomplished by simultaneous high velocity, horizontal jetting and pumping. The outside diameter of the jetting tool must be 1 in. (about 25 mm) less in diameter than the screen inside diameter. The minimum exit velocity of the jetting fluid at the jet nozzle should be 150 ft/sec (45 m/sec). The tool is rotated at a speed less than 1 rpm and positioned at one level for not less than 2 min and then moved to the next level, which is no more than 6 in. (150 mm) vertically from the preceding jetting level. Pumping from the well should be at a rate of 5 to 15% more than the rate at which water is introduced through the jetting tool. Water to be used for jetting must contain less than 1 ppm suspended solids.

(5) Air development. Development is conducted:

- Using a single pipe air pumping system either using the casing or the bore hole itself as the eductor line (casing open) or with the casing closed to the atmosphere.
- With a dual-line air system employing an air introducing pipe and an air and water eductor line.

(a) Sizing. Compressors, airlines, hoses, fittings, etc., should be of adequate size to pump the well by the airlift method at l-l/2 to 2 times the design capacity of the well. Each case is specific in terms of depth, submergence, well diameter, and screen hydraulic conductivity. For wells less than 300 ft (91.4 m) in depth, with 60% submergence possible, approximately 0.75 cfm of air compressor capacity is needed per gpm (0.133 cfm) (~5.6 m^3/sec of air per 1 m^3/sec water) of anticipated pumping rate (Driscoll 1986, Fig. 15.12). In practice, a 375-cfm compressor developing 100 psi can usually pump 400 to 500 gpm (approximately 44 to 67 cfm or 1.25 to 2.0 m^3/sec) of water with proper airline submergence.

(b) Development process. The first goal is to establish a piston effect (surging) and not to conduct airlift pumping. In surging, sufficient air is fed to raise the water level as high as possible, then released to let it drop. Airlift pumping is then used to pump the well periodically to remove sediment from the screen or borehole. When the well yields clear, debris-free water, the airline is lowered to a point below the bottom of the eductor line and air introduced until the water between the eductor pipe and the casing is raised to the surface. At this time the airline is raised back up into the eductor line causing the water to be pumped from the well through the eductor line. The procedure of alternating the relative positions of the air and eductor line is repeated until the water yielded by the well remains clear when the well is surged and backwashed by this technique.

(6) Combination tools and methods: The better features of several tools and methods can be combined. For example, combination surging and jetting tools are used to surge while jetting in acid.

d. Care in performing development. To avoid applying forces on the casing, screen, and grout that are beyond their capacity for resistance, care and attention to detail are required in development and redevelopment. Sufficient force, efficiently supplied, is needed to set formation particles in motion and to sheer off encrustation. However, this does not have to be violent force that damages the well. For example, causing an excessive difference in hydrologic pressure between the outside and inside of a casing may result in casing distortion. Sharp shock loading or unloading of some well screens may cause distortion or collapse.

(1) Development typically should proceed in 2.74- to 4.57-m (3- to 5-ft) segments.

(2) Tools should not impact sharply against casing joints or screen rods.

(3) In air development, especially, there is a tendency to “overdo it.” Sufficient air flow volume (cfm) should be available (paragraph 9-5d(5)(a)) to mobilize the water in the well and the near-well formation, but being careful to not disturb the filter pack. Exceeding a 10:1 air-water volume ratio can actually reduce airlift pumping flow rates because the well is impeded by excessive air volume.

9-6 Maintenance Monitoring Well Deterioration and Redevelopment Evaluation

a. Evaluation in the PM plan. Including recommendations, processes, and checklists for methods to evaluate well performance, its deterioration, and repair and treatment results in the well system PM plan permits evaluation of treatment effectiveness, the need for additional actions, or changes in subsequent treatment. An overview of maintenance monitoring schedule and parameter recommendations is provided in Sections 5-2 and 5-3.

b. PM evaluation instrumentation recommendations. The following are some specific instrument recommendations for maintenance monitoring:

(1) Physical-chemical monitoring for maintenance water quality testing. Electronic colorimetric or spectrophotometric instruments and electronic pH-mV, temperature, and conductivity meters are

sufficient for PM monitoring with proper calibration (CEGS 13405). If there is an established maintenance and calibration schedule for all instruments, accuracy is not sacrificed using onsite, commercially available instrumentation, and the greater frequency of analysis possible economically provides more data points to plot trends.

(2) Biofouling microbial component.

(a) Sampling. Pumped grab methods in time-series for BART and turbid sample analysis by microscopy and biofilm collection on surfaces (sidearm for outflow from wells to collect samples of biofouling indicative of that occurring in wells).

(b) Analysis. Light microscopy and BART methods (Section 2-8), biofilm mineralogical analysis (X-ray diffraction for mineralogy and elemental speciation to establish fouling mineral predominant components).

(c) Recommendation. A combination of time-series pumped sampling and BART analysis and microscopy for filamentous iron and sulfur bacteria and FeIII-oxide minerals provides a good profile of biofouling conditions. Routine monitoring can be limited to specific BART analyses selected to best gauge change and periodic sampling of biofouling solids to gauge changes in type and structure (Sections 5-2 and 5-3 provide a schedule). A one-time mineralogical (XRD) and elemental analysis of solids is useful to refine preventive maintenance chemical feed choices.

(d) Alternative. Particle counting and turbidity (both of which can be automated) can replace biofouling sampling in systems with known biofouling characteristics.

(3) Sand content testing. Sand content may be determined by sampling with a Rossum Valve sampler (Roscoe Moss Company 1992)

(a) At strategic intervals during well development.

(b) Averaging the results of five samples collected at incremental times during a pumping test. NGWA (1998) provides specific recommendations. A limit of 5 ppm is achievable and optimal criterion for well redevelopment completeness.

(c) Hydraulic monitoring using methods as described (Section 2-1).

c. Flow meter and other sensor maintenance. To ensure their usefulness in maintenance monitoring, flow meters, and other sensors must be maintained. An open pipe insert type or nonintrusive ultrasonic flow meter should be used to limit the effects of encrustation. Units that can be readily removed should be specified and installed. If used, venturi flow meters (vulnerable to clogging) and sensors (vulnerable to coating and fouling) should be periodically examined and cleaned as needed. Manual cleaning using a mild acid detergent and rinse should suffice.

Chapter 10
O&M Equipment Needed

10-1 Overview

There is a variety of equipment available for initial delivery of maintenance chemicals, developing wells, and handling well pumps. These are generally described in ADITC (1997), Borch et al. (1993), NGWA (1998), Alford and Cullimore (1999), and other publications with a focus on field equipment and techniques appropriate to well PM. The following recommendation is not intended to be all-inclusive, but illustrative. Such systems should not be assembled or operated without training by personnel experienced in these practices.

10-2 Example Basic Well Maintenance Field System

a. Chemical mixing. A tank trailer should be equipped with

- 500-gal (1.9 cu m) chemical mixing tank for chemicals (acid duty, see EM 1110-1-4008).
- A second set of tanks to contain purge water for transfer to treatment. These tanks often need to be augmented by additional portable tanks.
- Transfer pumps (in line to mix and feed to the well) and hoses with fittings to match those at treated wellheads.
- Provision to house personal protective gear and additional safety gear such as ventilator blowers and harnesses, MSDS, and material and instruction for neutralization and first aid, spare parts, and basic chemical mix recipes. Also included should be a convenient means to call for assistance such as a wireless telephone or site-frequency radio.

b. Equipment handling. A means of hoisting and handling chemical drums, pumps, and associated pipe systems is needed. Commonly this is a conventional water well pump hoist with a maneuverable boom, of sufficient size to hoist any object to be lifted in the well field (not < 5-ton (4535 k) hoisting capacity).

(1) Some hoists are equipped with reciprocating beams to permit surging. These are suitable for light surging redevelopment that is not of long duration.

(2) Alternatives include small, motorized, reversible pump puller units that apply force to pipe via rubber tires or tracks. The motion is reversible, suitable for surging, and also permits rapid pump pulling for service and inspection. This will save much time and effort. Rigid well pipe would be specified for this application.

(3) Flexible well discharge pipe is coiled in the same manner as fire hose. A wheel device to run the hose smoothly from the vertical to the horizontal orientation is needed. These are routinely supplied by the hose supplier.

c. A development and test pumping trailer. This trailer should house:

- Development tools such as surge blocks or jets, brushes, or equipment for recirculation cleaning.
- Spare pipe and hose.

- Orifice weirs or flow meters.
- Water-level probes and other instrumentation and spare components such as bolts, weir plates, and blocking.

d. Ancillary gear. Additional parts and equipment needed on hand include:

- Spare parts, pipe and hose, and pumps, which should be standardized to the extent possible.
- Air compressors, generators, etc.
- Hand tools.
- Biofouling (BART etc.) tests and portable water quality and power testing instruments for maintenance monitoring.
- Voltage, amperage, resistance meter

These can be housed separately or on one of the field trailers or vehicles.

10-3 Provision of Maintenance Equipment

a. Large and remote projects. Sizable and more remote sites should have equipment dedicated to the project as described in Section 10-2 and trained personnel on staff to perform maintenance. The criterion for this threshold is when a separate well service company would devote more than three-staff months on site per year to perform services.

b. Additional equipment and service provision options. Systems that can be serviced by qualified commercial well service providers should do so. These companies are typically in a better position to maintain and provide a wider range of equipment more cost-effectively than site project management. However, particular projects, sites, and O&M contractors may have specific skills, preferences, or needs that would result in a combination of approaches. Options include:

(1) Dedicate equipment to the site and maintain a well maintenance crew where the level of effort for well maintenance is six staff-months per year (crew of two, dedicating three work months each).

(2) Dedicate equipment to the site and out-source well maintenance crew services (where the level of effort for well maintenance is three to six staff-months per year). Maintaining equipment and parts onsite ensures their availability and reduces cross-contamination potential. Onsite operational personnel should be trained in and perform maintenance monitoring.

(3) Out-source well service entirely: Generally, where this is feasible, it is a preferred option to avoid tying up personnel and equipment to low-frequency tasks and to take advantage of competitive bidding. Onsite operational personnel should be trained in and perform maintenance monitoring.

c. Example costs. The costs listed in Table 10-1 are provided to offer a range of costs for well PM planning purposes. These numbers are based on past projects and are expressed in pre-1999 dollars for the items described in Section 10-2.

Table 10-1. Approximate Costs of PM Equipment

Equipment	Method	Cost
(1) Chemical mixing. A tank trailer equipped as recommended	Purchase	$3,500.00
(2) Equipment handling.		
(a) Standard 5-ton(4535-k)-hoisting capacity pump hoist equipped as described.	Purchase	$60,000.00
	Hired (per day)	$1,500.00
(b) Motorized, reversible pump puller unit	Purchase	$3,000.00
(c) Equipment to handle flexible well pipe	Purchase	$1,000.00
(3) Development and test pumping trailer (equipped).	Purchase	$5,000.00
(4) Ancillary gear.		
(a) Generator (5 kW)	Purchase	$3,200.00
(b) Air compressor (375-cfm (1.77 m^3/sec))	Rent per week	$200.00 to $1,000
(c) Maintenance monitoring instruments and apparatus including voltage, amperage, resistance meter	Purchase	$2,000.00
(d) Recommended spare parts and equipment	Purchase	$5,000.00

Appendix A
List of References and Bibliography

A-1 Required References

29 CFR 1910

29 CFR 1926

TI 814-1. Water Supply

TI 814-3. Water Distribution

TM 5-813-5. Water Supply, Water Distribution

TM 5-813-9. Water Supply: Pumping Stations

ER 385-1-92. Safety and Occupational Health Document Requirements for Hazardous, Toxic, and Radioactive Waste (HTRW) and Ordnance and Explosive Waste (OWE) Activities

ER 1110-345-700. Design Analysis, Drawings and Specifications

EM 385-1-1. Safety and Health Requirements Manual

EM 1110-1-4000. Monitoring Well Design, Installation, and Documentation at Hazardous, Toxic and Radioactive Waste Sites

EM 1110-1-4008. Liquid Process Piping

EM 1110-2-1914. Design, Construction, and Maintenance of Relief Wells

CEGS 02510. Water Distribution System.

CEGS 11212. Pumps, Water: Vertical Turbine

CEGS 11242. Chemical Feed Systems

CEGS 13405, Liquid Process Control

A-2 Related Publications

CEGS 02521. Water Wells

CEGS 02522. Groundwater Monitoring Wells

ER 1110-1-263. Chemical Data Quality Management for Hazardous, Toxic, Radioactive Waste Remediation Activities

ER 1165-2-132. Hazardous, Toxic, and Radioactive Waste (HTRW) Guidance for Civil Works Projects

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*b. Internet***.** The internet (specifically the World Wide Web) contains sources of information not necessarily published. The following were consulted, and should remain stable and available for reference.

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http://www.groundwatersystems.com Smith-Comeskey Groundwater Science well maintenance and rehabilitation information area.
http://www.ngwa.org National Groundwater Association (literature database).
http://www.dbi.sk.ca Droycon Bioconcepts (University of Regina) information on biological well clogging and deterioration.

*c. Concensus Standards***.** These are a partial listing of AWWA and ASTM Test Methods, Standard Tests, and Standard Guides relevant to this work. They are offered as references for procedures to consult and not necessarily as authoritative.

(1) AWWA.

AWWA B300, Chlorine.
AWWA B303, Potassium Permanganate.
ANSI/AWWA C503. Wet Barrel Fire Hydrants.
ANSI/AWWA C657-97. Well Chlorination.
ANSI/AWWA C654-97. Disinfection of Wells.

(2) ASTM.

A589-95a Standard Specification for Seamless and Welded Carbon Steel Water-Well Pipe.
D421 Standard Practice for Dry Preparation of Soil Samples for Particle-Size Analysis and Determination of Soil Constants.
D422 Standard Test Method for Particle-Size Analysis of Soils.
D 932 Test Method for Iron Bacteria in Water and Water-Formed Deposits.
D 4043-96 Standard Guide for Selection of Aquifer-Test Method in Determining of Hydraulic Properties by Well Techniques.
D 4044-96 Standard Test Method for (Field Procedure) for Instantaneous Change in Head (Slug) Tests for Determining Hydraulic Properties of Aquifers.
D 4050 Standard Test Method (Field Procedure) for Withdrawal and Injection Well Tests for Determining Hydraulic Properties of Aquifer Systems.

D 4104 Standard Test Method (Analytical Procedure) for Determining Transmissivity of Nonleaky Confined Aquifers by Overdaming Well Response to Instantaneous Change in Head (Slug Test).

D 4750 Test method for determining subsurface liquid levels in a borehole or monitoring well.

D 5088 Standard practice for decontamination of field equipment used at non-radioactive waste sites.

D 5092 Standard practice for design and installation of ground-water monitoring wells in granular aquifers.

D 5472 Standard test material for determining specific capacity and estimating transmissivity at the control wells.

D 5521 Standard guide for development of ground water monitoring wells in granular aquifers.

D5753-95 Standard Guide for Planning and Conducting Borehole Geophysical Logging.

D5786-95 Standard Practice for (Field Procedure) for Constant Drawdown Tests in Flowing Wells for Determining Hydraulic Properties of Aquifer Systems.

D5903-96 Standard Guide for Planning and Preparing for a Groundwater Sampling Event.

D5911-96 Standard Practice for Minimum Set of Data Elements to Identify a Soil Sampling Site.

D 5978 Standard Guide for Maintenance and Rehabilitation of Ground-Water Monitoring Wells.

D5979-96 Standard Guide for Conceptualization and Characterization of Ground-Water Systems.

D5980-96 Standard Guide for Selection and Documentation of Existing Wells for Use in Environmental Site Characterization and Monitoring.

D6034-96 Standard Test Method (Analytical Procedure) for Determining the Efficiency of a Production Well in a Confined Aquifer from a Constant Rate Pumping Test.

D6089-97 Standard Guide for Documenting a Ground-Water Sampling Event.

(3) NSF

ANSI/NSF Standard 61 Drinking Water System Components -- Health Effects. NSF International, Ann Arbor, MI.

Appendix B
Explanations of Abbreviations and Terms

(a) Attachment -- the act of a bacteria or a biocolloid becoming fixed to a surface. Growth may then follow leading to the formation of biofilms.

(b) BART -- a patented biological activity reaction test biodetection system which can be customized to determine the aggressivity and composition of selected consortia of microorganisms.

(c) BCHT -- a patented blended chemical heat treatment system which can be applied to rehabilitate biofouled wells and systems by a three-step technology.

(d) Biocides -- specific chemicals or compounds which have a deleterious impact on the targeted organism.

(e) Biodegradation -- the act of degrading a molecule to one or more smaller molecules by biochemical mechanisms (e.g., enzyme action).

(f) Biofilm -- a slime-like matrix composed of extracellular polymer substances (EPS) within which a consortium of microorganisms flourish. These biofilms may either grow over surfaces, or occupy voids in a porous medium.

(g) Biofouling -- any deleterious event in which a definable biological activity causes a deterioration in an engineered or natural process or system. Deleterious effects range from clogging, corrosion, and plugging to gas production and bioaccumulation.

(1) Bioaccumulation -- any buildup of biomass, extracellular products and associated mineral and particulate matter associated with biofilm formation and development.

(2) Biocorrosion -- biologically induced or accelerated corrosion (equivalent term: microbially induced corrosion, MIC)

(h) Biomass -- the mass of a living entity which may be expressed as either the wet or dry weight. Biomass may furthermore be given as the total mass including all associated mass, or as the viable mass which would include just the viable cells. In biofilms, the total mass would relate to the total weight of the "slime" as such (which has potential application in planning maintenance treatment) while the viable mass would include just the mass directly associated with the living cells.

(i) Clogging -- the generation of a mass which interferes with physical functioning (e.g., hydraulic conductivity) of a porous medium (e.g., gravel pack, sand filter) or transmitting capacity of a device or pipe. Clogging can be formed through the maturation of biofilms fouling the media and may become complex in structure.

(j) Consortium (plural: consortia) (synonym: community) -- communities or associations, often interdependent, of microorganisms.

(k) Corrosion -- the process of erosive deterioration in the physical form and engineered characteristics of a structure. These processes frequently involve electrolytic and/or corrosive chemical (e.g., acids) effects which are sometimes mediated by microbial activities (biocorrosion or microbially induced corrosion). It has been observed that corrosive pitting can form directly under biofilms.

(l) Depositional biofouling -- biofouling resulting in the deposition of slime, metal oxide, and other material on a surface or in a porous medium (bioaccumulation).

(m) Disinfection -- the act of destroying by chemical and/or physical means microorganisms that are causing an undesirable infestation at a site. It does not mean that all microorganisms are killed; it means that there is a selective action.

(n) Encrustation -- a relatively solid plate-like or crystalline structure coating a surface. It appears to be chemical in nature due to the hardness of the structure. Often brittle (when dry) or plastic (when wet), the organic content is usually relatively small.

(o) Extracellular polymer substances (EPS or ECPS) -- a general term for exopolymers produced by many microorganisms, typical carbohydrate based, outside the cell (equivalent term, glycocalyx).

(p) Heterotrophic microorganisms -- those microbes which obtain their energy from the breaking down of organic (carbon-containing) material. Some of these microbes are very specialized (e.g., cellulose degraders) while others can utilize a variety of organic compounds.

(q) Iron oxidizing bacteria (IOB) -- those bacteria able to oxidize iron by any means from a reduced form of iron (ferrous form) to an oxidized (ferric) state. Some authorities define genuine IOB as those chemolithotrophs that oxidize iron metabolically.

(r) Iron reducing bacteria -- those bacteria which are able to reduce iron by any means from an oxidized form (ferric) to a reduced (ferrous) state.

(s) Iron related bacteria (IRB) -- all of those bacteria which are able to accumulate iron in another form beyond that for basic metabolic functioning. These accumulated iron compounds generally collect within the slime (EPS) around the cells and gradually harden (crystallize) over time.

(t) Maintenance monitoring -- as part of a preventive maintenance strategy, monitoring of system parameters to detect indicators of deteriorating conditions.

(u) Maintenance treatment -- a cleaning treatment applied in a preventive or proactive manner, typically before performance of the system is impaired.

(v) Microbially induced corrosion -- see Biofouling.

(w) Preventive Maintenance (PM) -- a management strategy of ongoing monitoring and preventive repair and replacement of components of a system or process to prevent or delay recognized deterioration.

(x) Rehabilitation -- the returning of a well or other system to its original specified state by the application of suitable treatments.

(y) Redox (Eh) -- oxidation-reduction potential (ORP). Oxidation and reduction reactions mediate the behavior of many chemical constituents in the environment. This is a relative scale of the intensity of electron donor activity, as measured between a suitable reference electrode and an inert indicator electrode, and typically expressed in terms of Eh volts or millivolts (plus or minus) in relation to the reference.

(z)Redox fringe -- a term applied to transition zones that develop in formations around working wells where the predominant ion state of metal changes from the reduced, dissolved form (e.g., MnII, FeII) to the oxidized, low-solubility form (MnIV, FeIII). This zone tends to be important as a buildup point for clogging biofouling.

(aa) Shock treatment -- the application of a higher than normal chemical dose in order to maximize the effectiveness of the treatment being applied.

(bb) Slime -- a surface growth on, or originating from, a surface which may be jelly-like in form (typically EPS). Such slimes usually include various microorganisms and can act as sites for the bioaccumulation of various chemicals.

(cc) Slime forming bacteria -- bacteria which produce slimes (from EPS), but do not necessarily (or incidentally) accumulate iron within these slimes (BART acronym “SLYM” refers to these).

(dd) Sloughing -- the act of a slime, for whatever reasons, breaking up and releasing particles (from the slime) to the water passing over the slime.

(ee) Substrate (biological) -- conceptually equivalent to available organic carbon. Also used for surfaces on which biofilms attach.

(ff) Sulfate (or sulfur) reducing bacteria (SRB) -- anaerobic bacteria able to reduce sulfate (and some other sulfur species) to hydrogen sulfide. This event may initiate electrolytic corrosion and/or rotten egg taste and odors in water.

Appendix C
Experience Basis and Maintenance Treatment Example

C-1. Case Histories of Well Maintenance Activities

Case histories are illustrative of possible problems and how they were handled elsewhere. A number of water supply system case histories are summarized in Smith (1992), Borch, Smith, and Noble (1993), and Cullimore (1993) among others. These are illustrative of the worldwide distribution of problems of wells, and, in particular, those associated with Fe, Mn, and S biofouling, and how they have been addressed. Several other geotechnical and environmental-studies case histories are summarized in Smith (1995) and Alford and Cullimore (1999) and are the basis for the following.

(1) Problems associated with wells are largely the same all over the world.

(2) Lack of planning and adequate response to deterioration problems of wells results in reduced performance of wells and water collection and distribution systems.

(3) The economic impacts of this deterioration can be significant, but are only now being quantified adequately in the water supply setting (e.g., Sutherland, Howsam, and Morris 1994), but hardly at all in the HTRW remediation field. For water supply wells, Sutherland, Howsam, and Morris (1994) estimate that 40% of wells worldwide are operating inefficiently. It is estimated that $100 million is annually spent on well and well pump rehabilitation in North America.

(4) Preventive actions useful in limiting the effects of biofouling (as documented in open literature) have not been widely applied in the planning of ground water supply and control projects to date.

(5) Design and operations poorly matched to the aquifer being pumped (e.g., choice of corrodible materials or excessive pumping) aggravate environmental well deterioration causes.

(6) Adverse well deterioration effects on the reliability of ground water quality samples have been documented.

(7) Wells operating under vacuum and anaerobically exhibit fewer clogging symptoms.

(8) Injection of biocides has largely been ineffectual in solving the immediate well problems. They almost always fail to prevent a recurrence of problems, although recurrence of performance decline may be significantly delayed.

(9) Where attention to microbial fouling potential (or the symptoms of such fouling) results in the institution of a preventive maintenance program, biofouling-related problems can be controlled (see additional case histories summarized in this section). However, programs have to be revised in response to experience with a well field over time.

(10) New well construction may serve to temporarily avoid recurrence of a problem. However, current experience is demonstrating that clogging, biofouling, and Fe/Mn/S transformations may extend several meters away from wells with existing problems. The performance problems of the former wells cannot be considered solved with new construction. The problems are likely to recur with the new wells unless a maintenance program is implemented.

C-2. Maintenance Treatment for Wells: Basic Procedure

The procedure described below is an invasive maintenance treatment procedure that has proven to be generally effective in stemming biofouling-related decline of well system performance on HTRW sites. Note that some well situations will not require Steps 1 and 2, but most do at some point. An approach similar to this has been approved at a Superfund site location in New Hampshire.

1. Detach and remove the installed well pump and other equipment such as water-level gauge transducers. Set aside, service, or replace components as needed, and clean in preparation for re-installation. NOTE: It is better to remove the pump in most situations; however, if the well pump is on the bottom, or if the well is specially equipped, the pumping system can be used for circulation.

2. Brush casing and screen and bail or pump out to remove settled and surface-attached debris in the well. Brushes should be properly sized and designed to abrade surface deposits, but not to score or gouge casing or screen materials. These are often specially shop-fabricated for specific well applications.

3. (Optional): Conduct a downhole TV survey to assess damage or material changes. Conduct the survey before brushing is started.

4. Mix a solution for treatment in clean (sediment-free) chemical-resistant tanks: In a volume of clean (potable) water three times that of the calculated volume of the well screen (including the gravel pack volume often makes for an excessively large treatment volume), add sufficient nonphosphorus anionic wetting agent to make a 1% solution and mix, add sufficient industrial-grade glacial (87%+) acetic acid sufficient to make a 12% solution (range 10 to15 %), and amend with sufficient clean, industrial grade sulfamic acid to adjust the pH to < 2 (mix well to dissolve). Oxalic or citric acids can be used in place of acetic acid for heavy iron oxide encrustation in waters with less than about 120 to150 mg/L total hardness. Adjust pH as needed by adding acid. NSF International listed products are available for some of these applications.

NOTES:

Always add acids to water and not vice-versa. While relatively safe to handle, all the chemicals specified can cause chemical burns of skin, eyes, and respiratory tissues if mishandled. Anyone handling well treatment chemicals should have specific training for this purpose, and equipment should be supplied to minimize the potential for accidental spills or human exposure.

Both acetic acid and sulfamic acid are readily available from conventional chemical supply sources. While costly in relation to some acid products, acetic acid has the advantage of having some disinfection properties, is not highly reactive with metals and metal oxides (in contrast to mineral acids), and is the best detergent acid. Sulfamic acid is inexpensive and a readily transportable and storable solid. Both acetic and sulfamic acids are Class 55 detergents (nonhazardous), which adds flexibility in transport.

Highly concentrated acetic acid solutions freeze below about 12^{o} C (~ 55^{o} F) and should be kept above this temperature prior to mixing. Dilute treatment solutions have much lower freezing temperatures far below most ambient ground water temperatures. Where this may be critical (as in application under very cold surface conditions into near-freezing ground water), those conducting treatment should calculate the freezing points of dilute solutions. Hot water can be mixed with acetic acid to avoid freezing, or more dilute solutions can be used.

Constant rate pumping tests and slug tests (in which an instantaneous charge of water or a solid object is introduced into a well)

All surfaces potentially in contact with cleaning solution should be nonreactive with its components. Chemical-resistant hose, stainless steel, PVC, and high density polyethylene (HDPE) plastics in tanks, fittings, and pumps will provide good service.

5. After batch mixing, tremie into the screen zone by gravity from the bottom up across the screen surface. Apply very slowly (~ 10 gpm (~ 0.0379 cu m/min)) through a 1- to 2-in. (2.54- to 5.08-cm) -diameter pipe made of nonreactive materials.

6. Surge in place and leave overnight (12 to 24 hr). Do not leave in place more than a weekend.

NOTE: Surge tool and applications of conventional ground water technology for well development surging apply to HTRW well cleaning. For example, surge blocks should have size and weight to permit a 1- to 2-ft/sec (0.3- to 0.6- m/sec) fall.

VARIATION (pump in place): Remove the well cap, disengage pitless adapter, and pull up pumping discharge assembly to surface. Use a reversible friction pump puller to move the pump slowly up and down to provide a surging action. Pump at a low rate during surging, recirculating back down the well (monitor pH - treatment is finished if pH rises above about 5 or if water clears). Note: Watch for lockup and stop immediately if it occurs.

7. If satellite wells are installed around a pumping or injection well for treatment application (highly recommended), treat each 2- to 4-in (5.08- to 10.16-cm) -diameter well with a solution as in step 4, but six times the satellite well's screen diameter. Surge in place and leave overnight (see step 6).

8. For both the target and satellite wells, sound wells to determine depth and safety to insert development tools. Surge and pump to containment and necessary pretreatment prior to release to water/wastewater treatment. Release water should pass through the site's remediation treatment facility prior to release to the open environment.

NOTES:

Know the specific release and treatment requirements of the jurisdiction, project, and site.

Check pH and treat as needed to within 1 pH of background (pH 6.5 to 8.5 for wastewater treatment plants).

Tanks for containment should be sufficient in size to handle the expected discharge water volume requiring treatment without shutting down development. The system for neutralizing should permit continuous and not batch treatment.

If site remedial treatment is digestive, expect a radical increase in BOD and COD. Expect and plan for pretreatment for a large increase in mineral and encrustation-debris solids content.

9. Continue surging until a set standard for clarity is met (standard set realistically based on site experience. Some standards used are < 5 NTU turbidity, < 5 ppm sediment, and a predetermined percent recovery of specific capacity. Sound wells periodically and remove accumulated debris. Examine to determine the nature of solids (filter pack? formation?). If excessive filter pack is brought in, examine with downhole TV to determine if a screen or casing breach has occurred.

NOTE: This can be a lengthy process, especially if wells were not developed sufficiently when installed, or during remediation attempts. Frequent maintenance treatments should reduce the necessary development time considerably.

10. Reassemble, install, and test the pump and in-well instrumentation and return to service.

11. Benchmark biofouling and performance indicators using methods suggested.

12. Clean and make necessary repairs to treatment equipment.

C-3. Treatments for Heavily Impacted Wells

a. While the intended scope of this EP is the maintenance of well system performance, it is recognized that O&M personnel will usually find themselves in the situation of rehabilitating wells and systems that have deteriorated in performance. Rehabilitative treatments have many similarities to maintenance treatments such as the example outlined in paragraph C-2. Such treatments are summarized in Driscoll (1986), Borch, Smith, and Noble (1993), Cullimore (1993), Smith (1995). One such treatment summarized in Alford and Cullimore (1999) focuses on HTRW remediation applications.

b. Rehabilitation treatments outlined in these publications typically can be applied using adaptations of conventional ground water technology equipment. In addition, well rehabilitation has a number of specialty tool, equipment, supply, and service vendors. An attempt has been made to offer information on and Internet links to sites on well rehabilitation from the "Groundwater Science" website <http://www.groundwatersystems.com>.

Appendix D
Examples of Logs, Checklists, Calculations.

a. General: The logs and checklists in this appendix are provided as examples. Projects and service providers typically have existing forms that they use. Records can be kept in any convenient paper and/or electronic form with redundancy. Field checklists for well maintenance treatment should include at least the information asked for in the example. It may be useful to divide checklists into specialty topics, for example, separate pumping test, mechanical development, chemical dosing, and chemical treatment forms. The pumping test analysis diagrams provided are generated from a pumping test analysis computer program.

b. Calculations: A copy of Appendix 11.L of Driscoll (1986) is provided for calculation of volumes in well casings and screens. Generally, screen pipe size volume x 1.5 is a safe volume figure to use for treatment chemicals in maintenance. To calculate acid in pounds:

(1) Dry: well volume (WV) x 8.3 (convert water volume to lb) x (% acid/%active acid).
Example for a 10 % solution: 110 gal x 8.3 x (0.10/0.75) = 121.73 lb

(2) Liquid (gal): (WV x % acid)/(% available acid in solution).
Example for a 10 % solution from 84 % available acid stock:
110 gal x 0.10/0.84 = 13 gal of stock chemical

Note: Chemical suppliers may list acid solutions by weight. Suppliers can provide the specific gravity or weight per volume of the stock solution needed.

c. Plates D-1 through D-13 are examples of logs and checklists to help collect and organize data. The checklists are presented as aids but are not all-inclusive since each site has site-specific data.

EXTRACTION WELL PUMPING TEST DATA

CONTRACT DACW45-92-C-0156
OTT/STORY/CORDOVA SUPERFUND SITE
NORTH MUSKEGON, MICHIGAN

WELL:	DATE:						
DRAWDOWN AND FLOW MEASUREMENTS							
TIME	ELAPSED TIME (min)	METER READING (gal)	DEPTH TO WATER (ft) FILTER PACK	DEPTH TO WATER (ft) INNER REHAB WELL	DEPTH TO WATER (ft) SATELLITE WELL	DEPTH TO WATER (ft) SATELLITE WELL	DEPTH TO WATER (ft) ADJACENT WELL

OTHER DATA			
TOTAL PUMPED (gal)	TOTAL TEST DURATION (min)	AVERAGE FLOW RATE (gpm)	FINAL DRAWDOWN (ft)
SPECIFIC CAPACITY (gpm/ft)	FLOW METER IDENTIFICATION NUMBER	WELL WATER pH AFTER TEST	FINAL WATER TEMP. (°F)
WELL DEPTH BEFORE TEST (ft)	WELL DEPTH AFTER TEST (ft)	SAND IN DISCHARGE ? (YES or NO)	SAND CONCENTRATION (ppm)
AS-BUILT SPECIFIC CAPICITY (gpm/ft)	AS-BUILT WATER TABLE (ft. msl)	DATE INSTALLED (ORIGINAL)	

REMARKS

_______________________________ DATE

____ SIGNATURE OF QUALITY CONTROL REPRESENTATIVE

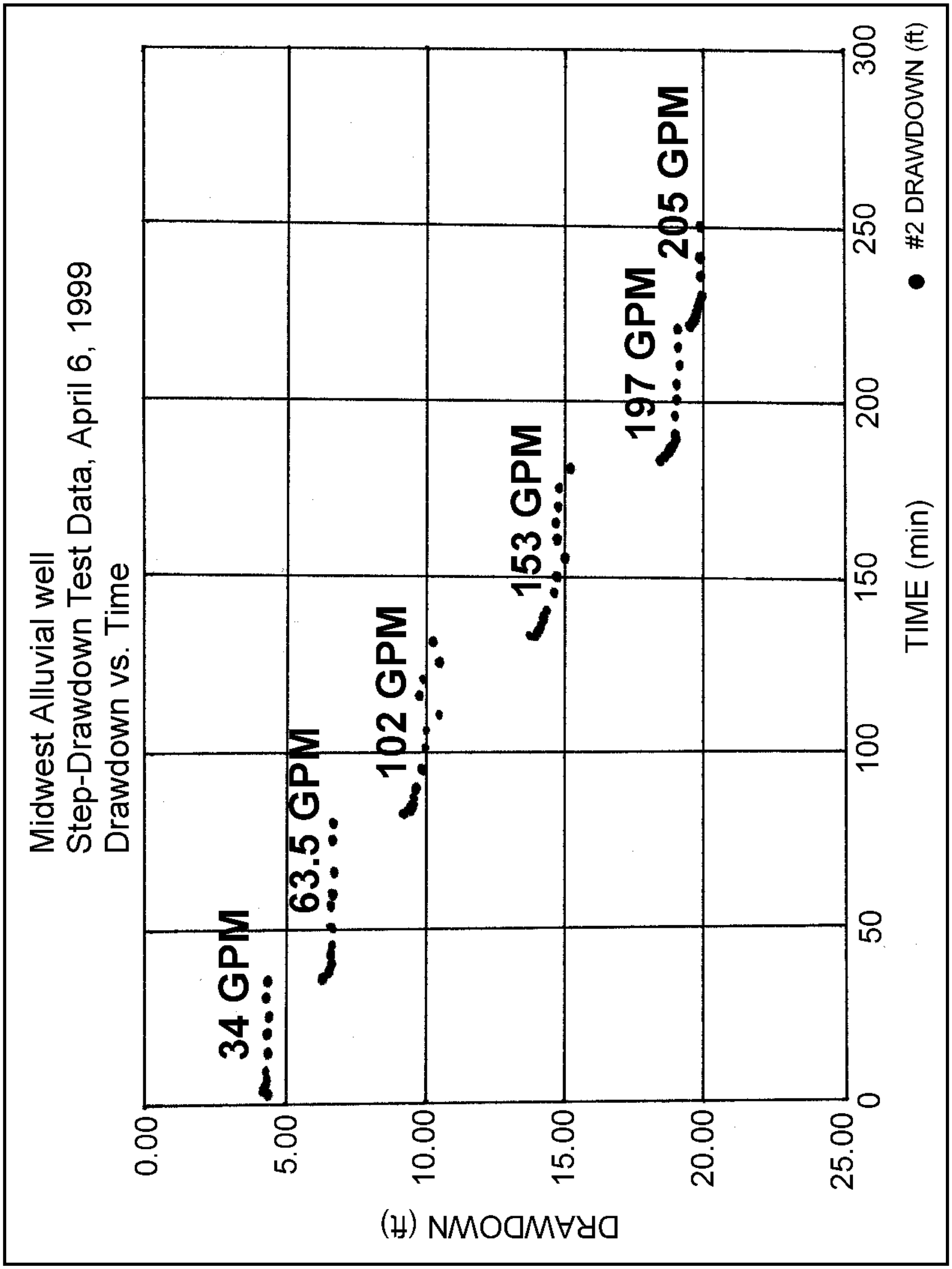

Midwest Alluvial well
Step-Drawdown Test Data, April 6, 1999
Drawdown vs. Time
34 GPM
63.5 GPM
102 GPM
153 GPM
197 GPM
205 GPM
DRAWDOWN (ft)
0.00
5.00
10.00
15.00
20.00
25.00
0
50
100
150
200
250
300
TIME (min)
#2 DRAWDOWN (ft)

Plate D-2

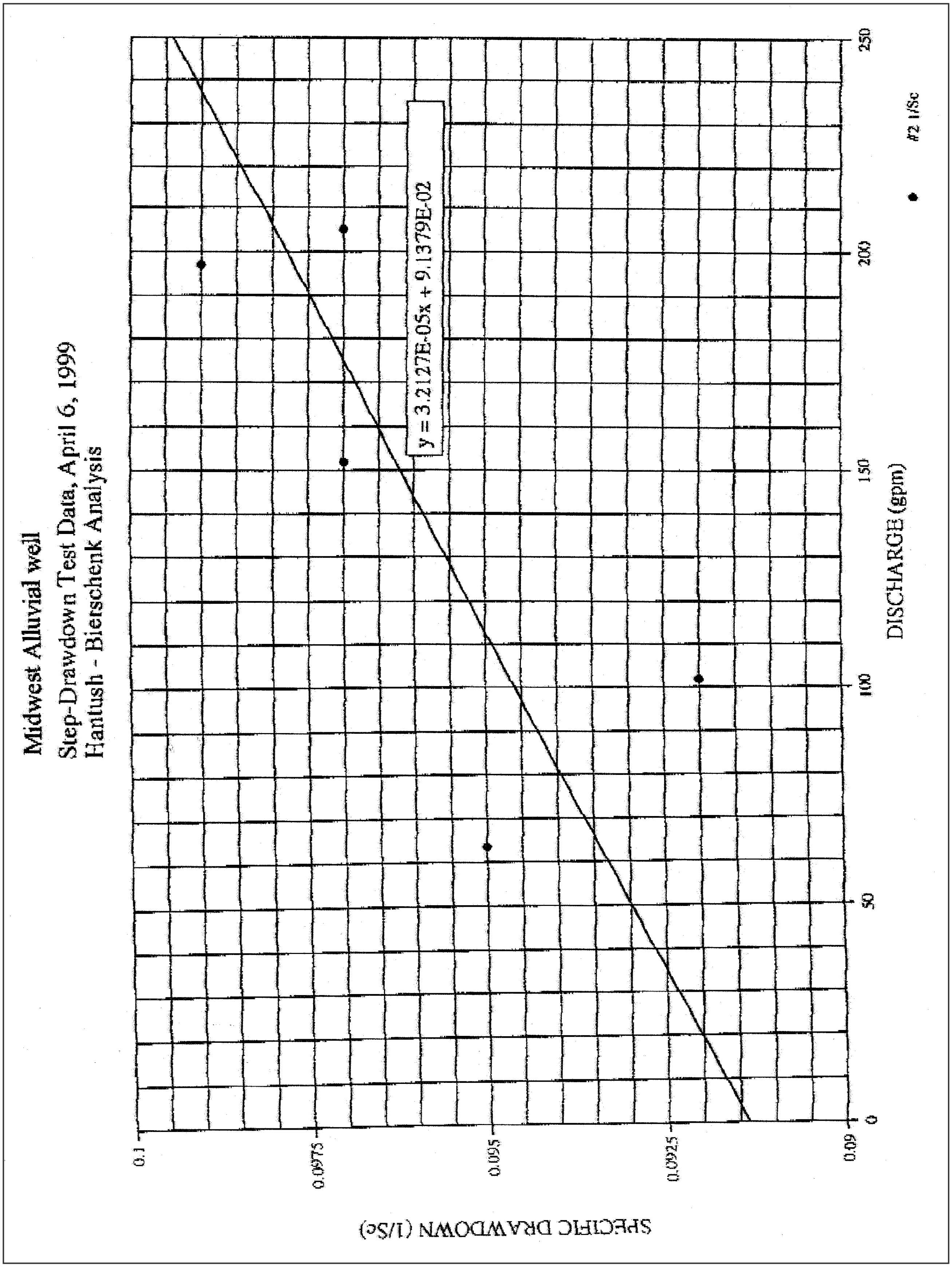

Midwest Alluvial well
Step-Drawdown Test Data, April 6, 1999
Hantush - Bierschenk Analysis
y = 3.2127E-05x + 9.1379E-02
DISCHARGE (gpm)
SPECIFIC DRAWDOWN (1/Sc)
0
50
100
150
200
250
0.09
0.0925
0.095
0.0975
0.1
#2 1/Sc

Plate D-3

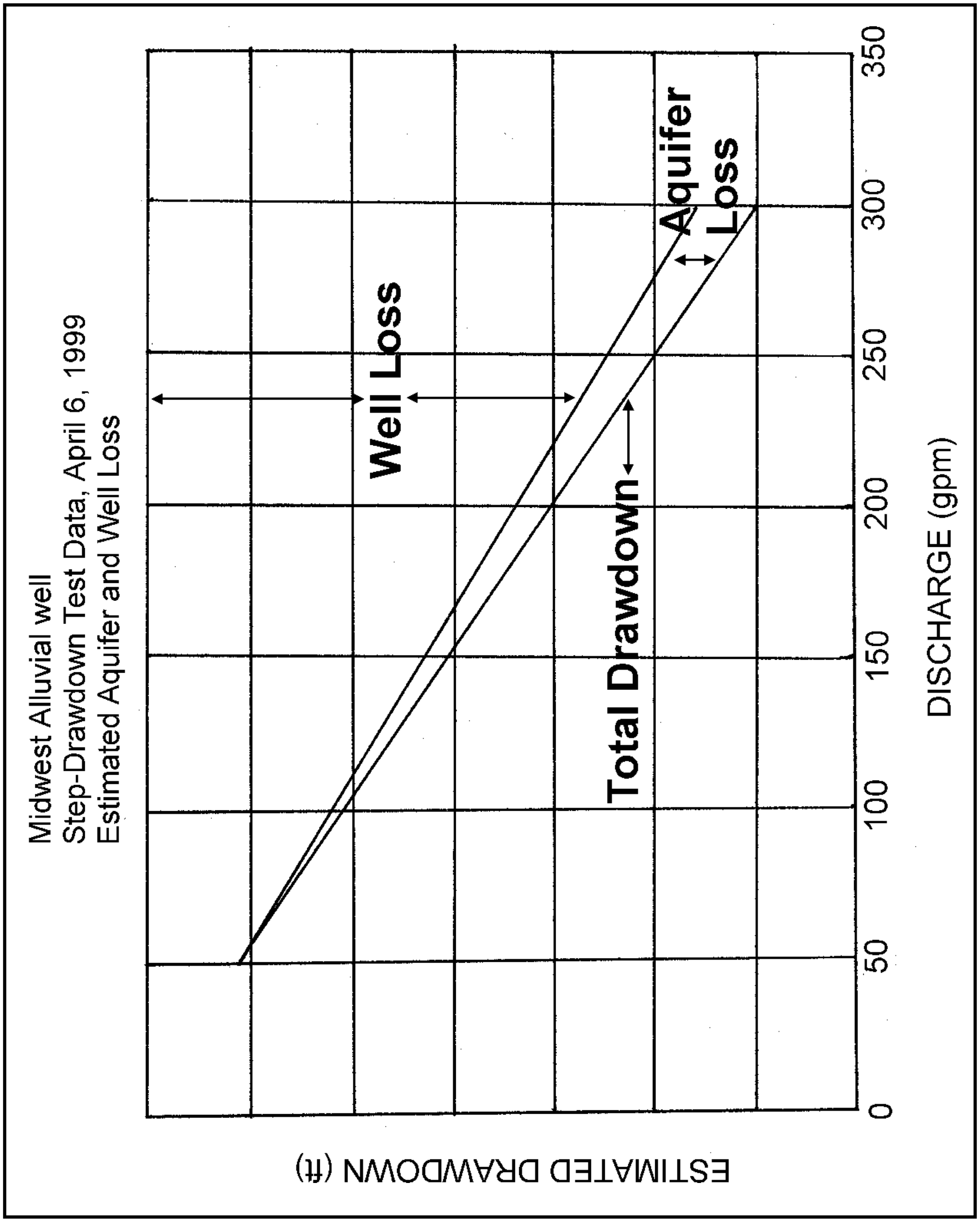

Midwest Alluvial well
Step-Drawdown Test Data, April 6, 1999
Estimated Aquifer and Well Loss
Well Loss
Aquifer Loss
Total Drawdown
ESTIMATED DRAWDOWN (ft)
DISCHARGE (gpm)
0
50
100
150
200
250
300
350

Plate D-4

Volume of Water in Casing or Hole*

Diameter of casing or hole (in)**	Gallons per foot of water column**	Cubic feet per foot of water column**	Liters per meter of water column**	Cublic meters per meter of water column**
2	0.163	0.0218	2.024	2.02×10^{-3}
4	0.653	0.873	8.11	8.11×10^{-3}
5	1.02	0.1364	12.67	12.67×10^{-3}
6	1.469	0.1963	18.24	18.24×10^{-3}
7	2	0.2673	24.84	24.84×10^{-3}
8	2.611	0.3491	32.43	32.43×10^{-3}
10	4.08	0.5454	50.67	50.67×10^{-3}
11	4.937	0.66	61.31	61.31×10^{-3}
12	5.875	0.7854	72.96	72.96×10^{-3}
14	8	1.069	99.35	99.35×10^{-3}
16	10.44	1.396	129.65	129.65×10^{-3}
18	13.22	1.767	164.18	164.18×10^{-3}
20	16.32	2.182	202.68	202.68×10^{-3}
24	23.5	3.142	291.85	291.85×10^{-3}
34	47.16	6.305	585.68	585.68×10^{-3}
36	52.88	7.069	656.72	656.72×10^{-3}

* After Driscoll (1986) Appendix 11.L.
** 1 in = 25.4 mm.
1 gallon = 3.785 L.
1 meter = 3.281 ft.
1 gallon water weighs 8.33 lb = 3.785 kg.
1 L water weighs 1 kg = 2.205 lb.
1 gallon per ft of depth = 12.419 L per ft of depth
1 gallon per m of depth = 12.419×10^{-3} cubic m per m of depth.

EXTRACTION, INJECTION, AND MONITORING WELLS
12/16/99

Introduction

This checklist is meant to evaluate the adequacy of maintenance of the extraction and monitoring wells on site. The adequacy of the extraction system should be evaluated using the Ground Water Extraction Subsurface Performance Checklist. The adequacy of the monitoring network should be evaluated using the Environmental Monitoring Checklist.

References

EM 1110-1-4000 Monitor Well Design, Installation, and Documentation at HTRW Sites
ETL 1110-1-201 Ground Water Extraction

Current Operating Conditions and/or Configuration

Record any deviations from as-builts ____
____
____

Adequacy of Operations and Maintenance:

Wellheads Protected from Standing Surface Water? ____
Is there settlement around the well (i.e. due to inadequate compaction or aquifer consolidation)? ____
Above-ground wellheads painted and clearly labeled? ____
Vault covers and vaults in good repair and clearly labeled? ____
Wellhead enclosures painted, well maintained, and clearly labeled? ____
Are concrete pads around the well in good condition? ____
Has there been physical damage to the well? ____
Is there evidence for frost heave/jacking of the protective casing or well casing? ____
Is there a regular program for evaluating the performance of the well (check specific capacity and accumulated sediment)? ____
Is there evidence of degradation of well performance? ____
What was the original specific capacity and how does it compare to the current capacity?
Is there a regular program to evaluate down hole conditions (e.g., camera survey) ____
Have BART tests or other bacteriological tests been utilized to evaluate biofouling? ____
For injection wells only, has the treated/injection water been tested for the potential to cause inorganic precipitation? ____
Is there a regular well maintenance program? ____
If so, What is the well maintenance protocol: ____
____
Can the prescribed well maintenance be carried out given the layout of the well and the available personnel and equipment? ____
When was the well last developed and when will it be redeveloped? ____
Is there evidence of well or drop pipe corrosion? ____
Is there an up-to-date logbook for recording performance & maintenance for each extraction well? ____
How many gallons of water has the well pumped since it was installed? ____
Is there a maintenance schedule for the pump and how is it documented? ____
Has there been excessive pump wear noticed due to sediments? ____
Are all of the flow meters/totalizers in good working order? ____
Is there an inventory of appropriate spare parts for the pumps and related equipment? ____
Is there evidence suggesting the lines between the wells and the plant are occluded? ____

Problems to Watch For

Well siltation (fine material enters the well and settles to the bottom, ultimately occluding the screen) *Solution: periodic sounding of the well and bailing the sediment when it reaches a certain height above the bottom cap.*
Well encrustation or fouling (common problem, scale or biological growth forms on well screen, reducing open area and increasing water entrance velocities, typically manifested by reduced specific capacity of the well). *Solution: periodic rehabilitation when the specific capacity decreases to a predetermined level according to a protocol appropriate for the cause of the reduced capacity.*
Physical damage to the well due to frost, vehicles, vandalism (can limit or prevent use of the well, compromise integrity of the well and allow contaminated surface water to migrate to the subsurface). *Solution: inspection and repair. Severe damage can require well replacement. Damaged well must be decommissioned in accordance with state requirements.*
Excess sand/turbidity production even after extensive redevelopment (due to corrosion, inadequate design of filter pack and/or screen). *Solution: well replacement. Other alternatives (e.g., selective pressure grouting of an affected zone or blank casing / small-slot screen inserts) could be considered for very expensive/deep wells but may not result in adequate well performance.*

Process Monitoring

Not Applicable

Alternatives for Possible Cost Savings

Extraction Wells:
Consider the following alternative
- Extraction trenches (have increased intake area, lower entrance velocities.
- Treatment walls or wells (see Ground Water Extraction Technology checklist)

Monitoring Wells
- Buried Sensors
- SeaMIST
- Direct Push Probes

Facility/Project Name	Local Grid Location of Well ______ m. ☐ N. ☐ S. ______ m. ☐ E. ☐ W.	Well Number
Facility License, Permit or Monitoring Number	Grid Origin Location Lat. ___ ___ ___ Long. ___ ___ ___ or	Date Well Installed (Start)
Type of Protective Cover: Above-Ground ☐ Flush-To-Ground ☐	St. Plane ______ m. N. ______ m. E.	Date Well Installed (Completed)
Well Distance From Waste/Source Boundary	Section Location of Waste/Source ___ ¼ of ___ ¼ of Sec. ___ T. ___ N.R. ___ ☐ E. ☐ W.	Well Installed By: (Person's Name & Firm) ______ ______
Maximum Depth of Frost Penetration (estimated)	Location of Well Relative to Waste/Source u ☐ Upgradient s ☐ Sidegradient d ☐ Downgradient n ☐ Not Known	

Note: Use top of casing (TOC) for all depth measurements.

A. Protective casing, top elevation ______ m. MSL
B. Well casing, top elevation ______ m. MSL
C. Land surface elevation ______ m. MSL
D. Surface seal, bottom ______ m. TOC or ______ m. MSL

16. USCS classification of soil near screen:
GP ☐ GM ☐ GC ☐ GW ☐ SW ☐ SP ☐
SM ☐ SC ☐ ML ☐ MH ☐ CL ☐ CH ☐
Bedrock ☐

17. Sieve analysis attached? ☐ Yes ☐ No

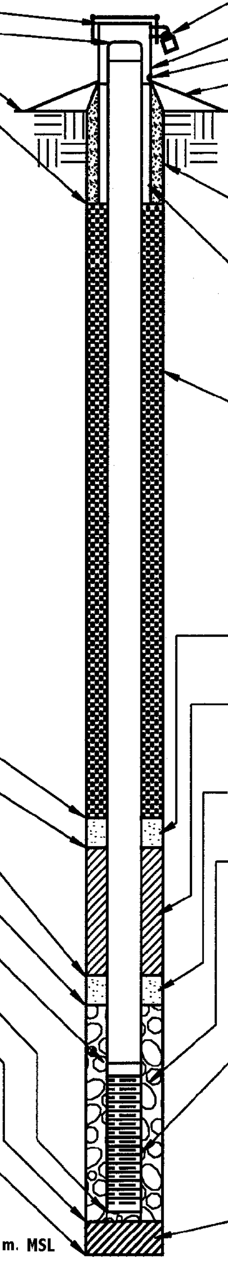
18. Drilling method used: Rotary ☐ Hollow Stem Auger ☐ ______ Other ☐

19. Drilling fluid used: Water ☐ Air ☐ Drilling Mud ☐ None ☐

20. Drilling additives used? ☐ Yes ☐ No
Describe ______

21. Source of water (attach analysis):
______

E. Secondary filter, top ______ m. TOC or ______ m. MSL
F. Bentonite seal, top ______ m. TOC or ______ m. MSL
G. Secondary filter, top ______ m. TOC or ______ m. MSL
H. Primary filter, top ______ m. TOC or ______ m. MSL
I. Screen joint, top ______ m. TOC or ______ m. MSL
J. Well bottom ______ m. TOC or ______ m. MSL
K. Filter pack, bottom ______ m. TOC or ______ m. MSL
L. Borehole, bottom ______ m. TOC or ______ m. MSL
M. Borehole, diameter ______ mm.
N. O.D. well casing ______ mm.
O. I.D. well casing ______ mm.
P. 24-hr water level after completion ______ m. TOC or ______ m. MSL



1. Cap and lock? ☐ Yes ☐ No
2. Protective posts? ☐ Yes ☐ No
3. Protective casing:
   a. Inside diameter: ______ mm.
   b. Length: ______ m.
4. Drainage port(s) ☐ Yes ☐ No
5. Surface seal:
   a. Cap — Gravel blanket ☐ Bentonite ☐ Concrete ☐ ______ Other ☐
   b. Annular space seal: Bentonite ☐ Cement ☐ ______ Other ☐
6. Material between well casing and protective casing: Bentonite ☐ Cement ☐ ______ Other ☐
7. Annular space seal: a. Granular Bentonite ☐
   b. ___ Lbs/gal mud weight .. Bentonite-sand slurry ☐
   c. ___ Lbs/gal mud weight .... Bentonite slurry ☐
   d. ___ % Bentonite .... Bentonite-cement grout ☐
   e. ______ m^3 volume added for any of the above
   f. How installed: Tremie ☐ Tremie pumped ☐ Gravity ☐
8. Centralizers ☐ Yes ☐ No
9. Secondary Filter ☐ Yes ☐ No
   a. Volume added ______ m^3 ______ Bags/Size
10. Bentonite seal: a. Bentonite granules ☐
    b. ☐ ¼in. ☐ ⅜in. ☐ ½in. Bentonite pellets ☐
    c. ______ Other ☐
11. Secondary Filter ☐ Yes ☐ No
    a. Volume added ______ m^3 ______ Bags/Size
12. Filter pack material: Manufacturer, product name & mesh size
    a. ______
    b. Volume added ______ m^3 ______ Bags/Size
13. Well casing: Flush threaded PVC schedule 40 ☐ Flush threaded PVC schedule 80 ☐ ______ Other ☐
14. Screen material: ______
    a. Screen type: Factory cut ☐ Continuous slot ☐ ______ Other ☐
    b. Manufacturer ______
    c. Slot size: 0. ______ in.
    d. Slotted length: ______ m.
15. Backfill material (below filter pack): None ☐ ______ Other ☐

EXTRACTION WELL CLEANING DATA
CONTRACT DACW45-92-C-0156
OTT/STORY/CORDOVA SUPERFUND SITE
NORTH MUSKEGON, MICHIGAN

EXTRACTION WELL	INITIAL DEPTH (FT)	AS-BUILT DEPTH (FT)	DATE

ACID TREATMENTS

ACID BLEND	

BACKGROUND WATER TEMP (• F)		BACKGROUND WATER pH		

					STARTING ACID			END 10' ZONE		
ZONE WORK PERFORMED	START TIME	END TIME	START WELL DEPTH (FT)	ACID BLEND VOL. (GAL)	pH	TEMP. (• F)	PRES S (PSI)	pH	WELL DEPTH (FT)	TEMP. (• F)

REMARKS

____________________ DATE

____________________ SIGNATURE OF QUALITY CONTROL REPRESENTATIVE

Plate D-8

EXTRACTION WELL DEVELOPMENT DATA
CONTRACT DACW45-92-C-0156
OTT/STORY/CORDOVA SUPERFUND SITE
NORTH MUSKEGON, MICHIGAN

EXTRACTION WELL	INITIAL DEPTH (FT)	AS-BUILT DEPTH (FT)	DATE

ACID TREATMENTS			
ACID BLEND			
BACKGROUND WATER TEMP (°F)		BACKGROUND WATER pH	

SURGING DATA					
ZONE WORKED PERFORMED	START TIME	END TIME	STARTING DEPTH (FT)	ENDING DEPTH (FT)	ENDING pH

WELL DEPTH BEFORE (FT)		WELL DEPTH AFTER (FT)		FINAL WATER pH	

REMARKS

______________________________ DATE

______________________________ SIGNATURE OF QUALITY CONTROL REPRESENTATIVE

WELL SERVICE RECORD

Job designation ______________________ Date started ______________________

Customer ______________________ Date finished ______________________

Job address ______________________ City ______________________ State ______

Work performed ____

Personnel ____

Checklist

__Surface facility inspection | __Pump test | __Pump removal, service, reset | __Well pumping test (pre-) | Type of test:: ______________________

__Mechanical well redevelopment | Type: ______________________ | __Well pumping test (post) | Type of test: ______________________

__Chemical well treatment | Type: ______________________

__Additional service | Type: ______________________

Describe equipment used ____

Well: ____________ Dimensions and capacities

Construction date		Well Depth		Casing diameter	
Original yield		Pump type		Screen slot size (state units)	
Current yield		Casing material		Screen diameter	
Original Q/s		Screen material		Screen length	
Q/s before action (@ what gpm)		Q/s after action @		Filter pack description	

Activity

Action description	Time interval	Dimensions	Notes/comments:

Sheet _1_ of ___

Signature and date (print name and title):

WELLS CONTRACTING LP *Groundwater Contractors*
345 Pumphoist Circle/St. Joseph, OH 46001/740-555-5555

WELL SERVICE RECORD

Job designation	Oil City routine maintenance	**Date started**	7/22/1999
Customer	Oil City Properties LLC	**Date finished**	7/24/1999
Job address	666 Lucky Ln	**City** Sweetwater	**State** WV

Work performed Scheduled well cleaning and pump service
Personnel Jeff Friederhorst, foreman; Ken Wells, journeyman

Checklist

__Surface facility inspection	**__Pump test**	**__Pump removal, service, reset**	**__Well pumping test (pre-)**	**Type of test::**	
__Mechanical well redevelopment	**Type:**	Surge and pump	**__Well pumping test (post)**	**Type of test:**	Specific capacity
__Chemical well treatment	**Type:**	Acetic + CB4	10 % sol.		
__Additional service	**Type:**	Fixed faulty	controller		
Describe equipment used		Surge block w/	pump		

Well: South pumping array PW-15 **Dimensions and capacities**

Construction date	5/1990	Well Depth	95 ft	Casing diameter	8 _
Original yield	127 gpm	Pump type	Goulds 50L	Screen slot size (state units)	0.040 in
Current yield	118 gpm	Casing material	PVC	Screen diameter	6 _
Original Q/s	13 gpm/ft	Screen material	315 stainless	Screen length	20.5 ft
Q/s before action (@ what gpm)	10 gpm/ft	Q/s after action @	12 gpm/ft	Filter pack description	3-in annular r. 0.060 silica

Activity

Action description	Time interval	Dimensions	Notes/comments:	
Checked equipment, power	13:15-13:45		All nominal	
Checked records, talked to site supervisor	13:45-14:00		Nothing new	
Pulled pump	14:00-14:30	45 ft of line	Covered in iron	bacteria
Steam clean pump	14:40-16:00		Cleaned up good	
Run in surge	14:40-15:00	In screen		
Run block	15:00-16:00	5 ft interval	7 min per section	
Shut down				
Start up surge	7:30			
Mix chemicals	7:40-9:00		60 gal H2O, 7 gal	84% acetic + .5 gal CB4 + 1 lb sulfamic
Pump in load	9:00-9:15			
Start on PW-18				
Surge	12:30-14:30			

Sheet 1 of __
Signature and date (print name and title):

HTRW DRILLING LOG	DISTRICT			HOLE NUMBER
1. COMPANY NAME	2. DRILLING SUBCONTRACTOR			SHEET OF SHEETS

3. PROJECT	4. LOCATION
5. NAME OF DRILLER	6. MANUFACTURER'S DESIGNATION OF DRILL
7. SIZES AND TYPES OF DRILLING AND SAMPLING EQUIPMENT	8. HOLE LOCATION
	9. SURFACE ELEVATION
	10. DATE STARTED / 11. DATE COMPLETED
12. OVERBURDEN THICKNESS	15. DEPTH GROUNDWATER ENCOUNTERED
13. DEPTH DRILLED INTO ROCK	16. DEPTH TO WATER AND ELAPSED TIME AFTER DRILLING COMPLETED
14. TOTAL DEPTH OF HOLE	17. OTHER WATER LEVEL MEASUREMENTS (SPECIFY)

18. GEOTECHNICAL SAMPLES	DISTURBED	UNDISTURBED	19. TOTAL NUMBER OF CORE BOXES			
20. SAMPLES FOR CHEMICAL ANALYSIS	VOC	METALS	OTHER (SPECIFY)	OTHER (SPECIFY)	OTHER (SPECIFY)	21. TOTAL CORE RECOVERY %
22. DISPOSITION OF HOLE	BACKFILLED	MONITORING WELL	OTHER (SPECIFY)	23. SIGNATURE OF INSPECTOR		

LOCATION SKETCH/COMMENTS

SCALE:

PROJECT	HOLE NO.

Sheet 1 of 2

Plate D-12

HTRW DRILLING LOG (CONTINUATION SHEET)

HOLE NUMBER		
PROJECT	INSPECTOR	SHEET OF SHEETS

ELEV. (a)	DEPTH (b)	DESCRIPTION OF MATERIALS (c)	FIELD SCREENING RESULTS (d)	GEOTECH SAMPLE OR CORE BOX NO. (e)	ANALYTICAL SAMPLE NO. (f)	BLOW COUNT (g)	REMARKS (h)

PROJECT	HOLE NO.

ENG FORM 5056A-R, AUG 94

(Proponent: CECW-EG)

Plate D-12

HTRW DRILLING LOG

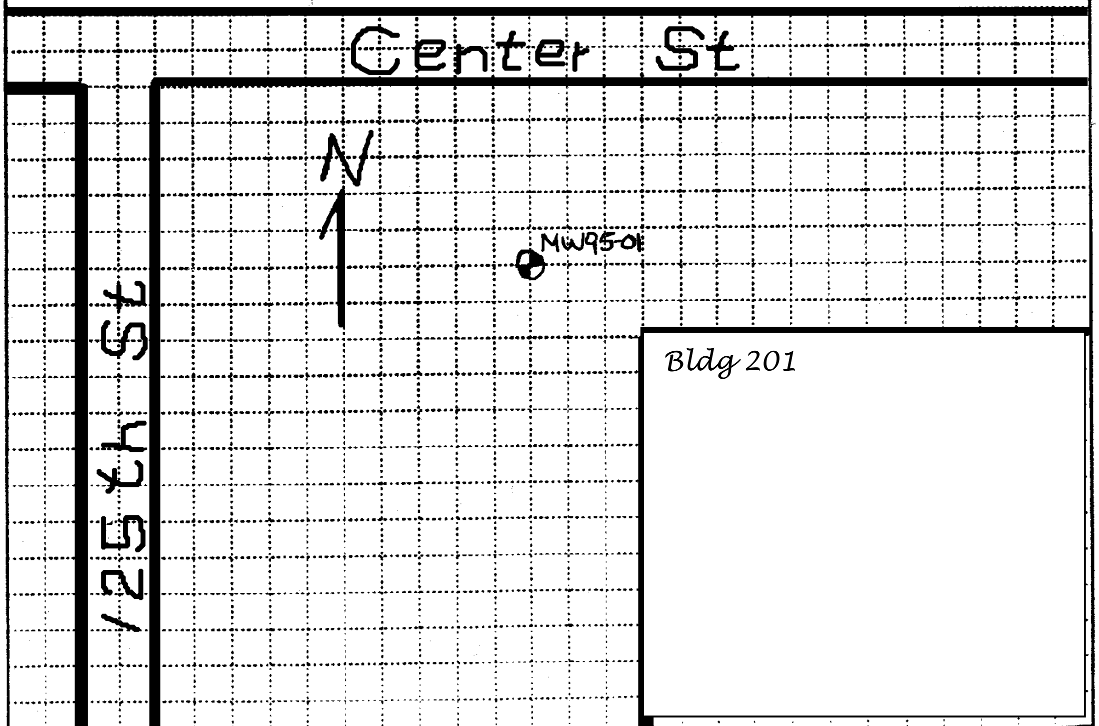
DISTRICT	OMAHA
HOLE NUMBER	MW95-01
1. COMPANY NAME	CONTRACTING FIRM, INC.
2. DRILL SUBCONTRACTOR	SUBCONTRACT DRILLERS, INC
SHEET / SHEETS	1 OF 3
3. PROJECT	BIG SUPERFUND SITE
4. LOCATION	Site A
5. NAME OF DRILLER	JOE SUPER DRILLER
6. MANUFACTURER'S DESIGNATION OF DRILL	CME-75 Milwaukee Heavy Duty Drill Rig
7. SIZES AND TYPES OF DRILLING AND SAMPLING EQUIPMENT	CME-75, using 4 1/4" hollow stem augers, 3" O.D. stainless steel split-spoons (chemical and geotech), bullet bit (outer) drag bit (inner)
8. HOLE LOCATION	See Map Below
9. SURFACE ELEVATION	Not Yet Available
10. DATE STARTED	8-6-95
11. DATE COMPLETED	8-7-95
12. OVERBURDEN THICKNESS	12.0'
13. DEPTH DRILLED INTO ROCK	ϕ
14. TOTAL DEPTH OF HOLE	12.0'
15. DEPTH GROUNDWATER ENCOUNTERED	5.0'
16. DEPTH TO WATER AND ELAPSED TIME AFTER DRILLING COMPLETED	4.5' TOC ~72 hours (in well)
17. OTHER WATER LEVEL MEASUREMENTS (SPECIFY)	

18. GEOTECHNICAL SAMPLES	DISTURBED	UNDISTURBED	19. TOTAL NUMBER OF CORE BOXES		
	ϕ	ϕ	ϕ		

20. SAMPLES FOR CHEMICAL ANALYSIS	VOC	METALS	OTHER (SPECIFY)	OTHER (SPECIFY)	OTHER (SPECIFY)	21. TOTAL CORE RECOVERY
			BTEX 4x4oz	TRPH 2x8oz	Lead 2x8oz	ϕ %

22. DISPOSITION OF HOLE	BACKFILLED	MONITORING WELL	OTHER (SPECIFY)	23. SIGNATURE OF INSPECTOR
		8-6-92		Field Geologist

LOCATION SKETCH/COMMENTS SCALE: 1" = 20'



PROJECT	HOLE NO.
BIG SUPERFUND SITE	MW95-01

ENG FORM 5056-R, AUG 94 (Proponent: CECW-EG)

Sheet 1 of 3

Plate D-13

HTRW DRILLING LOG (CONTINUATION SHEET)

HOLE NUMBER: MW95-01

PROJECT: BIG SUPERFUND SITE | INSPECTOR: Field Geologist | SHEET 2 OF 3 SHEETS

ELEV. (a)	DEPTH (b)	DESCRIPTION OF MATERIALS (c)	FIELD SCREENING RESULTS (d)	GEOTECH SAMPLE OR CORE BOX NO. (e)	ANALYTICAL SAMPLE NO. (f)	BLOW COUNT (g)	REMARKS (h)
	0 – 2	SC - Clayey Sand, medium dense, nonplastic, noncemented, dry, medium brown, fine grained, sub-rounded, 15-20% pieces of concrete	Calibrated Hnu w/ isobutylene at 55 ppm at 190 psi. BACKGROUND = 0.8 BREATH = 0.8 SCREEN = 0.9	0.0 – 1.3'; NO SAMPLE OR RECOVERY	S-MW01-02/BT 2x4oz jar; -02/T 1x8oz jar; -02/L 1-8oz jar	5, 10, 12, 12	Drilling in cow pasture - numerous manure piles - may be increasing Hnu readings. N (Blow) = 22. Rec (Recovery) = 1.3'. TIME - 1012
	3 – 5	SC - Clayey sand, same as above	BREATH = 0.8 SCREEN = 0.7	3.0' – 4.8'		9, 9, 12, 11	N = 21. Rec = 1.8'. Time - 1019
	5 – 8						Plug came off end of central rod. Tried driving split spoon - no recovery. Offset ~1.5' and drilled back down to 8.0'
	8 – 10	CL - Sandy Lean clay, stiff, low to medium plastic, noncemented, moist, ~15% very fine-grained sand, dark brown. SP - Poorly Graded sand, loose, non-plastic, noncemented, dry to slightly moist, light brown to white, very fine to fine-grained		8.0' – 10.0'		2, 4, 5, 6	N = 9. Rec = 2.0'. TIME = 1048

PROJECT: BIG SUPERFUND SITE | HOLE NO. MW95-01

ENG FORM 5056A-R, AUG 94 (Proponent: CECW-EG)

Sheet 2 of 3

Plate D-13

HTRW DRILLING LOG (CONTINUATION SHEET)

HOLE NUMBER: MW95-01

PROJECT: BIG SUPERFUND SITE | INSPECTOR: Field Geologist | SHEET 3 OF 3 SHEETS

ELEV. (a)	DEPTH (b)	DESCRIPTION OF MATERIALS (c)	FIELD SCREENING RESULTS (d)	GEOTECH SAMPLE OR CORE BOX NO. (e)	ANALYTICAL SAMPLE NO. (f)	BLOW COUNT (g)	REMARKS (h)
	10	SP- Poorly Graded sand, dense, non-plastic, patchy light cementation, moist, light brown to grayish white, very fine to fine-grained, subrounded	Breath = 0.8 Screen = 0.7	10.0 12.0'		6 24 56 60	N=80 Rec = 2.0' Time - 1144
	12	BOTTOM OF HOLE = 12.0'					Bailed sand from inside bottom of augers. Installed well to top of seal. 8-7-95 - Grouted to surface. Did surface completion. See attached well construction diagram.
	13						
	14						
	15						
	16						
	17						
	18						
	19						
	20						

PROJECT: BIG SUPERFUND SITE | HOLE NO. MW95-01

ENG FORM 5056A-R, AUG 94 (Proponent: CECW-EG)

Plate D-13