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FEMP GLACIAL TILL/VADOSE ZONE HYDRAULIC INVESTIGATIONS 0 WORK PLAN OPERABLE UNIT K APRIL 1993 REVISION 0

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REPORT

FEMP Glacial Till/Vadose Zone Hydraulic Investigations Work Plan

Operable Unit 5
Project Order 37
April 1993
Revision 0

Environmental Remedial Action Project
Fernald Environmental Management Project
Fernald, Ohio
FERMCO Subcontract No. 2-21487

PARSONS

Fairfield Executive Center
6120 South Gilmore Road
Fairfield, Ohio 45014

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FEMP Glacial Till/Vadose Zone Hydraulic Investigations Work Plan

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LIST OF ACRONYMS AND ABBREVIATIONS

CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CRU	CERCLA/RCRA Unit
DCR	Document Change Request
DO	Dissolved Oxygen
DQO	Data Quality Objectives
FEMP	Fernald Environmental Management Project
FERMCO	Fernald Environmental Restoration Management Corporation
GMA	Great Miami Aquifer
gpm	gallons per minute
GTIP	Glacial Till/Vadose Zone Hydraulic Investigations Work Plan
GT/VZ	Glacial Till/Vadose Zone
HSA	Hollow Stem Auger
ID	Internal Diameter
MEL	Material and Equipment List
OU	Operable Unit
psi	pounds per square inch
PSP	Project-Specific Health and Safety Plan
PVC	Polyvinyl Chloride
QAPP	Quality Assurance Program Plan
RCRA	Resource Conservation and Recovery Act
SCDM	Site Characterization Data Management
SCQ	*Sitewide CERCLA Quality Assurance Project Plan*
TAL	Target Analyte List
USCS	Unified Soils Classification System
VOC	Volatile Organic Compound

SECTION 1

INTRODUCTION

1.1 Project Background

1.1.1 Definition of Problem

The following additional information on the glacial till needs to be obtained:

1) The degree of hydraulic interconnection between various geologic materials within the glacial till

2) The degree of saturation of various geologic materials within the glacial till

3) Hydraulic conductivity of geologic materials within the glacial till

4) The relationship between the hydraulic conductivity of geologic materials and the degree of saturation in the till

This Glacial Till/Vadose Zone Hydraulic Investigation Work Plan (GTIP) focuses on saturated flow conditions. The acquisition of data on unsaturated flow (i.e., the degree of saturation and unsaturated hydrogeological characteristics of the till) is not covered by this work plan. Unsaturated flow data will need to be addressed though to correctly design a vadose zone monitoring network and to aid in the design of selected clean up alternatives. Work is in progress to assess the types, amount, and timing of the collection of additional unsaturated flow data.

1.1.2 Application of Additional Information Collected Under this Work Plan

Data collected under this work plan is needed to support preparation of an improved solute transport model for the vadose zone by the summer of 1993. This model will be used to support the CRU-5 risk assessment.

The improved vadose zone model will be used to provide better estimates of source concentrations and volume rates being transported to the Great Miami Aquifer from multiple source areas distributed across the site. The objective of modeling is to produce conservative but realistic risk estimates that will aid in the selection of clean-up alternatives. The modeling improvement project is being conducted under a separate scope of work which will utilize data collected during this study.

1.1.3 Strategy for the Collection of Additional Hydraulic Conductivity Data

A logic similar to that presented by Bradbury and Muldoon (1990) was followed to prepare this work plan for the collection of additional hydraulic conductivity data. Bradbury and Muldoon explain that the "true" hydraulic conductivity of saturated near-surface materials is difficult to obtain due to measurement scale effects. Physical characteristics of geologic materials (particle size, roundness, sorting, etc.) vary spatially and this spatial variation can be large in many glacial and fluvial settings as a result of changes in depositional environments occurring over short distances. Tests and measurements of hydraulic conductivity of such variable material (such as glacial till) produce average values for the volume of the material being measured or tested. It is this "averaged" value that is used to address the problem at hand, not the "true" value.

As larger or smaller volumes of material are tested, a larger or smaller number of aquifer heterogeneities, which might be regarded as more or less conductive zones, are encountered. Hydraulic conductivity tests can generally be grouped into four operational scales based upon the volume of material sampled.

1) Small Scale Tests ($< 1 m^3$): Permeameter tests and particle-size estimates.

2) Site-Specific Tests ($1 m^3$ to Hundreds of Cubic Meters): Single well pumping tests, packer tests, and slug tests.

3) Local Tests (Hundreds of Cubic Meters to Thousands of Cubic Meters): Multiple well pumping tests.

4) Regional Tests (Thousands of Cubic Meters): Regional aquifer analyses and inverse models.

Regional aquifer analyses and inverse models were judged to be beyond the scope of this project, but the first three operational scales are considered. Data collected from this project will be used in a separate but parallel work effort to improve the FEMP vadose zone solute transport model.

Selection of what scale test would be applied to what area of the site was based upon lithostratigraphic work conducted for the CRU-5 RI/FS (IT 1993). Hydraulic conductivity data collected under this work plan will be used to help determine hydrostratigraphic units from this lithostratigraphic work.

CRU-5 lithostratigraphic work indicates that the nature of the lithostratigraphic units becomes increasingly more heterogeneous from east to west across the site. Tills situated on the eastern half of the site have a greater percentage of clay with the occurrence of sand lenses increasing to the west. One sand unit of significant areal extent (extending from the Plant 2/3 area to Paddy's Run) has been identified.

Local scale hydraulic conductivity tests will be used in the large sand unit extending from the Plant 2/3 area to Paddy's Run. Site-specific hydraulic conductivity tests will be used in areas within and outside of the large sand unit. Small scale hydraulic conductivity tests will be used at all new drilling locations where a suitable laboratory sample can be collected. Matrix conductivities will be compared to bulk conductivities to assist in the determination of hydraulic interconnections.

Conclusions outlined by Bradbury and Muldoon (1990) will be taken under consideration to interpret this additional hydraulic conductivity data. Specifically:

1) Measured values of hydraulic conductivity tend to increase as the scale of the measurement increases.

2) Results of laboratory permeameter tests are usually lower in values than the results of field tests on the same materials.

3) Hydraulic conductivity measurements based on particle-size distributions give widely varying results depending on the estimation method used and the type of material being evaluated.

Site-specific or single well tests generate data that can be used to calculate the hydraulic conductivity of geologic materials surrounding a single well. As indicated by Bradbury and Muldoon, scale is very influential on hydraulic conductivity determinations. This scope of work at best will result in ranges of hydraulic conductivity. A certain degree of subjectivity will be required to infer "true" values.

The presence of hydraulic communication between different geologic units within the glacial till will be determined through several pumping activities, referred to in the plan as yield tests. The pumping actions will be monitored by transducers situated in surrounding wells. Hydraulic communication will be determined if pressures propagated from the pumping action are detected by the transducers placed in surrounding wells. Several such pumping and monitoring actions will help delineate hydraulic communication within the glacial till.

1.2 Purpose and Objectives

This GTIP provides specific guidance to implement hydraulic transport and recharge studies and hydraulic conductivity test measurements for the Glacial Till/Vadose Zone (GT/VZ). This plan includes specific methods for completing the following:

1) Drilling, sampling, testing, and equipment installation in the GT/VZ
2) Analysis, interpretation, and reporting of the investigation results

The results of this characterization work will be used to refine the current conceptual model for the GT/VZ and will be used in the development of a computer model for the site. The ultimate goal is to build a fully validated and highly defendable model for the feasibility study, remedial design, and engineering design performance assessment activities at the FEMP.

The GT/VZ investigation program is based on the *Development of Glacial Till/Vadose Zone Investigation Program for Operable Unit 5* - November 13, 1992 (Ebasco and CH2M Hill 1992). Activities 1 and 2 of the Ebasco/CH2M Hill report identified tasks and general methodologies for evaluating the vertical and horizontal migration of groundwater through the glacial till and into the Great Miami Aquifer (GMA). During scoping meetings, FERMCO and PARSONS established the tasks to be completed and their areas under this GTIP. These tasks and areas are based on current interpretations of the GT/VZ depositional environment and hydrology.

The major tasks to be completed under this GTIP include the following:

1) Perform slug tests in 63 wells.

2) Install three test wells and 18 piezometers in the central area of the FEMP (Fernald Environmental Management Project) for the purpose of conducting three pumping tests in the large sand unit that lies between Plant 2/3 and Paddy's Run.

3) Pump four existing wells screened in other saturated sand units underlying the production area and the waste pits to determine yield and any connection with the large sand unit or other sand units.

4) Conduct open-hole packer tests in two test borings and all three test wells described in Item 2.

5) Drill six lysimeter borings and install one suction lysimeter in each boring.

6) Prepare a comprehensive report that provides a complete analysis of all collected field data and describes the results of the field investigations.

Sections 2 through 6 of this plan define the specific requirements of these major tasks. The data obtained will provide horizontal and vertical hydraulic conductivity values for the various lithologies and storage coefficients for the sand and gravel layers, and evidence of saturation in the clay layer at the base of the glacial overburden along with evidence for saturated communication. Groundwater sampling from wells and lysimeters will provide analysis of uranium, general chemistry, and volatile organic compounds (VOCs). The data will be used as input to the GT/VZ computer model.

1.3 Overall Summary of Activities

1.3.1 Slug Tests

An area-wide distribution of hydraulic conductivity in the "perched" groundwater zones can be obtained by collecting measurements from several representative wells. Thirty-seven slug tests have already been performed in areas underlying all of the operable units, but most tests are limited to the Plant 2/3 area. Additional tests will provide greater sitewide coverage. Additional slug test locations for this scope of work are based on the following:

1) Location of previously tested wells
2) Well integrity and accessibility
3) The spatial distribution of existing wells in currently identified depositional units
4) Lithology and screened interval

The wells will be tested to evaluate the hydraulic characteristics of the various depositional units across the site. Most of the wells have been selected to minimize the lithologic variations that occur within the screened (including filter pack) intervals in each of the monitoring wells (i.e., attempts have been made to segregate wells completed in sand, silt, or clay). This process will enhance the ability to correlate the lithologies encountered in each well with the results of the corresponding slug tests.

1.3.2 Pumping Tests

Selection of pumping test locations was based on assumptions about the ability of identified sand units to produce meaningful results. The most promising area consists of the large sand unit extending from Paddy's Run to the Plant 2/3 area.

Existing data indicate that this area may change from confined to unconfined conditions. In addition, it is suspected that the sand unit may be hydraulically connected to another sand unit beneath the waste pits. A yield test in the saturated sand underlying the waste pit area will be conducted to support or refute this possibility.

The three pumping tests described in this work plan have been selected and located for the following reasons:

1) Determine transmissivity of the thickest portion of the sand and two downgradient areas close to the edge of the sand

2) Provide for apparent variations in hydrostratigraphy across the sand unit and overlying materials

3) Take advantage of lower levels of contamination in these areas and the ability to manage the discharge of the test wells over an extended period of time

Laboratory physical (geotechnical) and chemical analyses will be performed on samples collected from pumping test wells. Also, slug tests will be performed on each of the test (pumped) wells.

1.3.3 Lysimeter Installation

A study of the migration of meteoric waters through the glacial till is required to identify the potential for contaminants to move through the GT/VZ and into the GMA. Suction lysimeters will be placed in two zones of the GT/VZ - (1) the unoxidized (reduced) clay layer at the basin of the glacial overburden and (2) the unsaturated portion of the GMA. The lysimeters will be used to obtain water samples from these unsaturated zones. The samples will be used to determine if the clay layer at the base of the glacial overburden is saturated and to determine water chemistry in both zones if possible.

The location selections were based on representativeness of contaminated areas and the thickness of the glacial overburden. Two locations have been selected where the overburden is thin and also believed to be free of any contamination introduced by the FEMP. Another location was selected where a thick sequence of till exists near, but not in, a contaminated area.

1.3.4 Packer Tests

Packer tests will be conducted to provide vertical profiles of horizontal hydraulic conductivities in the glacial till. The packer tests will be conducted as pump-in tests and will be performed only in materials with low permeability. Sand and/or gravel units will not be tested.

Two borings will be drilled for these tests. One boring will be drilled in an area of the site where the glacial overburden is thick. The other boring will be drilled in an area of relatively thin glacial overburden.

In addition, packer tests will be performed at all three pumping test locations in the clay unit at the base of the glacial overburden. The test well from each area will be selected for packer testing. The pumping test wells will be packer tested for wider coverage of the clay zone.

Shelby or Dennison tube samples will be recovered from the borings and test wells. Laboratory tests will be performed to determine geotechnical properties of the till materials. Tests will include grain size analysis and permeability measurements, among others.

1.3.5 Yield Tests

Four short-duration yield tests will be conducted to determine the hydraulic relationship between the coarse-grained depositional units beneath the site. Current interpretations suggest a hydraulic relationship between the large sand body lying between Plant 2/3 and Paddy's Run and other sand units beneath the site. If a hydraulic connection exists between the larger sand body and any of the other bodies, the information from the yield tests will aid in determining chemical mixing and/or dilution of the water in the large unit by waters in the other units. The locations for the three yield tests were based on the location of the sand bodies and the degree of contamination as well as management of the discharge from the test wells.

Another longer duration yield test will be performed on Monitoring Well 1785 in the Plant 2/3 area. Information from this test will be helpful in establishing pumping rates for the pumping tests described in Subsection 1.3.2. Information from this test will also be useful in determining the distance of the observation wells from the test wells in the pumping tests. The length of this test will be up to 72 hours.

1.4 Management and Responsibilities

Figure 1-1 illustrates the organizational relationship between FERMCO and PARSONS for these tasks. FERMCO CRU-5 and Site Characterization and Data Management (SCDM) will be responsible for the procurement of all drilling, sampling, equipment installation, and testing in the GT/VZ. FERMCO SCDM will also be responsible for direct daily oversight of all field activities described in this work plan. Project oversight will be the responsibility of CRU-5.

PARSONS will have a representative on site during all key field activities to ensure that all procedures are implemented as defined in this work plan. PARSONS field oversight responsibilities are further defined under the activities described in the following sections. Response to contingencies and field changes that may arise during the course of field activities will be the responsibility of CRU-5 and in accordance with the *Sitewide CERCLA Quality Assurance Project Plan* (SCQ) (WEMCO 1992). Table 1-1 shows a list of groups who may be called upon to provide instruction if a contingency is encountered. Names and telephone numbers of representatives from each group will be provided to field personnel at the operational readiness review prior to initiation of field activities.

PARSONS will also compile, analyze, and interpret all of the field data generated and collected and prepare a comprehensive report of all activities and results.

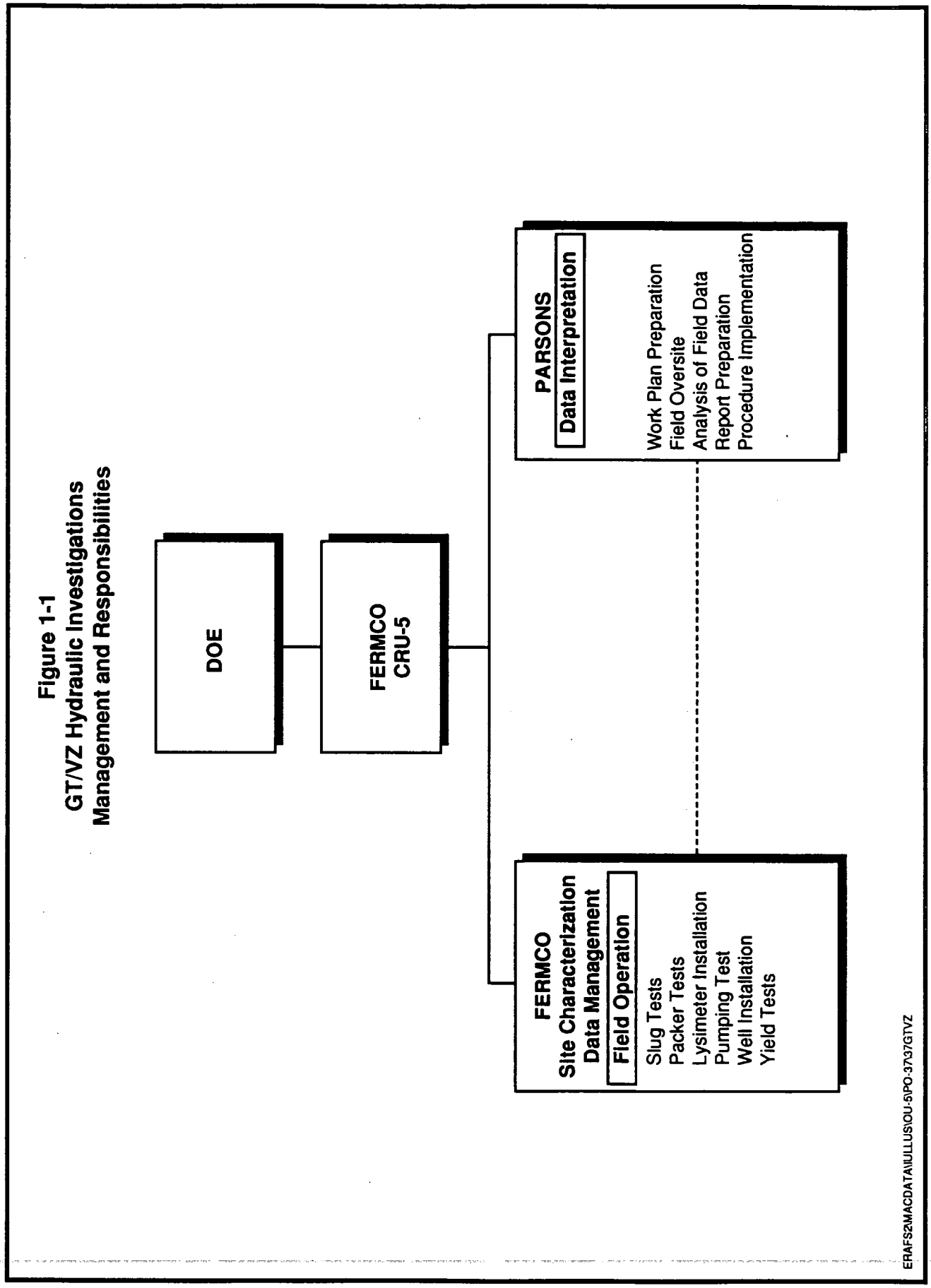

Figure 1-1 - GT/VZ Hydraulic Investigations Management and Responsibilities

Table 1-1 - Agencies, Contractors, and Subcontractors
Providing Response to Field Changes and Contingencies

Organization	General Responsibilities	Telephone Number
Drilling Contractors *(Name)*	Well installation Lysimeter installation Pumping test equipment	
Inflatable Packer Supplier *(Name)*	Packer installation and operation	
Test Pump Supplier Pump Supplier *(Name)*	Pump installation and operation	
Data Logger and Pressure Transducer Supplier *(Name)*	Drawdown and Recovery Measurement Equipment	
Lysimeter Supplier *(Name)*	Lysimeters	
U.S. DOE *(Name)*	Policy and Procedural Guideline	
FERMCO - CRU-5 *(Name)* FERMCO - Site Characterization Data Management	Procedural Guidance Operations	
Emergency Response *(Name)*	Health and Safety--Fire, Ambulance, Hospital, and Police	
Ohio EPA *(Name)*	Regulatory Requirement	
PARSONS *(Name)*	GT/VZ Test Requirements	
US EPA *(Name)*	Regulatory Requirements	
Miscellaneous Suppliers *(Name)*	Miscellaneous Equipment and Supplies	

1.5 Schedule

In order to meet the requirements of the GT/VZ modeling effort, many of the field investigations will be performed in parallel during the Spring field work season. Figure 1-2 shows the current schedule for implementation of activities under this plan.

Five major activities will commence when this scope of work plan is implemented:

1) Slug testing
2) Well and piezometer drilling for the pumping tests
3) Lysimeter installation
4) Packer testing
5) Yield tests

Baseline data for the pumping tests will also be collected during initial field activities. The pumping tests will begin midway through the first month of field activities.

Analysis of field hydraulic data will begin upon acquisition. Calculations of the hydraulic properties within the GT/VZ will be used as input to the computer model. Results of groundwater sampling and analysis, as well as geotechnical analyses will be used as input to the model when available.

Figure 1-2
GT/VZ Hydraulic Investigations Schedule

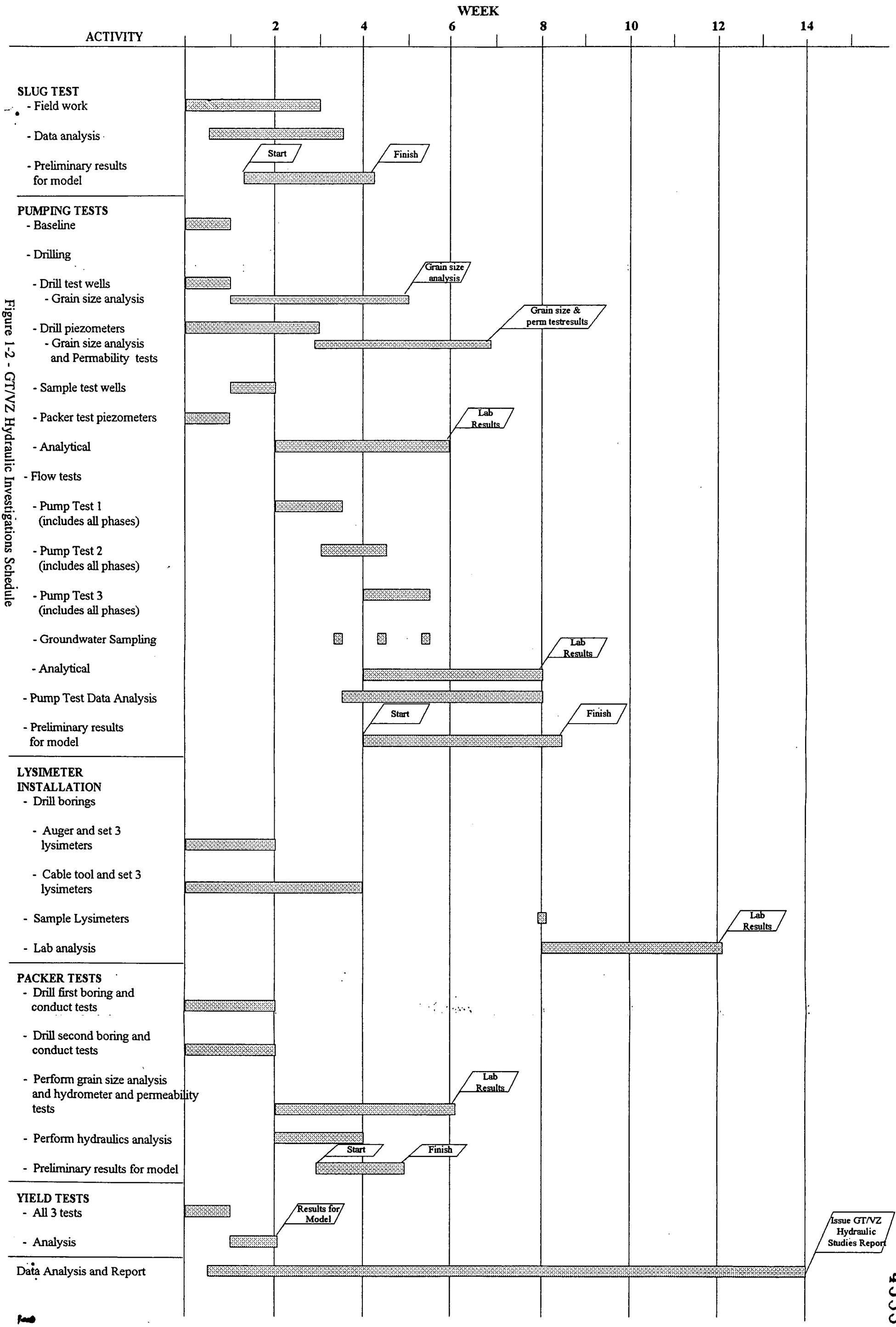

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Figure 1-2 - GT/VZ Hydraulic Investigations Schedule

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SECTION 2

SLUG TESTS

2.1 Specific Objectives

Slug tests will be performed to obtain point measurements of hydraulic conductivity in the GT/VZ. As described previously, 63 existing wells will be tested. The three-well cluster of each pumping test network drilled (described in Section 4) will also be included in the slug test program.

2.2 Well Locations

Figure 2-1 shows the 63-well slug test network and Table 2-1 also lists these wells. Well selections are based on the ability of each well to provide representative data. Attachment A includes lithologic strip logs with well construction information for each of the test wells.

2.3 Slug Test Field Implementation

The slug tests will be performed under the policies and guidelines provided in the SCQ. Procedures pertaining to slug testing activities are referenced to the SCQ in Table 2-2.

2.3.1 Required Personnel

One or more teams of two field personnel each will conduct the slug tests. The personnel will be experienced with slug test techniques and will be capable of operating all of the equipment associated with the tests. The team leader will be a qualified technician. A "geologist-in-charge," as defined in Appendix J.3 of the SCQ, will supervise the activities of all field personnel.

The PARSONS field representative will consult with the geologist-in-charge regarding the calibration of all electronic equipment (data loggers, pressure transducers, etc.) and concur that it is working properly before use in accordance with manufacturer's specifications and requirements of SCQ. The PARSONS field representative will also consult and concur with the geologist-in-charge that each test well is able to provide a representative test. The geologist-in-charge will inspect all equipment to ensure that it is decontaminated in accordance with the SCQ requirements.

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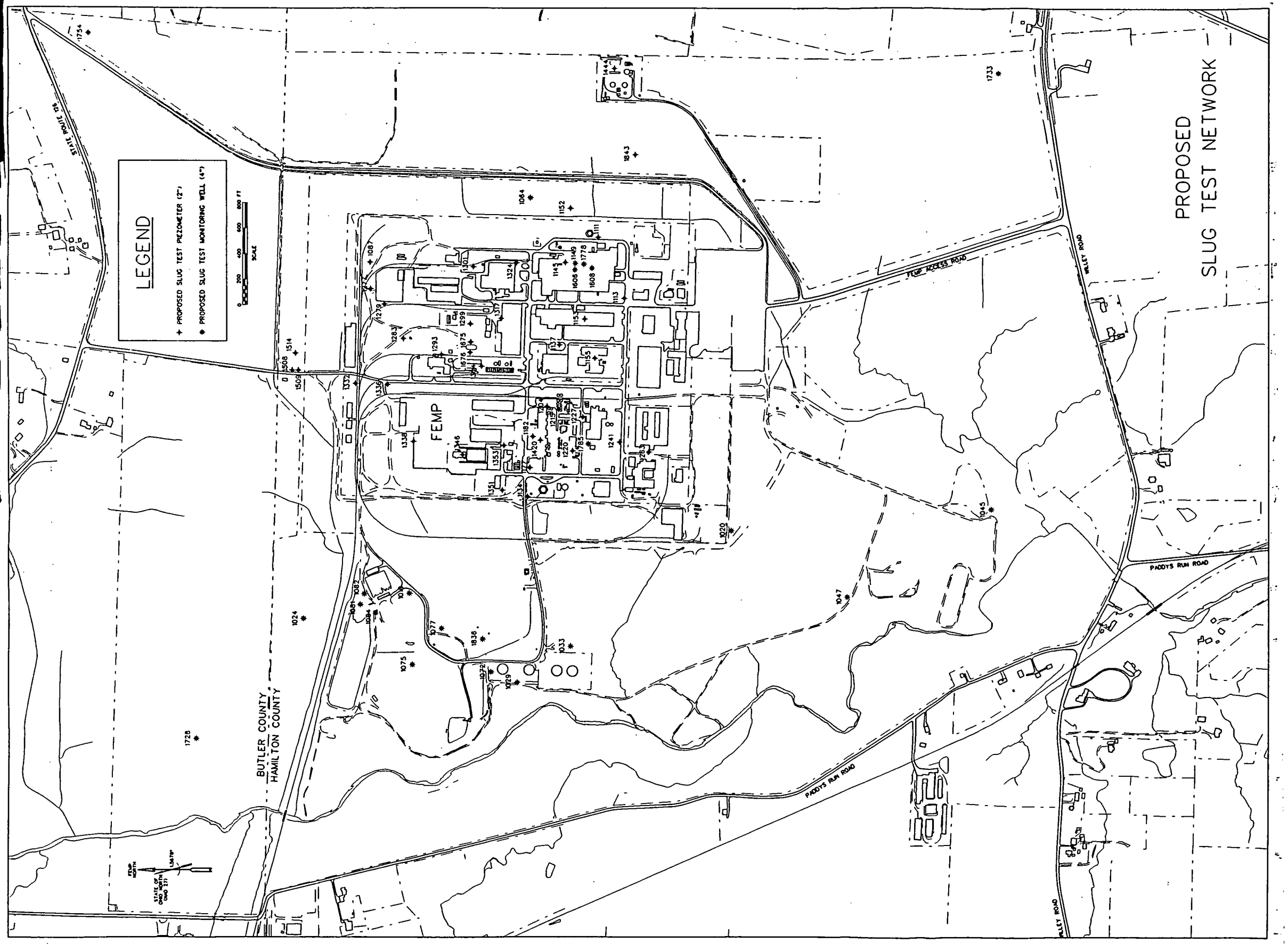

Figure 2-1 - Proposed Slug Test Network

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Table 2-1 - Proposed Wells for Slug Testing within Glacial Till

Well	Dia.	Well	Dia.	Well	Dia.	Well	Dia.
		1111	2"	1277	2"	1353	2"
1019	4"	1113	2"	1279	2"	1420	2"
1020	4"	1134	2"	1283	2"	1444	2"
1024	4"	1137	2"			1508	2"
1029	4"	1145	2"			1509	2"
1033	4"	1149	4"	1293	2"	1514	2"
1045	4"	1152	2"	1299	2"	1606	4"
1047	4"	1153	2"	1301	2"	1608	4"
		1155	2"	1304	2"	1675	2"
1064	4"	1177	2"	1317	2"	1676	2"
1072	4"	1182	2"	1324	2"	1728	4"
1075	4"	1204	2"	1332	2"	1733	4"
1077	4"	1215	2"	1336	2"	1754	4"
1081	4"	1220	2"	1338	2"	1778	4"
1082	4"	1227	2"			1785	2"
1084	4"	1241	2"	1346	2"	1836	4"
1087	4"	1263	2"	1351	2"	1843	2"

Table 2-2 - Slug Test Procedures

PROCEDURE	REFERENCE	
Administrative Procedures	**FEMP SCQ (1992) Section**	**New Procedure Attachment**
Chain-of-Custody	7.1	
Corrective Action	15.2	
Daily Logs	5.1 and Appendix J, Subsection J.4.1	
Variances	15.4	
Field Procedures		
Ground Water Level Measurement	Appendix K.4.2.1	
Water Level Measurement Form		E-1
Slug Tests	Section 5.2.5 and Appendix J, Subsection J.4.6	
Decontamination	Appendix K, Subsection K.11	
Field Calibration Requirements	Appendix I	
Field Test:		
Temperature	Appendix K, Subsection K.4.1.1	
pH	Appendix K, Subsection K.4.1.2	
Specific Conductance	Appendix K, Subsection K.4.1.3	
Dissolved Oxygen	Appendix K, Subsection K.4.1.4	

2.3.2 Test Equipment and Methods

Falling head, rising head, and bail/purge slug test methods will be performed. For procurement, a material and equipment list (MEL) can be found in Attachment B-1. A summary of the required equipment is as follows:

1) Multi-channel data loggers (In Situ® Hermit 2000 or equivalent) with fifteen 20 pounds per square inch (psi) transducers with necessary fittings and cables. The data logger and transducer system will be capable of recording at rates as frequently as two readings per second. Cables will be of sufficient length to reach from the data logger to a maximum of 40 feet below ground level. Data logger cables will be protected from chemicals in the groundwater that may degrade them. A 1-inch PVC tube with adapter for the transducer will be used to protect the cable from deterioration.

2) Electrical water level measuring tape graduated in hundredths of a foot for water level measurement.

3) Stopwatches and digital wristwatches capable of being synchronized within 1 second for each member of the slug test team.

4) One centralized weather station capable of measuring barometric pressure, temperature, and rainfall.

5) White nylon cords of sufficient length for lowering and retrieving slugs from each well.

6) Pocket knife.

7) Indelible pens and/or pencils.

8) Field book.

9) Health and safety equipment and clothing.

10) Slug test log forms (Attachment E-1).

11) Plastic visqueen sheeting to place slugs and cord on prior to lowering into and after retrieval from each well.

12) Combined pH, conductivity, dissolved oxygen (DO), and temperature meter (if possible); otherwise, instruments to measure all four parameters.

13) Disposable polyvinyl chloride (PVC) bailers.

14) Purge pump (2-inch).

15) Laptop or similar portable computer with internal power source.

16) A total of 12 slugs will be constructed to the following diameters and lengths:

Slug Length (ft.)	Number of Slugs for 4-inch wells	Number of Slugs for 2-inch wells
1.5	1	2
2.0	1	2
3.0	1	2
5.0	1	2

Slugs that will be inserted in 4-inch wells will have a nominal OD of 2 inches. Slugs that will be inserted in 2-inch piezometers will have a nominal OD of 1 inch. The materials for constructing slugs are described on the MEL in Attachment B-1. The materials will come in appropriate lengths to construct the above described slugs.

Slug tests will be performed in accordance with SCQ Appendix J.4.6.2 procedures. These procedures are found in Attachment C of this document.

The slugs will be solid cylinders of known volumes, and each slug will have dimensions that allow it to occupy (as much as possible) an interval no more than 1 foot above the base of the well screen and no less than 1/2 foot below static water level once the well has equilibrated. The slugs will consist of materials (in most cases PVC) that cannot be physically degraded by contaminants in the groundwater and can also be easily decontaminated. Decontamination of slugs, transducers, cables, and electronic water level probes will be performed after each test in accordance with SCQ procedures (Table 2-2).

Water levels will be measured with pressure transducers and recorded on a data logger. Operation of the pressure transducer and data logger system will be in accordance with manufacturer's instructions. The pressure transducers will be installed no lower than 1 foot above the base of the well screen. Since a high well density exists in some areas of the site, multiple slug tests can be performed in a short period of time if enough slugs, pressure transducers, and a multichannel data logger are available. Therefore, two or three data loggers with four channels (In Situ® Hermit 2000 or equivalent) will be used along with pressure transducers attached to 150-foot cables on spools.

Since pressure transducers will be used to measure water level recoveries, care should be taken when lowering the slugs into the well. Striking the transducer with a slug or sudden pressure increases on the transducer caused by suddenly dropping the slug in the well may damage the transducer; therefore, carefully lower the slug to the prescribed depth. The slug will be lowered into and retrieved from the well with white nylon cord. A fresh new white nylon cord will be attached to the slug for each test.

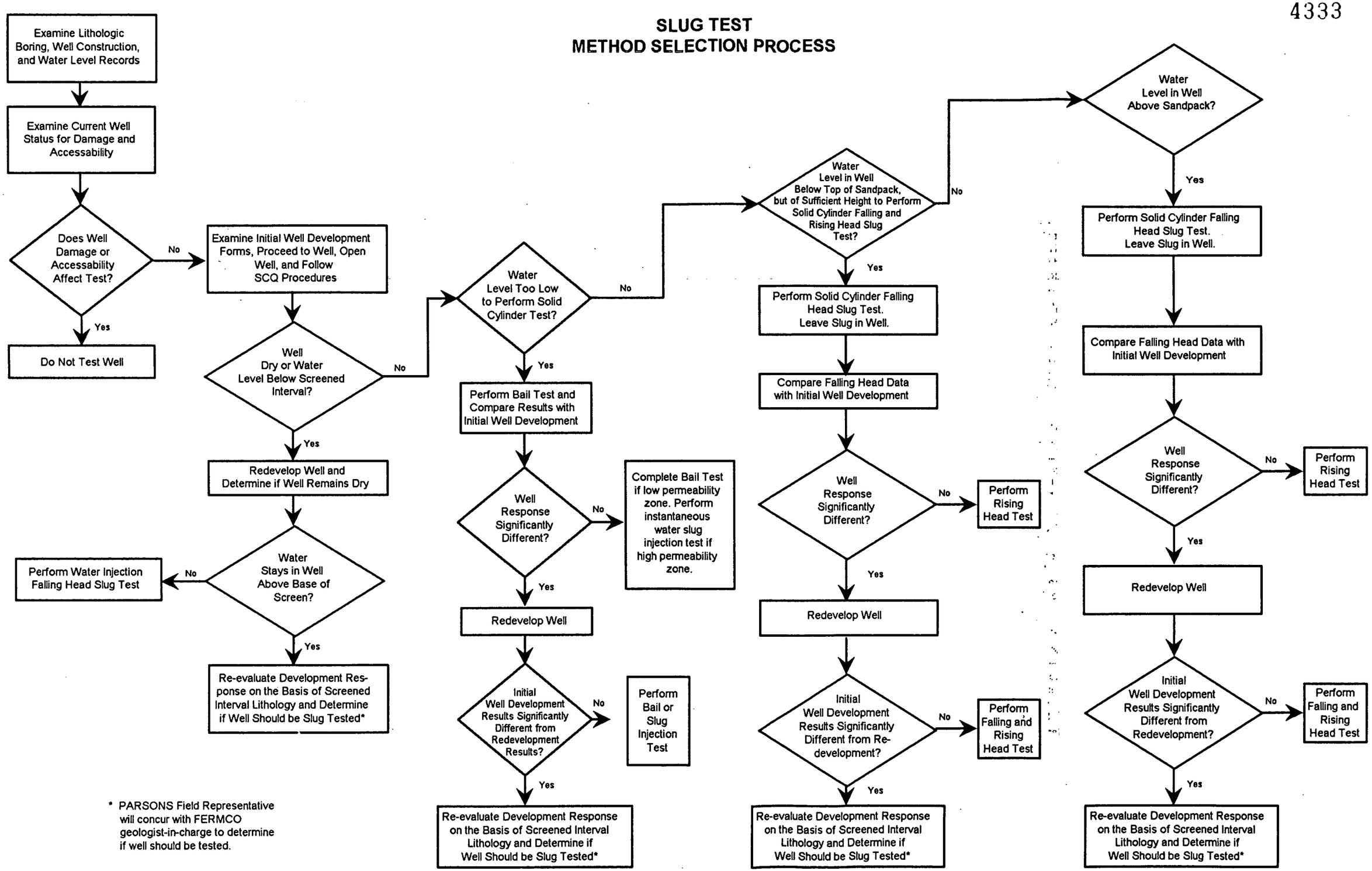
Many of the wells may have elevated concentrations of hazardous or radioactive constituents. Attachment D provides the concentration of contaminants in each well. The rising head slug test is the preferred method; however, before the rising head test is performed, several conditions will be met. Figure 2-2 illustrates the logic involved in the selection of a slug test method. This process will ensure that the proper methods are used for each test. Attachment A contains lithology and well construction information. Well development records will be available for the field team prior to the start of the tests.

Using a falling head slug test, the data logger will be started and the slug will be instantaneously lowered into the well. The well will be allowed to equilibrate to static water level. When it is concluded from well development checks that the well is responding properly, a rising head test will be performed. The slug will be removed and the water will be allowed to recover while water levels are recorded with the data logger/pressure transducer system. The falling head test will determine at what rate the water levels will be recorded; however, unless the static water table is above the screen and filter pack, the falling head data will not be used to calculate hydraulic conductivity. For low yield wells, slugs can be inserted in wells and left overnight to equilibrate. Slug test data will be recorded on the same type of form shown in Attachment E-1.

If the rising head method of slug testing cannot be applied to a test well because the water column is shorter than any of the slugs described in item 16, another falling head method of slug testing will be applied by the introduction of a known volume of water into the casing annulus. A slug of deionized water will be introduced instantaneously with an instrument as described and illustrated in Figure B, Attachment B-1. Water levels will be recorded with pressure transducers in the same fashion described above for the rising head method. It should be noted that this method is valid for calculation purposes only if the static water level in the well stands above the top of the sand pack interval.

If a falling head or rising head method of slug testing cannot be applied to a test well because of slow recoveries (e.g., in a tight clay), a rising head test will be employed using a bail down method. For this method, the low-yield well will be bailed or purged dry. Then, water level measurements will be taken manually at 1-minute intervals for the first 5 minutes with a depth probe. If little recovery is noted after 5 minutes, water level measurements will be taken every 5 minutes for the first hour of the test, then at 10 minute intervals until a trend is established. If a measurable quantity of water has not entered the well bore after 3 hours, the test will be terminated.

SLUG TEST
METHOD SELECTION PROCESS



* PARSONS Field Representative will concur with FERMCO geologist-in-charge to determine if well should be tested.

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Figure 2-2 - Slug Test Method Selection Process

Wells with water levels that are too low to measure with the rising head method and that are below the top of the filter pack interval (including dry wells) will be tested with another form of falling head test. This test will be set up with pressure transducers as described above. The data logger will be started and deionized water will be introduced into the well bore until it reaches the top of the casing. A measurement of the decline in head will be recorded at a rate determined by well development response (Figure 2-2). Since the screened (and filter packed) zone is not fully saturated, hydraulic conductivity cannot be calculated.

Each well will respond differently during the test. The length of a test may range from less than a minute to several hours. As specified in the SCQ Appendix J.4.6.2, the test shall continue until the water level in the test well returns to equilibrium, or for slowly recovering wells, until a sufficient number of readings have been made to clearly show a trend on a semi-log plot of time versus water level. The readings can be recovered from the data logger during the test and will be recorded along with other pertinent information on test forms as seen in Attachment E-1 of this plan.

2.4 Data Analysis

Slug test forms will be submitted to PARSONS along with data logger field tapes and computer disks. Data from the slug tests will be analyzed using the Bouwer and Rice (1976) or Cooper et al. (1967) methods of analysis. The calculations will be performed with the AQTESOLV™ (Duffield and Rumbaugh 1991) software package. Data will be analyzed to determine the hydraulic conductivity in the vicinity of each well tested. The software will be verified in accordance with PARSONS ERA Project Procedures (PARSONS 1992).

SECTION 3

PUMPING TESTS

3.1 Specific Objectives

Pumping tests are performed to calculate hydraulic properties of the water bearing sand zones in the GT/VZ. Data from these tests will be used to determine the hydraulic conductivity, storativity, and anisotropic conditions that may exist in the vicinity of the test wells. If the sand unit is confined or partially confined, the vertical hydraulic conductivity (K′) of the overlying aquitard can be calculated. Hydraulic boundaries may also be identified during these tests. Following the installation of the test wells, groundwater samples will be taken and analyzed for total uranium, general chemistry (anions and cations), and volatile organic compounds (VOCs).

Each pumping test will be performed in three stages. The first stage will involve a step-drawdown test to determine the optimum flow rate for the constant rate test. The second stage of each pumping test will be a constant rate test that will last until the test approaches steady-state or a maximum of 7 days. The third stage of the pumping test will consist of an aquifer recovery period (immediately after the constant rate pumping ceases) where groundwater elevations will be observed and recorded in the pumping well and all piezometers and pumping wells in each test network. Data from the pumping tests will be analyzed and included in the GT/VZ hydraulic investigations report.

3.2 Well Placement and Design

As mentioned in Section 1, three areas (designated W, X, and Y) have been selected for the pumping tests. Figure 3-1 shows the test well and observation well networks for the three pumping tests. Certain monitoring wells that currently exist in the vicinity of the pumping tests will also be used as observation wells. Figure 3-2 shows the basic configuration of the well installation program for each pumping test network (areas W, X, and Y). The FERMCO SCDM group will secure the necessary penetration and radiation worker permits for these wells. Attempts will be made to include an existing monitoring well in each of the pumping test networks.

Due to uncertainties with respect to drawdown in the large sand body beneath Plant 2/3 the distances of observation wells and piezometers from the test wells will be refined using a phased approach. Data from the short- and long-term yield tests (Section 6) will help define drawdown at specific distances from a pumped well. Monitoring Well 1785 is a good candidate for a long-term yield test because a pump already exists in the well and several monitoring wells and piezometers are around it. Also, Monitoring Well 1785 is in a thick section of sand lying between Plant 2/3 and Paddy's Run. The short-term yield

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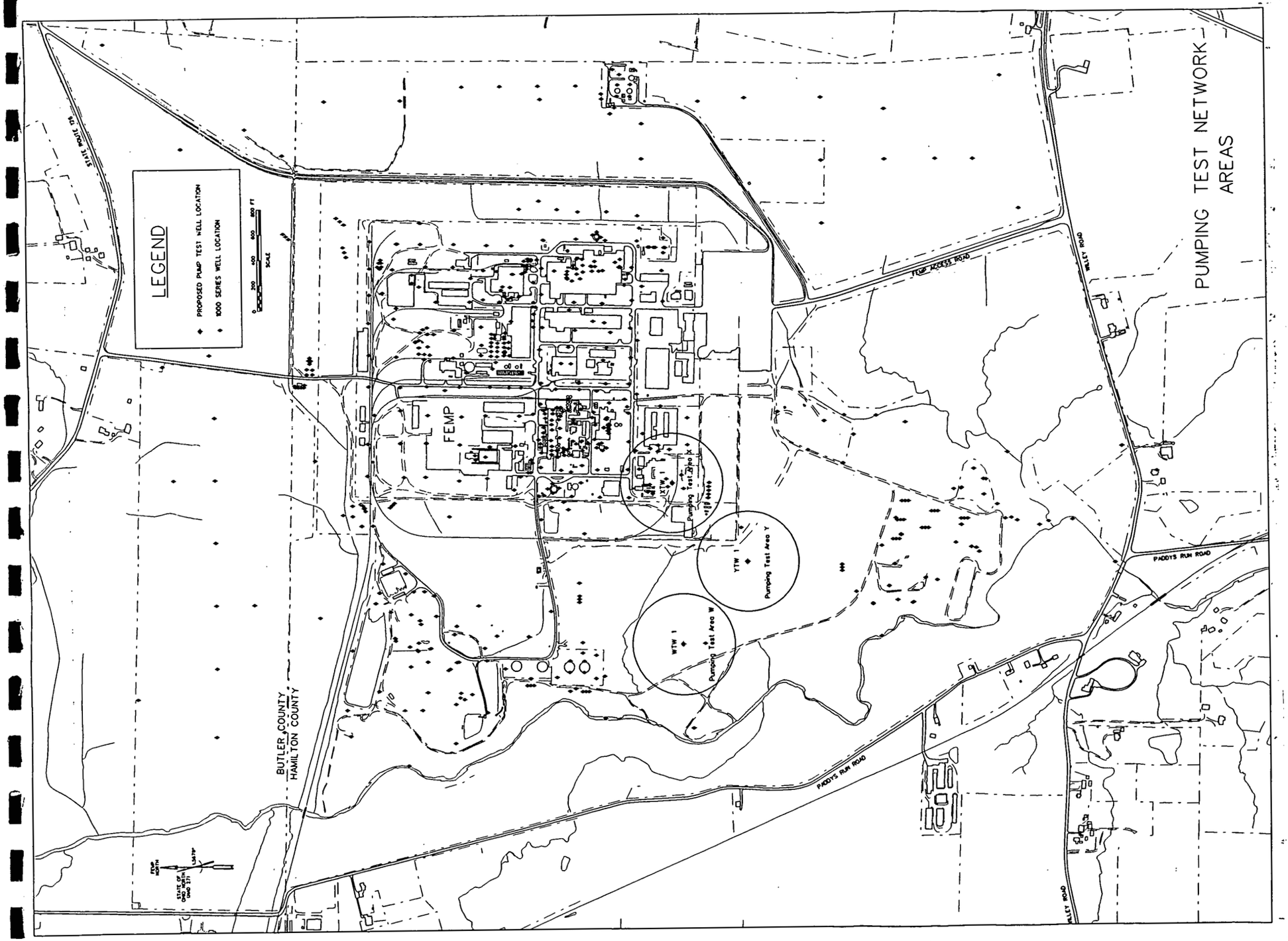
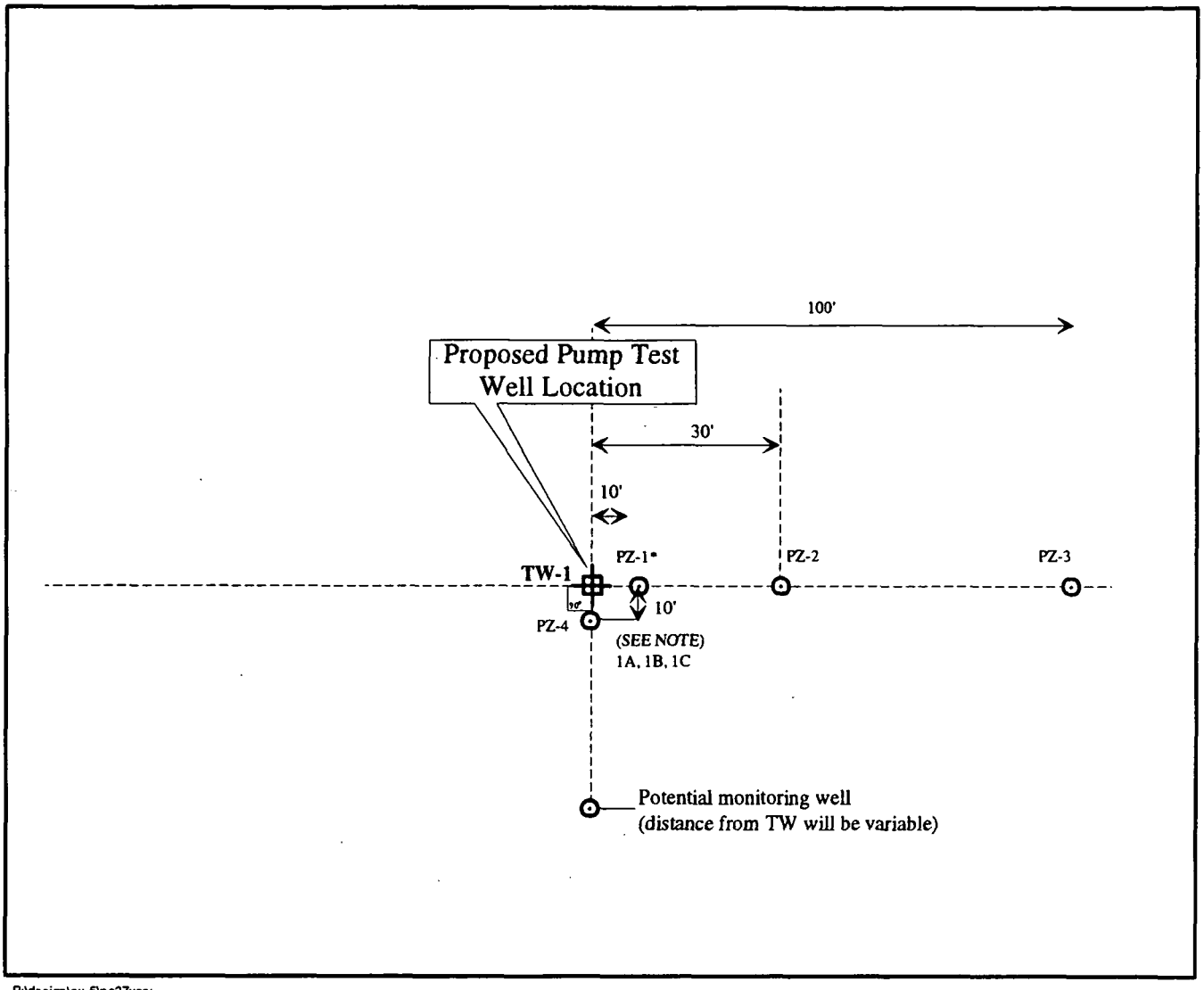


Figure 3-1 - Pumping Test Network Areas



P:\design\ou-5\po37wxy

Not to Scale

Proposed piezometer

Proposed test well location

Bearing Line

Note: SPPZ-1 consists of 1A, 1B, 1C

Figure 3-2 - General Location for Piezometers in Areas W, X, and Y

tests (Monitoring Wells 1076, 1339, and 1274) will also provide useful drawdown data for the test wells that may be screened in sands with different permeabilities.

Piezometers locations will be selected for each test based on the results of other pumping tests performed under this work plan. Results of the first pumping test will be used to refine the piezometer distances for the second pumping test. Results of the first and second pumping test will be used to refine piezometer distances for the third pumping test.

The test well in the pumping test network will be packer tested in the lower clay zone at the base of the overburden. Prior to packer testing, undisturbed soil samples will be recovered from the test well. The undisturbed samples will be collected over a continuous 5-foot section in the lower clay zone at the base of the overburden. This will provide a clean hole for the pump-in packer test.

3.2.1 Design and Installation of Test Wells

The test wells and piezometers will be installed under the policies and guidelines provided in the SCQ. Table 3-1 references procedures pertaining to drilling and well installation activities to the SCQ.

Table 3-2 provides construction details for each test well in areas W, X, and Y. General drilling practices will be in accordance with the SCQ. The wells will be advanced by hollow stem auger methods. Each test well will be drilled through the saturated sand unit. Table 3-2 shows the approximate depth of each test well; however, the geologist-in-charge in concurrence with the PARSONS field representative will be responsible for selecting the total depth and screen intervals for each test well.

Continuous split spoon samples or undisturbed samples will be collected from the surface to the base of each test well boring. Field screening of samples will be conducted with HNu, beta, and gamma scanners. Samples will be collected in accordance with SCQ requirements, and a lithologic log will be generated for each boring in accordance with Appendix J.4.1.2 and Appendix B, Form J-1 of the SCQ. Samples will be archived as directed by FERMCO SCDM. Well completion logs will be completed in accordance with SCQ Appendix B, Form J-2. Attachment A of this document includes boring logs for wells in the vicinity of the pumping tests for comparison purposes. Geotechnical lab analyses will be performed in accordance with SCQ procedures (Table 3-1) for each well on selected samples from different lithologic units. For split spoon samples, the geotechnical lab will perform grain size analysis, visual descriptions, and also Unified Soils Classification System (USCS) classification. The geologist-in-charge will be responsible for selection of these samples in concurrence with the PARSONS field representative. For undisturbed (Shelby/Dennison tube) samples, grain size with hydrometer analysis, moisture content, porosity, void ratio, Atterberg limits, lab density, specific gravity, constant head permeability (triaxial cell with back pressure), visual descriptions, and USCS classifications will be performed.

Table 3-1 - Pumping Test Well and Piezometer Installation Procedures

PROCEDURE

Administrative Procedures	**FEMP SCQ (1992) Section**	**New Procedure Attachment**
Chain-of-Custody	7.1	
Corrective Action	15.2	
Daily Logs	5.1 and Appendix J.4.1	
Variances	15.4	
Field Procedures		
General Drilling Practices	5.2.1 and Appendix J.4.2	
Subsurface Sampling	Appendix K.5.3	
Monitoring Well/Piezometer Design, Installation, and Abandonment	5.2.2 and Appendix J.4.3 *EM-GW-004	
Well Development	5.2.3 and Appendix J.4.4	
Field Screening of Samples for Radioactive Contamination	Appendix K.5.3.2	
Decontamination	Appendix K.11	
Field Storage and Shipment of Samples	Appendix K.10	
Packer Testing		C-5
Pressure Pulse Test		C-7
Laboratory Test Procedures		
Grain Size Analysis	Attachment I, Volume V	
Hydrometer Analysis	Attachment I, Volume V	
Permeability Testing		C-3
Atterberg Limits	Attachment I, Volume V	
Moisture Content	Attachment I, Volume V	
Void Ratio	Attachment I, Volume V	
Porosity	Attachment I, Volume V	
Lab Density and Specific Gravity	Attachment I, Volume V	

* Well abandonment will also follow this procedure listed in the *WEMCO Environmental Monitoring Procedures Manual*, Rev. 28 (June 16, 1992).

Table 3-2 - Test Well

Parameter	Criteria
Pump Test Wells: WTW-1	Est. State Planar Coordinates: 497900N and 1378500E
XTW-1	Est. State Planar Coordinates: 480200 and 1379650E
YTW-1	Est. State Planar Coordinates: 479000 and 1379850E
Static Water Level Depth (Relative to ground surface)	Approximately 5 to 10 feet
Base of Well Screen Depth (Relative to ground surface)	Anticipated maximum depth approximately 20-25 feet (i.e., the base of the upper lacustrine sand)
Anticipated Drawdown	10-20 feet at 20 gpm (maximum)
Screen	5.8-inch ID, 6.7 OD stainless steel wire wrap 0.02 slot - 10 to 15 feet per well
Filter Pack	Medium or coarse sand, from top to base of sand being tested.
Sump	4 feet 316 stainless steel 6-inch ID
Casing	6-inch ID 316 Stainless Steel - 10 to 15 feet of riser per well
Screen and Filter Pack Interval	A minimum of 85 percent of the saturated thickness of the sand being tested
Pump Inlet Placement	Below base of screen in 4-foot sump 3 feet from bottom of sump. Cooling shroud to prevent overheating during 7-day test, if required.
Pump Flow Rate	Variable - between 0.5 and 20 gpm with ability to sustain a maximum 20 gpm for 7 days. Up to 200,000 gallons of water per well may be pumped.
Pump Type	Submersible 2 inch or 4 inch
Pumping Appurtenances	1) Backflow preventer - check valve to prevent water in discharge line from re-entering well 2) Flow Control - variable speed drive or throttled discharge valve 2) Flow measurement - flow meter on discharge line 3) Sampling - sampling port on discharge line
Drawdown Measurement	1-inch PVC stilling pipe inside the well

Construction of the test wells will be as illustrated in Figure 3-3 and will be in accordance with SCQ procedures. The PARSONS field representative will be present during all well construction activities (i.e., when screens, filter packs, and seals are being set).

A 4-foot sump will be installed at the base of the screened interval. The sump will enclose the submersible pump for the pumping test.

The screen will be installed from the base of the sand unit being tested to 1 foot below the base of the overlying clay; however, attempts will be made to screen no less than 85 percent of the entire sand body. The filter pack will be installed from the base of the boring to the top of the sand. The filter pack will be capped by a 5-foot bentonite pellet seal. The bentonite seal will be covered with volclay grout to within 1 foot of the surface. The wellhead will be completed with an aboveground locking protective cover assembly in accordance with of the SCQ procedures. Well development will also be in accordance with the SCQ procedures.

Following well development, one round of groundwater samples will be collected from all three test wells. Analyses will be performed for total uranium, general chemistry, and VOCs. The target analyte list (TAL) and container/preservation requirements can be found in DQO 2 in Attachment F-2 of this document.

3.2.2 Design and Installation of Piezometers

Tables 3-3 through 3-5 provide the specific design requirements for the piezometers in each area. As shown in Figure 3-2 a total of six piezometers will be installed for each of the three pumping test networks (WPZ-1A, 1B, 1C, 2, 3, and 4), (XPZ-1A, 1B, 1C, 2, 3, and 4), and (YPZ-1A, 1B, 1C, 2, 3, and 4). In each area, four 2-inch internal diameter (ID) piezometers (WPZ-1B, 2, 3, and 4; XPZ-1B, 2, 3, and 4; and YPZ-1B, 2, 3, and 4) will be installed in the saturated sand unit. Also in each area, one 2-inch ID piezometer (WPZ-1A, XPZ-1A, and YPZ-1A) will be installed in the confining clay layer above the sand, and one 2-inch ID piezometer (WPZ-1C, XPZ-1C, and YPZ-1C) will be installed in the confining layer below the sand unit. The locations and spacing of the piezometers are subject to changes in hydraulic conditions observed in other tests. These locations will be selected and verified with representatives from FERMCO CRU-5 and PARSONS prior to installation.

The piezometers will be advanced by hollow stem auger methods. Drilling will be in accordance with the SCQ. Tables 3-3 through 3-5 show the approximate depth of each of these piezometers; however, the geologist-in-charge in concurrence with the PARSONS field representative will be responsible for selecting the total depth and screen intervals for each piezometer.

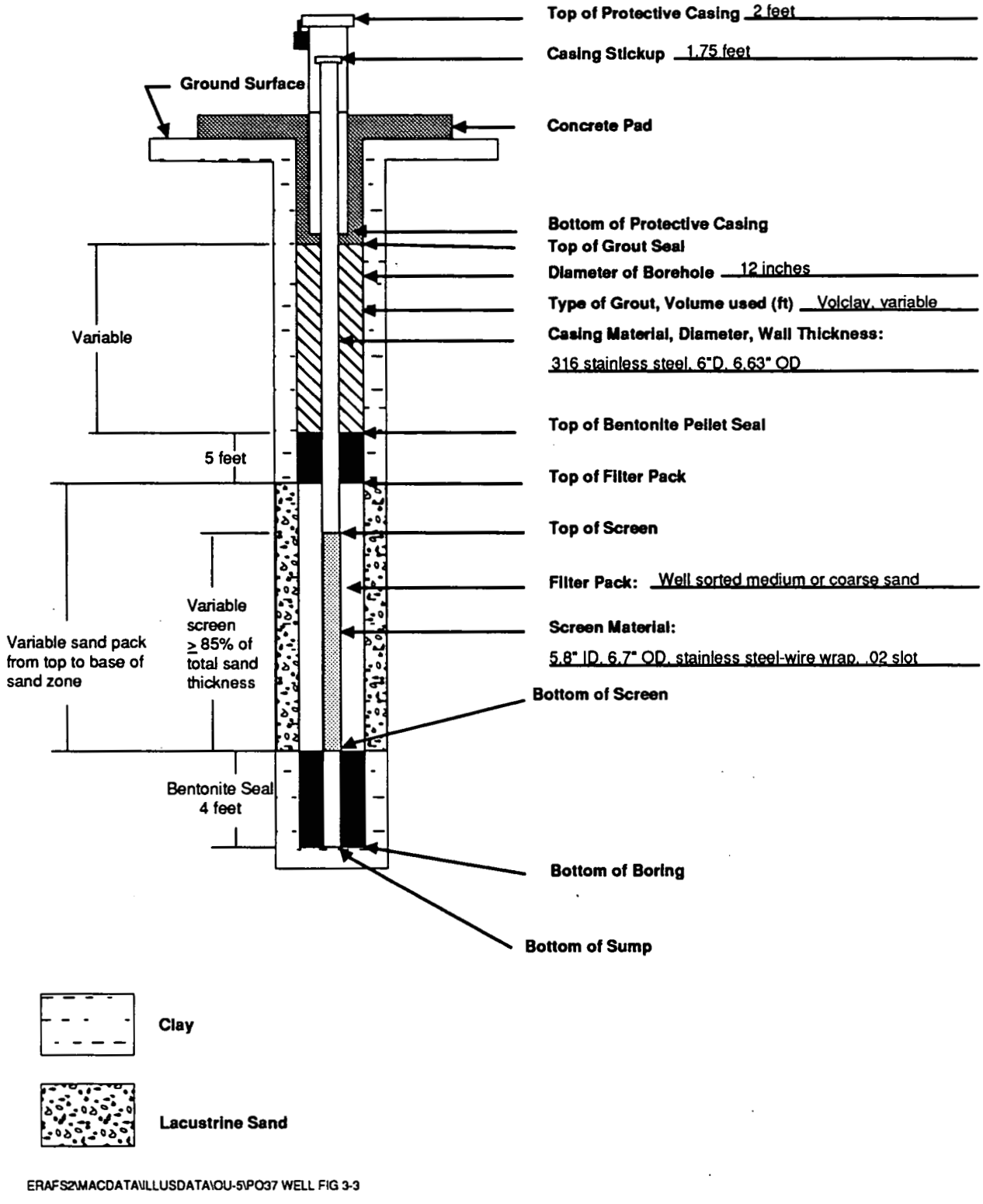


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Figure 3-3 - Example Completion for Test Well

Table 3-3 - Piezometer Design Requirements: Area W

Parameter	Requirement
Casing Diameter	2-inch minimum ID PVC
Screen Diameter	2-inch minimum ID PVC
Screen Slot Size	0.01-inch
Screen Interval	1) WPZ-1B, 2, 3, and 4 - a minimum of 85% of the saturated thickness of the lacustrine sand 2) WPZ-1A - upper clay unit - 1-foot interval WPZ-1C - lower clay unit - 1-foot interval
Filer Pack	1) Medium or coarse sand
Locations in Relation to WTW-1	1) WPZ-1A, at a distance of 10 feet from WTW-1: Depth approximately 6 feet. 2) WPZ-1B, in a cluster with WPZ-1A: approximately 20 feet. 3) WPZ-1C, in a cluster with WPZ-1A and WPZ-1B: Depth approximately 25 feet. 4) WPZ-2, at a distance of 30 feet from WTW-1; and on line with WPZ-1 cluster, depth approximately 20 feet. 5) WPZ-3, at a distance of 100 feet from WTW-1, and on same bearing line as from WPZ-1 and WPZ-2. 6) WPZ-4, at a distance of 10 feet from WTW-1 and at 90 degree to the bearing line with WPZ-1, -2, and -3. 7) Potential monitoring well at a distance to be determined (approximately 50-100 feet from WTW-1 and on a bearing line with WTW-1 and WPZ-4.

Table 3-4 - Piezometer Design Requirements: Area X

Parameter	Requirement
Casing Diameter	2-inch minimum ID PVC
Screen Diameter	2-inch minimum ID PVC
Screen Slot Size	0.01-inch
Screen Interval	1) XPZ-1B, 2, 3, and 4 - a minimum of 85% of the saturated thickness of the lacustrine sand 2) XPZ-1A - upper clay unit - 1-foot interval XPZ-1C - lower clay unit - 1-foot interval
Filter Pack	1) Medium or coarse sand
Locations in Relation to XTW-1	1) XPZ-1A, at a distance of 10 feet from XTW-1: Depth approximately 6 feet. 2) XPZ-1B, in a cluster with XPZ-1A: approximately 20 feet. 3) XPZ-1C, in a cluster with XPZ-1A and XPZ-1B: Depth approximately 25 feet. 4) XPZ-2, at a distance of 30 feet from XTW-1; and on line with XPZ-1 cluster, depth approximately 20 feet. 5) XPZ-3, at a distance of 100 feet from XTW-1, and on same bearing line as from XPZ-1 and XPZ-2. 6) XPZ-4, at a distance of 10 feet from XTW-1 and at 90 degrees to the bearing line with XPZ-1, -2, and -3. 7) Potential monitoring well at a distance to be determined (approximately 50-100 feet from XTW-1 and on a bearing line with XTW-1 and XPZ-4.

Table 3-5 - Piezometer Design Requirements: Area Y

Parameter	Requirement
Casing Diameter	2-inch minimum ID PVC
Screen Diameter	2-inch minimum ID PVC
Screen Slot Size	0.01-inch
Screen Interval	1) YPZ-1B, 2, 3, and 4 - a minimum of 85% of the saturated thickness of the lacustrine sand 2) YPZ-1A - upper clay unit - 1-foot interval YPZ-1C - lower clay unit - 1-foot interval
Filter Pack	1) Medium or coarse sand
Locations in Relation to YTW-1	1) YPZ-1A, at a distance of 10 feet from YTW-1: Depth approximately 6 feet. 2) YPZ-1B, in a cluster with YPZ-1A: approximately 20 feet. 3) YPZ-1C, in a cluster with YPZ-1A and YPZ-1B: Depth approximately 25 feet. 4) YPZ-2, at a distance of 30 feet from YTW-1; and on line with YPZ-1 cluster, depth approximately 20 feet. 5) YPZ-3, at a distance of 100 feet from YTW-1, and on same bearing line as from YPZ-1 and YPZ-2. 6) YPZ-4, at a distance of 10 feet from YTW-1 and at 90 degrees to the bearing line with YPZ-1, -2, and -3. 7) Potential monitoring well at a distance to be determined (approximately 50-100 feet from YTW-1 and on a bearing line with YTW-1 and YPZ-4.

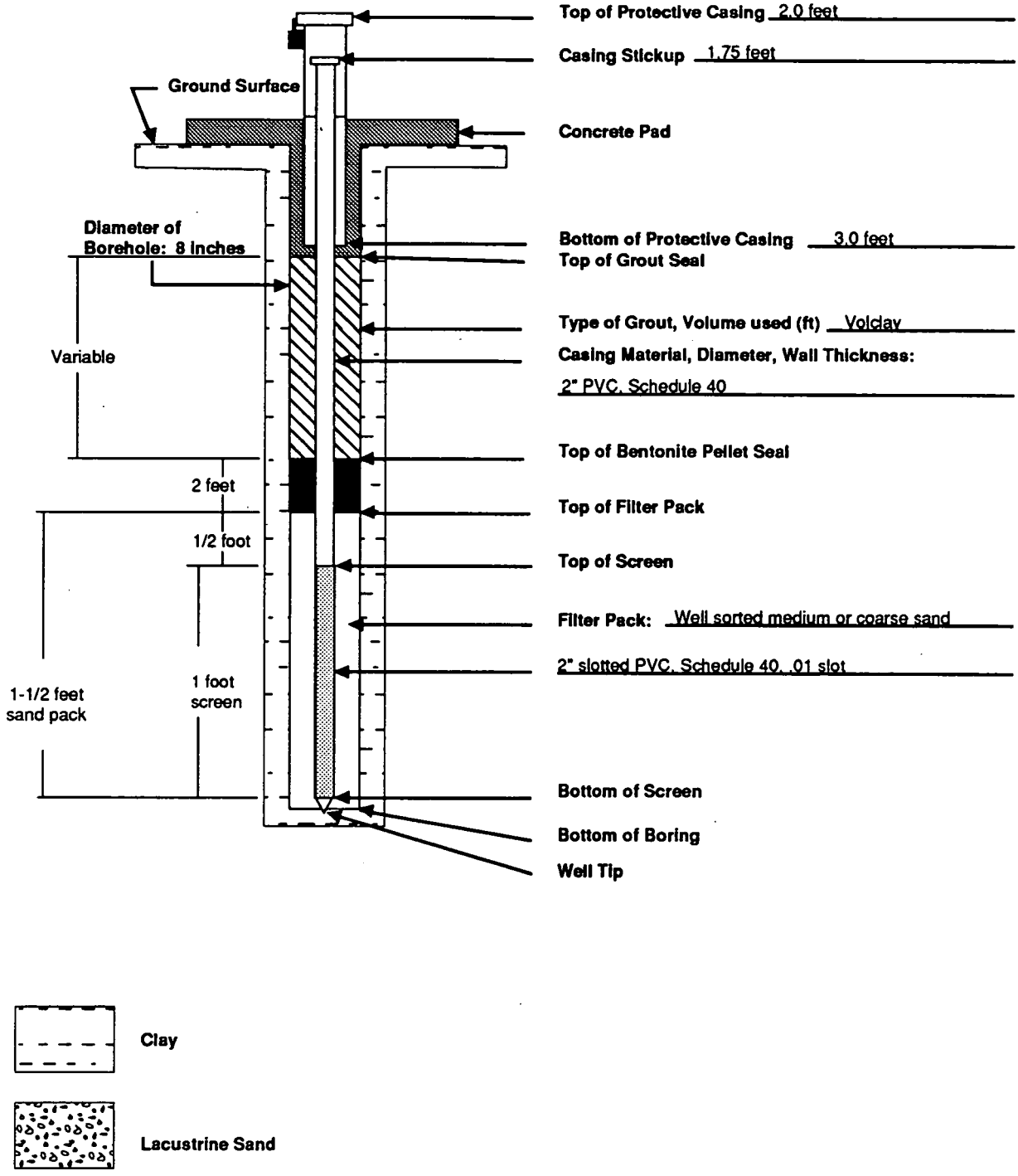
In all three areas, continuous split spoon sampling will be conducted from the surface to the base of each piezometer boring. Samples will be archived as directed by the FERMCO SCDM group.

Split spoon and undisturbed samples will be collected, preserved, and shipped in accordance with SCQ requirements. A lithologic log will be generated for each boring in accordance with Appendix J.4.1.2 and Appendix B, Form J-1 of the SCQ. Piezometer completion logs will be completed in accordance with SCQ Appendix B, Form J-2. For comparison purposes, boring logs for wells in the vicinity of the pumping tests are enclosed in Attachment A. Grain size (sieve) analysis will be performed for each piezometer completed in the sand unit. The geologist-in-charge will be responsible for selecting samples in concurrence with the PARSONS field representative. Grain size analysis will be performed in accordance with methods in the SCQ. Requirements for geotechnical laboratory containers for all tasks are provided in DQO No. 3 (Attachment F-3).

Construction of the piezometers will be as illustrated in Figures 3-4 through 3-6 and will be in accordance with SCQ procedures. Variances may be required depending on screen depths, lithologic conditions, water table elevations, etc. Piezometers WPZ-1B, 2, 3, and 4; XPZ-1B, 2, 3, and 4; and YPZ-1B, 2, 3, and 4 will be installed first followed by WPZ-1A, XPZ-1A, and YPZ1-A and then WPZ-1C, XPZ-1C, and YPZ-1C. The PARSONS field representative will be present during all piezometer construction activities (i.e., when screens, filter packs, and seals are being set). Piezometer development will also be in accordance with the SCQ procedures.

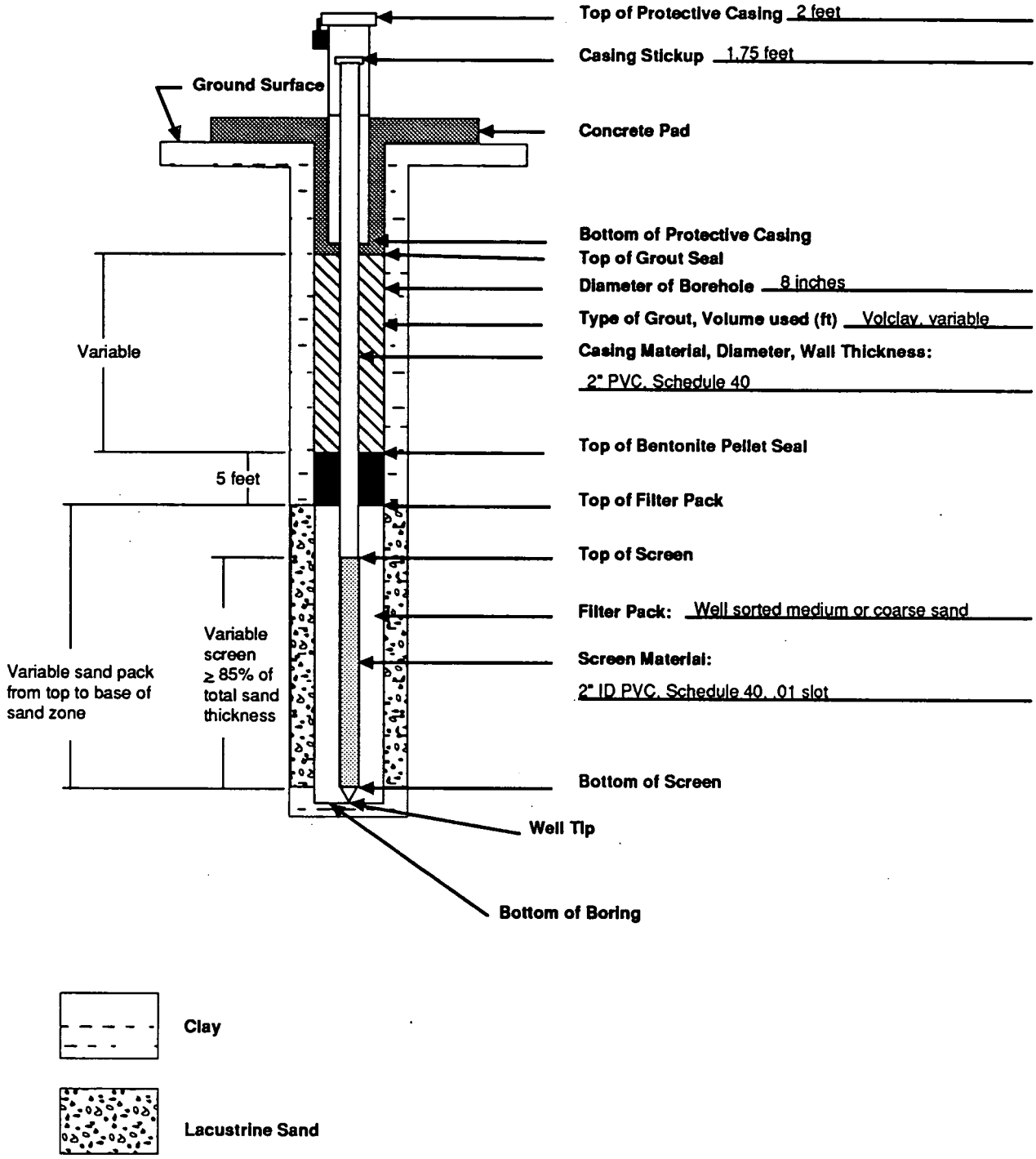
For piezometers WPZ-1B, 2, 3,and 4; XPZ-1B, 2, 3, and 4; and YPZ-1B, 2, 3, and 4, the screen will be installed from the base of the sand unit being tested to 1 foot below the base of the overlying clay; however, attempts will be made to screen no less than 85 percent of the entire sand body. The filter pack will be installed from the base of the boring to the top of the sand unit being tested. The filter pack will be capped by a 5-foot bentonite pellet seal. The bentonite pellet seal will be covered with volclay grout to within 1 foot of the surface. The wellhead will be completed with an aboveground locking protective cover assembly in accordance with the SCQ procedures.

For piezometers WPZ-1A, XPZ-1A, and YPZ1-A, the borings will be advanced to a depth of 2 feet above the top of the of the sand being tested (as identified in piezometers WPZ-1B, XPZ-1B, and YPZ-1B, respectively). A 1-foot screen will be set from the base of each boring with a 1-1/2-foot filter pack capped by a 5-foot bentonite pellet seal. The base of the filter pack will be set approximately 2 feet above the sand unit. The sand unit will not be penetrated by the boring. The bentonite pellet seal will be covered with volclay grout to within 1 foot of the surface with an aboveground locking protective cover assembly in accordance with the SCQ procedures. The wellhead will be completed with an aboveground locking protective cover assembly in accordance with the SCQ procedures.



ERAFS2\MACDATA\ILLUSDATA\OU-5\PO37 WELL FIG 3-4

Figure 3-4 - Example Completion for Piezometers WPZ-1A, XPZ-1A, and YPZ-1A



ERAFS2\MACDATA\ILLUSDATA\OU-5\PO37 WELL FIG 3-5

Figure 3-5 - Example Completion for Piezometers WPZ-1B, XPZ-1B, and YPZ-1B

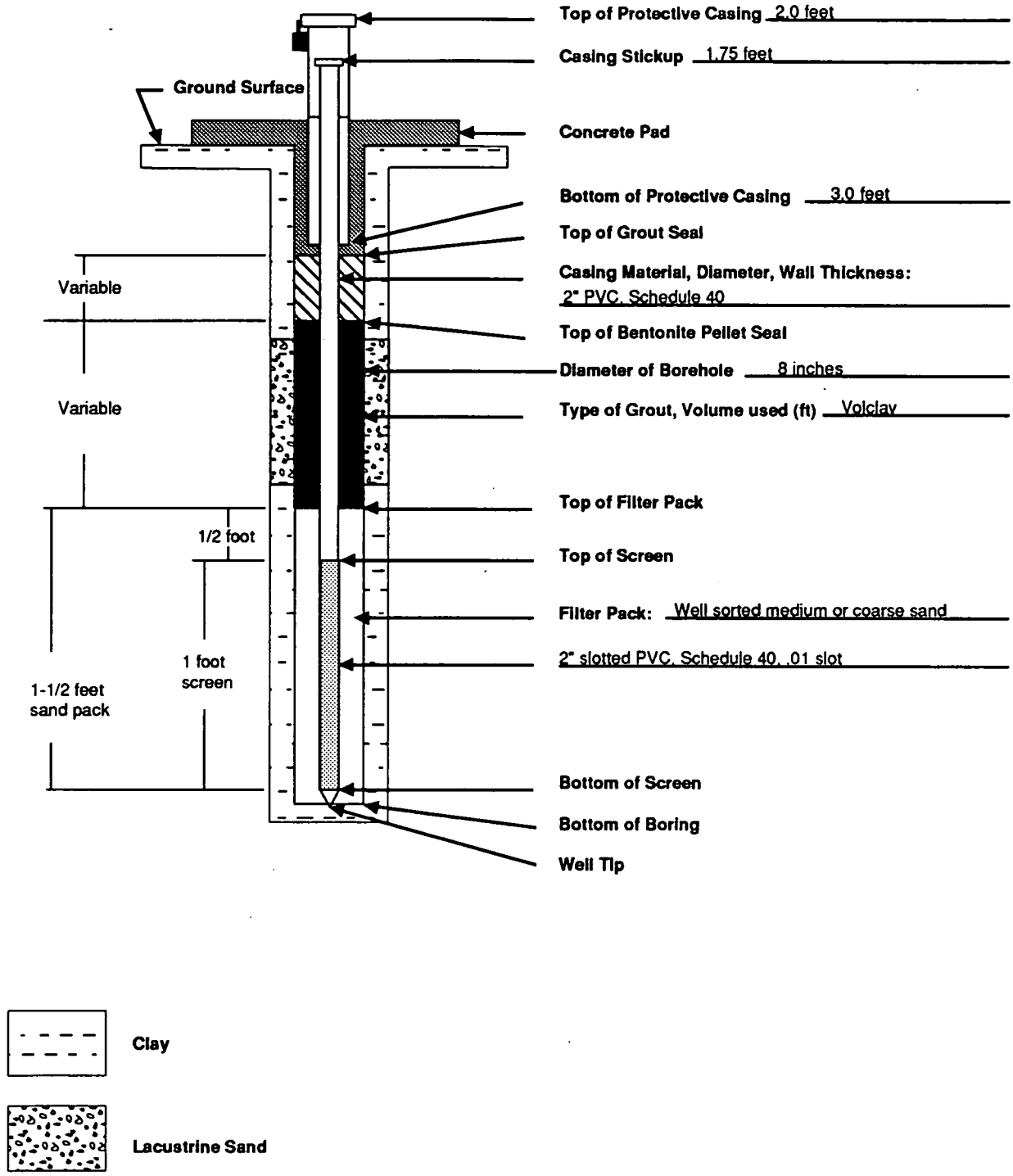


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Figure 3-6 - Completion for Piezometers WPZ-1C, XPZ-1C, and YPZ-1C

For piezometers WPZ-1C, XPZ-1C, and YPZ-1C, the borings will be drilled to a depth of 5 feet below the sand unit being tested. A 1-foot screen will be placed below the sand unit with a 1-1/2-foot filter pack. The top of the filter pack will be 2 feet below the base of the overlying sand. The filter pack will be capped by a bentonite pellet seal to 1 foot above the top of the overlying sand unit, and the seal will be covered with volclay grout to within 1 foot of the surface. The wellhead will be completed with an aboveground locking protective cover assembly in accordance with the SCQ procedures.

3.3 Pumping Test Design and Field Implementation

As discussed in Section 4.1, data will be acquired in three stages during the pumping test:

1) A step-drawdown test
2) A constant rate test up to 7 days
3) A water level recovery period

Each stage of the test will be used to define the next stage. Each stage is detailed in the following sections. The test design is based on Stallman (1971), U.S. Department of the Interior (1981), Driscoll (1986), Walton (1987), and Kruseman and deRidder (1990).

3.3.1 Required Personnel

During the actual performance of the pumping test, the following personnel will be required at various times on site:

1) FERMCO SCDM Task Manager: Responsible for overall coordination of the project

2) SCDM Lead Pumping Test Specialist (geologist-in-charge): Responsible for test setup and procedures

3) SCDM Technicians: Responsible for data collection, well measurements, pump installation and operation, piping hookups, routing and operation of discharge lines, pressure transducer installation and operation of data logger, and groundwater sampling

4) FERMCO CRU-5 Health and Safety: Responsible for directing personnel and equipment across controlled access areas

5) PARSONS Field Representative: Available to assist and consult with the FERMCO geologist-in-charge during the implementation of each pumping test according to work plan specifications

The Lead Pumping Test Specialist shall possess the necessary skills to perform as well as to direct the activities of the technicians. Participants shall be able to address contingencies competently and efficiently so that time and data are not lost. All field contingencies should be resolved to the fullest extent possible during the equipment shakedown period described below.

3.3.2 Test Equipment and Methods

The following equipment will be required for each pumping test:

1) Two 1.8-inch submersible pumps (Grundfos®, Rediflo-2, or equivalent) with check valve to prevent water from siphoning back into the well. Pumps are to include controller boxes and 50 feet of associated cables (2 wire assembly for 230 volt operation). Pump must be capable of pumping between 0.5 and 10 gpm and must be able to pump against static and friction head to its discharge point.

2) Two 3-15/16-submersible pumps (Grundfos® Model 25S05-3 or equivalent with check valve to prevent water from siphoning back into the well. Pumps are to include controller boxes and 50 feet of associated cables (2 wire assembly for 230 volt operation). Pump must be capable of pumping between 10 and 30 gpm and must be able to pump against static and friction head to its discharge point.

3) Electrical source (230 volt) supplied by the site to power the pump for as long as 7 days of continuous operation compatible with the 230 volt pump cable.

4) Discharge hose (1-inch ID) and necessary fittings from pump to discharge point.

5) Electrical source (110 volt) for ancillary field equipment.

6) Gate valve or other flow control device to control discharge from the test well.

7) Flow meter with totalizer to measure flow in gpm and total discharge in gallons.

8) Multi-channel data loggers (In Situ® Hermit 1000 and 2000 or equivalent) with 15 transducers with necessary fittings and cables. Data logger and transducer system will be capable of recording at rates as frequent as two readings per second. A 1-inch 1D PVC tube with adapter for the transducer will be used to protect the cable from deterioration.

9) A single channel data logger and transducer for backup purposes, particularly during recovery period.

10) Seven steel tapes with chalk, or electrical water level measuring tapes (both types at least 200 feet long and graduated in hundredths of a foot) for water level measurement.

11) Stop watches and digital wrist watches capable of being synchronized within 1 second for each member of the pump test team.

12) Lightplant or other lighting for overnight activities.

13) Portable hand-held lighting (e.g., flashlights and lanterns) for each member of the team.

14) A weather station capable of measuring barometric pressure, temperature, and rainfall.

15) Combined pH, Specific Conductance, and Dissolved Oxygen meter.

16) Thermometers (at least two).

17) Sample bottles and shipping containers.

18) Portable computer.

19) Log-log 3- by 5-cycle and semi-log 3-cycle graph paper for plotting drawdown data.

20) Distilled water and equipment for decontamination of probes and steel tapes.

21) Sampling port on flowline for groundwater sampling.

22) Health and safety equipment and clothing.

23) Indelible pens and/or pencils.

24) Field notebook and water level recording forms.

3.3.3 Procedures

Procedures for performing the tasks associated with the pump test will be consistent with guidelines provided in the SCQ and new procedures developed as part of this plan. These procedures are referenced in Table 3-6. Any procedure that is not already in the SCQ will be submitted as a Document Change Request (DCR) to the SCQ. The new procedures are described in detail in Attachment C.

Table 3-6 - Pump Test Procedures

PROCEDURE	REFERENCE	
Administrative Procedures	**FEMP SCQ (1992) Section**	**New Procedure Attachment**
Chain-of-Custody	7.1	
Corrective Action	15.2	
Daily Logs	5.1 and Appendix J.4.1	
Variances	15.4	
Field Procedures		
Ground Water Level Measurement	Appendix K.4.2.1	
Water Level Measurements - Metal Tape		C-5
Water Level Measurement Form		E-2
Aquifer/Permeability Testing	5.2.5 and Appendix J.4.6	
Decontamination	Appendix K.11	
Field Storage and Shipment of Samples	Appendix K.10	
Field Calibration Requirements	Appendix I	
Verification of Well Sensitivity		
Field Test:		
Temperature	Appendix K.4.1.1	
pH	Appendix K.4.1.2	
Specific Conductance	Appendix K.4.1.3	
Dissolved Oxygen	Appendix K.4.1.4	
Laboratory Test Procedures		
Total Uranium	Attachment I, Volume V, Method No. FM-RAD-0120	
Volatiles	Attachment I, Volume V	
General Chemistry	Attachment I, Volume V	

3.3.4 Equipment Shakedown and Background Data

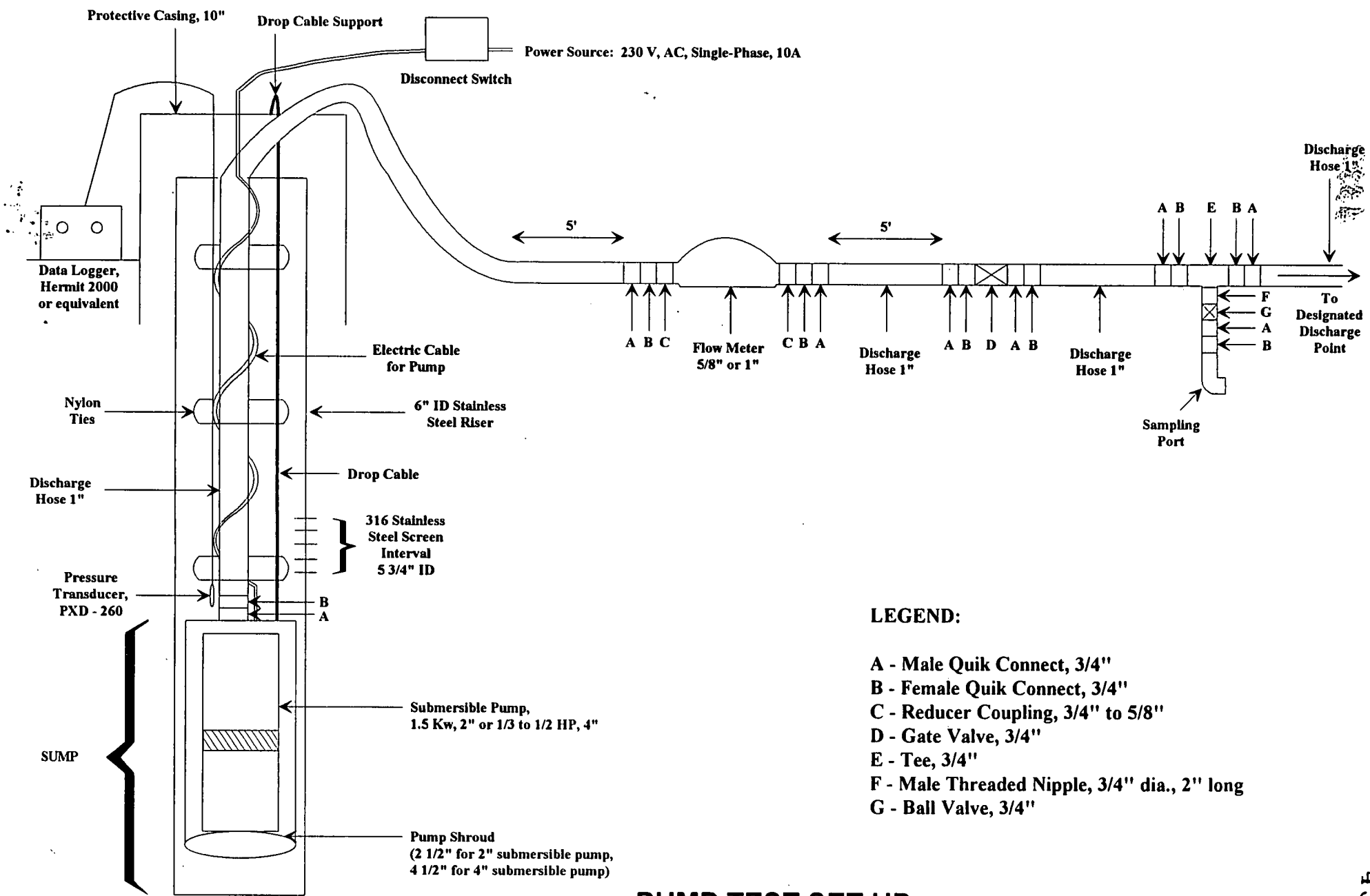
The pumping test equipment for the test wells (WTW-1, XTW-1, and YTW-1) will be installed in accordance with Figure 3-7. In order to minimize unforeseen problems, all equipment will be subjected to a performance shakedown at least 1 day prior to the test. Power supplies, the pump, flow lines and discharge collection systems, valves, gauges, meters, lighting, recorders, data loggers, and any other equipment subject to mechanical, structural, and/or electrical failure will be inspected and field tested prior to startup of the pumping test. The shakedown will attempt to duplicate the elements of the step drawdown test (pumping rates, measurement techniques, tolerance interval, etc.) described below. The PARSONS field representative will be present during the equipment shakedown to concur that all equipment is properly calibrated and functioning.

Water level measurements of the test well, piezometers, and primary observation wells will be collected four times a day for 1 week prior to the start of the test. Also, 1 week before the test, two background wells will be selected several hundred to 1,000 feet away from the test wells and equipped with a data logger/transducer system to monitor water levels every 1/2 hour. The background wells will be screened in the sand unit that extends from Plant 2/3 to Paddy's Run. One will be monitored where it appears to be confined; the other where it appears to be unconfined. Data logger/pressure transducer systems will be placed in four of the monitoring wells and allowed to collect data for 1 week prior to the test. The data loggers will be set to record a water level reading every 30 minutes. The PARSONS field representative will be available to consult with FERMCO personnel on the installation, calibration, and use of the data logger and pressure transducer system.

3.3.5 Step Drawdown Test

A step drawdown test will be conducted to determine well yield and optimum pumping rate for each constant rate pumping test. The test well will be pumped at three successively higher rates: 1, 5, and 10 gpm are recommended; these rates may be adjusted in the field as necessary. Each step will have a duration of 2 hours (longer if a drawdown trend has not been established, shorter if the well runs dry). During each step period, flow will be maintained at + or - 5 percent (within the tolerance interval suggested by Stallman [1971]) of the designated rate by means of a throttling device or other flow control method.

Water levels will be measured in the test well and primary observation wells by pressure transducers linked to a data logger. Water levels will also be monitored periodically utilizing electrical water level indicators and/or steel measuring tapes so that data logger readings can be cross checked. Tables 3-7 through 3-9 list all the wells and piezometers to be used for observation purposes during the test and the method of water level measurement. Information from the drawdown measurements will be used to determine if the well can pump at a sufficiently high rate to adequately stress the saturated sand zone.



PUMP TEST SET UP
(Not to Scale)

Figure 3-7 - Pump Test Setup (Not to Scale)

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Discharge and disposal of the water from the step drawdown tests will be to holding tanks and then trucked to the FEMP's wastewater treatment facility. Current estimates are approximately 2,400 gallons for each test if run for a period of 8 hours.

Water level measurements shall be recorded on a form similar to that shown in Attachment E-2. Water levels will be measured relative to the top of the well casing reference point. The PARSONS field representative will be available to consult with FERMCO personnel on the installation, calibration, and use of the data logger and pressure transducer system.

3.3.6 Constant Rate Test

After the step drawdown test and before commencement of the constant rate test, the water in the sand zone must be allowed to recover and stabilize at or near pre-pumping levels. For this test, the water level should recover and stabilize until the day following the step drawdown test, 12 hours or a period equal to the duration of the step test, whichever is longer.

Each test well will be pumped at the optimum rate determined by the step drawdown test (as agreed by the PARSONS field representative and the FERMCO geologist-in-charge) for a maximum period of 7 days or until steady state conditions are reached, whichever is shortest. Discharge will be measured with a flow meter and maintained within + or - 5 percent of the designated rate by means of a throttled gate valve or other flow control method. Discharge will be checked and adjusted as necessary every 10 minutes during the first hour of pumping and at 30-minute intervals thereafter. The discharge and time of measurement will be recorded and any adjustment will be noted. The flow rate will be recorded every minute for the first 10 minutes of the test, every 5 minutes for the next 4 hours, then every 15 minutes thereafter. Discharge from the well will be calibration checked four times a day with a stop watch and 5-gallon bucket. Volume discharged to the bucket will be recorded versus time and compared to the flow meter rate.

Table 3-7 - Measurements of Wells and Piezometers for Constant Rate Pumping Test: Area W

Well ID	Method of Measurement
WTW-1 (PW)	Pressure Transducer and Electronic 4-Channel Data Logger
WPZ-1B	Pressure Transducer Attached to Data Logger at WTW-1
WPZ-4	Pressure Transducer Attached to Data Logger at WTW-1
WPZ-1A	Pressure Transducer and Electronic 2-Channel Hermit Data Logger
WPZ-1C	Pressure Transducer Attached to Data Logger at WPZ-1A
WPZ-2	Pressure Transducer and Electronic 2-Channel Hermit Data Logger
WPZ-3	Pressure Transducer Attached to Data Logger at WPZ-2

Table 3-8 - Measurements of Wells and Piezometers for Constant Rate Pumping Test: Area X

Well ID	Method of Measurement
XTW-1	Pressure Transducer and Electronic 4-Channel Data Logger
XPZ-1B	Pressure Transducer Attached to Data Logger at XTW-1
XPZ-4	Pressure Transducer Attached to Data Logger at XTW-1
XPZ-1A	Pressure Transducer and Electronic 2-Channel Hermit Data Logger
XPZ-1C	Pressure Transducer Attached to Data Logger at XPZ-1A
XPZ-2	Pressure Transducer and Electronic 2-Channel Hermit Data Logger
XPZ-3	Pressure Transducer Attached to Data Logger at XPZ-2

Table 3-9 - Measurements of Wells and Piezometers for Constant Rate Pumping Test: Area Y

Well ID	Method of Measurement
YTW-1	Pressure Transducer and Electronic 4-Channel Data Logger
YPZ-1B	Pressure Transducer Attached to Data Logger at YTW-1
YPZ-4	Pressure Transducer Attached to Data Logger at YTW-1
YPZ-1A	Pressure Transducer and Electronic 2-Channel Hermit Data Logger
YPZ-1C	Pressure Transducer Attached to Data Logger at YPZ-1A
YPZ-2	Pressure Transducer and Electronic 2-Channel Hermit Data Logger
YPZ-3	Pressure Transducer Attached to Data Logger at YPZ-2

The wastewater from the pumping tests will be discharged to holding tanks and trucked to the FEMP's wastewater treatment facility. Current estimates are approximately 50,000 to 100,000 gallons of water for each test. FERMCO will be responsible for managing the discharge and trucking of water generated by the pumping test.

As in the step test, drawdown in the test well and the primary observation wells will be recorded with the pressure transducer and data logger system. Time will be recorded in minutes. The water level drawdown data, measured in feet, will be plotted against a logarithmic time scale; therefore, water level data will be collected more frequently during the early time portion of the test to provide sufficient data points for curve matching analysis. Measurement intervals for piezometers and wells are recommended according to Table 3-10 (In Situ® Inc. 1992 and Walton 1987). Since the data logger transducer system will be preprogrammed to collect more data points at the beginning of the test and is capable of recording at rates as low as two readings per second, sufficient data points will be available for the logarithmic data plots. Data will be downloaded from the data logger during the test and plotted on semi-logarithmic graph paper to determine the shape of the drawdown curve. This will aid in determining the length of the pumping test.

Groundwater samples will be collected from the pumping wells near the end of the test and analyzed for total uranium, VOCs, and general chemistry (anion and cations). The TAL and container/preservation requirements can be found in DQO 2 in Attachment F-2 of this document.

3.3.7 Water Level Recovery Measurements

The water level recovery measurements will begin simultaneously with pump shutdown. The monitoring of rising water levels will be performed in the same manner as performed during pumping. Measurements will be recorded according to the same schedule as the constant rate test (Table 3-10) until required recovery is achieved. At least one piezometer or the test well will be equipped with an independent water level measurement system to assure that early time recovery data is not lost. Measurements will continue for approximately 24 hours or until three successive water level measurements at 1-hour intervals show less than 0.1-foot difference in recovery at the test well (U.S. Department of the Interior 1981).

3.4 Data Analysis

Based on the observed response of the water levels, appropriate analytical techniques will be selected to calculate the hydraulic properties of the saturated sand zone. The screen of each test well and five of the six offsetting piezometers have been specified to cover at least 85 percent of the saturated sand zone. With this screen coverage, the well and piezometers are defined as fully penetrating the test zone (Todd 1980). For the step drawdown test, methods based on Jacobs' equations (Walton 1987) will be used.

Table 3-10 - Measurement Intervals for Piezometers and Observation Wells

Time Since Start of Pumping	Approximate Time Intervals
Primary Observation Wells and Piezometers (Connected to Data Logger)	
0 - 10 Seconds	0.5 Seconds
10 - 20 Seconds	1 Second
20 - 120 Seconds	5 Seconds
2 - 10 Minutes	30 Seconds
10 - 100 Minutes	2 Minutes
100 - 1,000 Minutes	10 Minutes
1,000 - 10,000 Minutes	100 Minutes
10,000 Minutes - Shutdown of the Pump	500 Minutes
Secondary Observation Wells and Piezometers	
0 - 24 Hours	2 Times per Day
24 Hours - Shutdown of Pump	1 Time per Day

Methods of test analysis will depend on screen interval as well as hydrologic conditions. Methods based on Neuman, Theis, Cooper-Jacob, and Hantush will most likely be used to calculate hydraulic conductivity (K) and storativity (S). All of these methods are explained in Kruseman and Ridder (1990). Other methods of analysis will be used where appropriate. The computer software package, Aqtesolv™ (Duffield and Rumbaugh 1991) will be used where applicable.

Where data allows, the Hantush-Jacob method will be used for estimating the vertical hydraulic conductivity (K') of the overlying aquitard (Kruseman and deRidder 1990). Vertical groundwater movement will also be evaluated in accordance with methods developed by Neuman and Witherspoon (Javandel 1984). Depending on well response, several other methods of analysis may be applicable for calculating K, S, and K'.

SECTION 4

LYSIMETER INSTALLATION

4.1 Specific Objectives

Six borings will be advanced into two separate zones of the GT/VZ. One deep-sampling lysimeter will be placed in each boring. The six borings will be drilled as clusters with two lysimeters to each cluster. One lysimeter in each cluster will be used for sampling pore moisture in the lower clay at the base of the glacial overburden. The other will be used for sampling the unsaturated sand and gravel above the water table of the GMA.

The lysimeters will be sampled to determine the extent of saturation of the lower clay layer at the base of the overburden and also the GMA. Any samples recovered from the lower clay or the GMA will be analyzed for general chemistry (anions and cations) and total uranium.

4.2 Boring and Lysimeter Placement

The six lysimeter borings will be located as seen in Figure 4-1. Each cluster will be drilled in distinctly separate areas of the site (designated A, B, and C). The FERMCO SCDM will provide the necessary penetration permits for these borings.

4.3 Lysimeter Field Implementation

4.3.1 Boring Methods

The borings will be drilled under the policies and guidelines provided in the SCQ. Procedures pertaining to drilling and abandonment activities are referenced to the SCQ in Table 4-1.

Tables 4-2 and 4-3 provide details of the borings that will be drilled in Areas A, B, and C. The lysimeter borings will be advanced by cable tool methods to the top of their respective test zones.

For lysimeter placed in the clay layer at the base of the overburden, an 8-inch hole will be advanced by cable tools to the top of this clay layer. The casing will be cemented in place to prevent migration of any uphole formation waters down into the lower clay. A 6-inch boring will be telescoped by 6-inch dry hollow stem auger or dry core methods. The telescoped boring will be drilled approximately 5 feet into the lower clay. Once the telescope boring is completed, a lysimeter will be installed in accordance with methods described in Section 4.3.2.

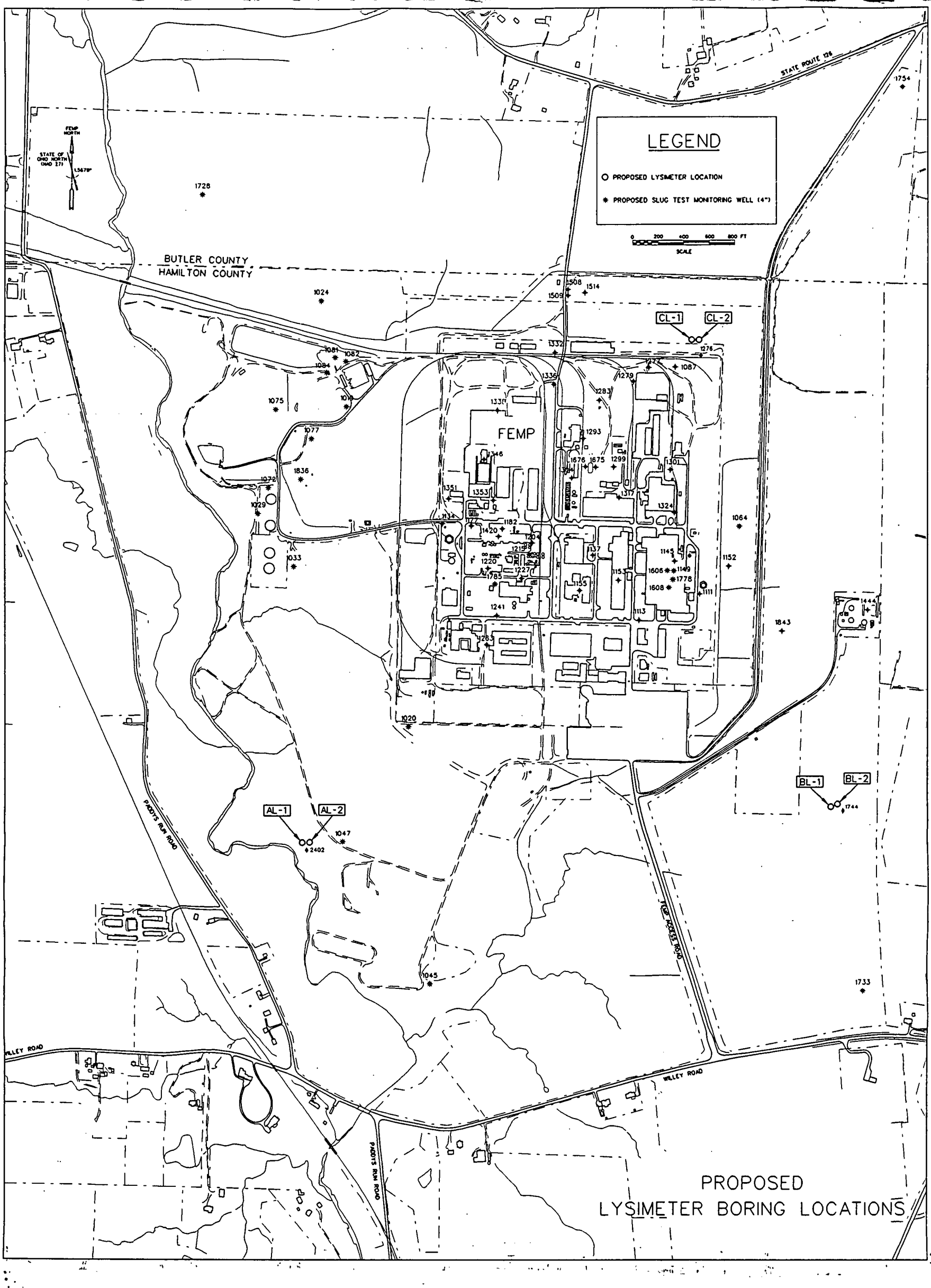

Figure 4-1 - Lysimeter Boring Locations

Table 4-1 - Lysimeter Installation Procedures

PROCEDURE	REFERENCE	
Administrative Procedures	**FEMP SCQ (1992) Section**	**New Procedure Attachment**
Chain-of-Custody	7.1	
Corrective Action	15.2	
Daily Logs	5.1 and Appendix J.4.1	
Variances	15.4	
Field Procedures		
General Drilling Practices	5.2.1 and Appendix J.4.2	
Subsurface Sampling	Appendix K.5.3	
Lysimeter	5.2.2 and Appendix J.4.3	C-4
Design, Installation, and Abandonment	*EM-GW-004	
Field Screening of Samples for Radioactive Contamination	Appendix K.5.3.2	
Decontamination	Appendix K.11	
Field Storage and Shipment of Samples	Appendix K.10	
Laboratory Test Procedures		
Grain Size Analysis	Attachment I, Volume V	
Hydrometer Analysis	Attachment I, Volume V	
Permeability Testing		C-3
Atterberg Limits	Attachment I, Volume V	
Moisture Content	Attachment I, Volume V	
Void Ratio	Attachment I, Volume V	
Porosity	Attachment I, Volume V	
Lab Density and Specific Gravity	Attachment I, Volume V	
Total Uranium	Attachment I, Volume V	
Volatiles	Attachment I, Volume V	
General Chemistry	Attachment I, Volume V	

* Well and boring abandonment will also follow this procedure listed in the *WEMCO Environmental Monitoring Procedures Manual*, Rev. 28 (June 16, 1992).

Table 4-2 - Lysimeter Boring Requirements: Zone 3

Lysimeter ID	Approximate Base of Boring Below Land Surface (Feet)	Base of Lysimeter Tip, Below Land Surface (Feet)	Boring Diameter (Inches)	Estimated State Coordinates
AL-1	15 feet or 5 feet into clay	14 feet or 5 feet into clay	6" OD	N 478200E1378700
BL-1	20 feet or 5 feet into clay	19 feet or 5 feet into clay	6" OD	N 478650E1383050
CL-1	24 feet or 5 feet into clay	23 feet or 5 feet into clay	6" OD	N 482050E1381900

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Table 4-3 - Lysimeter Boring Requirements: GMA

Lysimeter ID	Base of Boring Below Land Surface (feet)	Base of Lysimeter TIP, Below Land Surface (feet)	Boring Diameter (Inches)	Estimated State Coordinates
AL-2	22 feet or no more than 10 feet into unsaturated GMA	21 feet or no more than 10 feet into unsaturated GMA	8" OD HSA	N 478200E1378700
BL-2	46 feet or no more than 10 feet into unsaturated GMA	45 feet or no more than 10 feet into unsaturated GMA	8" OD HSA	N 478650E1383050
CL-2	86 feet or no more than 10 feet into the unsaturated GMA	85 feet or no more than 10 feet into unsaturated GMA	8" OD HSA	N 482050E1381900

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For lysimeter placed in the GMA, a 10-inch hole will be advanced by cable tool methods approximately 5 feet into the lower clay at the base of the overburden. The casing will be cemented in place to prevent migration of any uphole formation waters down into the lower clay. An 8-inch OD boring will be telescoped by dry core and/or dry hollow stem auger methods.

The telescoped boring will be augered or cored through the clay and hollow stem augered no more than 10 feet into the unsaturated portion of the GMA. A lysimeter will be placed in the unsaturated portion of the GMA.

General drilling practices will be in accordance with the SCQ. Tables 4-2 and 4-3 show the approximate depth of each boring; however, the geologist-in-charge in concurrence with the PARSONS field representative will be responsible for selecting the total depth for each boring.

In the deepest boring of each couplet, continuous split spoon samples will be recovered from the surface to the base of the boring. Two undisturbed samples using Shelby Tube methods will be collected from the lower clay. Dennison sampling will not be attempted. The undisturbed samples will be sent to a geotechnical lab and analyzed for grain size with hydrometer analysis, moisture content, porosity, void ratio, Atterberg limits, lab density, specific gravity, constant head permeability (triaxial cell with back pressure), visual descriptions, and USCS classifications. Continuous split spoon sampling and undisturbed sampling will be conducted in accordance with SCQ requirements and archived as directed by the FERMCO SCDM. The split-spoon samples will be analyzed for grain size and USCS classification with visual descriptions by the geotechnical lab. Samples will be selected by the geologist-in-charge in concurrence with PARSONS. A lithologic log will be generated for each boring in accordance with Appendix J.4.1.2 and Appendix B, Form J-1 of the SCQ. For comparison purposes, Attachment A includes boring logs for wells and borings in the vicinity of the lysimeter borings. Sample container/preservation methods are presented in DQO 3 in Attachment F-3.

4.3.2 Lysimeter Installation

A lysimeter will be installed in the lower clay of the glacial overburden and the GMA at each well piezometer cluster. The lysimeter (TIMCO™ Deep-Sampling Cup or equivalent) proposed is a 2-inch diameter vacuum/pressure soil pore water sampler as presented in Attachment C-4. The lysimeter allows water to enter a micro-porous ceramic cup at the instrument's base through capillary forces. The ceramic cup is attached to an 18-inch PVC cylindrical body with full-depth riser and a PVC head. The head assembly attaches to the riser and connects sample and pressure ports to the lysimeter via 1/4-inch nylon tubing. The lengths of the nylon tubing extend from the lysimeter body through the riser head at the surface and are used for vacuum extraction and pressure sampling. The sample tube extends from the head through the lysimeter to a point just in contact with the inside base of the lysimeter. The vacuum extraction tube extends into the lysimeter to a point approximately 3 inches below the inside of the cap.

Each length of tubing will be clearly identified and attached to the proper fitting at the lysimeter head. Installation will be in accordance with manufacturer's recommendations as shown in Attachment C-4. Applicable SCQ procedures for lysimeter installation are listed in Table 4-1 and can be found in Attachment C-4.

In addition, the lysimeter and associated tubing will be decontaminated prior to installation in accordance with SCQ procedures used for well screens. After lysimeter and nylon tube decontamination, the ends of the tube will be clamped off at the surface to avoid the inadvertent introduction of foreign material into the tubing. The lysimeter components will then be assembled and installed with a full-depth, 2-inch PVC riser screwed on to the lysimeter body to house the nylon tubing. The tubing will be measured and cut to allow approximately 2 feet of stick-up at the surface. A 3- to 6-inch-thick slurry of silica flour and distilled water will be tremied into the open borehole. The lysimeter and riser will be gently lowered into the boring and secured at the surface to prevent floating.

Additional slurry will be placed 2 to 4 inches above the top of the ceramic tip of the lysimeter. At that point, 80/100 mesh sand will be poured to a minimum of 3-6 inches above the top of the lysimeter, followed by a column of Volclay grout to within 3 feet of the surface. This grout will be placed with a tremie line and will prohibit shallow water from draining into the lysimeter zone. The lysimeter head will then be connected to the tubing.

4.4 Lysimeter Sampling and Analysis

Sample recovery from the lysimeter will be in accordance with manufacturer's instructions and general SCQ protocol. After satisfactory installation of each lysimeter, a vacuum hand pump will be attached to the pressure port of the lysimeter and used to lift the sample into the holding chamber of the lysimeter. Pressure should be gently increased until 9 psi is achieved to lift the sample into the holding chamber of the Deep-Sampling Lysimeter. CAUTION! If 9 psi is applied instantly, it is possible to damage the silica flour pack resulting in a lysimeter system failure.

Finally, apply the correct amount of pressure required to lift the sample to the surface and into the collection container. A pressure of 0.44 psi is required per foot of depth. In the event a shallow-sampling lysimeter is required, sampling will be performed in accordance with the manufacturer's instructions.

If the formation will yield water to the lysimeter, enough water will be collected to satisfy the requirements of total uranium, and anion/cation analysis. TALs and sample container preservation methods are provided in DQO 2 in Attachment F-2. All samples will be handled, documented, shipped, and validated according to SCQ procedures. Results will be made available to PARSONS for incorporation in the investigations report.

SECTION 5

PACKER TESTS

5.1 Specific Objectives

Packer tests are performed to estimate the hydraulic conductivity of the fine silts and clays of the glacial till in the GT/VZ. Data from these tests will be used to provide a vertical profile of horizontal hydraulic conductivity. Up to 15 packer tests are planned in two borings and three wells. As the lithology of the glacial till changes during the two boring operations, a series of 5-foot intervals will be tested by constant head pressure test methods. The borings will be advanced until the next clay unit is encountered, and another 5-foot interval will be tested. The borings will continue to be advanced and tested in this manner from the surface to the lower clay of the glacial overburden. One undisturbed soil sample (Shelby or Dennison) will be recovered for geotechnical laboratory analysis as each test zone is identified. Sand units or units where the hole will not stand open in the glacial till will not be tested; however, split spoon samples will be collected for grain size analysis. The unsaturated sands of the GMA will not be penetrated.

The test wells installed for the pumping tests will also use the packer test procedure described herein, but only for the lower clay zone that lies above the unsaturated sand of the GMA. Again, the GMA will not be penetrated. The constant head pump-in pressure test method will also be used for the wells.

5.2 Boring and Piezometer Placement

The two borings and three wells for the packer tests will be located as seen in Figure 5-1. Each boring will be drilled in distinctly separate areas of the site (designated N and S). The test wells in areas W, X, and Y (as described in Section 3.2) have been selected for packer tests of the lower clay at the base of the glacial overburden. The FERMCO Site Characterization group will secure the necessary penetration permits for these borings.

5.2.1 Boring Methods

The borings will be installed under the policies and guidelines provided in the SCQ. Procedures pertaining to drilling and abandonment activities are referenced to the SCQ in Table 5-1.

Table 5-2 provides details of the borings to be drilled in area N and area S. The borings will be advanced by spin casing methods using the FEMP's potable water; however, water will not be recirculated through pits. Only fresh potable water will be used to circulate in while drilling. General drilling practices will be in accordance with the SCQ. Each boring will be drilled to the base of the

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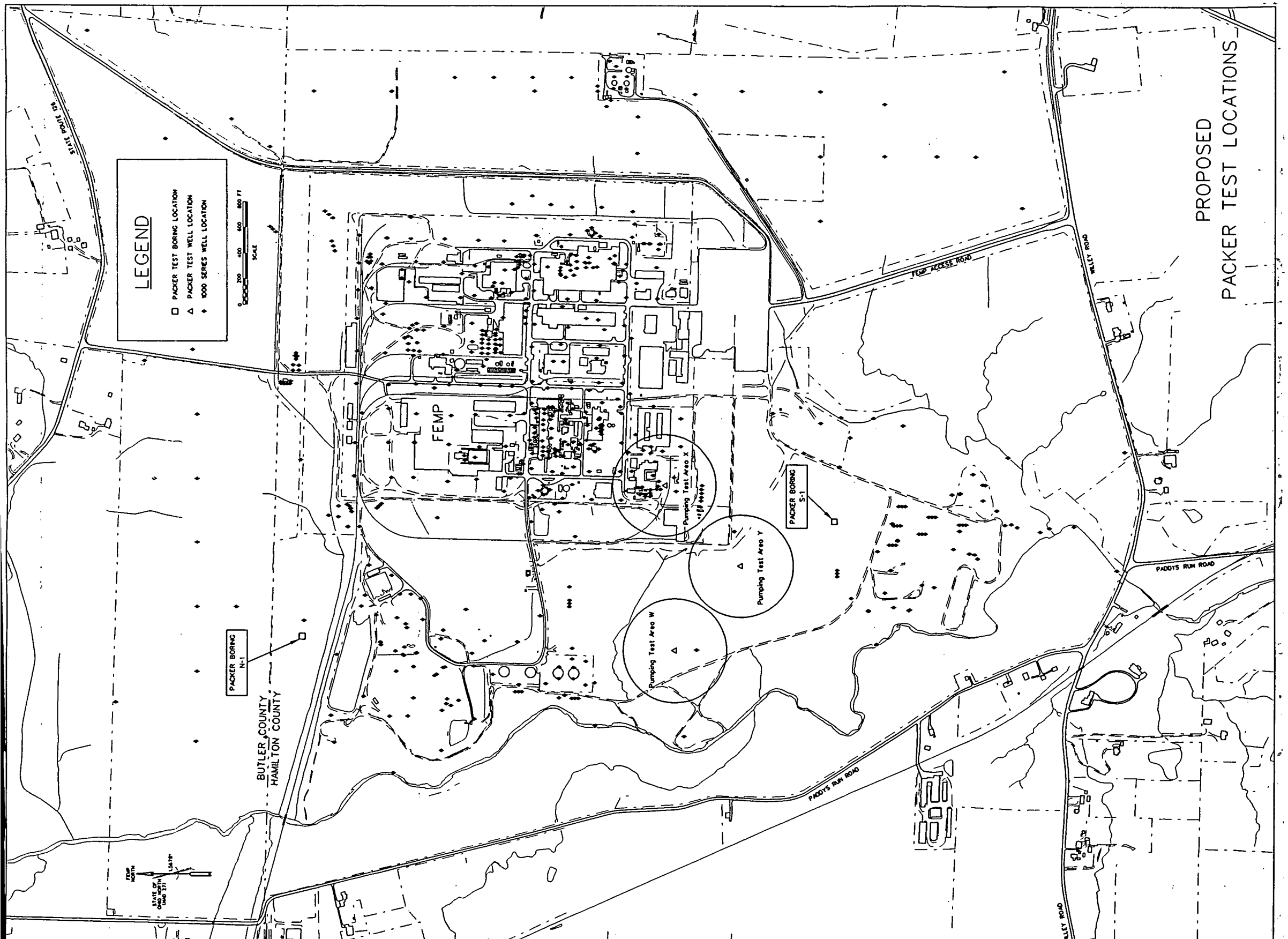

Figure 5-1 - Packer Test Locations

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Table 5-1 - Soil Boring Installation and Abandonment Procedures

PROCEDURE	REFERENCE	
Administrative Procedures	**FEMP SCQ (1992) Section**	**New Procedure Attachment**
Chain-of-Custody	7.1	
Corrective Action	15.2	
Daily Logs	5.1 and Appendix J.4.1	
Variances	15.4	
Field Procedures		
General Drilling Practices	5.2.1 and Appendix J.4.2	
Subsurface Sampling	Appendix K.5.3	
Soil Boring	5.2.2 and Appendix J.4.3	
Design, Installation, and Abandonment	*EM-GW-004	
Field Screening of Samples for Radioactive Contamination	Appendix K.5.3.2	
Decontamination	Appendix K.11	
Field Storage and Shipment of Samples	Appendix K.10	
Laboratory Test Procedures		
Grain Size Analysis	Attachment I, Volume V	
Hydrometer Analysis	Attachment I, Volume V	
Permeability Testing		C-3
Atterberg Limits	Attachment I, Volume V	
Moisture Content	Attachment I, Volume V	
Void Ratio	Attachment I, Volume V	
Porosity	Attachment I, Volume V	
Lab Density and Specific Gravity	Attachment I, Volume V	
Volatiles	Attachment I, Volume V	
Total Uranium	Attachment I, Volume V	
Anions and Cations	Attachment I, Volume V	

* Well abandonment will also follow this procedure listed in the *WEMCO Environmental Monitoring Procedures Manual*, Rev. 28 (June 16, 1992).

Table 5-2 - Packer Test Boring Details

Soil Boring ID	Anticipated Base of Soil Boring Below Land Surface (feet)	Anticipated Depth to Lower Clay (Shelby/Dennison tube horizon)	Boring Diameter (Inches)	Estimated State Coordinates
Area N	40 feet or 5 feet into clay at base of overburden	25	6" ID 6-5/8" OD	N482500E1378875
Area S	30 feet or 5 feet into clay at base of overburden	20	6" ID 6-5/8" OD	N478310E1379690

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glacial till, but will not penetrate the GMA. The approximate depth of each test boring is shown in Table 5-2; however, the geologist-in-charge in concurrence with the PARSONS field representative will be responsible for selecting the total depth and packer intervals for each boring.

In both borings continuous split spoon samples will be recovered from the surface to the top of the lower clay unit at the base of the glacial overburden; however, an undisturbed (Shelby or, if required, Dennison tube) sample will be recovered as soon as each test unit is identified. Packer tests will be performed over each 5-foot borehole interval and then each boring will be sampled to total depth. The PARSONS Field Representative will be present when the split spoon and undisturbed samples are recovered. Sample container/preservation requirements are presented in DQO 3 in Attachment F-3.

All aspects of borehole advancement and sampling--spin casing, Shelby tubes, Dennison tubes, and split spoons--will be conducted in accordance with Appendix J.4.1.2 and Appendix B, Form J-1 of the SCQ. For comparison purposes, boring logs for wells and borings in the vicinity of the packer tests are enclosed in Attachment A. Grain size (sieve) analysis and USCS classification will be performed for each borehole on selected split spoon samples from different lithologic units. The FERMCO geologist-in-charge in concurrence with the PARSONS field representative will be responsible for selection of these samples.

Shelby tube/Dennison tube samples will be analyzed for the following geotechnical parameters:

1) Grain size (sieve) analysis with hydrometer
2) Moisture content
3) Soil density
4) Atterberg limits
5) Constant Head Permeability Tests (triaxial cell with back pressure)
6) Specific gravity
7) Void ratio
8) Porosity
9) USCS classification

This information will be used to calculate the degree of saturation by NAVFAC DM7.01, 1986.

Borings will be abandoned with volclay grout to within 12 inches of the surface. After settling, a cement plug will be placed over the grout to the surface.

5.2.2 Packer Tests in Wells

The wells for the packer tests will be installed as defined in Section 3.2.1 of this document. Wells WTW-1, XTW-1, and YTW-1 will be used for the packer tests. As discussed above, only the lowermost clay at the base of the glacial overburden will be packer tested.

5.3 Packer Test Design and Field Implementation

The packer tests are based on the following procedures: U.S. Department of the Interior (1990 and 1981), ASTM (1986), and US EPA (1986). These procedures can be found in Attachment C. Table 5-3 lists SCQ procedures applicable to testing. Constant head pressure injection tests will be performed across a 5-foot section of hole that will be isolated by a packer. If the formation exhibits very low permeability conditions that will not allow the performance of a constant head test, a pressure pulse method (Bredehoeft and Papadopulos 1980) for tight formations will be employed (Attachment C-7). Equipment that will be required to perform the packer tests is listed specifically in Attachment B-4, and is generally as follows:

1) Set of inflatable packers capable of inflating to the anticipated diameter of the borehole

2) Drilling rig and crew to install and retrieve the packers

3) Nitrogen source for packer inflation

4) Sufficient supply of potable/de-ionized water for injection into the formation

5) Pump, flow, and pressure meters, valves and fittings for injection and control of water into the formation

6) Stopwatches and digital wrist watches capable of being synchronized within 1 second for each member of the packer test team

7) Health and safety equipment and clothing

8) Indelible pens and/or pencils

9) Field notebook and water level recording forms

Table 5-3 - Packer Test Procedures

PROCEDURE	REFERENCE	
Administrative Procedures	**FEMP SCQ (1992) Section**	**New Procedure Attachment**
Corrective Action	15.2	
Daily Logs	5.1 and Appendix J.4.1	
Variances	15.4	
Field Procedures		
Calibration of Flow Meters and Pressure Gauges	I.2.2	
Aquifer Permeability Testing	J.4.6	
Decontamination	Appendix K.11	
Packer Testing		C-6
Pressure Pulse Testing		C-7
Packer Test Forms		E-3, 4, and 5

* Well abandonment will also follow this procedure listed in the *WEMCO Environmental Monitoring Procedures Manual*, Rev. 28 (June 16, 1992).

5.3.1 Selection of Test Interval

5.3.1.1 Borings

Beginning at the ground surface, continuous split spoon samples will be collected. The split spoon samples will be used to identify the presence of a 5-foot length homogeneous lithologic section. A 6-inch ID (6-5/8" OD) rotary casing with a saw tooth bit will be advanced behind the split spoon intervals. When the 5-foot section has been identified, the rotary casing will be withdrawn from the interval so that the base of the casing is no more than 1 foot above the open 5-foot zone. After the zone is packed off and tested, the packer will be removed, and the split spoons and rotary casing will be advanced until a change in lithology is encountered and a subsequent homogeneous 5-foot lithologic section is encountered. The casing will be retrieved and the interval will be tested as previously described. This process will continue until the lower clay unit at the base of the overburden is identified, at which time a Shelby tube or Dennison tube sample will be collected, and the clay will be subsequently packer tested.

Potable water will be pumped into the rotary casing in order to flush the drill cuttings to the surface. Cuttings will be circulated up between the outside of the casing and the borehole wall. The cuttings will be allowed to settle in a steel pit and removed from the pit in accordance with disposal procedures defined in the SCQ.

To reduce the production of mud and to reduce any possible effects of water invasion on the samples, the introduction of water during the drilling process will be kept to a minimum. Any water that is added to the borehole during the boring process or during the packer testing process will be from the FEMP plant potable water system. A chemical sample of such water will be collected from each tank that is used during the drilling or packer testing procedures. Each sample will be analyzed for VOCs and total uranium. The TAL and sample container/preservation requirements are shown at the end of DQO 2 in Attachment F-2.

5.3.1.2 Test Wells

As discussed above, Test Wells WTW 1-C, XTW-1C, and YTW-1C will be advanced to the top of the lower clay zone and the upper 5 feet of the clay will be bored with Shelby tubes or Dennison samplers. Packer tests will be performed on these 5-foot clay intervals.

5.3.2 Setting the Packer

Prior to setting the packer, the test zone will be cleaned with a brush and the cuttings allowed to fall to the bottom of the hole. If the borehole is saturated, some limited bailing of drill cuttings will be

conducted to clean the hole; if it is dry, a single packer and pressure transducer will be inserted through the 6-inch ID rotary casing, and the packer will expand against the wall of the augured hole and provide a seal capable of withstanding the downhole differential pressure (the hydrostatic pressure that will be created in the test cavity by the constant head test and the hydrostatic pressure created by water in the borehole above the packer). Attachment C-6 provides a description of the transducer and packer system.

A sufficient number of packers with various diameters will be required to seal the 6-5/8-inch OD rotary casing borehole or the 5-5/8-inch OD Dennison tube borehole. If a 3-inch Shelby tube is collected, then an appropriate packer size will be used. It is anticipated that a single packer will be used to seal the borehole; however, sufficient equipment will be on site to provide for a double or straddle packer arrangement if required.

A pneumatic or electric pressure transducer of sufficient capacity to withstand pump-in pressure of up to 50 psi will be inserted through the packer to monitor the horizon being tested. The transducer and cable will be set with the packer system. If a pneumatic transducer is used, it will be connected to a nitrogen source and readout box (Attachment C-6). If an electronic transducer is used, it will be connected to a data logger.

If any water is present in the borehole, sufficient time will be allowed to permit the water level in the borehole to re-establish its level prior to the introduction of the packer system. The depth to water in the borehole will be measured and converted to units of psi, which will be used to calculate the inflation pressure for the packer. In order to monitor any interaction between the waste pit and the intervals being packer tested in Boring N-1, electronic pressure transducers will be placed in selected piezometers that are located in any of the covered pit areas.

Electronic pressure transducers and data loggers will monitor the water levels in any piezometers within the W, X, and Y areas.

Prior to starting the test, calibration of the packer test equipment and water flow meters will be conducted. Verification of the proper operation of the electronic transducers and data logger will also be accomplished. The PARSONS Field Representative will be present during equipment calibration.

5.3.3 Constant Head Pump-In Packer Test

The test will start after the packers have been inflated to the required pressure from a cylinder of compressed nitrogen.

The maximum water injection pressure to be maintained during the test will be established based on site-specific conditions. Due to the shallow depth of the horizon being tested and the unconsolidated matrix

of the borehole, the maximum pressure to be injected will not exceed 0.5 psi/foot of depth to the top of the packer.

Three flow rates will be introduced into each zone up to the maximum pressure described in the preceding paragraph. If the packer zone is above the water table, then water will be added at a constant pressure until the flow rate stabilizes, at which time the flow will be measured over a 5-minute intervals with pressure and flow measured every minute. If the packer zone is below the water table, the time for stability may be less. Once stabilization has been achieved for a minimum of 5 minutes, the pump pressure will be increased to a mid-range between the initial and maximum pressure, allowed to stabilize, and measured for 5-minutes with measurements recorded every minute. After stabilization has been achieved at the intermediate pump-in pressure for a minimum of 5 minutes, the pump-in pressure will be increased to the maximum allowable and a 5-minute flow period will be measured at 1-minute intervals. The pump will then be shut off and back pressure and holding pressure decay recorded. Flow pressures and back pressures will be recorded on forms shown in Attachments E-3, -4, and -5. This procedure is to be followed for each successive interval that is to be tested within the borehole.

5.3.4 Pressure Pulse Packer Test

In the event that packer test intervals will not respond to the constant rate test, a pump-in pressure pulse method will be used for determining the hydraulic properties of the borehole. This method is described in ASTM 4631-86 and is included in Attachment C-7. This method can be applied to soil as well as rock. The technique will employ the same equipment as the constant rate packer test.

The test is conducted by rapidly pressurizing the packed interval. The pump is then quickly shut off, and the pressure decay recorded over time. Note that the maximum pressure should not exceed 0.5 psi/foot of overburden.

5.4 Data Analysis

For the constant head pressure injection test, hydraulic conductivity can be calculated from the equation:

$$K = \frac{q}{2\pi LH} \ln\frac{L}{r} \quad \textit{where } L \geq 10r$$

or

$$K = \frac{q}{2\pi LH} \sinh^{-1} \quad \textit{where } 10r \geq L \geq r$$

where

K = hydraulic conductivity (cm/s)
q = constant rate of flow into the test interval (cm^3/s)
L = length of the test interval (cm)
H = differential head of water at test interval (cm)
r = radius of borehole (cm)

Reference: Bureau of Reclamation (1990).

For the pressure pulse test, the Brederhoeft-Papadopulos (1980) method will be used to analyze the decay curve measurements. The relationship of head change to total head is given by the equation $H/H_0 = F(\alpha,\beta)$.

where

$$\alpha = \frac{\pi r_s^2 S}{V_w C_w \rho_w g}$$

$$\beta = \frac{\pi r_s^2 S}{V_w C_w \rho_w g}$$

r = radius of the tested interval (cm)
S = Storativity (dimensionless)
T = Transmissivity of the tested interval (cm^2/sec)
t = time elapsed since pressurization (sec)
V_w = Volume of water within the pressurized section of the system (cm^3)
C_w = Compressibility of water (cm) (sec^2)/gm
P_w = density of water (gm/cm^3)
g = gravitational acceleration (cm/sec^2)

A family of type curves will be prepared showing the variation of $F(\alpha,\beta)$ against β with α as a running parameter. For a detailed explanation of these parameters, see Attachment C.

The observed values of H_0/H will be plotted on the y-axis of semi-log paper, and time (t) will be plotted on the x-axis. The plot of H/H_0 versus t will be matched with the type curves of $F(\alpha,\beta)$ versus $\alpha\beta$ to obtain values for α, derive β, and calculate the transmissivity and storativity.

SECTION 6

YIELD TESTS

6.1 Specific Objectives

Short-term yield tests will be performed in Monitoring Wells or Piezometers 1077 (waste pit area), 1340 (northwest of the boiler plant), 1275 (north of the old drum bailing area), and 1785 in the Plant 2/3 area. Yield tests will be performed in a manner similar to a step drawdown test. The wells defined above will be pumped and water levels will be monitored over a maximum period of 8 hours. Each step will be determined in the field. Other monitoring wells and piezometers surrounding the pumped wells will be monitored for water level changes during the course of the test. Water levels will also be monitored in all of the wells over the course of the recovery period when the pumps are shut down. Data will be used to calculate hydraulic conductivity and make interpretations of the hydraulic connection between the various sand units beneath the production area and waste pits.

In addition to the three short-term yield tests, a long-term 48- to 72-hour yield test will be performed on Monitoring Well 1785. The long-term yield test will be performed in a manner similar to the constant rate pumping tests described in Subsection 3.3.5. Other wells and piezometers in the vicinity of Well 1785 will be used as observation wells. Data will be used to calculate hydraulic conductivity and storativity in the upper sand below the Plant 2/3 area. The data will be used to estimate the proper distance requirements between test wells and observation wells in the pumping tests described in Section 3.

6.2 Well Locations

The four wells that will be pumped and the associated wells that will be used as observation wells are shown on Figure 6-1 and listed in Table 6-1. Well selections are based on the methods discussed in Section 1.2. Well completion and lithologic logs for each of the test wells are included in Attachment A.

6.3 Yield Test Field Implementation

The yield tests will be performed under the policies and guidelines provided in the SCQ. Procedures pertaining to yield testing activities are referenced to the SCQ in Table 6-2.

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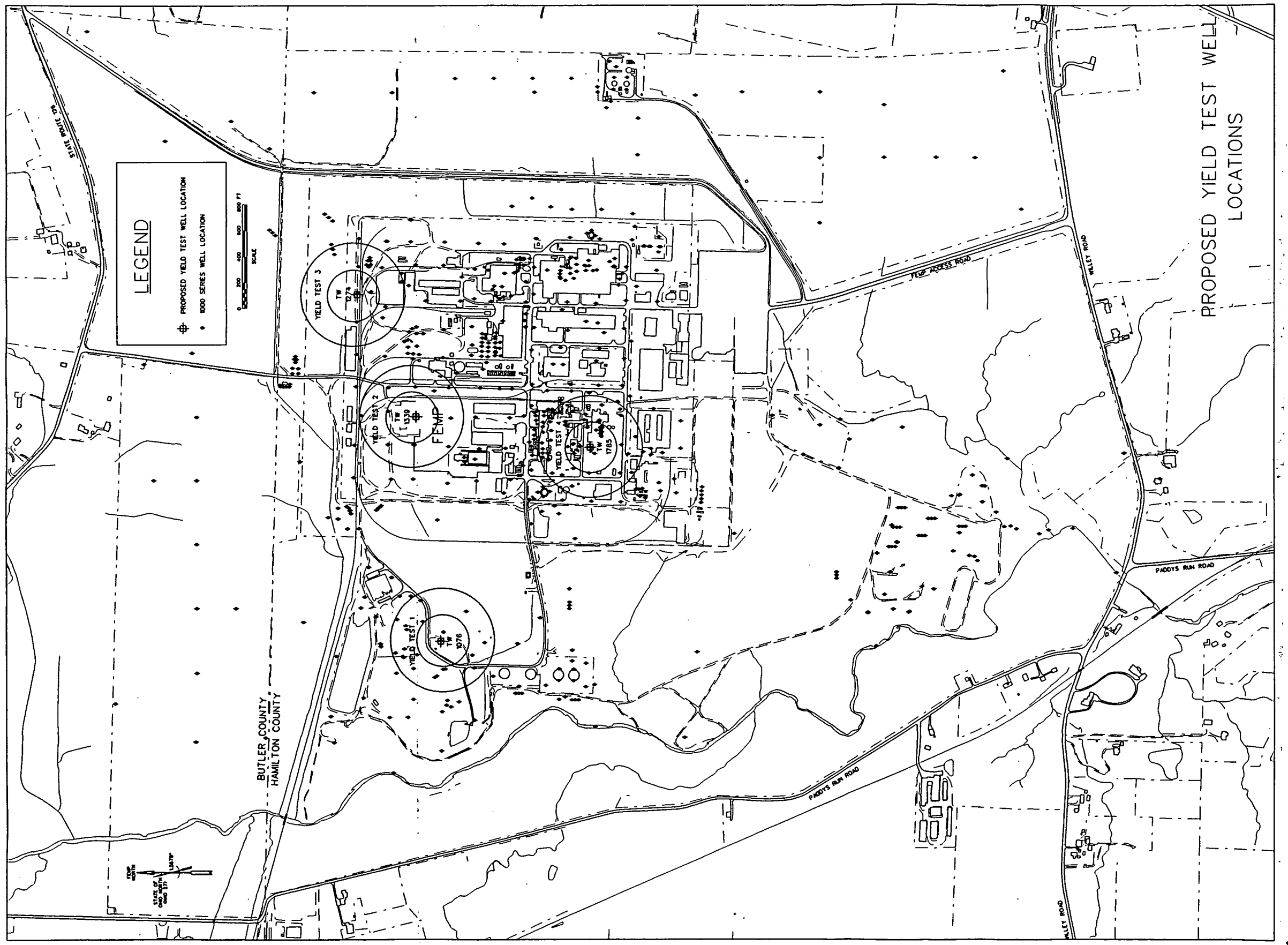

Figure 6-1 - Proposed Locations of Yield Test Wells

Table 6-1 - Yield Test Wells and Piezometers

Well ID	Radius from Pumped Well	State Coordinates
1339 (test well)		N481650E1380500
1055	235	N481500E1380720
1336	312	N481800E1380720
1340	230	N481625E1380720
1338	225	N481625E1380250
1343	267	N481150E1380500
1342	350	N481150E1380250
1344	337	N481150E1380720
1077 (test well)		N481435E1378800
1076	66	N481470E1378750
1030	233	N481250E1378970
1274 (test well)		N482060E1381470
1273	225	N482060E1381250
1277	200	N481970E1381500
1088	225	N482000E1381650
1279	237	N481875E1381340
1785 (test well)		N480340E1380220
1230	200	N480300E1380030
1231	62	N480250E1380155
1233	25	N480250E1380220
1234	75	N480200E1380220
1235	144	N480250E1380350

Table 6-2 - Yield Test Procedures

PROCEDURE	REFERENCE	
Administrative Procedures	**FEMP SCQ (1992) Section**	**New Procedure Attachment**
Corrective Action	15.2	
Daily Logs	5.1 and Appendix J.4.1	
Variances	15.4	
Field Procedures		
Ground Water Level Measurement	Appendix K.4.2.1	
Water Level Measurements - Metal Tape		C-5
Water Level Measurement Form		E-2
Aquifer/Permeability Testing	5.2.5 and Appendix J.4.6	
Decontamination	Appendix K.11	
Field Calibration Requirements	Appendix I	
Verification of Well Sensitivity		
Field Test:		
Temperature	Appendix K, Subsection K.4.1.1	
pH	Appendix K, Subsection K.4.1.2	
Specific Conductance	Appendix K, Subsection K.4.1.3	
Dissolved Oxygen	Appendix K, Subsection K.4.1.4	

6.3.1 Required Personnel

During the actual performance of the yield test, the following personnel will be required at various times on site:

1) FERMCO SCDM Task Manager: Responsible for overall coordination of the project

2) FERMCO SCDM Lead Yield Test Specialist (geologist-in-charge): Responsible for test setup and procedures

3) FERMCO SCDM Technicians: Responsible for data collection, well measurements, pump installation and operation, piping hookups, routing and operation of discharge lines, pressure transducer installation and operation of data logger, and groundwater sampling

4) FERMCO CRU 5 Health and Safety: Responsible for directing personnel and equipment across controlled access areas

5) PARSONS Field Representative: Available to the FERMCO geologist-in-charge for consultation and assistance during the implementation of each yield test according to work plan specifications

The Lead Yield Test Specialist shall possess the necessary skills to perform as well as direct the activities of the technicians. Participants shall be able to address contingencies competently and efficiently so that time and data are not lost.

6.3.2 Setup and Procedure

6.3.2.1 Short-Term Yield Tests

Each short- and long-term yield test well will be pumped at three successively higher rates. Beginning with 1 gpm, additional rates will be set based on the observed response of the test well and observation wells. Each step will have a duration of 1 hour (longer if the water level in the pumping well has not stabilized; shorter if the well runs dry). During each step period, flow will be maintained at + or - 5 percent (within the tolerance interval suggested by Stallman, [1971]) of the designated rate by means of a throttling device or other flow control method.

Water levels will be measured in the test well and primary observation wells will be recorded with pressure transducers linked to a data logger. The data logger will be set to record water levels at the time intervals defined in Table 3-10. Water levels will also be monitored periodically using electrical water level indicators and/or steel measuring tapes so that data logger readings can be cross checked. Tables

6-3 through 6-6 list all the wells and piezometers to be used for observation purposes during the test and the method of water level measurement. For the yield test at Monitoring Well 1077, two wells (1775 and 1765) will be monitored in the waste pits to ensure drawdown is not occurring. If drawdown is noticed, the yield test will be immediately terminated.

Water level measurements will be recorded on a form similar to that shown in Attachment E-2. Water levels will be measured relative to the top of the well casing reference point. Installation, calibration, and use of the data logger and pressure transducer system will be performed by the FERMCO geologist-in-charge. PARSONS will be available to assist the FERMCO personnel during calibration and installation of equipment.

6.3.2.2 Long-Term Yield Test

The long-term yield test will be conducted in the same manner as a pumping test. After a pumping rate is selected from the step test, Well 1785 will be adjusted to flow at a specified rate for a period of 48 to 72 hours. Water levels will be measured with pressure transducers and electrical water level indicators and/or steel tapes as shown in Table 6-6.

During the long-term yield test, flow will be maintained at + or -5 percent of the designated rate by means of a throttling device or other flow control method. Discharge will be checked and adjusted as necessary every 10 minutes during the first hour of pumping and at 30 minute intervals thereafter. The flow rate will be recorded every minute for the first 10 minutes of the test, every 5 minutes for the next 3 hours, and then every 15 minutes thereafter. The flow meter will be calibration checked before and during the test with a 5-gallon bucket and stop watch.

Water level measurements will be recorded on a form similar to that shown in Attachment E-2. Water levels will be measured relative to the top of the casing. As described above, PARSONS will be present during the installation and calibration of the data logger and transducer.

6.3.3 Water Level Recovery Measurements

The water level recovery measurements will begin simultaneously with pump shutdown. The monitoring of rising water levels will be performed in the same manner as performed during pumping. Water level measurements will be measured at the time intervals defined in Table 3-10.

Measurements will continue for approximately 8 hours for short-term yield tests and 24 hours for long-term yield tests or until three successive water level measurements at 1-hour intervals show less than 0.1-foot difference in recovery at the test well (U.S. Department of the Interior 1981).

Table 6-3 - Measurement of Wells and Piezometers for Yield Tests in the Waste Pit Area

Well ID	Method of Measurement
1077 (PW)	Pressure Transducer and Electronic 2-Channel Hermit Data Logger
1076	Pressure Transducer Connected to the same Electronic Data Logger that is used for Well 1077
1030	Pressure Transducer and Electronic 2-Channel Hermit Data Logger
1775	Pressure Transducer and Electronic 2-Channel Hermit Data Logger
1765	Pressure Transducer and Electronic 2-Channel Hermit Data Logger

Table 6-4 - Measurement of Wells and Piezometers for Yield Tests in Plant 1 Area

Well ID	Method of Measurement
1339 (PW)	Pressure Transducer and Electronic 4-Channel Data Logger
1055	Pressure Transducer and Electronic 4-Channel Data Logger
1336	Electric Water Level Indicator
1340	Pressure Transducer and Electronic 2-Channel Hermit, Data Logger
1338	Pressure Transducer and Electronic 2-Channel Hermit, Data Logger
1343	Electric Water Level Indicator
1342	Electric Water Level Indicator
1344	Electric Water Level Indicator

Table 6-5 - Measurement of Wells and Piezometers for Yield Tests in Old Drum Bailing Area

Well ID	Method of Measurement
1274 (PW)	Pressure Transducer and Electronic 4-Channel Data Logger
1277	Pressure Transducer and Electronic 4-Channel Data Logger
1273	Pressure Transducer and Electronic 4-Channel Data Logger
1088	Pressure Transducer and Electronic 4-Channel Data Logger
1279	Electric Water Level Indicator

Table 6-6 - Measurement of Wells and Piezometers for Yield Tests in Plant 2/3 Area

Well ID	Method of Measurement
1785 (PW)	Pressure Transducer and Electronic 4-Channel Data Logger
1233	Pressure Transducer Connected to Data Logger at Well 1785
1231	Pressure Transducer Connected to Data Logger at Well 1785
1234	Pressure Transducer Connected to Data Logger at Well 1785
1235	Pressure Transducer and Electronic 2-Channel Hermit Data Logger
1230	Pressure Transducer and Electronic 2-Channel Hermit Data Logger

6.4 Data Analysis

Based on the observed response of the water levels, appropriate analytical techniques will be selected to calculate the hydraulic properties of the saturated sand zone. Methods for partially screened intervals will be applied as necessary. For the short-term yield tests, methods based on Jacobs' equations (Walton 1987) will be used.

In the Plant 2/3 area, Well 1758 and the surrounding wells and piezometers are screened at different levels and in different units. Methods of test analysis will depend on screen intervals as well as hydrologic conditions. Methods based on the Neuman, Theis, Cooper-Jacob, and Hantush will most likely be used. If the well is partially penetrating and confined, the Hantush method will be used. All of these methods are explained in Kruseman and deRidder (1990). Other methods of analysis will be used where appropriate. The computer software package AQTESOLV™ (Duffield and Rumbaugh 1991) will be used where applicable.

Where data allows, the Hantush-Jacob method will be used for estimating the vertical hydraulic conductivity (K') of the overlying aquitard (Kruseman and deRidder, 1990). Vertical groundwater movement will also be evaluated in accordance with methods developed by Neuman and Witherspoon (Javandel, 1984). Depending on well response, several other methods of analysis may be applicable for calculating K, S, and K'.

SECTION 7

DATA REDUCTION AND REPORTING OF RESULTS

As mentioned in Subsection 1.4, PARSONS will be responsible for data reduction and reporting of results. The field work that will be performed under this work plan will provide data that will be used for developing a GT/VZ computer model. Due to scheduling requirements for development of the computer model, field data will be immediately analyzed as it becomes available. The preliminary results will be forwarded to the computer modeling group for input into the GT/VZ model. As shown in Figure 1-2, yield test and slug test analysis will provide the first data input for the computer model. Most of the preliminary data and analysis will be available as input to the computer model within 2 months of field work initiation.

The laboratory(ies) performing the work will deliver the preliminary results (analytical and geotechnical) to FERMCO CRU-5 or SCDM, who will immediately provide PARSONS with a copy. PARSONS will use the preliminary lab results for further calculations or incorporate the data into the model and the final report where appropriate. All laboratory-generated data will be provided as an appendix to the final report. After all field data are obtained and analyzed, the final report will be prepared so that a concise and complete description of all field activities and the generated data will be available. The final report will describe the overall performance of each task and provide a complete summary of the data collected and the results of calculations and laboratory analysis. Tables, figures, and methods of calculations and laboratory testing will also be discussed. The final report will be divided into individual sections for each major activity. An overall summary of the data collected, analyses, and applicability of results will be provided at the end of the report.

SECTION 8

HEALTH AND SAFETY

Health and safety requirements for well drilling, soil investigations, pump testing, slug testing, installing lysimeters, packer testing, performing yield test, and groundwater sampling are provided in a project-specific health and safety plan (PSP) (PARSONS 1993). The PSP will be consistent with FERMCO's *Comprehensive Environmental Occupational Safety and Health Program*, Rev. 0 (FERMCO 1993). FERMCO will provide the necessary work permits required by FEMP procedures. Also, FERMCO will provide the necessary health and safety supervision and radiation safety personnel to conduct this work safely.

Subcontractor personnel shall have completed the necessary FEMP training and medical monitoring requirements prior to commencing project work. Training and medical monitoring requirements are defined by FERMCO.

SECTION 9

QUALITY ASSURANCE/QUALITY CONTROL

All work will be conducted in accordance with the requirements of the overall quality assurance program at the FEMP which is described in the SCQ. Drilling, sampling, well and piezometer installation, pump testing, slug testing, lysimeter installation, packer testing, and laboratory testing shall be assigned the proper analytical support level (ASL) by FERMCO. The SCQ provides guidelines for matching of quality program requirements to the ASLs. FERMCO will review specific quality items to verify that the quality requirements are adequate and consistent with the assigned ASL. Appendix J of the SCQ and specific procedures not covered in the SCQ are attached to this document (Attachment C). Data Quality Objectives (DQOs) are attached to this document (Attachment F) and it will be the responsibility of FERMCO CRU-5 to obtain DQO approval from SCQ management.

SECTION 10

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ATTACHMENT A

WELL INSTALLATION AND SOIL SAMPLING RECORDS

KEY FOR LITHOLOGIC INFORMATION

Hand written visual classifications of soil were reviewed to identify stratigraphic distinctions. The field descriptions were converted to a code and entered into a data base. All cross sections were created using the data base with ERMA GIS. The following is an explanation of the codes used in the data base and shown on the cross sections.

Each boring has a sequence of coded descriptions adjacent to the trace of the boring. Ticks on the boring trace mark lithologic changes.

- The first character, a letter, represents the field classification of moisture content - D=dry, M=moist, W=wet, X=not described
- The second character(s), a number, represents the USCS grain size classification of soil based on field descriptions of hand samples - see table below
- The third character, a letter, represents the field description of color - B and D are sediments with brown hues, C and D are sediments with grey hues (see table below)
- The fourth character, a number, is an artifact of an attempt to enter correlations into the original data base structure - it should be ignored
- The bottom of each boring is marked by a designation for the termination of the boring:

BOT/15	bottom of glacial overburden where it lies upon bedrock
BOT/A	bottom of glacial overburden where it lies upon S & G aquifer
BOB	bottom of boring
BOA/A	Base of Paddys Run alluvium where it rests upon the sand and gravel aquifer

Examples of lithologic codes:

M1B = moist clay (CL) with minor sand and/or gravel, brown
W4A = wet sand (SM or SC) with appreciable fines, grey
M3B = moist silt (ML), brown

Mulder f:\wp51\ou5\codes.geo

USCS SOIL CLASSIFICATION

1	CL w/ trace to minor amounts of sand and gravel	8	CL fill
2	CL		
3	ML	9	ML fill
4	SM/SC	10	SM/SC fill
5	SP/SW	11	SP/SW fill
6	GC/GM	12	GC/GM fill
7	GW/GP	13	GW/GP fill
14	concrete/pavement	15	Bedrock (limestone/shale)
16	CL w/ minor laminae of sand and/or gravel		
17	ML w/ minor laminae of sand and/or gravel		
18	Waste material (e.g. flyash, waste pit contents,...)		
21	Undescribed strata		

MUNSELL SOIL COLORS

Grey equates to unweathered/unoxidized and brown equates to weathered/oxidized

GREY	Hue 10YR - all values of chroma /1 (2/1 to 8/1), and 6/2 Hue 2.5Y - all values of chroma /0 (N2/ to N8/), 6/2 and 7/2 Hue 5Y - all values of chroma /1 (2.5/1 to 8/1), and six of the seven colors of chroma /2 (2.5/2 to 7/2)
BROWN	Hue 10YR - all colors of 10YR not listed as grey in the above Hue 2.5Y - all colors of 2.5Y not listed as grey in the above Hue 5Y - all colors of 5Y not listed as grey in the above

Mulder f:\wp51\ou5\codes.geo

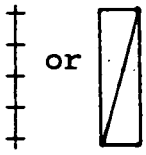
COARSE-GRAINED SOILS

CLEAN GRAVELS (LITTLE OR NO FINES)	GW	WELL-GRADED GRAVELS, GRAVEL-SAND MIXTURES, LITTLE OR NO FINES
	GP	POORLY-GRADED GRAVELS, GRAVEL-SAND MIXTURES, LITTLE OR NO FINES
GRAVELS WITH FINES (APPRECIABLE AMOUNT OF FINES)	GM	SILTY GRAVELS, GRAVEL-SAND-SILT MIXTURES
	GC	CLAYEY GRAVELS GRAVEL-SAND-CLAY MIXTURES
CLEAN SANDS (LITTLE OR NO FINES)	SW	WELL-GRADED SANDS, GRAVELLY SANDS, LITTLE OR NO FINES
	SP	POORLY-GRADED SANDS, GRAVELLY SANDS, LITTLE OR NO FINES
SANDS WITH FINES (APPRECIABLE AMOUNT OF FINES)	SM	SILTY SANDS, SAND-SILT MIXTURES
	SC	CLAYEY SANDS, SAND—CLAY MIXTURES

FINE-GRAINED/HIGHLY ORGANIC SOILS

SILTS AND CLAYS LIQUID LIMIT (LESS THAN 50)	ML	INORGANIC SILTS AND VERY FINE SANDS, ROCK FLOUR, SILTY OR CLAYEY FINE SANDS OR CLAYEY SILTS WITH SLIGHT PLASTICITY
	CL	INORGANIC CLAYS OF LOW TO MEDIUM PLASTICITY, GRAVELLY CLAYS, SANDY CLAYS, SILTY CLAYS, LEAN CLAYS
	OL	ORGANIC SILTS AND ORGANIC SILTY CLAYS OF LOW PLASTICITY
SILTS AND CLAYS LIQUID LIMIT (GREATER THAN 50)	MH	INORGANIC SILTS, MICACEOUS OR DIATOMACEOUS FINE SANDY OR SILTY SOILS
	CH	INORGANIC CLAYS OF HIGH PLASTICITY, FAT CLAYS
	OH	ORGANIC CLAYS OF MEDIUM TO HIGH PLASTICITY, ORGANIC SILTS
HIGHLY ORGANIC SOILS	PT	PEAT, HUMUS, SWAMP SOILS WITH HIGH ORGANIC CONTENTS

Key For Well Construction Information

VG	Volclay Grout
BS	Bentonite Seal
SP	Sand Pack
	Well Screen Interval

1019

RI/FS BORING NO.

2/85

DATE DRILLED

AREA

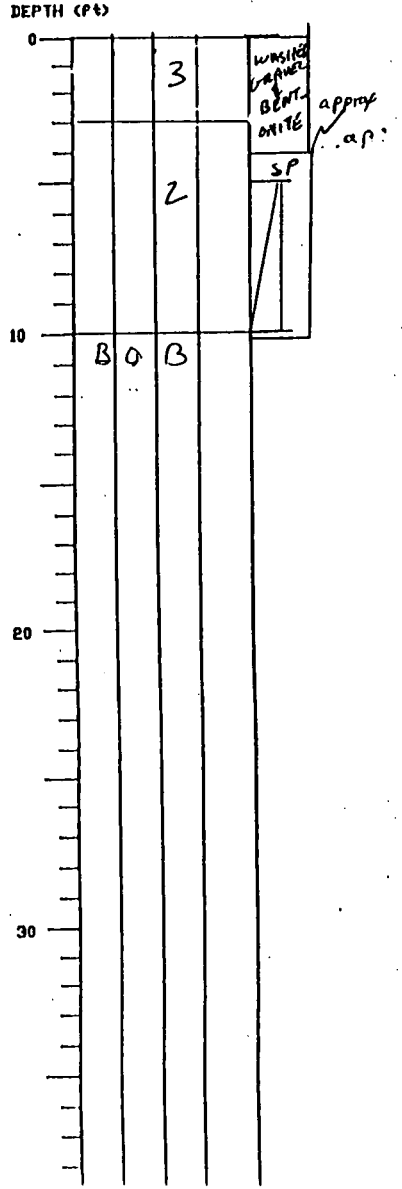
DAMES & MOORE

DRILLING PROGRAM

582.96'?

SURFACE ELEVATION

DEPTH (ft)



1020

RI/FS BORING NO.

1/85

DATE DRILLED

AREA

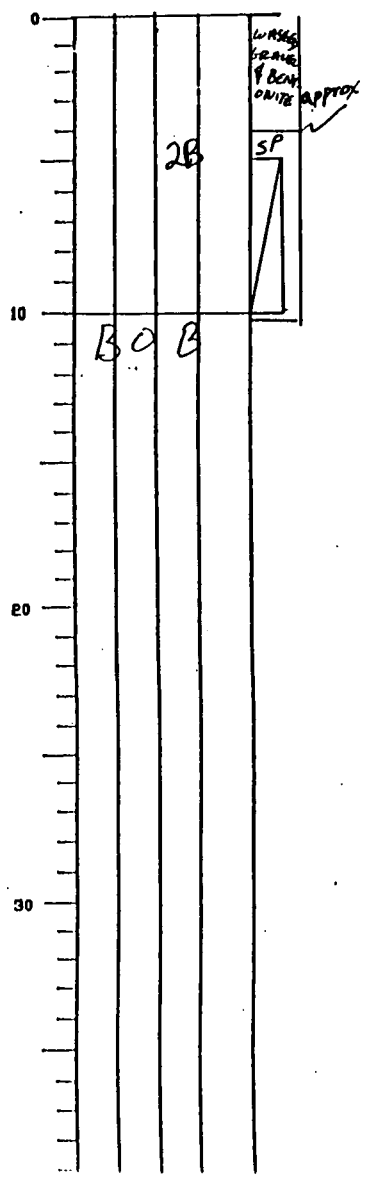
DAMES & MOORE

DRILLING PROGRAM

573.21

SURFACE ELEVATION

DEPTH (ft)



1024

RI/FS BORING NO.

10/16/87

DATE DRILLED

West

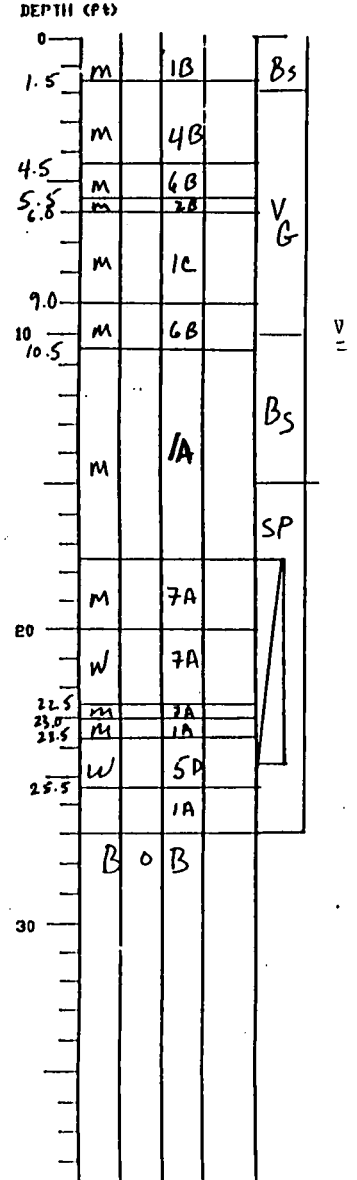
AREA

DRILLING PROGRAM

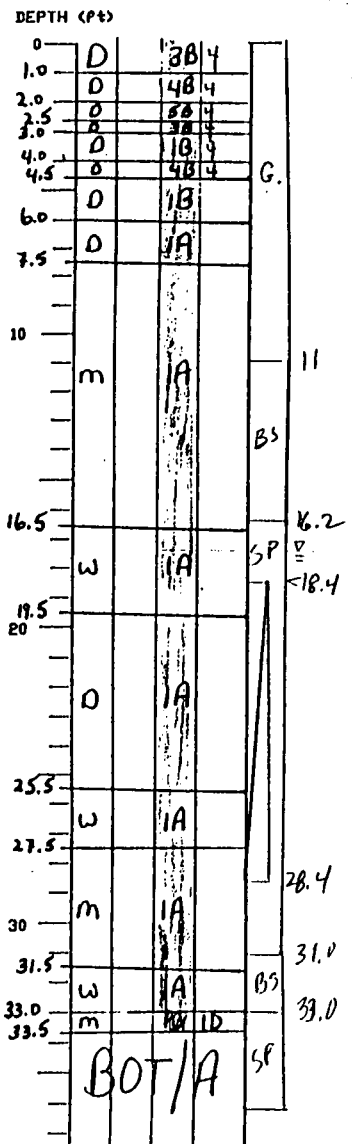
579.9 (MW 3024)

SURFACE ELEVATION

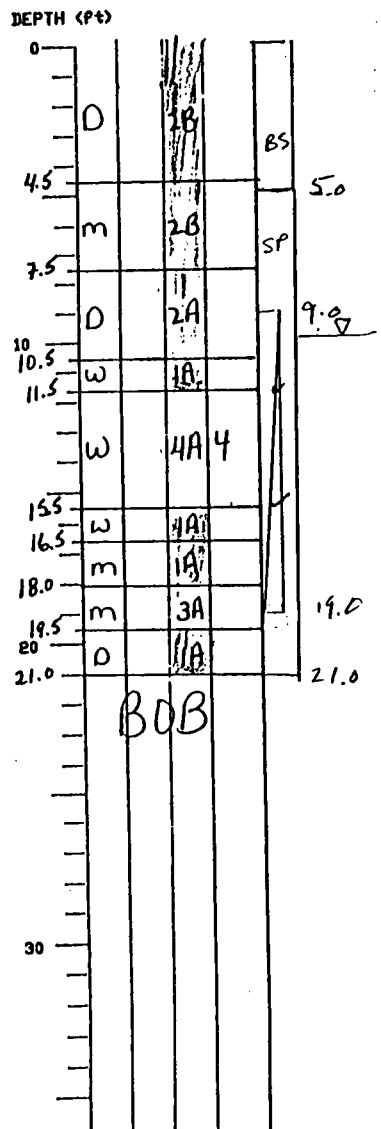
DEPTH (ft)



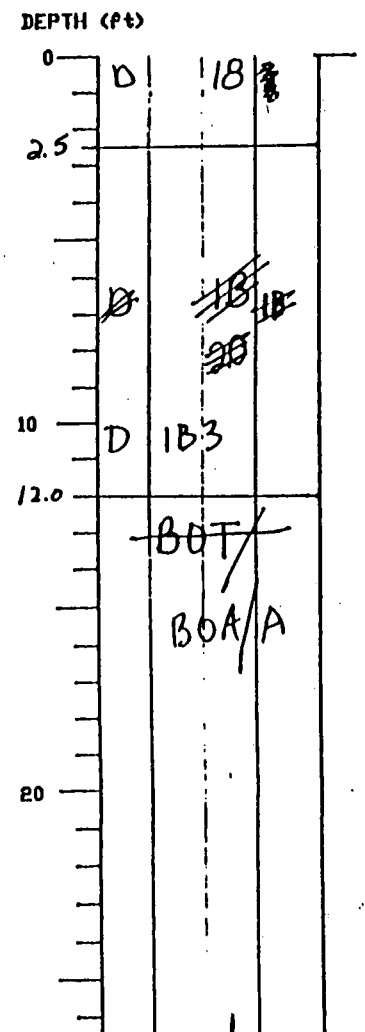
1029
RI/FS BORING NO.
10-21-87/D. Oakley
DATE DRILLED
West
AREA
RI/FS
DRILLING PROGRAM
577.3'
SURFACE ELEVATION



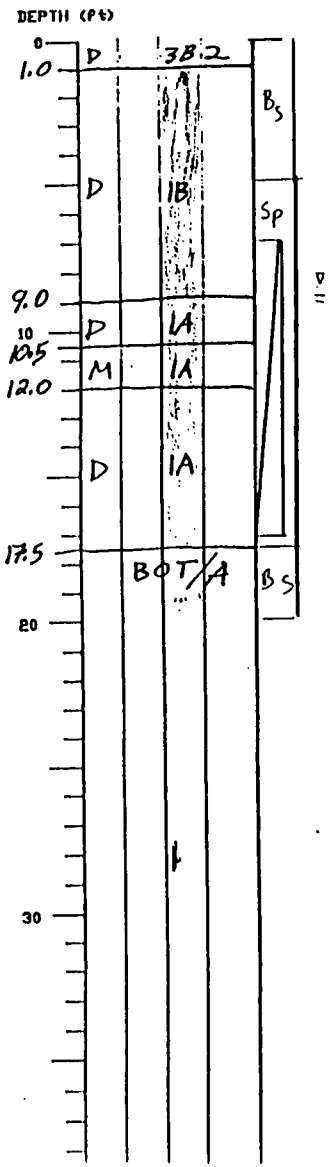
1033
RI/FS BORING NO.
4-8-88/m. Goldberg
DATE DRILLED
West
AREA
RI/FS
DRILLING PROGRAM
577.0'
SURFACE ELEVATION



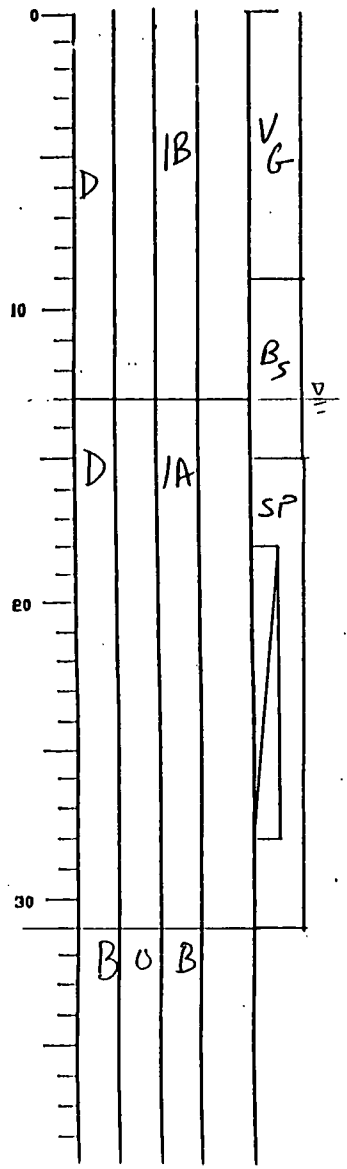
1045
RI/FS BORING NO.
10-6-87/D. Oakley
DATE DRILLED
South Side
AREA
RI/FS
DRILLING PROGRAM
546.2'
SURFACE ELEVATION



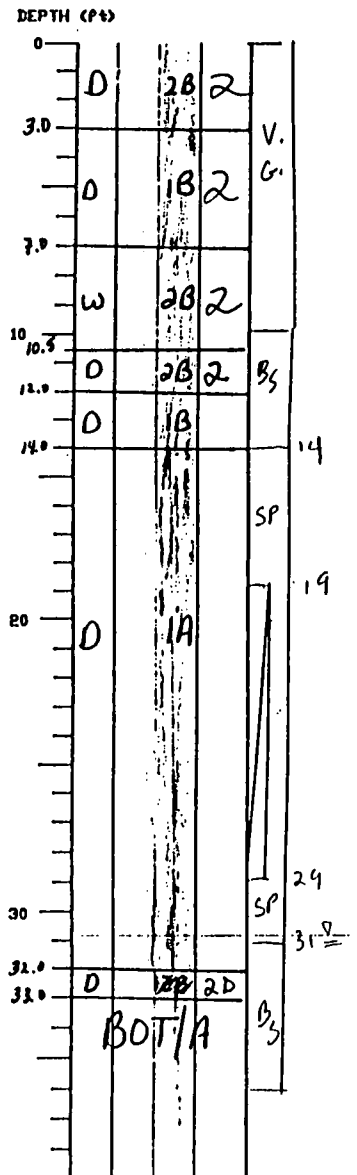
1047
RI/FS BORING NO.
10-15-87 / Wille
DATE DRILLED
South Side
AREA
RI-FS
DRILLING PROGRAM
568.7
SURFACE ELEVATION



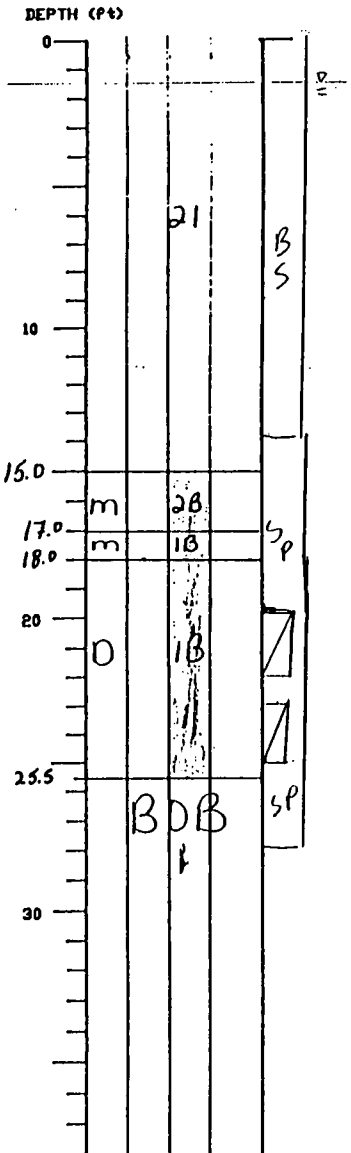
1064
RI/FS BORING NO.
12-7-88
DATE DRILLED
AREA
RI/FS
DRILLING PROGRAM
587.8 (MW 2064)
SURFACE ELEVATION



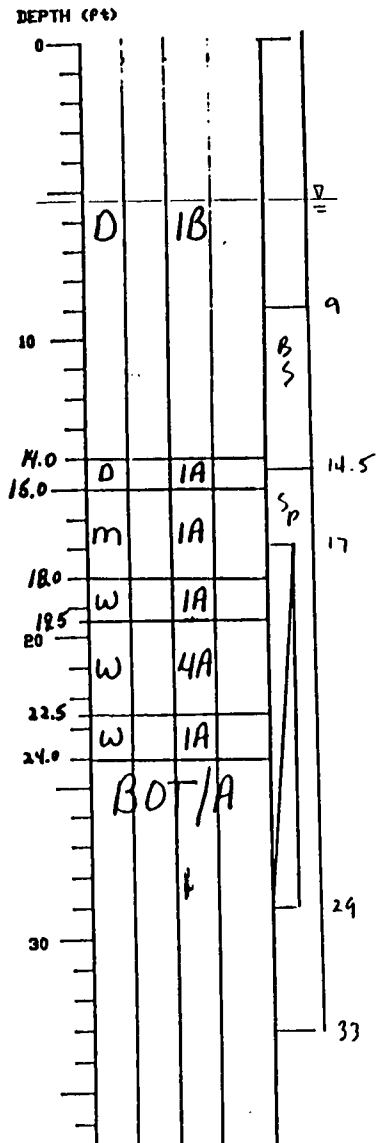
1072
RI/FS BORING NO.
3-6-88 / M. Goldberg
DATE DRILLED
West
AREA
RI/FS
DRILLING PROGRAM
575.9'
SURFACE ELEVATION



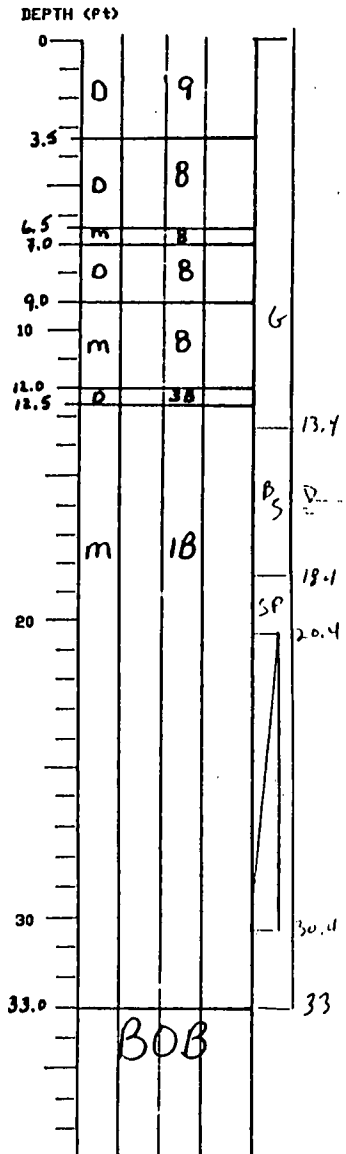
1075
RI/FS BORING NO.
4-23-88
DATE DRILLED
West
AREA
RI/FS
DRILLING PROGRAM
581.5'
SURFACE ELEVATION



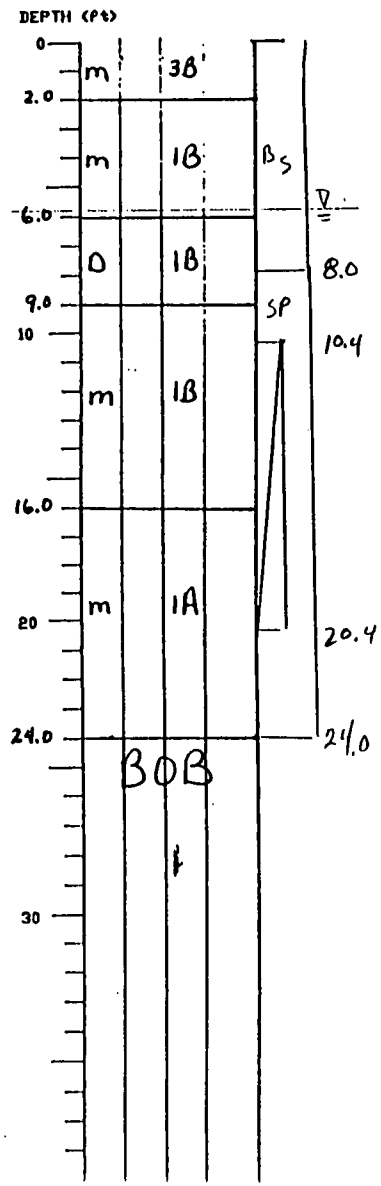
1077
RI/FS BORING NO.
3-18-88/m Slusarski
DATE DRILLED
West
AREA
RI/FS
DRILLING PROGRAM
583.2'
SURFACE ELEVATION



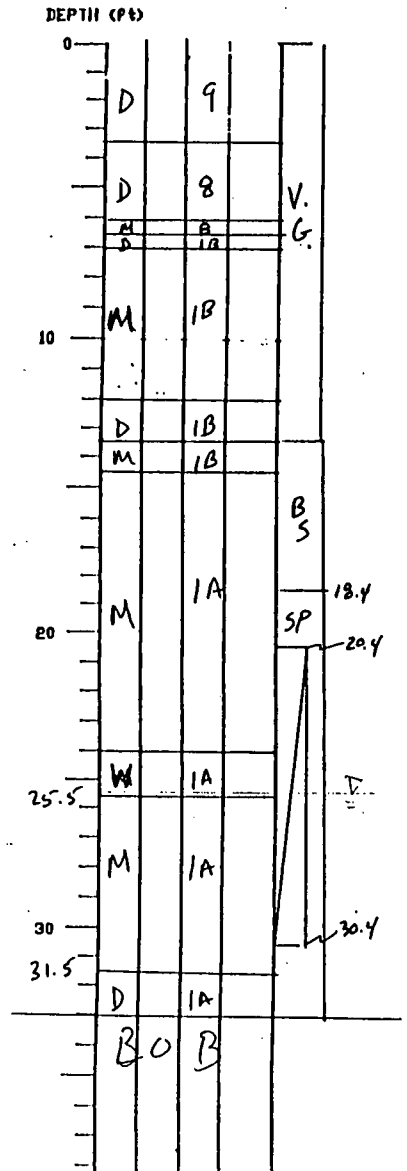
1081
RI/FS BORING NO.
12-1-87/D. Oakley
DATE DRILLED
West
AREA
RI/FS
DRILLING PROGRAM
590.7'
SURFACE ELEVATION



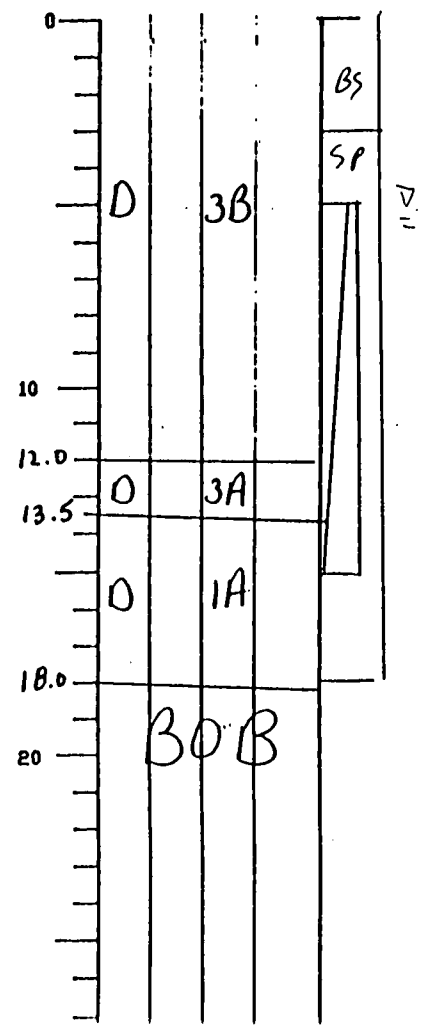
1082
RI/FS BORING NO.
12-4-87/D. Oakley
DATE DRILLED
West
AREA
RI/FS
DRILLING PROGRAM
583.9'
SURFACE ELEVATION



1084
RI/FS BORING NO.
1-9-87
DATE DRILLED
1-9-87 WEST
AREA
WEST RI/FS
DRILLING PROGRAM
583.6
SURFACE ELEVATION



1087
RI/FS BORING NO.
3-21-88/W. Kegley
DATE DRILLED
Production (PA2)
AREA
RI/FS
DRILLING PROGRAM
590.1'
SURFACE ELEVATION



98

4333

1111

RI/FS BORING NO.

12-2-88/E. Trollinger

DATE DRILLED

Production (PA-4)

AREA

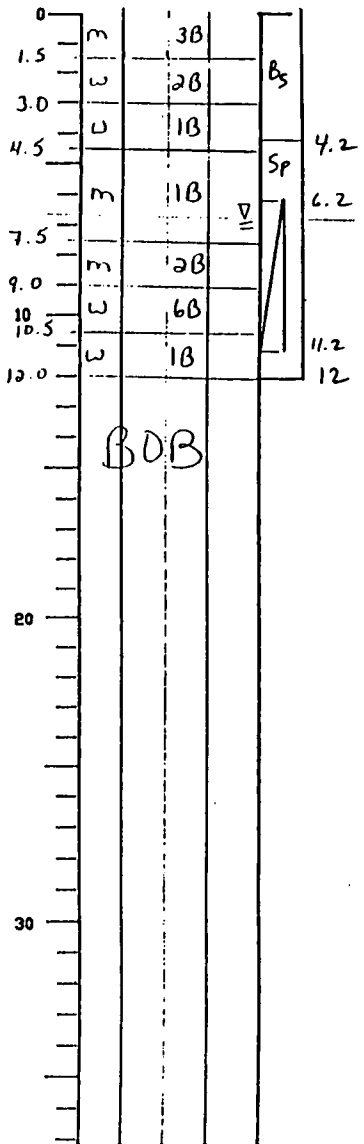
RI/FS

DRILLING PROGRAM

579.7'

SURFACE ELEVATION

DEPTH (ft)



1113

RI/FS BORING NO.

12-1-88/E. Trollinger

DATE DRILLED

Production (PA-4)

AREA

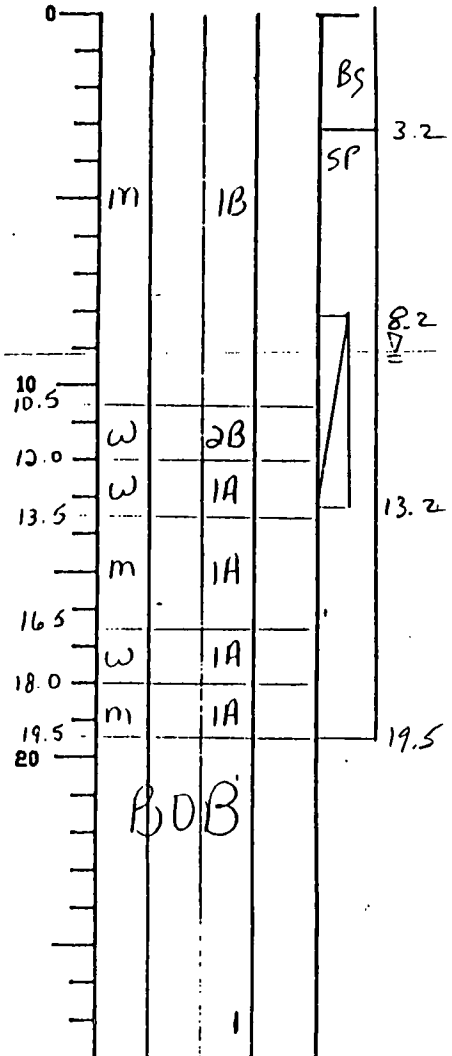
RI/FS

DRILLING PROGRAM

579.1'

SURFACE ELEVATION

DEPTH (ft)



1134

RI/FS BORING NO.

5-3-89/Sinfield

DATE DRILLED

PA-6

AREA

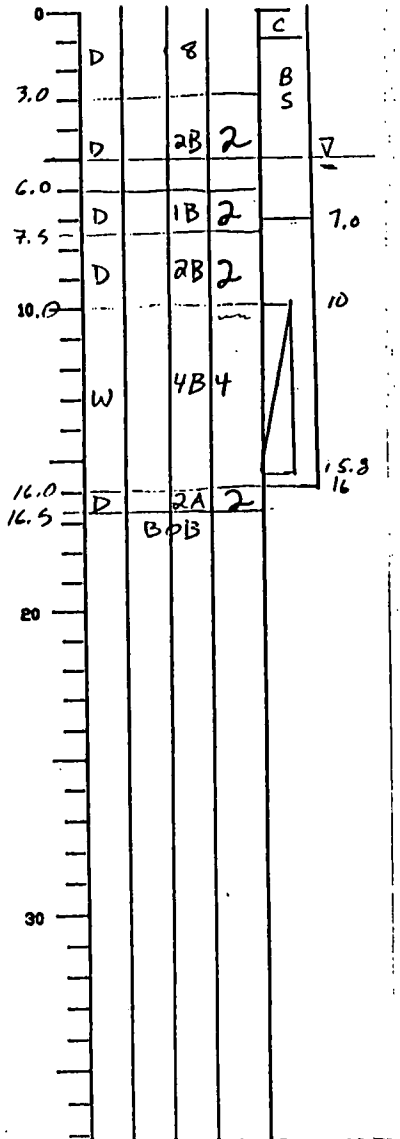
RI-FS

DRILLING PROGRAM

579.8

SURFACE ELEVATION

DEPTH (ft)



1137

RI/FS BORING NO.

4-5-89/ L. Sinfield

DATE DRILLED

Production (PA-4)

AREA

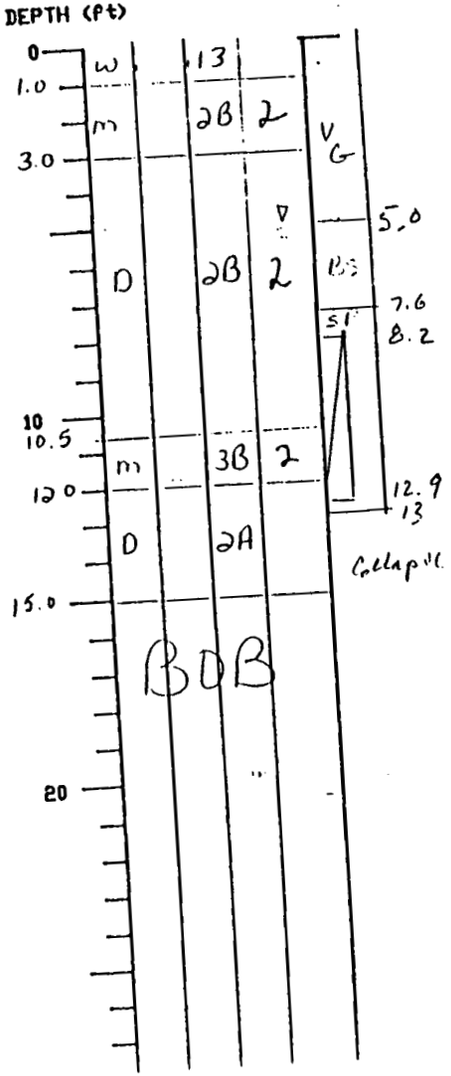
RI/FS

DRILLING PROGRAM

579.4'

SURFACE ELEVATION

DEPTH (ft)



1145

RI/FS BORING NO.

8-15-89/L. Sinfield

DATE DRILLED

Production (PA-4)

AREA

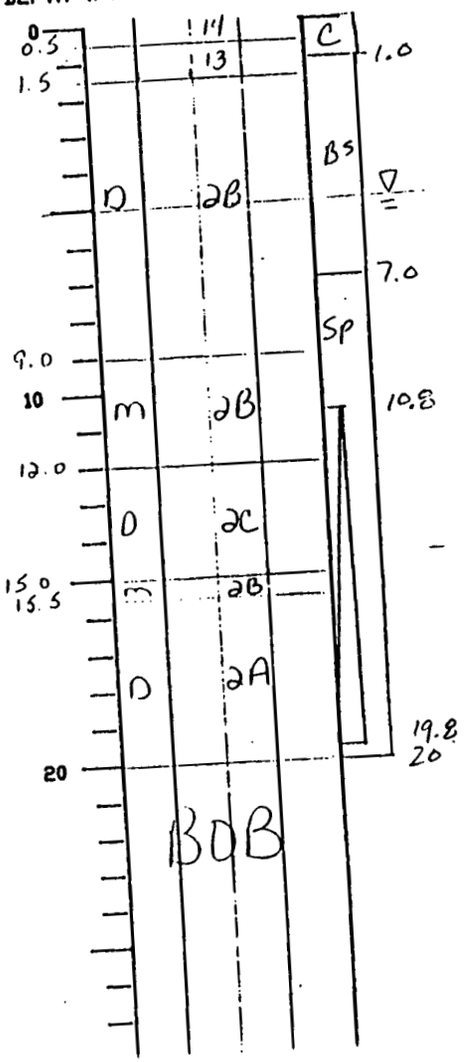
RI/FS

DRILLING PROGRAM

580.2'

SURFACE ELEVATION

DEPTH (ft)



1149

RI/FS BORING NO.

7-15-89/ Grube Trollinger

DATE DRILLED

Production (PA-4)

AREA

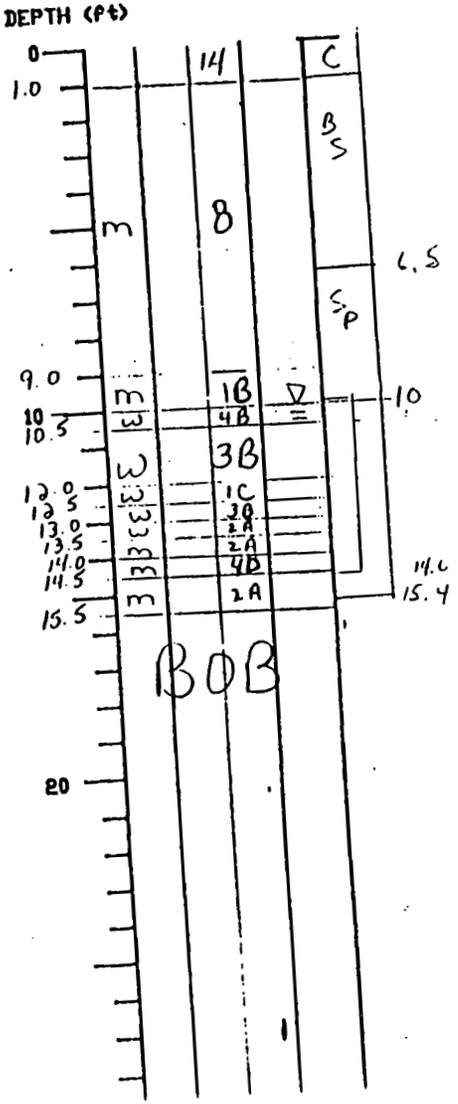
RI/FS

DRILLING PROGRAM

580.2'

SURFACE ELEVATION

DEPTH (ft)



1152

RI/FS BORING NO.

4-4-89 / Grube Slusarski

DATE DRILLED

Production (PA-4)

AREA

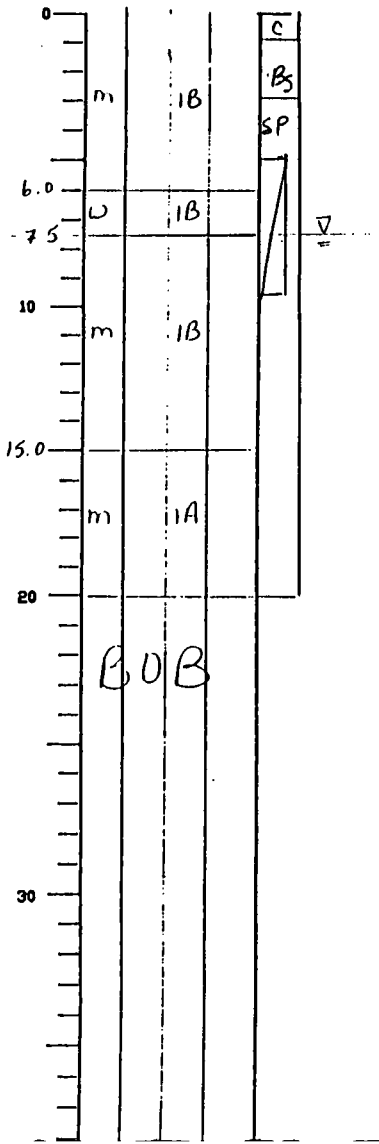
RI/FS

DRILLING PROGRAM

577.7'

SURFACE ELEVATION

DEPTH (Ft)



1153

RI/FS BORING NO.

8-9-89 / L. Sinfield

DATE DRILLED

Production (PA-4)

AREA

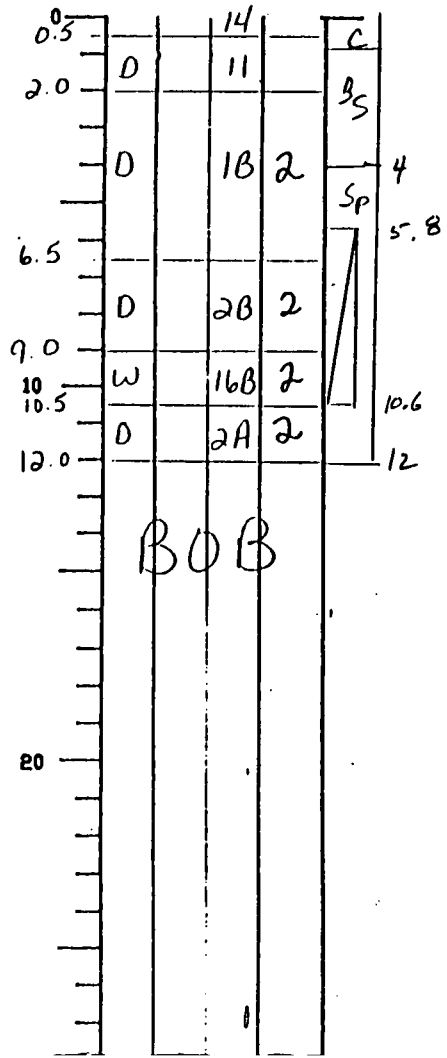
RI/FS

DRILLING PROGRAM

580.4'

SURFACE ELEVATION

DEPTH (Ft)



1155

RI/FS BORING NO.

4-29-89 / L. Sinfield

DATE DRILLED

Production (PA-4)

AREA

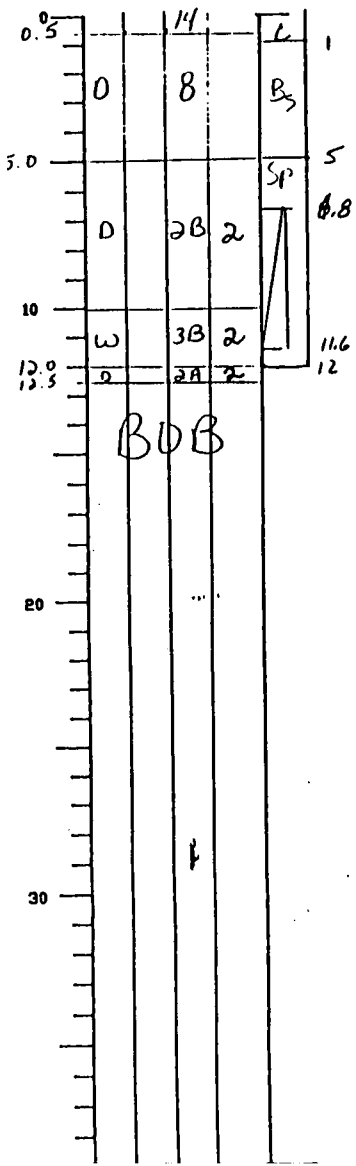
RI/FS

DRILLING PROGRAM

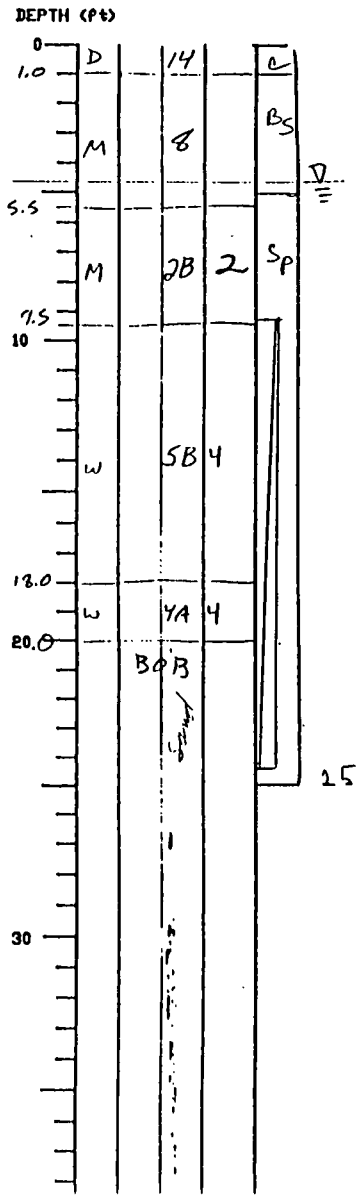
579.7'

SURFACE ELEVATION

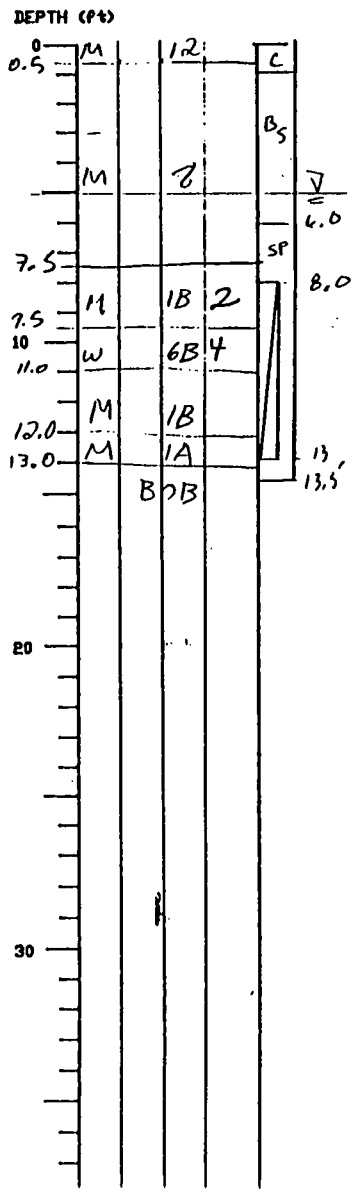
DEPTH (Ft)



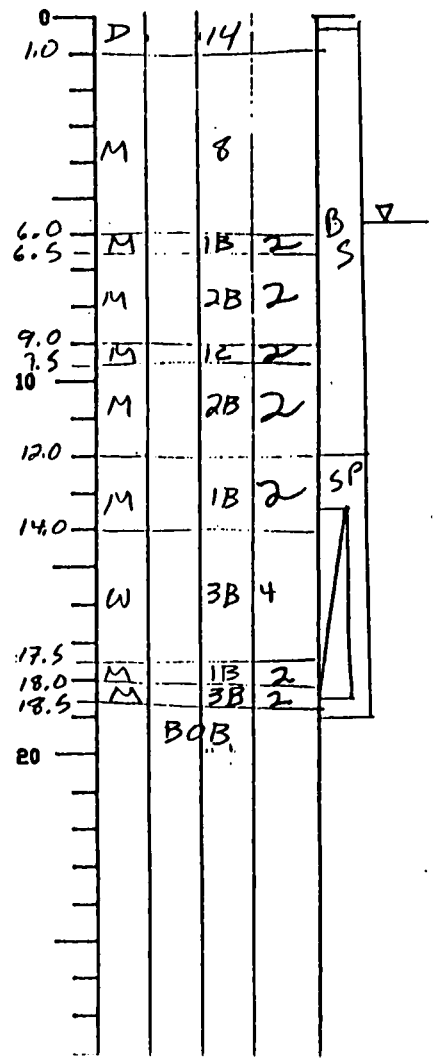
1177
RI/FS BORING NO.
8-13-89/Trollinger
DATE DRILLED
PA 6
AREA
RI-FS
DRILLING PROGRAM
579.35
SURFACE ELEVATION



1182
RI/FS BORING NO.
10-22-89/Grube
DATE DRILLED
PA 6
AREA
RI-FS
DRILLING PROGRAM
579.5
SURFACE ELEVATION



1204
RI/FS BORING NO.
1-4-90/Garman
DATE DRILLED
PA 6
AREA
RI-FS
DRILLING PROGRAM
579.84
SURFACE ELEVATION



102

4333

1215

RI/FS BORING NO.

10-22-89/Hardner

DATE DRILLED

PA 6

AREA

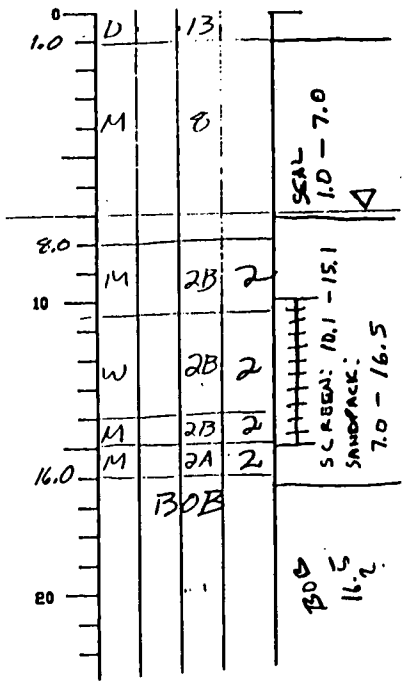
R1-FS

DRILLING PROGRAM

580.2

SURFACE ELEVATION

DEPTH (ft)



1220

RI/FS BORING NO.

5-25-89/Sinfield

DATE DRILLED

PA 6

AREA

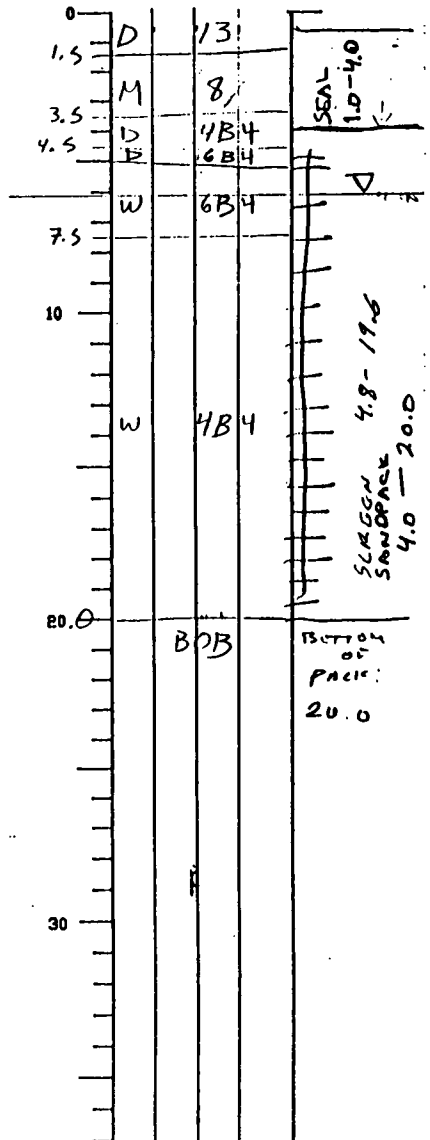
R1-FS

DRILLING PROGRAM

580.11

SURFACE ELEVATION

DEPTH (ft)



1227

RI/FS BORING NO.

5-12-89/Sinfield

DATE DRILLED

PA 6

AREA

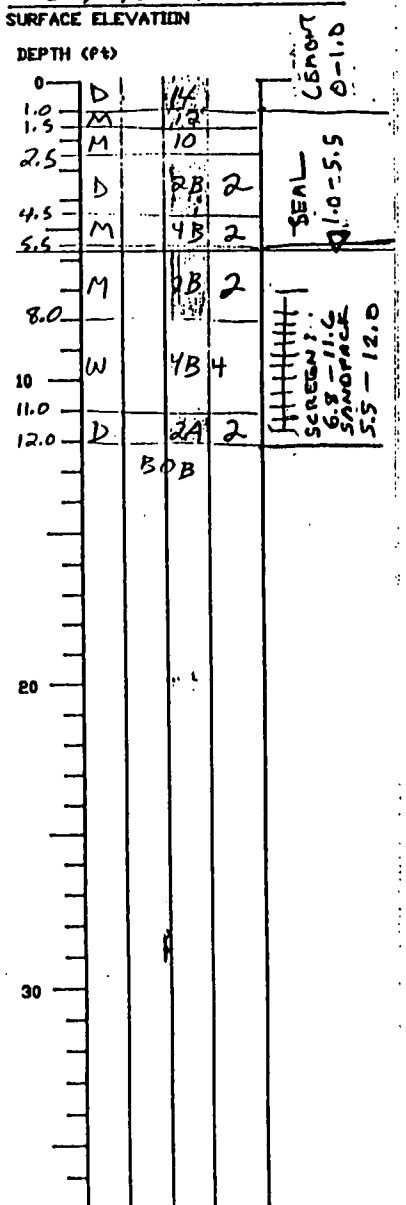
R1-FS

DRILLING PROGRAM

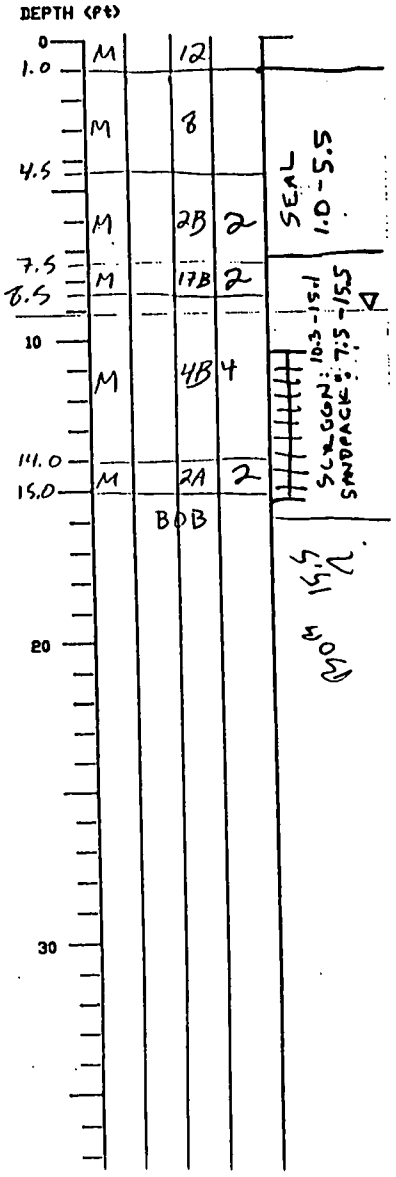
579.77

SURFACE ELEVATION

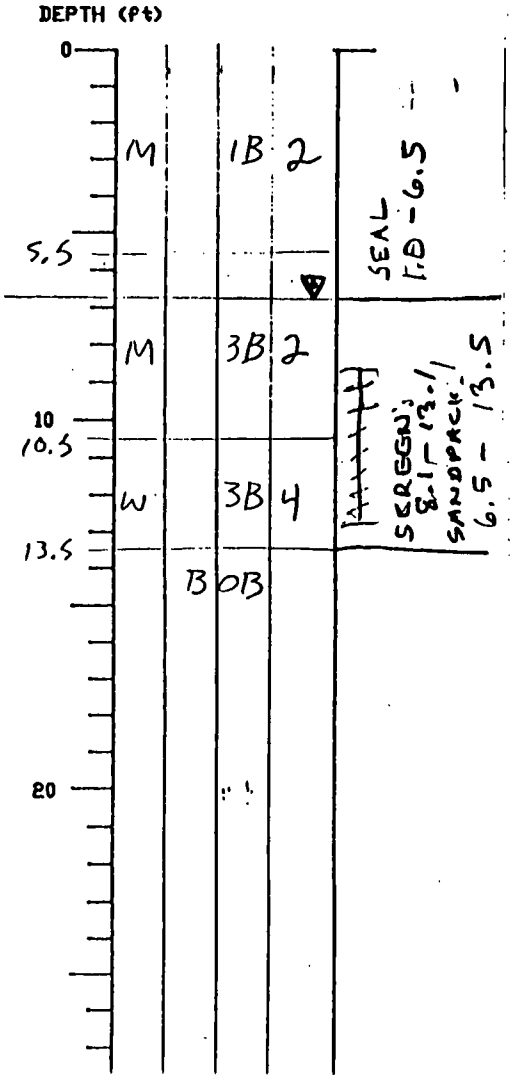
DEPTH (ft)



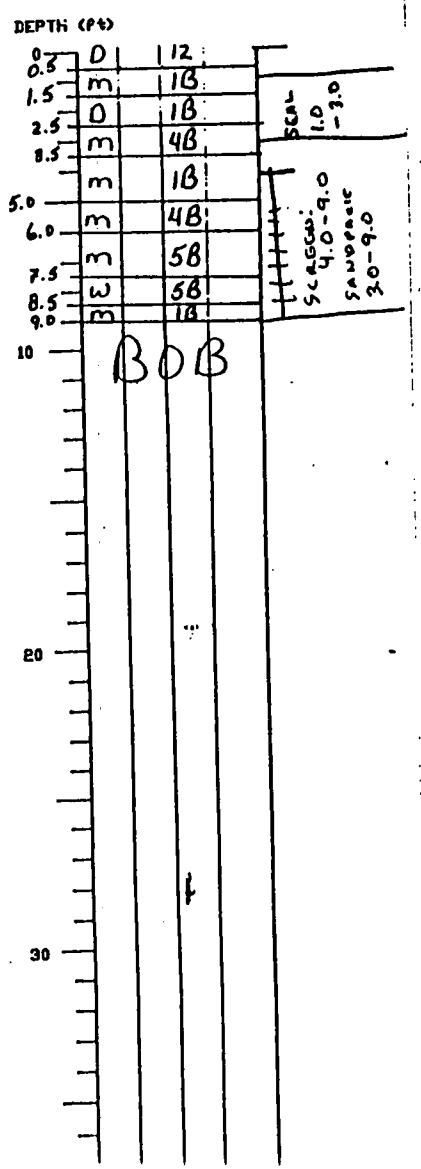
1241
RI/FS BORING NO.
5-11-89 / Sinfield
DATE DRILLED
PA6
AREA
RI-FS
DRILLING PROGRAM
579.13
SURFACE ELEVATION



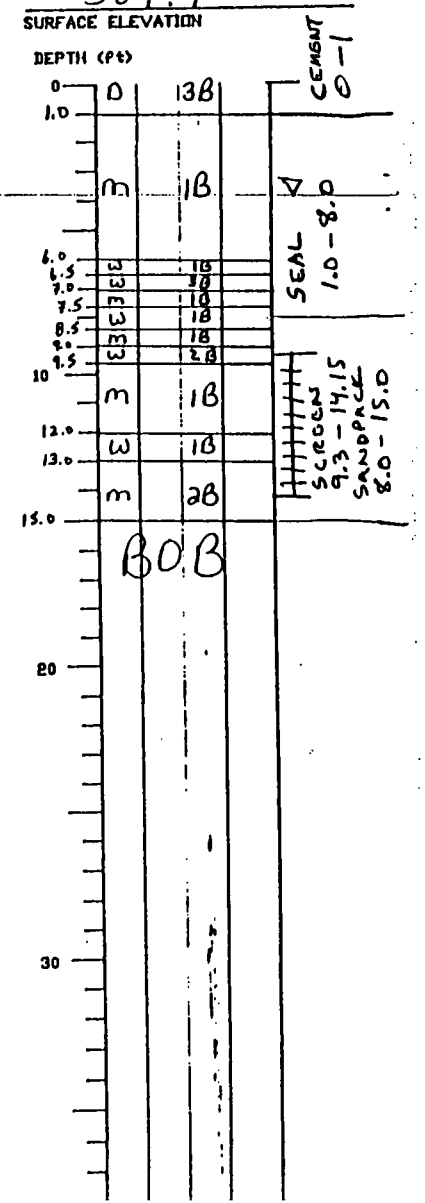
1263
RI/FS BORING NO.
8-31-89
DATE DRILLED
PA5
AREA
RI-FS
DRILLING PROGRAM
576.9
SURFACE ELEVATION



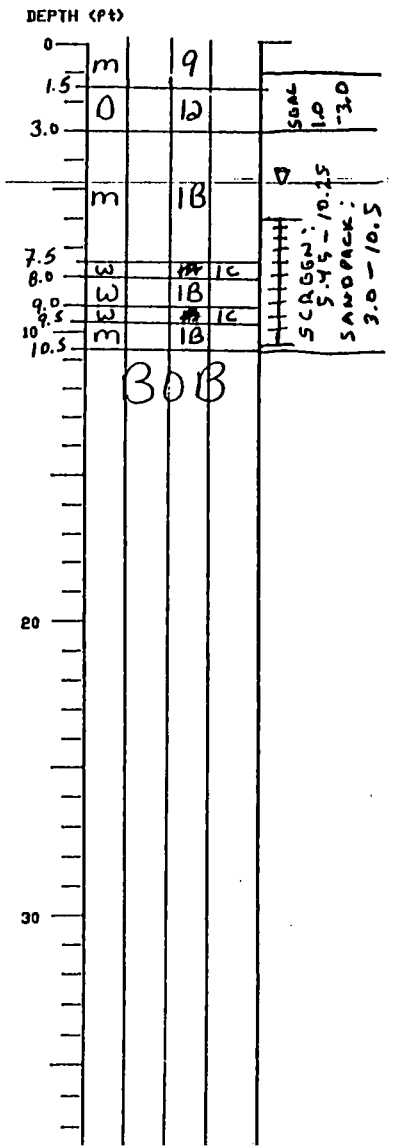
1277
RI/FS BORING NO.
6-27-89 / C. Grube
DATE DRILLED
Production (PA2)
AREA
RI/FS
DRILLING PROGRAM
590.7'
SURFACE ELEVATION



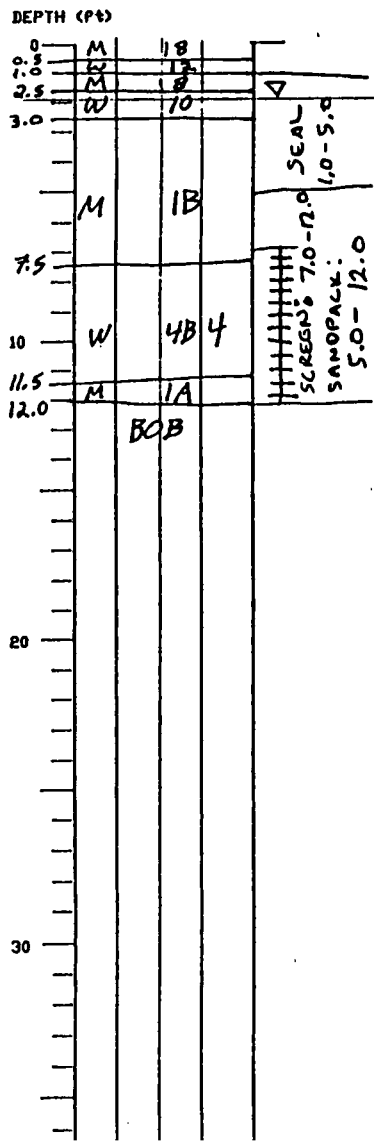
1279
RI/FS BORING NO.
7-17-89/L. Adams
DATE DRILLED
Production (PA2)
AREA
RI/FS
DRILLING PROGRAM
589.9'
SURFACE ELEVATION



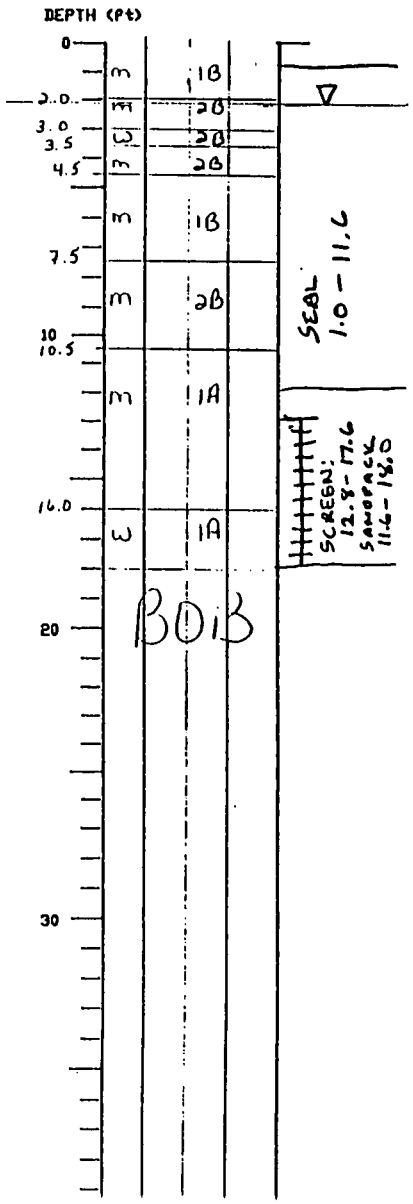
1283
RI/FS BORING NO.
7-18-89/L. Adams
DATE DRILLED
Production (PA2)
AREA
RI/FS
DRILLING PROGRAM
589.9'
SURFACE ELEVATION



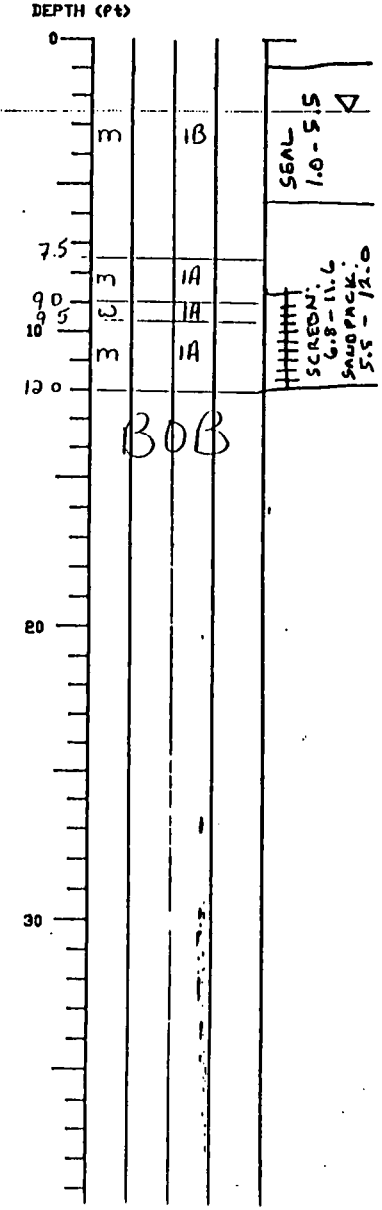
1293
RI/FS BORING NO.
7-25-89/Grube
DATE DRILLED
PA-2
AREA
RI-FS
DRILLING PROGRAM
586.99
SURFACE ELEVATION



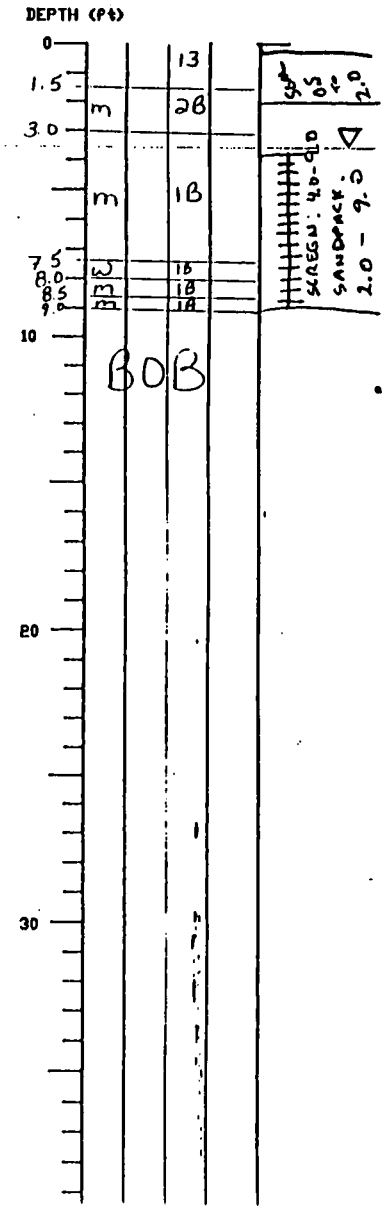
1299
RI/FS BORING NO.
7-16-89/ L. Adams
DATE DRILLED
Production (PA-3)
AREA
RI/FS
DRILLING PROGRAM
585.1'
SURFACE ELEVATION



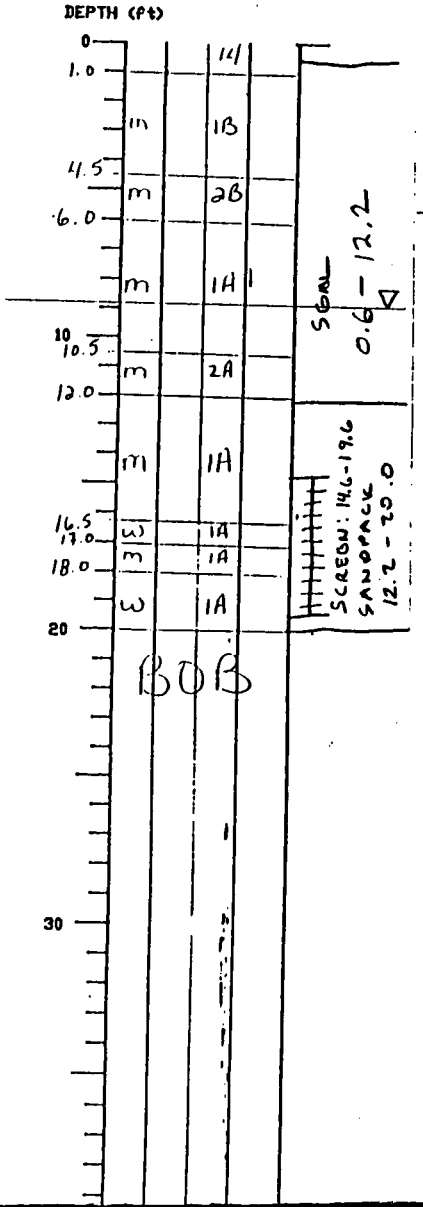
1301
RI/FS BORING NO.
7-14-89/ L. Adams
DATE DRILLED
Production (PA-3)
AREA
RI/FS
DRILLING PROGRAM
585.6'
SURFACE ELEVATION



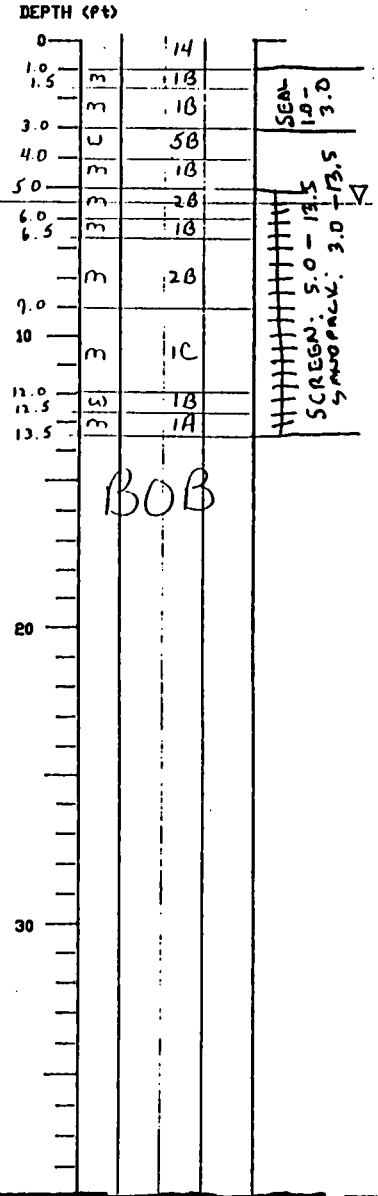
1304
RI/FS BORING NO.
Garman
1-17-90/ Swanson
DATE DRILLED
Production (PA-3)
AREA
RI/FS
DRILLING PROGRAM
584.3'
SURFACE ELEVATION



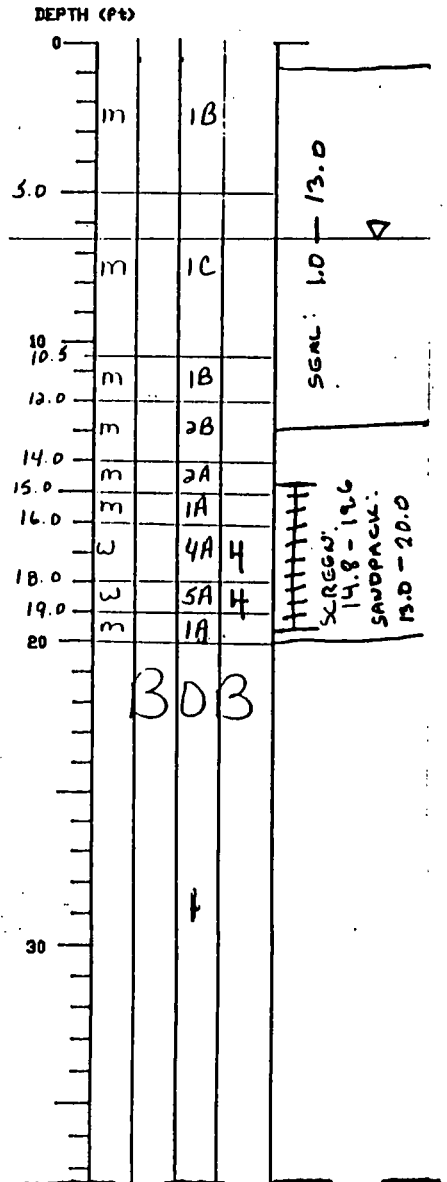
1317
RI/FS BORING NO.
11-14-89/B. Nies
DATE DRILLED
Production (PA-3)
AREA
RI/FS
DRILLING PROGRAM
580.9'
SURFACE ELEVATION



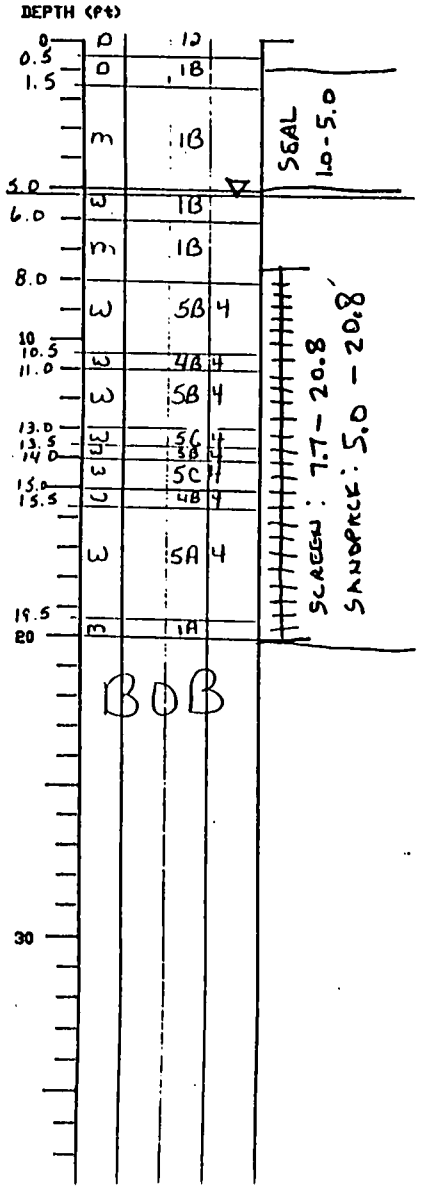
1324
RI/FS BORING NO.
11-3-89/B. Nies
DATE DRILLED
Production (PA-3)
AREA
RI/FS
DRILLING PROGRAM
580.5'
SURFACE ELEVATION



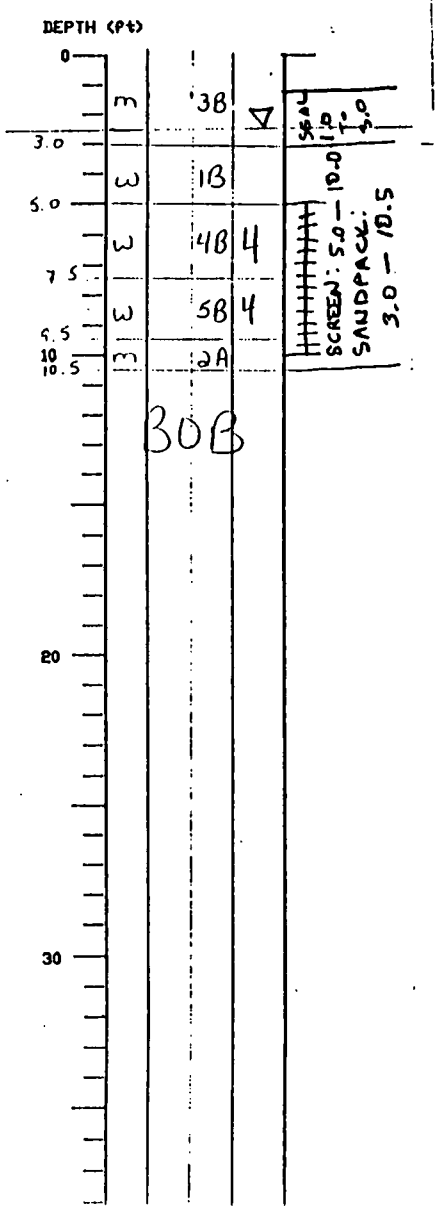
1332
RI/FS BORING NO.
7-30-89/Slusarski
DATE DRILLED
Production (PA-1)
AREA
RI/FS
DRILLING PROGRAM
590.6'
SURFACE ELEVATION



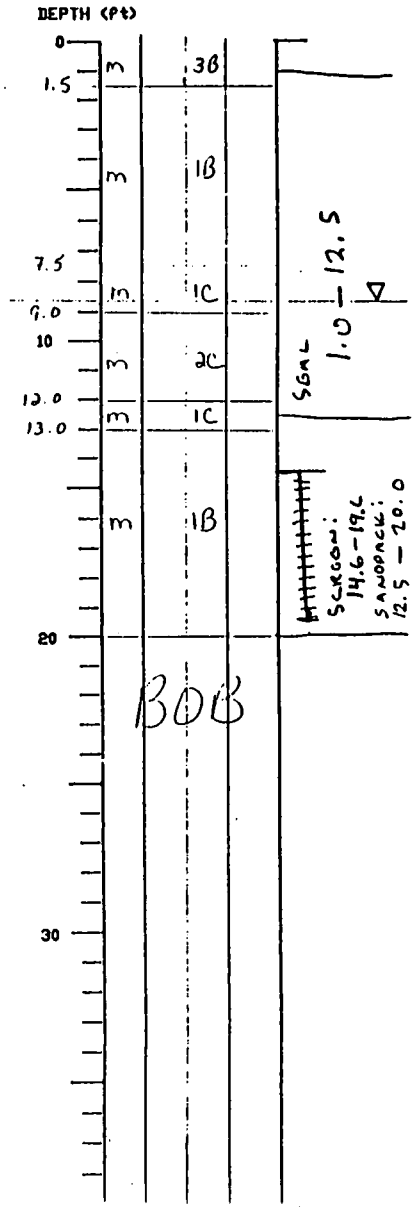
1336
RI/FS BORING NO.
8-2-89/M. Slusarski
DATE DRILLED
Production (PA-1)
AREA
RI/FS
DRILLING PROGRAM
589.1'
SURFACE ELEVATION



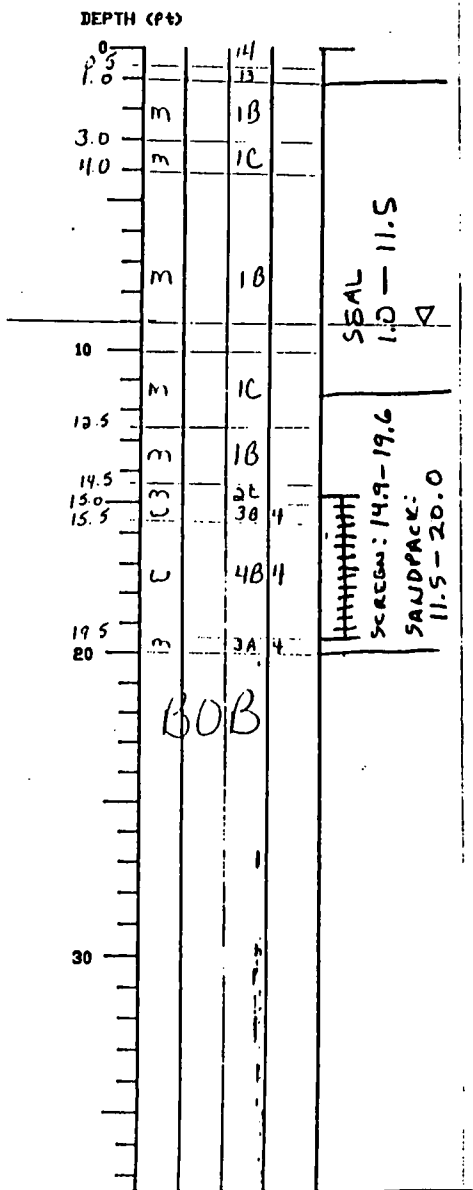
1338
RI/FS BORING NO.
8-8-89/ Slusarski Trollinger
DATE DRILLED
Production (PA-1)
AREA
RI/FS
DRILLING PROGRAM
585.6'
SURFACE ELEVATION



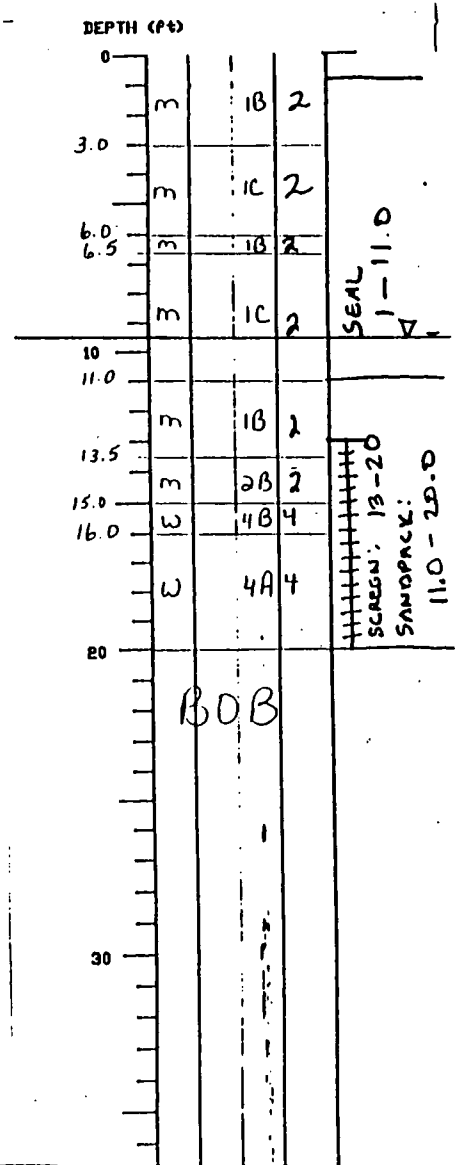
1341
RI/FS BORING NO.
10-4-89/ Trollinger Slusarski
DATE DRILLED
Production (PA-1)
AREA
RI/FS
DRILLING PROGRAM
585.8'
SURFACE ELEVATION



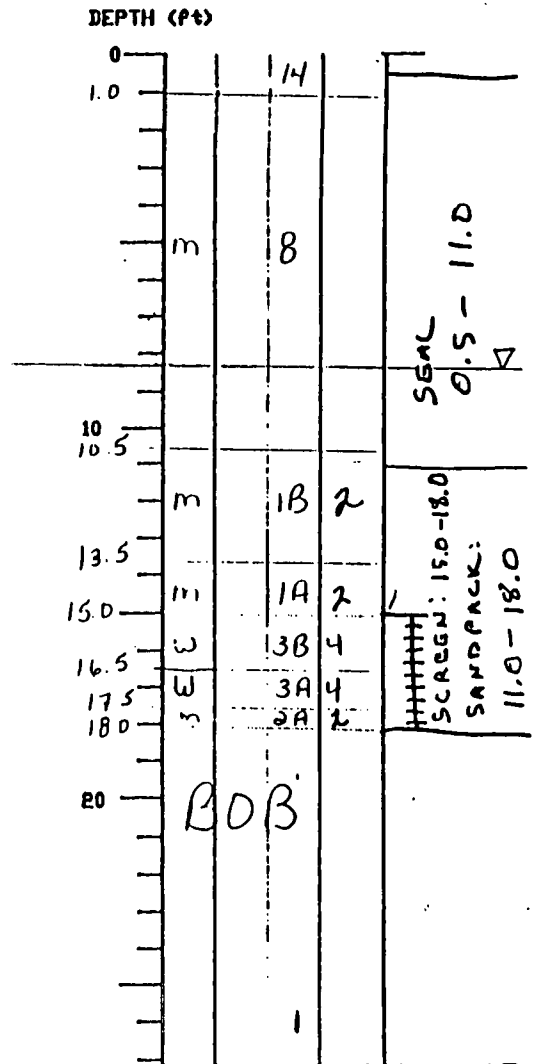
1346
RI/FS BORING NO.
1-6-90/C. Grube
DATE DRILLED
Production (PA-1)
AREA
RI/FS
DRILLING PROGRAM
585.0'
SURFACE ELEVATION



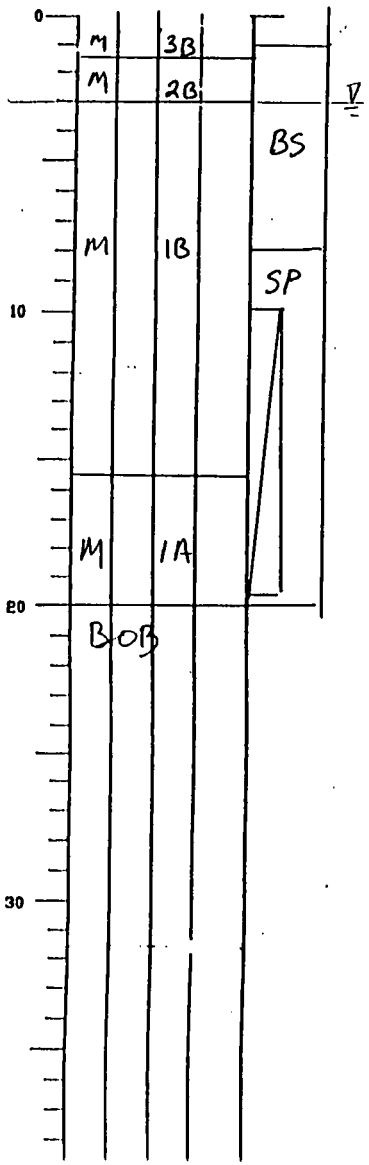
1351
RI/FS BORING NO.
8-10-89/Slusarski
DATE DRILLED
Production (PA-1)
AREA
RI/FS
DRILLING PROGRAM
584.5'
SURFACE ELEVATION



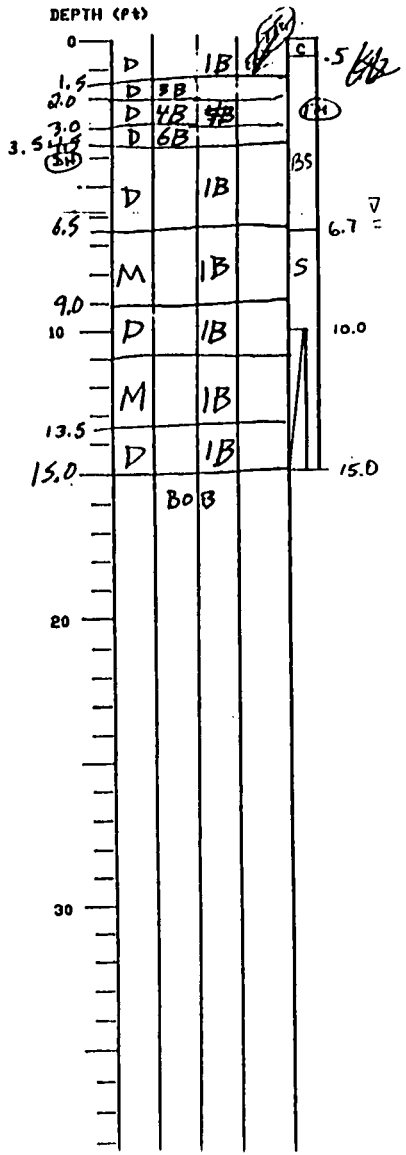
1353
RI/FS BORING NO.
10-5-89/ Trollinger Slusarski
DATE DRILLED
Production (PA-1)
AREA
RI/FS
DRILLING PROGRAM
585.2'
SURFACE ELEVATION



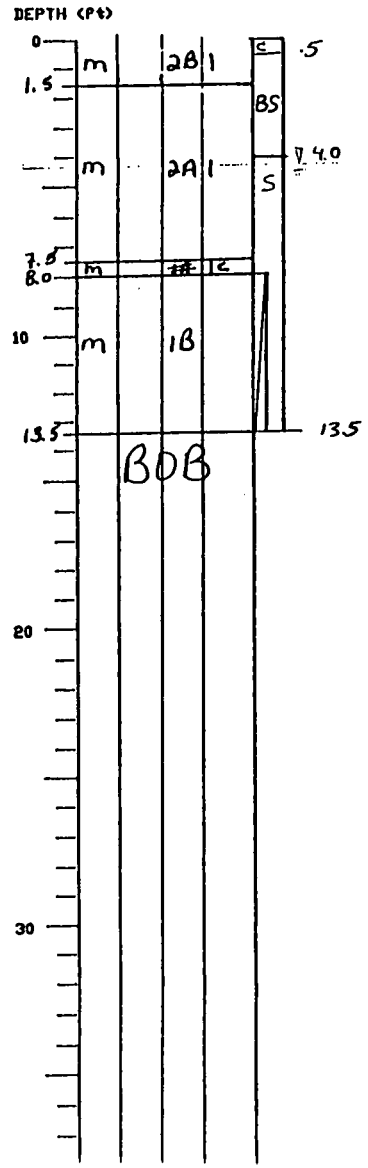
1420
RI/FS BORING NO.
1-20-93
DATE DRILLED
East
AREA
RI/FS
DRILLING PROGRAM
580.1 (MW 2420)
SURFACE ELEVATION



1444
RI/FS BORING NO.
11-20-89 / Garman
DATE DRILLED
E. Side
AREA
RI-FS
DRILLING PROGRAM
600.3 #
SURFACE ELEVATION



1508
RI/FS BORING NO.
2-2-90 / Garman, Swanson
DATE DRILLED
North
AREA
RI/FS
DRILLING PROGRAM
590.9'
SURFACE ELEVATION



1509

RI/FS BORING NO.

2-2-90 / Swanson Garman

DATE DRILLED

North

AREA

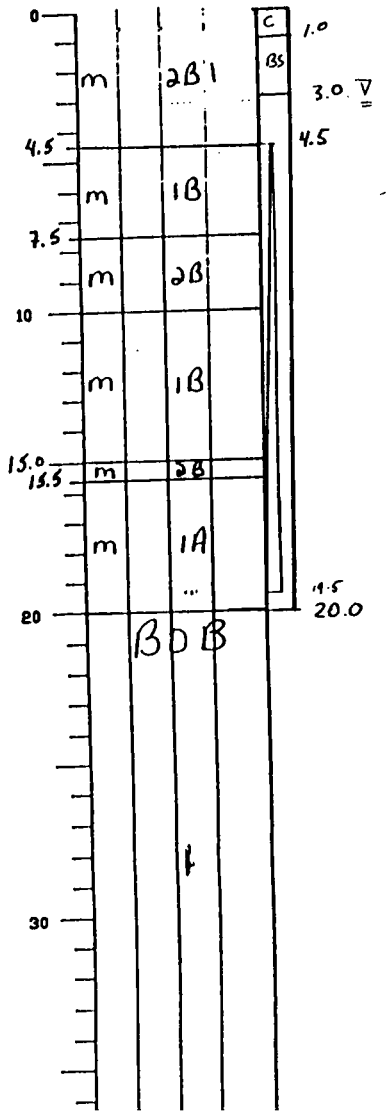
RI/FS

DRILLING PROGRAM

590.8

SURFACE ELEVATION

DEPTH (Ft)



1514

RI/FS BORING NO.

2-7-90 / M. Learman

DATE DRILLED

North

AREA

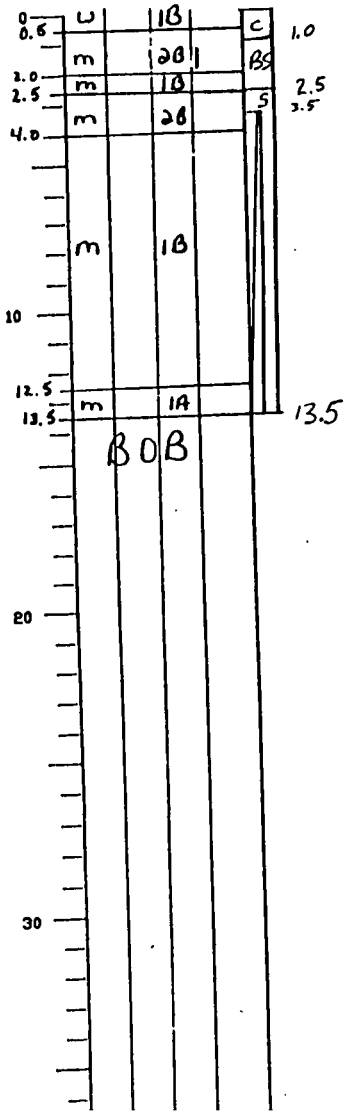
RI/FS

DRILLING PROGRAM

590.8

SURFACE ELEVATION

DEPTH (Ft)



1606

RI/FS BORING NO.

2-17-91 / J. Lear

DATE DRILLED

Production (PA-4)

AREA

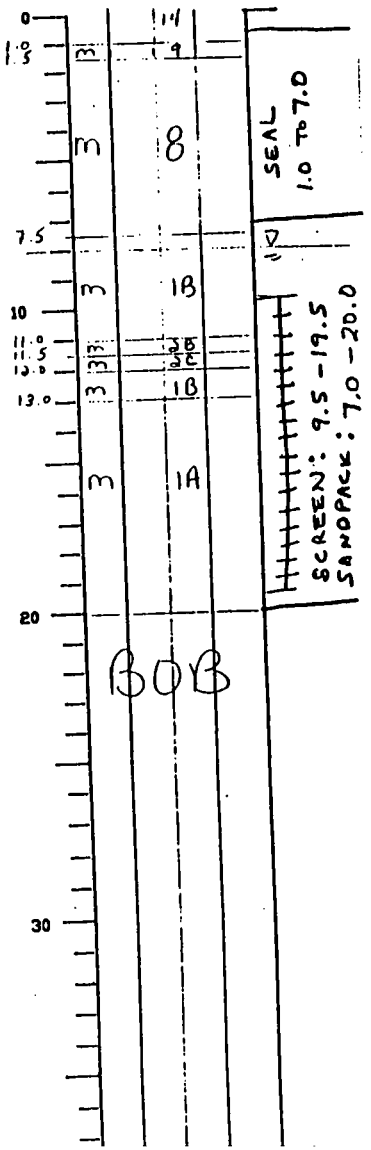
RI/FS

DRILLING PROGRAM

580.3'

SURFACE ELEVATION

DEPTH (Ft)



1608

RI/FS BORING NO.

2-20-91/J. Lear

DATE DRILLED

Production (PA-4)

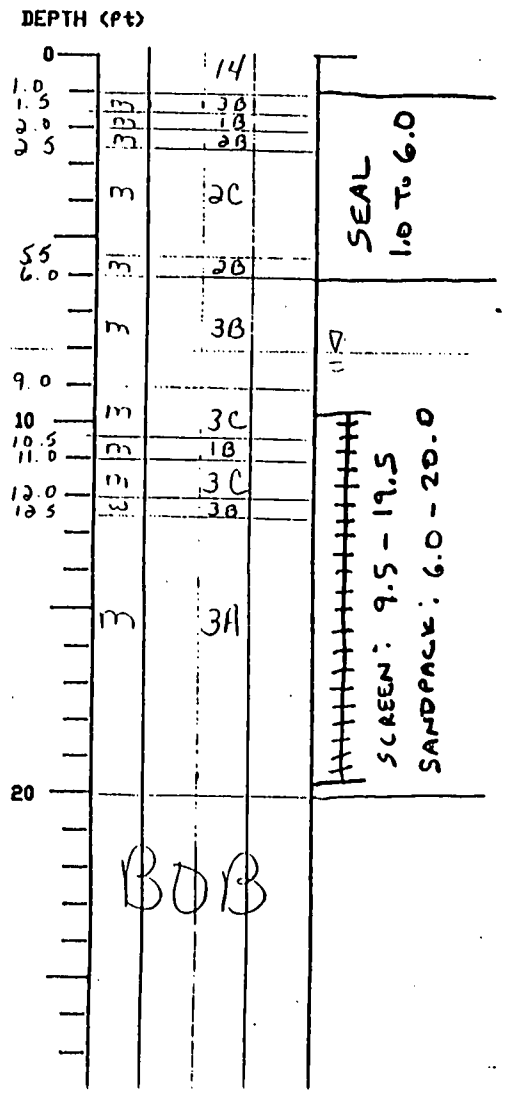
AREA

RI/FS

DRILLING PROGRAM

580.3'

SURFACE ELEVATION



1675

RI/FS BORING NO.

3-5-91/J. Lear

DATE DRILLED

Production (PA-3)

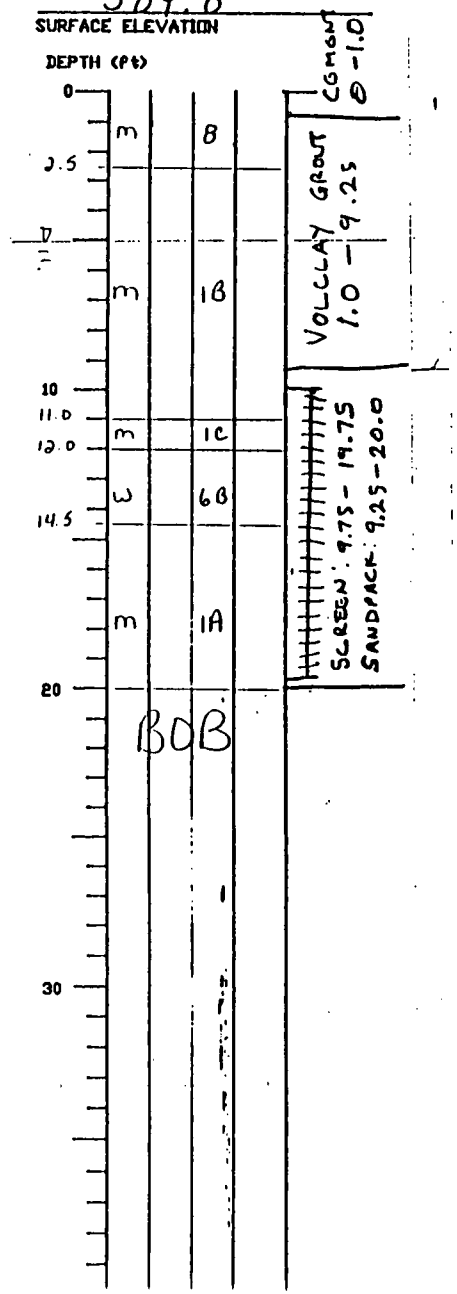
AREA

RI/FS

DRILLING PROGRAM

587.8'

SURFACE ELEVATION



1676

RI/FS BORING NO.

3-8-91/J. Lear

DATE DRILLED

Production (PA-3)

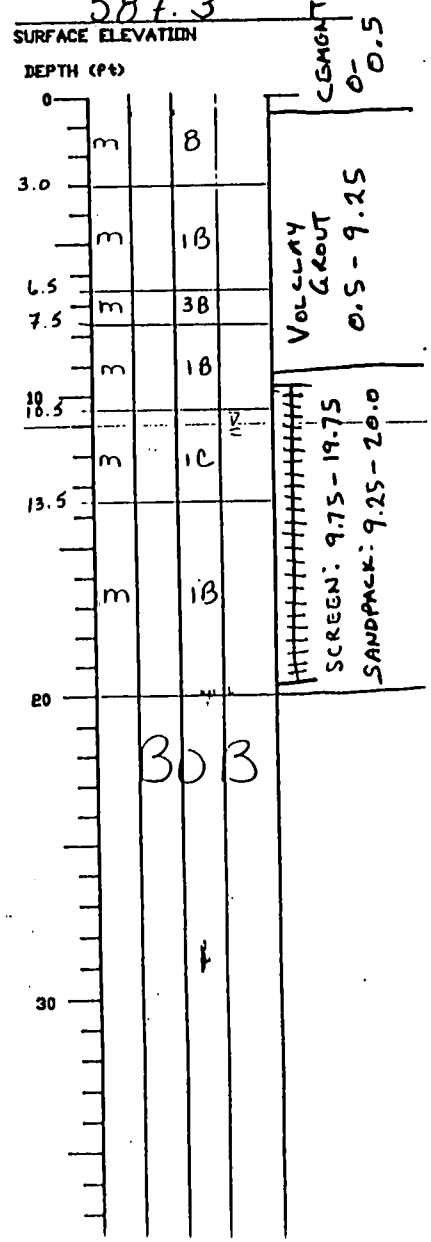
AREA

RI/FS

DRILLING PROGRAM

587.3'

SURFACE ELEVATION



1728

RI/FS BORING NO.

~~1-15-92~~ 2-6-92

DATE DRILLED

North

AREA

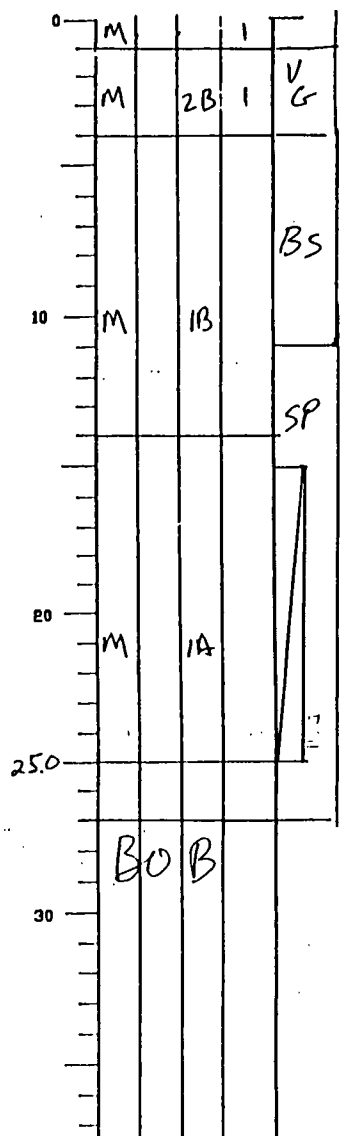
RI/FS

DRILLING PROGRAM

594.7 (MW 2728)

SURFACE ELEVATION

DEPTH (Ft)



1733

RI/FS BORING NO.

1-8-92

DATE DRILLED

EAST Side

AREA

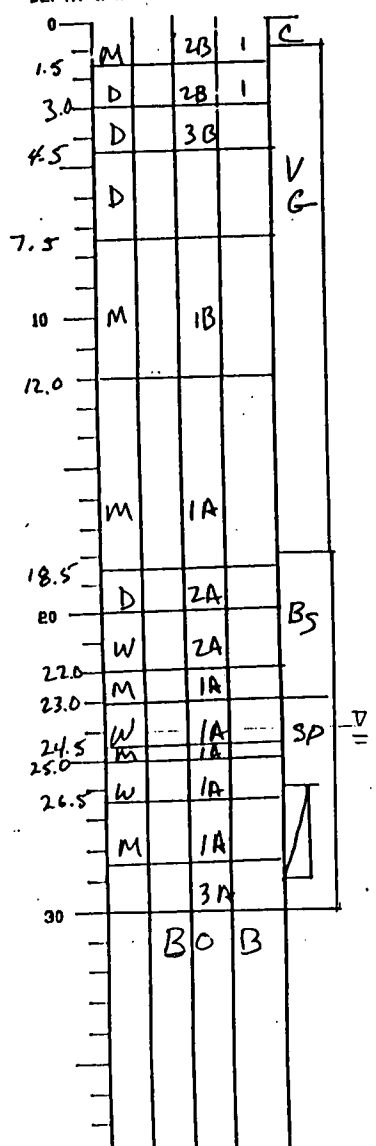
RI/FS

DRILLING PROGRAM

604.9 (MW 2733)

SURFACE ELEVATION

DEPTH (Ft)



1754

RI/FS BORING NO.

4/27/92

DATE DRILLED

AREA

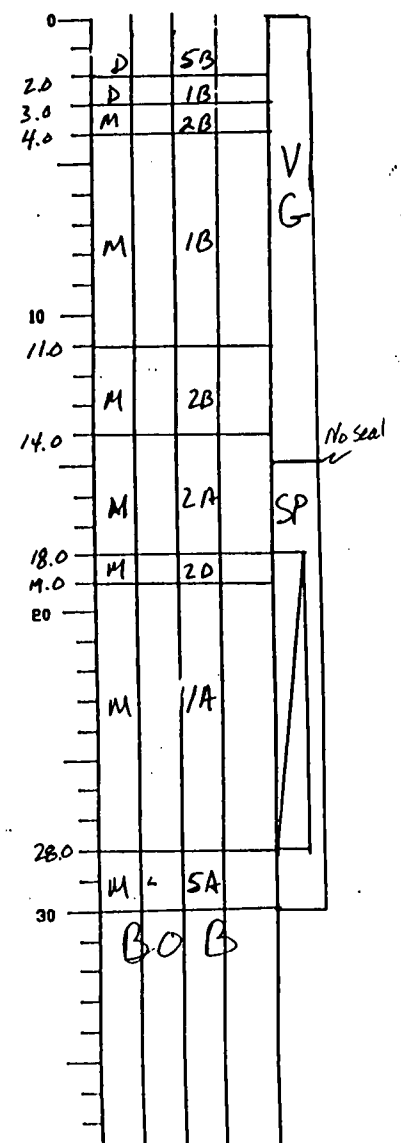
RI/FS

DRILLING PROGRAM

610.0 (MW 2754)

SURFACE ELEVATION

DEPTH (Ft)



1778

RI/FS BORING NO.

2-4-91 / Garman Lear

DATE DRILLED

Production (PA-4)

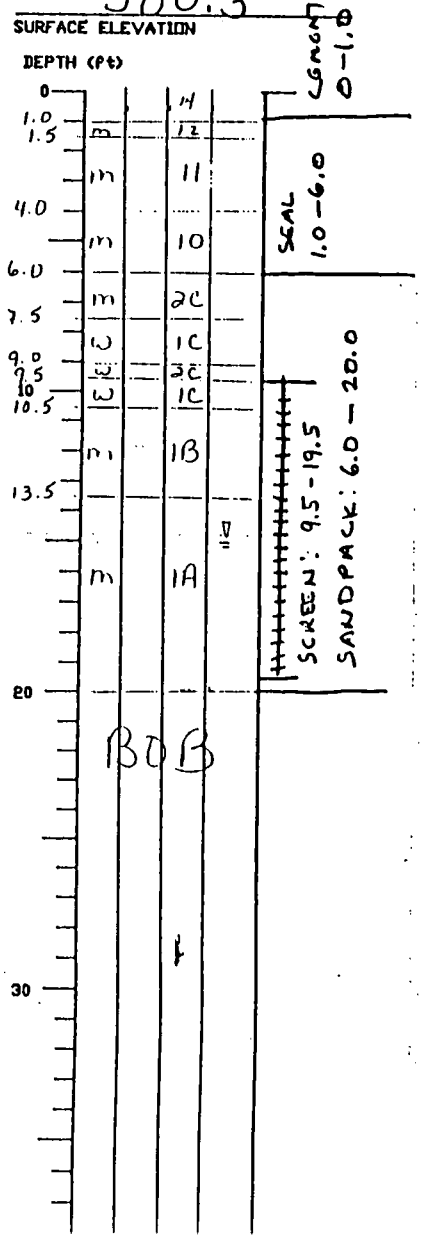
AREA

RI/FS

DRILLING PROGRAM

580.3'

SURFACE ELEVATION



1785

RI/FS BORING NO.

8-20-91 / K. Marion

DATE DRILLED

Production (PA-6)

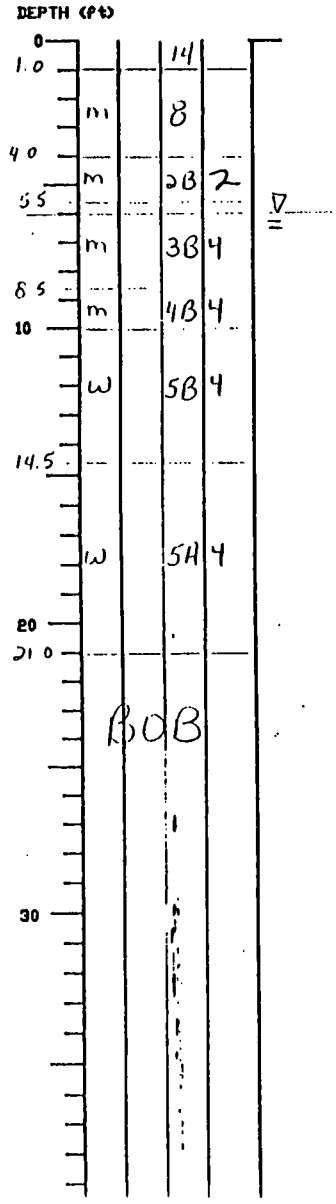
AREA

RI/FS

DRILLING PROGRAM

579.75

SURFACE ELEVATION



1836

RI/FS BORING NO.

7-2-92 / K. Marion

DATE DRILLED

West Side

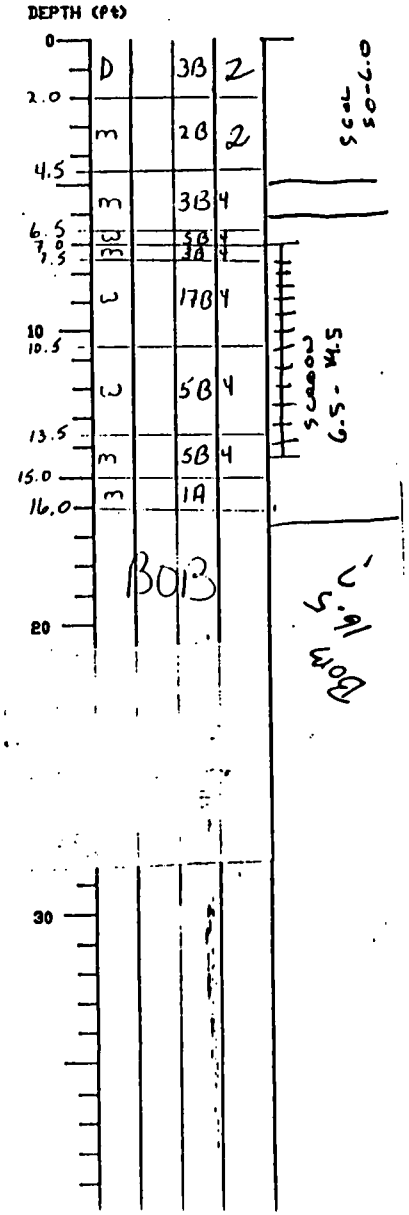
AREA

RI/FS

DRILLING PROGRAM

579.6'

SURFACE ELEVATION



1843

RI/FS BORING NO.

6-8-92 / Marion

DATE DRILLED

E Side

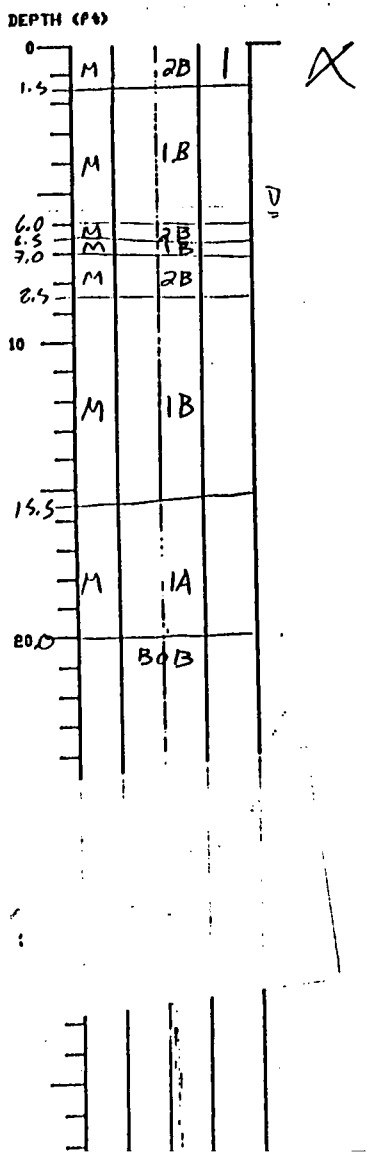
AREA

RI-FS

DRILLING PROGRAM

591.37

SURFACE ELEVATION



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ATTACHMENT B

MATERIAL AND EQUIPMENT LIST

Material and Equipment List

CONTENTS

SECTION

B1 Slug Tests . . . . . .

B2 Pumping Tests . . . . . .

B3 Lysimeter Installation . . . . . .

B4 Packer Tests . . . . . .

B5 Yield Tests . . . . . .

B1 SLUG TESTS

A) Slugs

Solid, threaded PVC, of 1-inch and 2-inch OD sufficient to form the various lengths and diameters described in Subsection 2.3.2 of the work plan. An eyebolt or other method of attaching nylon cord to the slug is also required (see Figure A). Slug requirements are as follows:

Description	Length	Quantity
2-inch diameter solid PVC cylinder threaded both ends	6-inch	3
2-inch diameter solid PVC cylinder threaded both ends	12-inch	11
2-inch ID threaded end caps for 2-inch PVC cylinders	1-inch	10
2-inch ID threaded couplings for 2-inch PVC cylinders	2-inch	10
1-inch diameter solid PVC cylinder threaded both ends	6-inch	6
1-inch diameter solid PVC cylinder threaded both ends	12-inch	22
1-inch ID threaded couplings for 1-inch PVC cylinders	2-inch	20
1-inch ID threaded end caps for 1-inch PVC cylinders	1-inch	20

2,000 feet of 3/16" or 1/4" nylon cord for lowering and retrieving slugs.

B) Data Logger and Accessories:

	Quantity
In Situ® Hermit 2000, 4-channel data loggers (or equivalent)	3
In Situ® Hermit 1000C, 2-channel data loggers (or equivalent)	3
Field printers: (GFP-80) and (SE1004B)	1
20 psi, PXD transducers	15
50-foot transducer cable	8
100-foot transducer cable	7

	Cable (s) for interfacing with data loggers, field printers, and laptop computers	1
	Set of plans for chemical protection of transducer cables (PVC pipe)	1

		Quantity
C)	Solinst (or equivalent) Electronic Water Level Measuring Tapes graduated in hundredths of a foot	8

		Quantity
D)	Stopwatches and Digital Wristwatches	2

E) Visqueen (or equivalent) Clear Plastic Sheeting - Sufficient for 68 slug tests

		Quantity
F)	YSI/Grant 3800 Water Quality Monitor (or equivalent) Combined pH, DO, specific conductance, and temperature meter.	2

		Quantity
G)	Laptop Computer: Capable of interfacing with the Hermit 2000 and 1000C data loggers (IBM compatible, 286 or higher).	1

		Quantity
H)	Apparatus for injecting slug of water into well (see Figure B) must be able to attach to either 2-inch or 4-inch well.	1

		Quantity
I)	Disposable PVC Bailers	20

J) Personal Protective Equipment: -
Gloves, Boots, Tyvek, Respirators, Rain Gear

K) (8) 5-gallon buckets, de-ionized water, decon tub, containers for purged water, "kim wipes," paper towels, wash bottles

		Quantity
L)	Purge pump (2" OD); Grundfos Redi-Flo-2 (or equivalent)	1

		Quantity
M)	Small folding field table	1
N)	Miscellaneous items: Camera, tool box, flashlights, calculator, insect spray, field books, pens and pencils, well keys, pocket knife, field notebook.	

B-2 - PUMPING TEST

	Description	Quantity
1.	Hollow Stem Auguring:	
	12-inch O.D. Boreholes	3
	8-inch O.D. Boreholes	18
2.	6-inch I.D. Well Installation	3
3.	2-inch I.D. Piezometer Installation	18
4.	Well Development	21
5.	Well/Borehole Abandonment	As needed
6.	Water Sampling	As needed
7.	Hauling Water	As needed
8.	Hauling Drums	As needed
9.	Stand By and Moving Between Sites	As needed
10.	Shelby, Dennison, and Split Spoon Sampling	15
11.	Well Completion Materials:	
	10-foot x 5 3/4-inch I.D., No. 316 Stainless Threaded, Flush Joint Screen, 0.02-inch Slot	3
	5-foot x 5 3/4-inch I.D., No. 316 Stainless Threaded, Flush Joint Screen, 0.02-inch Slot	3
	4-foot x 6-inch I.D., No. 316 Stainless Threaded, Flush Joint Sump	3
	10-foot x 6-inch I.D., No. 316 Stainless Threaded, Flush Joint Steel Casing	3
	5-foot x 6-inch I.D., No. 316 Stainless Threaded, Flush Joint Steel Casing	3
	10-foot x 2-inch I.D., Schedule 40, 0.01 Slot, Slotted PVC Screen	18

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B-2 - PUMPING TEST (Continued)

	Description	Quantity
11. (con.)	5-foot x 2-inch I.D., Schedule 40, 0.01 Slot, Slotted PVC Screen	18
	2-foot x 2-inch I.D., Schedule 40, 0.01 Slot, Slotted PVC Screen	18
	1-foot x 2-inch I.D., Schedule 40, 0.01 Slot, Slotted PVC Screen	36
	1-foot x 2-inch I.D., Schedule 40, PVC Sump	12
	2-inch I.D. PVC Well Tips	6
	10-foot x 2-inch I.D. Schedule 40 Riser	18
	5-foot x 2-inch I.D. Schedule 40 Riser	18
	2-foot x 2-inch I.D. Schedule 40 Riser	18
	1-foot x 2-inch I.D. Schedule 40 Riser	36
	Welder will be available to cut and/or weld casing, screen, and sumps to test well specifications	
	5-foot x 10-inch I.D. x 1/4-inch thick Black Iron Protective Casing with Locking Cap	3
	5-foot x 6-inch I.D. x 1/4-inch thick Black Iron Protective Casing with Locking Cap	18
	Sand Pack: Well Sorted Medium or Coarse Sand	As needed
	Sodium Bentonite Pellets	As needed
	Volclay Grout	As needed
	Cement	As needed
12.	Support Truck - Drilling Contractor	per day
13.	Decontamination Equipment - Drilling Contractor	per day
14.	Per Diem - Drilling Contractor	per day

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B-2 - PUMPING TEST (Continued)

	Description	Quantity
15.	Test Well Pumps:	
	Grundfos Redi-Flo 2 (or equivalent)	2
	Redi-Flo-2 Control Box	1
	Grundfos 16-S05-5 (1/2 HP) 230 Volt 2 Wire	2
	Grundfos 10-S03-6 (1/3 HP) 230 Volt 2 Wire	2
	100-Foot 230 Volt 2 Wire Cable, 12 Gauge with Necessary Adapter to Power Source	As required
16.	Test Pump Fittings:	
	Pump Cooling Shrouds, Schedule 5 Stainless Steel with Eyebolt or Mechanism to Attach Drop Cable:	
	Redi-Flo 2: 2 1/2-inch I.D.	2
	10-S: 4 1/2-inch I.D.	2
	16-S: 4 1/2-inch I.D.	2
	Backflow Preventer/Check Valve:	
	Redi-Flo 2: 1/2-inch NPT	2
	10-S: 1 1/4-inch NPT	2
	16-S: 1 1/4-inch NPT	2
	1/2-inch I.D. Discharge Hose for 2-inch Pump	As required
	1-inch Discharge Hose for 4-inch Pump	As required

B-2 - PUMPING TEST (Continued)

	Description	Quantity
16. (con.)	1/8-inch Cable to be Attached to Pump Shroud for Pump Support	As required
	Assorted Quick Connects, Reducer Couplings, Fittings, Elbows (3/4 inch to 1 inch)	As required
	Flow Control or Gate Valve	2
	Flow Meter with Totalizer Capable of Measuring Flow Rates from 1/2 to 20 gpm	2
	Flow Meter with Totalizer Capable of Measuring Flow Rates from 3 to 50 gpm	2
	Sampling Port on Flow Line	1
17.	Flood Lights	As required
18.	Electric Power Source:	
	ONAN DKD 7.5 kw, Single-Phase with 230 Volt/110 Volt Outlets, 60 Hertz (or equivalent) Sufficient to power well pumps and flood lights	1
*19.	Data Logger and Accessories:	
	In Situ, Hermit 2000, 4-Channel Data Loggers (or equivalent)	3
	In Situ, Hermit 1000C, 2-Channel Data Loggers (or equivalent)	3
	Field Printers: (GFP-80) and (SE1004B) (or equivalent)	1
	20 psi, PXD 260 Transducers	15
	Transducer Cables	As required
20.	Laboratory Analyses - Physical Samples:	
	Geotechnical lab analysis to include split spoon samples, grain size (sieve) analysis, visual description, and USCS classification	15 minimum

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B-2 - PUMPING TEST (Continued)

	Description	Quantity
20. (con.)	Shelby Tube/Dennison Samples:	15 minimum
	Geotechnical lab analysis to include visual description, grain size (sieve) analysis with hydrometer, moisture content, soil density, Atterberg limits, constant head permeability tests (triaxial cell with back pressure), specific gravity, void ratio, porosity, and USCS classification.	6 minimum
	Laboratory Analysis - Groundwater and Soil Moisture Samples:	
	Volatiles	20 minimum
	Total Uranium	20 minimum
	General Chemistry (Anions/Cations)	20 minimum
	Isotopic Analysis - ^{3}H, $^{18}O/^{16}O$	20 minimum
*21.	Stopwatches	2
*22.	Solinst (or equivalent) Electronic Water Level Measuring Tapes (graduated to 100ths of a foot)	8
23.	Flashlights or Other Portable Lighting	10
*24.	Combined pH, DO, Spec. Cond. Temperature Meter	2
25.	Sample Bottles and Shipping Containers	As required
*26.	Laptop Computer	1
*27.	5-gallon Buckets, De-ionized Water, Decon Tanks, "Kim Wipes," Paper Towers, Wash Bottles	As required
28.	Log-Log 3 x 5 Cycle Paper and Semi-Log 3-Cycle Paper	As required
*29.	Personal Protective Equipment: Gloves, Boots, Tyvek, Respirators, Rain Gear	As required
*30.	Small Folding Field Table	1
31.	Miscellaneous Items:	
	Camera, Tool Box, Calculator, Insect Spray, Field Books, Pens and Pencils, Well Keys, Pocket Knife	As required

*These items have been requested for slug tests and may be used again for pumping tests.

B-3 - LYSIMETER INSTALLATION

	Description	Quantity
1.	Hollow Stem Auguring: 4.25-inch I.D. Boreholes	6
	Cable Tool - 8-inch	3
	Cable Tool - 10-inch	3
2.	Zone 3 Lysimeter Installation - Cup Type, Deep Sampling Lysimeter, with Head Assembly	3
3.	GMA Lysimeter Installation - Cup Type, Deep Sampling, with Head Assembly	3
4.	Hauling Water	As needed
5.	Drumming Cuttings and Hauling Drums	As needed
6.	Standby and Moving Between Sites	As needed
7.	Continuous Split Spoon Sampling	As needed
8.	Lysimeter Completion Materials	
	2-inch O.D., Vacuum/Pressure Deep Soil Pore Water Sampler	6
	0.25-inch Polyethylene or Teflon Tubing	As needed
	2-inch I.D., Schedule 40, PVC Threaded Riser	As needed
	200 Mesh Silica Flour (50-pound pail)	As needed
	80/100 Mesh, Washed Quartz Sand	As needed
	Bentonite	
	Volclay Grout	As needed
	Protective Steel Casing	
	Distilled Water	6

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B-3 - LYSIMETER INSTALLATION (Continued)

	Description	Quantity
9.	Support Truck - Drilling Contractor	Per day
10.	Decontamination Equipment - Drilling Contractor	Per day
11.	Per Diem - Drilling Contractor	Per day
12.	Laboratory Analysis - Soil Moisture	
	^{3}H, $^{18}O/^{16}/O$	6
	General Chemistry	6
	Total Uranium	6
13.	Miscellaneous Items	
	Camera, Insect Spray, Field Books, Pencils and Pens, and Pocket Knife	As required
14.	Personal Protective Equipment: Gloves, Boots, Tyvek, Respirators, Rain Gear	As Required

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B-4 - PACKER TESTS

	Description	Number
1.	Borehole Advancement:	
	Boreholes N-1, N-2	
	Soil Boring: 6-inch I.D.	
	Spin Casing Technique	2
	Shelby Tube Samplers (36 inches x 3 inches O.D. x 2-15/16 inches I.D.)	15
	Dennison Tube Samples (30 inches x 5-1/2 inches O.D. with 5-5/8" cutting head x 3-1/2 inches I.D. sampler)	As required
	Piezometers: WPZ 1-C, XPZ 1-C, YPZ1C as specified in Attachment B-2:	
	Decontamination	per day
	Moving Between Sites	As required
	Borehole Abandonment	As required
	Placing Drill Cuttings in Drums and Hauling Drums to Storage Area	As required
2.	Packer Testing, Pump-In, and Pressure Pulse	15
	Hauling Water	As required
	Setting Packers/Run Test	per hour
	Nitrogen Supply	As required
	Constant Pressure Pump (to 40 gpm at 120 psi)	1
	Surge Chamber	1
	Disk-Type Flow Meter with Totalizer	1
	Approved Potable Water	As required
	Support Truck	per day
	Per Diem	per day

B-4 - PACKER TESTS (Continued)

	Description	Number
3.	Packers:	
	Inflatable Packers with Transducer Aardvark Tigre Tierra with In-Situ PXD 260 Transducer 25 psi and 50 psi (or equivalent); Single and Straddle (5-foot spacing between packers); suitable for packer testing; a 3-inch to 6-inch Borehole	1
	Additional Packer Tubing (Dimensions as Required)	35 feet
	Nitrogen Pressure Regulator	1
4.	Laboratory Analyses - Physical Samples:	
	Geotechnical lab analysis to include split spoon samples, grain size (sieve) analysis, visual description, and USCS classification	As required
	Shelby Tube/Dennison Samples:	
	Geotechnical lab analysis to include visual description, grain size (sieve) analysis with hydrometer, moisture content, soil density, Atterberg limits, constant head permeability tests (triaxial cell with back pressure), specific gravity, void ratio, porosity, and USCS classification.	12 minimum
*5.	Data Logger, Transducers, and Cables (25 psi and 50 psi)	
*6.	Laptop Computer	1
*7.	Stopwatch	2
*8.	Electronic Water Level Measuring Tapes	8
*9.	Log-Log 3 x 5 and Semi-Log Three-Cycle Paper	As required
*10.	Personal Protective Equipment: Gloves, Boots, Tyvek, Respirators, Rain Gear	As required
*11.	Small Folding Field Table	1
*12.	Miscellaneous Items: Camera, Tool Box, Calculator, Insect Spray, Field Books, Pens, Pencils, Pocket Knife, and Flashlight	As required
13.	Sample Bottles and Shipping Containers for Water Quality Samples and Undisturbed Soil Samples	As required
*14.	Decontamination Equipment: Buckets, Deionized Water, Decontamination Tanks, Kim Wipes, Paper Towels, and Waste Bottles	As required

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B-4 - PACKER TESTS (Continued)

*These items have been requested for slug tests and pump tests and may be used again for pumping tests.

B-5 - YIELD TESTS

	Description	Quantity
1.	Well Development	4
2.	Hauling Development Water	As needed
3.	Support Truck - Drilling Contractor	Per day
4.	Decontamination Equipment - Drilling Contractor	Per day
5.	Per Diem - Drilling Contractor	Per day
6.	Test Well Pumps:	
	Grundfos Redi-Flo 2 (or equivalent)	2
	Redi-Flo-2 Control Box	1
	Grundfos 16-S05-5 (1/2 HP) 230 Volt 2 Wire	2
	Grundfos 10-S03-6 (1/3 HP) 230 Volt 2 Wire	2
	100-Foot 230 Volt 2 Wire Cable, 12 Gauge with Necessary Adapter to Power Source	As required
7.	Test Pump Fittings:	
	Pump Cooling Shrouds, Schedule 5 Stainless Steel with Eyebolt or Mechanism to Attach Drop Cable:	
	Redi-Flo 2: 2 1/2-inch I.D.	2
	10-S: 4 1/2-inch I.D.	2
	16-S: 4 1/2-inch I.D.	2

B-5 - YIELD TESTS (Continued)

	Description	Quantity
*7. (con.)	Backflow Preventer/Check Valve:	
	Redi-Flo 2: 1/2-inch NPT	2
	10-S: 1 1/4-inch NPT	2
	16-S: 1 1/4-inch NPT	2
	1/2-inch I.D. Discharge Hose for 2-inch Pump	As required
	1-inch Discharge Hose for 4-inch Pump	As required
	1/8-inch Cable to be Attached to Pump Shroud for Pump Support	As required
	Assorted Quick Connects, Reducer Couplings, Fittings, Elbows (3/4 inch to 1 inch)	As required
	Flow Control or Gate Valve	2
	Flow Meter with Totalizer Capable of Measuring Flow Rates from 1/2 to 20 gpm	2
	Flow Meter with Totalizer Capable of Measuring Flow Rates from 3 to 50 gpm	2
	Sampling Port on Flow Line	1
8.	Flood Lights	As required
*9.	Electric Power Source:	
	ONAN DKD 7.5 kw, Single-Phase with 230 Volt/110 Volt Outlets, 60 Hertz (or equivalent), or permanent source sufficient to power well pumps	1
*10.	Data Logger and Accessories:	
	In Situ, Hermit 2000, 4-Channel Data Loggers (or equivalent)	3
	In Situ, Hermit 1000C, 2-Channel Data Loggers (or equivalent)	3
	Field Printers: (GFP-80) and (SE1004B) (or equivalent)	1

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B-5 - YIELD TESTS (Continued)

	Description	Quantity
10. (con.)	20 psi, PXD 260 Transducers	15
	Transducer Cables	As required
*11.	Stopwatches	2
*12.	Solinst (or equivalent) Electronic Water Level Measuring Tapes (graduated to 100ths of a foot)	8
*13.	Flashlights or Other Portable Lighting	10
*14.	Combined pH, DO, Spec. Cond. Temperature Meter	2
15.	Sample Bottles and Shipping Containers	As required
*16.	Laptop Computer	1
17.	5-gallon Buckets, De-ionized Water, Decon Tanks, "Kim Wipes," Paper Towers, Wash Bottles	As required
18.	Log-Log 3 x 5 Cycle Paper and Semi-Log 3-Cycle Paper	As required
19.	Personal Protective Equipment: Gloves, Boots, Tyvek, Respirators, Rain Gear	As required
20.	Small Folding Field Table	1
21.	Miscellaneous Items:	
	Camera, Tool Box, Calculator, Insect Spray, Field Books, Pens and Pencils, Well Keys, Pocket Knife	As required

* These items have been requested for the slug tests and pumping tests and may be used again for yield tests.

ATTACHMENT C

PROCEDURES

ATTACHMENT C1

APPENDIX J OF SCQ FIELD ACTIVITY METHODS

Procedures

CONTENTS

SECTION

C1 Appendix J of SCQ Field Activity Methods . . . . . .

C2 Slug Test Methods . . . . . .

C3 Constant Head Permeability . . . . . .

C4 Lysimeter Installation Manual . . . . . .

C5 Water Level Measurements . . . . . .

C6 Packer Test Methods . . . . . .

C7 Pressure Pulse Hydraulic Conductivity Test Methods and Analysis . . . . . .

APPENDIX J

FIELD ACTIVITY METHODS

J.1 PURPOSE

This appendix prescribes field methods for producing data in compliance with DOE and EPA requirements and meeting Data Quality Objectives (DQO) for FEMP.

J.2 SCOPE

General procedures for field activities are provided in subsection J.4 as follows.

- Daily Logs (paragraph J.4.1)
- General Drilling Practices (paragraph J.4.2)
- Well Design, Installation, and Abandonment (paragraph J.4.3)
- Well Development (paragraph J.4.4)
- Geophysical Surveys (paragraph J.4.5)
- Aquifer/Permeability Testing (paragraph J.4.6)
- Well Maintenance (paragraph J.4.7)

Additional procedures may be provided in the Project-Specific Plans (PSPs) to provide detailed instructions applicable only to the specific project.

J.3 RESPONSIBILITIES

J.3.1 FEMP Project Manager

The FEMP Project Manager shall be responsible for safe and prompt completion of project activities and for securing permits required by state, local, or on-site authorities. Underground and above-ground utilities shall be located and avoided to protect drilling operations personnel from danger. Copies of permits and other applicable documentation shall be posted on site whenever drilling operations are being conducted.

J.3.2 Geologist In Charge

A qualified geologist, hydrogeologist, or geological engineer shall be responsible for on-site operations at each drilling rig and geophysical survey unit and for supervising personnel assigned to the activity. The geologist-in-charge shall be present whenever a borehole is being advanced and during well development activities.

The geologist-in-charge shall be responsible for preparation of subsurface boring logs that shall be generated for each boring, for complete and accurate generation of a daily log of project activities, and for preparing lithologic logs in the field.

J.4 PROCEDURES

J.4.1 Daily Logs

A daily log is a written record of activities and measurements conducted in the field by a team on a given date and may include daily field activity logs, boring logs, well-construction logs, media-specific sampling logs, photographs, and sketches. The log shall be in a bound book with printed, sequentially numbered pages or on sequentially numbered, printed daily log forms as specified by the PSP.

J.4.1.1 Daily Log Entries. The geologist-in-charge is responsible for entries in the daily log, which shall include the following information as applicable.

- Subject of field activity
- General work activity
- Unusual events
- Changes to plans and specifications
- Visitors on site
- Time, depth, and identification number of samples
- Chain-of-custody tracking number
- Surveillance observations and findings
- Calibration checks

- Subcontractor progress and specifications
- Communication with regulatory agencies or others
- Weather conditions

J.4.1.2 Lithologic Logs. The geologist-in-charge is responsible for preparing lithologic logs in the field that provide the following information.

- Footage drilled
- Materials penetrated
- Depth to significant changes in lithology
- Samples collected (identified by depth, sample number, and collection method)
- Qualitative degree of saturation of each sample
- Depth to saturated zones and potential confining beds
- Fluid losses
- Surface casing used and method of installation
- Zones of unusual pressure gradients

An example of a lithologic log form is provided in Form J-1 in Appendix B.

J.4.1.3 Types of Field Activities. Daily entries in logs shall include, but not be limited to, the following types of field activities as applicable to the project.

- Footage drilled
- Materials used
- Sample collection start and completion times
- Samples collected
- Description of samples
- Bottom casing depth

- Surveys conducted
- Decontamination activities
- Well construction
- Aquifer testing
- Special activities
- Well installation activities
- Unusual occurrences

J.4.1.4 Daily Log Completion. The following procedures shall be performed.

1. Record field measurements and comments on applicable forms and complete lines on the forms as applicable. If the information requested does not apply or is not known, insert an "NA" (not applicable) or "NK" (not known) as appropriate. Do not leave a line blank. Initial and date each page. If part of a page is left blank, draw a line across the empty area.

2. If steps or procedures were not performed as described in the PSP, state reason as completely as possible on form or submit an attachment if necessary to explain fully.

3. Identify photographs with project number, date and time taken (using 24-hour time), and a brief description on the back.

4. Place identified photographs in an album in easily retrievable fashion and file.

NOTE

Information in activity-specific logs shall not duplicate other required documentation but rather support it.

5. As part of the daily log, generate activity-specific logs (e.g., subsurface boring logs, water sampling logs, sediment sampling logs) to document field conditions.

J.4.1.5 Filing Requirements. The following documentation of field activities shall be filed as indicated. These copies will provide adequate documentation of work activities if originals are destroyed, lost, or stolen.

1. Send photocopies of daily log entries to the FEMP project manager or representative and others as required at least weekly.

2. Maintain originals of field records in the project central file. Keep photocopies of bound books in the central file until the book is complete and entered in the file system.

3. During performance of field program, maintain copies of field records in FEMP project manager file.

J.4.2 General Drilling Practices

Number, location, depth of borings, type of sampling, and testing required are dependent on intended use of the data. The type of drilling method selected for a particular project at FEMP depends on the intended use of the borehole and samples collected. Ability to acquire data of sufficient quality for intended use and personnel health and safety are primary factors considered when selecting a drilling method.

Guidelines for determining a particular drilling method shall be presented in PSPs. The FEMP project manager is responsible for determining that the drilling technique used is appropriate for site conditions and project objectives. The chosen drilling method shall reflect the FEMP policy of waste minimization. Drilling methods that may be selected include, but are not limited to, the following.

- Cable-tool
- Hollow-stem auger
- Drive casing
- Spin casing
- Direct mud rotary
- Air rotary with casing driver
- Air rotary with swing-out, under-reaming bit and casing advancer
- Reverse-air or mud rotary

Drilling operations shall be conducted as follows.

1. Decontaminate drilling equipment before each use as specified in Appendix K to prevent contamination of the borehole and after each use to prevent off-site transport of contaminants.

2. Minimize introduction of contaminants into the environment and spreading of contaminants between zones.

3. Set surface casing when a potentially contaminated zone is drilled prior to reaching the target zone.

4. When drilling through areas where near-surface contamination is indicated from past experience or during screening of samples while drilling, grout surface casings in place and make them part of the permanent installation. The borehole diameter shall be at least four inches larger than the diameter of the surface casing to allow for an adequate grout seal.

5. In outlying areas not suspected of being contaminated, advance large diameter temporary casings as necessary for bore-hole control.

6. Minimize production of fluids, cuttings, and other waste by using above-ground mud pits, drums, or plastic-lined structures for containment of drilling fluids and cuttings unless otherwise specified in PSPs.

NOTE

The water source approved for use in drilling operations at FEMP is the plant potable water system.

7. Use only an approved water source during drilling operations.

NOTE

Use of additives in drilling fluids is discouraged except in unusual circumstances.

8. If an additive is to be used, obtain prior approval from the FEMP project manager.

9. Analyze a sample of the additive for parameters of interest, and review analysis results for potential impact on objectives of the data-collection program.

10. Collect cuttings or core samples at frequency specified in the PSP in accordance with the requirements for subsurface soil sampling in Appendix K.

The geologist-in-charge shall include in the daily log the information specified in paragraph J.4.1.2 and prepare lithologic logs in the field that provide the following information.

J.4.3 Well Design, Installation, and Abandonment

For clarity, the term "well" shall include ground water sampling points such as four-inch diameter monitor wells, above-ground and surface-finished piezometers, and former production wells.

The FEMP project manager is responsible for locating wells and for selecting the appropriate portion of an aquifer so that project objectives defined in the PSP are met. The geologist-in-charge is responsible for overseeing well installation in the field and for properly documenting construction details.

The following procedures are required to ensure quality control of well design and installation and successful completion of field drilling investigations for hydrogeological and future water quality information.

J.4.3.1 <u>Materials</u>. Use the following materials for construction of wells.

1. Use 316 stainless-steel well casing with flush-thread joints below the water table.

NOTE

Use of glues or solvents is prohibited.

2. Use schedule-40 PolyVinyl Chloride (PVC) or 316 stainless-steel casing with flush-thread joints for piezometers and above the water table in wells if preferred.

3. Use two to fifteen-foot sections of commercial wire-wound stainless steel screens with flush-thread joints compatible with the well casing (minimum three square inches open area per foot of screen). Determine size of screen openings based on effective grain size of monitored zone and filter pack size suggested by Aller (1989).

NOTE

Screen openings shall be capable of catching between 85 and 100 percent of filter pack materials to allow accurate measurement of hydraulic properties, minimize turbulence during sample collection, and optimize capacity to develop the

well completely and efficiently. Slotted or wound PVC screens with flush-thread joints compatible with the well casing may be used in piezometers. However, hydraulic data collected from piezometers shall be carefully evaluated to determine whether measurements are representative of the aquifer or of well materials.

4. Use well-sorted quartz sand for filter pack material.

NOTE

Selection of filter pack grain size is a function of grain size distribution in the natural formation.

5. Multiply the median formation grain size by a factor of two to arrive at a suitable filter pack grain size (Driscoll 1986).

6. Obtain one quart or one liter of a representative sample of each type of proposed filter-pack material from contractor for approval prior to use.

NOTE

Typically, graded sand meeting requirements of American Society for Testing and Materials C-33 for fine aggregate (concrete sand) is sufficient.

7. Describe each filter pack sample in terms of lithology, grain size distribution, and source (company where purchased, lot number, and pit or quarry of origin). Place description in project files.

8. Set bentonite pellet seals in the annulus directly above the filter pack in wells screened across the water table. Use pellets one-quarter to one-half inch in diameter.

9. Record brand name and lot numbers of bentonite in project files.

10. Use an annular grout consisting of a slurry of high-solids bentonite (e.g., Volclay) mixed to manufacturer specifications.

11. Reserve a sample of each type, brand, and size of backfill material used during the project for potential analysis of contaminants of interest.

J.4.3.2. Well Construction. Immediately (within 8 hours) after drilling is complete and the borehole has been cleaned of cuttings, construct well as follows.

1. Place desired length of screen and casing inside open borehole, temporary casing, or hollow-stem augers.

2. Place filter pack in annular space between screen/casing and temporary casing or augers by the tremie line method as follows.

   a. Insert a small diameter pipe to the desired depth.

   b. Pour or pump the filter pack in place under hydraulic pressure.

   3. Raise the tremie pipe so that it remains 0.5 to 3 feet above the top of the filter pack.

3. Make periodic measurements to check uniform placement of filter pack.

4. Record depth to top of filter pack to nearest 0.1 foot.

5. Remove temporary casing gradually and install backfill materials so that bottom of the temporary casing is kept below the top of backfill material.

6. Backfill glacial drift wells and wells screened across water table of the regional aquifer (1000- and 2000-series wells) as follows.

   a. Install a filter pack to a height of two to five feet above the screen.

   b. Place a five-foot sodium bentonite pellet plug on top of filter pack.

   c. Hydrate pellet seal with five to ten gallons of water from an approved source.

   d. Install a high-solids bentonite grout seal from top of bentonite seal to within 30 inches of ground surface.

7. Backfill wells screened in the middle and at the bottom of the regional aquifer (3000- and 4000-series wells) as follows.

   a. Install a filter pack to a height of approximately five feet above the screen.

   b. Place a high-solids bentonite grout to within 30 inches of ground surface using pumps and tremie line method.

8. For above ground completions, finish top of well casing with 24 to 30 inches of casing stickup, a vented stainless-steel cap, or an airtight cap and vent hole not more than six inches from top of casing.

9. Finish ground-flush completions with an airtight cap.

10. File a notch approximately one-half inch deep at top of each well casing, measure elevation of base of notch, and reference each water-level measurement to the elevation.

11. Install the following minimum protection around wells.

    a. Ground-flush installations

        (1) Ensure that completions are either water tight or free-draining (containing a drainage layer of coarse sand at the bottom of the flush-mount box).

        (2) Provide a well cap with lock.

        (3) Install a protective cover secured with bolts that prevent precipitation from entering the protective casing.

        (4) Install manhole-type boxes large enough to accommodate the well casing, well cap, and a lock.

    b. Above-ground installations

        (1) Use a five-foot-long black iron pipe, minimum one-quarter-inch thick, and at least four inches greater in diameter than the well casing as a protective casing.

        (2) Place well casing within four inches of top of protective casing.

        (3) Fit protective casing with a hinged cap, hasp, and lock.

        (4) Drill a drain hole in the oversleeve one foot above land surface.

        (5) Place a mixture of cement, sand, and potable water in a ratio approximately 1:4:0.5 (by weight) between well riser and outer protective casing to a height just below the drain hole to allow water entering the annulus to drain.

NOTE

To limit movement of pad by frost heaving, pour pad and annular backfill in one operation.

(6) Install a three-foot square by six-inch thick, wire-reinforced, concrete pad around the protective casing with at least two inches, but not more than three inches, of the pad below grade. Backfill upper 30 inches of borehole annulus with concrete.

c. All installations

(1) Paint protective casings with high-visibility orange paint.

(2) Mark well location on well protector in three places as follows.

- On inside of cover with enamel-type paint
- Welded, stamped, engraved, or permanently painted on top of locking cover or flush-mount cover
- Engraved or marked with indelible marker on outside of well cap.

NOTE

Guardposts may be necessary in high traffic areas or where vegetation or debris obscures the well casing.

(3) If guardposts are necessary, install three-inch-diameter steel posts, radially located around the well at four-foot intervals, two feet below ground surface, and four feet (minimum) above surface. Concrete in place and fill guardposts with concrete or cement grout.

12. Regrade and restore disturbed drilling areas.

13. Prepare a well completion log (Form J-2, Appendix B) that includes the following information.

- A sketch of each well installation showing the following.
  - Bottom of the boring by depth from surface grade
  - Screen location
  - Granular backfill, seals, grout, and cave-in
  - Centralizers if used
  - Top of riser relative to ground surface
  - Details of well protection and above-ground completion
- Composition of grout, seals, and granular backfill
- Screen length, slot size (in inches), and slot configuration (wound or machine slotted)

J.4.3.3 Dedicated Equipment. Use of dedicated ground-water sampling equipment is encouraged in cases where the following conditions exist.

- High concentrations of contaminants are present at a well site, making handling and decontamination of sampling equipment a problem
- Well access is a problem
- Fixed equipment that cannot be decontaminated is used

Types of equipment that may be dedicated to a sampling location include, but are not limited to, the following.

- Bladder-type sampling pumps
- Submersible impeller-type purge pumps
- Submersible piston-type purge pumps
- Packers
- Hoses
- Bailers

- Water-level measurement equipment

The following procedures apply when installing, maintaining, and using dedicated sampling equipment.

NOTE

Equipment that requires special handling, shall be installed and maintained only by manufacturer-trained personnel.

1. Store sampling equipment in well casing between uses or pull it from the well and store it in a designated storage structure. If stored outside the well, designate the well (by well number) to which it is dedicated.

2. Decontaminate equipment removed from a well as specified in Appendix K prior to re-installation.

NOTE

Maintenance may include decontamination to remove mineral precipitation or biological growths.

3. Perform maintenance as specified by manufacturer or, if specifications are not available, on a set schedule based on past usage or when performance is declining.

J.4.3.4 Well Abandonment. The objectives of well abandonment procedures include the following.

- Elimination of physical hazards
- Prevention of ground-water contamination
- Conservation of aquifer yield and hydrostatic head
- Prevention of intermixing of subsurface waters
- Compliance with reasonable property owner requests

The following procedures shall apply when abandoning a well.

1. If well casings and screens must be removed for an adequate seal, remove well casing and screens by pulling or overdrilling prior to grouting the borehole.

NOTE

Overdrilling is required when flowing sands are encountered.

a. If casing is to be overdrilled, the outside diameter of the drilling tool shall be at least as large as the original borehole.

b. If screen material is considered relatively inert in the hydrogeologic environment, overdrilling may be terminated at the top of the monitored zone, leaving the screen and filter pack in place.

c. If screen and filter must be removed, continue overdrilling to bottom of original borehole before grouting.

2. Remove annular fill material before grouting.

3. If well casing and screen are pulled from the borehole, make provisions (e.g., fill the borehole with drilling mud) to prevent borehole collapse within evacuated area.

4. Measure the open depth of the borehole using the tremie pipe and calculate the volume of grout needed to fill the borehole to a depth of 30 inches below grade.

5. If the tremie pipe can be inserted to the original depth, proceed as follows.

   a. Grout the borehole by the tremie method from the bottom up.

   b. Measure the volume of grout added.

   c. If significantly more grout is added than that calculated in step 4 (i.e., 25 percent), stop grouting and consult the FEMP project manager.

6. If the tremie pipe cannot be inserted to the original depth of the borehole, overdrill the boring with a bit at least as large as the original borehole to the original depth before grouting. (Use measurements from original drilling records.) Insert grout to within 30 inches of land surface and allow to harden for 24 hours.

7. Use a concrete plug to fill uppermost 30 inches of the borehole.

8. Insert a metal pin to mark the abandoned well site.

9. Record materials used and materials removed from the borehole.

10. Dispose of removed material as specified in the PSP for well abandonment.

J.4.4 Well Development

Wells shall be developed to yield accurate aquifer test results and ground-water samples representative of aquifer conditions. Well development may be conducted using bailers, submersible pumps, bladder pumps, or peristaltic pumps. Surging techniques using surgeblocks are recommended in relatively high-yield aquifers. Excessive drawdown should be avoided, reducing the purge rate if necessary.

The FEMP project manager shall specify the well development method in the PSP where sufficient historical data exists to make an informed decision. Where historical well development data are lacking, the well development method shall be based on observed aquifer response during drilling.

The following procedure applies when developing a well.

1. Decontaminate equipment and materials used for well development as specified in Appendix K before each use.

2. Develop well as soon as possible after well installation, but no sooner than 48 hours after grouting is completed.

3. Continue development until the water is visually clear and temperature, pH, and specific conductance have stabilized.

4. As a minimum, attain the following well conditions.

   a. If the boring was made without use of drilling fluid water, remove five times the standing water volume in the well (water in well screen and casing plus saturated filter pack).

   b. If recharge is so slow that required amount of water cannot be removed in a reasonable amount of time, or the water remains discolored, or it contains visible particulates after the five-volume removal, contact the FEMP project manager or representative for direction to use an alternate procedure based on recommendation of the field representative.

   c. If it appears necessary to add water to the well to assist development, obtain written approval from the FEMP project manager before proceeding.

NOTE

Do not use chemicals (e.g., dispersing agents, disinfectants, or acids) during well development.

d. If the boring was made or enlarged using drilling fluid (water), remove five times the measured amount of total fluids lost while drilling plus five times the standing water volume. If slow recharge, discolored, or particulate-laden water is a problem, proceed as in step b.

5. During development, attempt to remove standing water from points near the bottom of the well screen and from the top of the water column.

6. If problems are encountered during development, promptly notify the FEMP project manager or representative.

7. Record field measurements and comments on applicable data reporting forms. If some steps or procedures are not performed as specified, state the reason as completely as possible on the form or in an attached statement. Include the following data on the form.

   a. Well designation (location ID)

   b. Date of well installation

   c. Date and time of well development (start and finish)

   d. Static water level before and after development

   e. Quantity of water removed and time of removal

   f. Depth to bottom of the well inside the casing before and after development

   g. Physical character of removed water including changes during development of temperature, turbidity, pH, specific conductance, color, and odor at regular intervals

   h. Physical characteristics of removed sediments including lithology and grain size

   i. Descriptions of equipment used including type and size/capacity of pump and/or bailer used

j. Description of surge techniques used

J.4.5 Geophysical Surveys

Geophysical methods shall be chosen based on project objectives. See Environmental Protection Agency (1987) for a brief description of commonly used methods.

Specific techniques for conducting geophysical surveys by borehole logging or surface methods shall be provided in the PSP based on the following guidelines.

J.4.5.1 Borehole Geophysical Logging. Borehole geophysical methods are used to acquire information about subsurface geological characteristics such as the following.

- Formation breaks
- Thickness of individual beds
- Porosity
- Nature of borehole and formation fluids
- Identification of high-permeability zones
- Depth of penetration of drilling fluids
- Borehole size

A minimum of one quality control duplicate run shall be made with each tool used on each project where borehole geophysical logging is specified. When performance of the logging operation has met project objectives, the geophysical team leader shall sign and date completed logging forms (step 4).

The following procedure applies generally to geophysical surveys and logging of activities.

1. Clean and decontaminate downhole tools and cables prior to downhole logging operation and between each borehole as specified in Appendix K.

2. Calibrate logging equipment and provide the FEMP project manager with applicable documentation before and after survey calibrations.

3. Properly clean and decontaminate logging equipment at conclusion of operation.

NOTE

The FEMP project manager or representative shall ensure that specified originals and copies of logs are placed in project files. The team leader shall record progress of logging activities.

4. Complete applicable forms and record unusual occurrences in the daily log as follows.

   a. Include remarks on the log header.

   b. Identify the log run on the log header.

   c. Enter logging speed, length of tool and resolution, borehole identification, and team member names on the log header.

   d. Mark each curve on the log using a unique line format for every curve.

   e. Mark the vertical scale in feet and record total depth of the borehole at the bottom of the log.

   f. Identify and graduate the horizontal scale for each log run, labeling a minimum of every ten grid spaces horizontally on the log.

5. Transfer copies of data to the FEMP project manager or representative for distribution, analysis, and archiving. Transmit magnetic recordings generated during the course of downhole logging along with results of logging runs immediately. (Recordings shall be in a format specified by the FEMP project manager or designee.)

J.4.5.2 <u>Surface Geophysical Surveys</u>. Surface geophysical methods provide subsurface information without the need for excavation. Information that can be obtained includes the following.

- Delineation of contaminant plumes
- Identification of high-permeability zones
- Location of disposal areas
- Location of subsurface anomalies
- Identification of subsurface utilities and stratigraphic data

The PSP shall specify the geophysical method and instruments to be used, grid spacing, time

frame for survey, information desired, and frequency of duplicating lines for quality control purposes.

A minimum of five percent of the total linear distance of the survey shall be duplicated. Provisions for verifying interpretations through use of borings or excavations shall be included in the PSP.

The following general procedures are applicable for surface geophysical surveys.

1. Operate instruments as specified in manufacturer instructions or in the PSP.

2. If manufacturer instructions are not used, provide justification for this variance as specified in Section 15.

3. Provide the following information on project-specific logging forms.

   - Date of activity
   - Times survey was begun and finished
   - Times of breaks in activity
   - Temperature variations
   - Descriptions of variation from an established line caused by topography or vegetation; crossing of drainage features; crossing of swampy areas; instrument settings, calibrations, or malfunctions; and operators.

J.4.6 Aquifer/Permeability Testing

A decision to conduct an aquifer test for each project shall be made in accordance with guidelines in the PSP. Guidelines for determining test type, location, and objectives for each project shall also be specified in the PSP. Every aquifer test should be considered unique.

Following are requirements for hydraulic tests to characterize certain properties of hydrogeologic units (e.g., hydraulic conductivity, transmissibility, and storability). Data obtained during field hydraulic tests may include the following.

- Static water level
- Pumping well water discharge rate or volume of water displaced
- Drawdown or pressure versus time data for pumping and monitoring wells

- Water temperature, pH, and specific conductance
- Test interval

J.4.6.1 General Test Procedure. The following general procedure shall be performed in addition to procedure specified in the PSP.

1. Use equipment specified in the PSP based on approximations of the properties of interest from previous drilling and testing data.

2. Record the following information as applicable for each test.

   - Type of test (e.g., slug test, specific-capacity test)
   - Type of data recorded (e.g., recovery or drawdown)
   - Test well identification
   - Identification and relative position of observation wells including a diagram
   - Depth and length of screened or open interval
   - Diameter of both well casing and boring
   - Known or estimated thickness of the aquifer
   - Static water level
   - Start and completion times of test
   - Start and completion times of pumping if applicable
   - Drawdown versus time measurements
   - List of equipment used including pumps, hoses, slugs, transducers, data loggers, and water level measurement devices
   - Weather conditions including duration and intensity of precipitation
   - Testing personnel

3. Maintain complete original test records in project files and make copies available to hydrogeologists and field representatives who performed the test.

4. Prepare a diagram of equipment used in each aquifer or permeability test (by the responsible hydrogeologist). Indicate the tubing dimensions, depth of water intake, and location of gauges and packers. Include the diagram in the data records of each test.

5. Calibrate gauges, flowmeters, and other instrumentation used and check for proper operation before use.

6. Obtain copies of calibration documentation from the instrument or testing service company; maintain calibration records consisting of laboratory measurements, and, if performed, on-site zero adjustment and/or calibration. Include these records in the project file.

7. If a weir or an orifice is used to measure flow volumes or rates, check these devices on site using a vessel of known volume and a stopwatch. Document accuracy before testing proceeds.

8. Install equipment and demonstrate to the hydrogeologist that it is in proper working order and performing to specifications before start of pumping test.

9. If past monitoring data indicate that the water does not contain hazardous constituents or possess characteristics of hazardous waste as defined by the Resource Conservation and Recovery Act, dispose of water pumped from the well during the aquifer or permeability test in the general sump and treat it in the FEMP wastewater system.

NOTE

Direct questions about whether water from a certain well constitutes a hazardous waste to FEMP environmental compliance personnel.

10. Make special storage arrangements prior to removing water that may contain hazardous waste.

11. Decontaminate equipment used in boreholes, wells, or piezometers as specified in Appendix K prior to use and between each test site.

J.4.6.2 Borehole Hydraulic Testing for Aquifer Characteristics. The following procedures apply for determining hydraulic parameters of aquifers using slug tests and pumping tests. Generally, the procedures in paragraph J.4.6.1, steps 1 through 9, apply to both slug tests and aquifer pumping tests. If there are variations to the following procedures, they shall be specified in applicable PSPs.

Slug Tests - Slug tests are a quick and inexpensive method of estimating the hydraulic conductivity or transmissibility near the screened zone of the well.

1. Use the following equipment to conduct a slug test.

NOTE

A number of water-level measuring devices may be used for measuring depth to water in a well. Accurate readings can be obtained with electric water-level indicators, pressure transducers, or weighted tapes. Avoid water-level measurement by the weighted-tape method except when conducting tests of intervals suspected of having a very low K value. It may be difficult to obtain enough readings for analysis of the tests if the water level recovers quickly in a short period of time.

- Water level measuring device
- Known volume of slug (solid cylinder or volume of water added or removed) that will fit into the well, borehole, or container to add or remove a known volume of water
- Timer accurate to one second or a pressure transducer and data-logger combination
- Semi-log graph paper and indelible pen or pencil and paper or verified slug-test analysis software

2. Record the following information before beginning the test.

- Site identification and well or borehole location
- Location and elevation of reference point from which water depth measurements are made
- Elevation of ground water with respect to reference point
- Date and time of test

- Well depth, screen length, riser pipe radius, well screen radius, radius of gravel pack plus well screen or borehole depth and radius
- Thickness of ground water zone to be tested
- Volume of slug added or removed
- Type of measuring device used
- Names of personnel conducting test

3. Determine static water level in well by periodically measuring depth to water for several minutes and taking average of readings.

NOTE

It is important to remove or add the volumes as quickly as possible because the analysis assumes that an instantaneous change in volume is created in the well.

4. Instantaneously introduce or remove a slug of known volume to displace water level.

NOTE

The number of depth/time measurements necessary to complete the test are variable, but it is critical to make as many measurements as early as possible in the test.

5. Assign time zero to the moment of volume addition/subtraction, measure, and record depth to water and time of each reading. Measure depth to the nearest 0.01 foot.

NOTE

Time required for slug test completion is a function of volume of the slug, hydraulic conductivity of the formation, and type of well completion. Slug volume shall be large enough that a sufficient number of water level measurements can be made before water level returns to equilibrium. Length of test may range from less than a minute to several hours.

6. Continue measuring and recording depth/time until water level returns to equilibrium or, for slowly recovering wells, until a sufficient number of readings have been made to clearly show a trend on a semi-log plot of time versus depth.

7. If the FEMP project manager, EPA, and Ohio Environmental Protection Agency approve addition of water to the monitoring well, use water from an uncontaminated, tested source. Transport water in a clean, approved container.

8. Decontaminate bailers and measuring devices prior to the test as specified in Appendix K.

9. If tests are performed on more than one monitoring well, avoid cross contamination of wells by using decontamination procedures specified in Appendix K.

Aquifer Pumping Test - Aquifer pumping tests, commonly referred to as pump tests, are used to determine hydraulic properties of water-bearing zones. Pump tests influence a larger area and provide results that are often more representative of the overall aquifer characteristics than slug tests. Aquifer characteristics that may be obtained from pumping tests include hydraulic conductivity, transmissibility, and specific yield for unconfined aquifers and storage coefficient for confined aquifers.

Equipment, personnel, and time commitments needed for pumping tests are greater than those for slug tests. Constant-rate discharge, variable-rate, and injection tests are types that may be used. Test method and procedures shall be specified in the PSP.

Equipment needed for pumping tests includes the following items.

NOTE

Pumps are commonly of the submersible or turbine type and are sized consistently with expected aquifer conditions. The well should be developed prior to testing.

- One or more completed observation well/piezometer hydraulically connected to the pumped test aquifer and completed to specifications for the particular test

- Orifice, weir, flow meter, container or other type of water measuring device to accurately measure and monitor discharge from the pumped well

- Pipe to transport pumped water from pumping well to holding tank or effluent location

- Valve on discharge pipe to control pumping rate

- Outlet valve near well head for water quality sampling
- Depth-to-water measuring devices for each observation and pumping well (may include steel tapes, electric sounding probes, Stevens recorders, or pressure transducers)
- Thermometer and other necessary water quality equipment
- Watches capable of reading to the nearest second, stopwatch, or pressure transducers with data loggers
- A 3-by-5-cycle log and 5-cycle semi-log graph paper or appropriate, verified computer software, and necessary hardware
- Indelible pens or pencils and form for recording times and drawdown measurements at each well
- Appropriate references and calculator for field determinations
- Barometer or recording barograph for tests conducted in confined aquifers

The following general procedure applies to pumping tests.

1. Prior to the test, monitor water levels in the observation well to measure diurnal fluctuations. (Number of wells and the monitoring period shall be specified in PSPs.)
2. Record the following information during the test.
    - Identification numbers or locations of pumped well and each observation well
    - Location and elevation of each well
    - Location and elevation of reference point from which water depth measurements are made and elevation of ground surface with respect to the reference point
    - Weather conditions
    - Method of measurement
    - Date and time of test

- Well depth, pump depth, screen length, well radius, and radius of filter pack plus well screen for each well

3. Calibrate measuring equipment used for pumping tests before use.

4. Maintain calibration records that consist of laboratory measurements and on-site zero adjustment and/or calibration performed.

5. File copies of calibration documentation with test records.

6. When a weir or an orifice is used to measure flow rates, check it on site with a container of measured volume and stopwatch. Verify the accuracy of the meters before proceeding with the test. Check meters hourly during the test, and document each check.

7. Record changes in barometric pressure during the test, preferably with an on-site barograph, to correct water levels for fluctuations that may occur as a result of changing atmospheric conditions.

8. Measure water levels to provide data required to meet test requirements. Early in the test, ensure that sufficient personnel are available to collect at least ten measurements per log cycle (i.e., 1-to-10 and 10-to-100 minutes) at each selected observation well, or install a pressure transducer and data logger at each well to collect the data at the given frequency.

9. Measure water level recovery after pumping stops to verify results obtained during drawdown portion of the test. Measure recovering water levels in the pumped well and in observation wells for a period of time immediately following cessation of pumping.

10. Perform monitoring during recovery period as specified in PSP.

J.4.7 Well Maintenance

It is important to maintain ground-water monitoring wells in order to extend the life of the wells and provide representative levels and samples of ground water surrounding the wells. The following aspects of well maintenance shall be addressed.

- Well evaluation
- Redevelopment
- Maintenance check lists

- Well head protection

The FEMP prime operating contractor shall be responsible for well maintenance activities, conducting a maintenance survey of ground water monitoring wells, and evaluating well maintenance aspects such as water quality, structural integrity, and well-head protection. Well maintenance activities shall comply with applicable regulatory and site requirements.

J.4.7.1 **Well Evaluation.** Existing ground-water monitoring wells shall be evaluated for the ability to provide representative samples and may include the following activities.

- On-site inspections
- Review of existing well installation documentation
- Review of well history (whether it produced consistently clear or turbid samples). (Wells with irreconcilable turbidity or lacking information on design and construction may be abandoned under circumstances described in paragraph J.4.3.4.)
- Review of ground water sampling field records
- Down-the-hole camera inspections
- Review of other sources of information that may be applicable to a specific well
- Review of the hydraulic characteristics of the aquifer adjacent to the well that shall include pump and slug tests to determine the following.
    - **Pump Tests** - for aquifer characteristics, degree of hydraulic interconnection between different water-bearing units, and recharge rates
    - **Slug Tests** - for in-situ hydraulic conductivity of low-permeability formations through addition or removal of an inert solid of known volume

J.4.7.2 **Well Inspection and Repair.** The following procedure shall be conducted at each well as applicable to that specific well.

1. Ensure that guard posts are in good repair.
2. Inspect ground surrounding well for the following conditions and repair as required.
    - Ground must be free of depressions and channels that allow surface water to collect and flow towards well head.
    - Surrounding area must be clean of debris and foreign material that could leach

contaminates into subsurface or otherwise interfere with well sampling.

3. Inspect locking lids for the following conditions and repair or replace as applicable.

   - Lid must open with minimal effort.
   - Eyelets on lid and protective casing must align for easy removal of padlock.
   - Ensure integrity of hinge and seal on lids, which must also serve as sanitary seal.
   - Padlocks must be free of accumulated debris within key slot and locking mechanism.
   - Padlocks must operate freely.
   - Padlocks must be installed with key-slot down to prevent rainwater from entering locking mechanism.

4. Inspect the well caps for the following conditions and repair or replace them as applicable.

   - Cap must be free of spider and insect debris, molds, fungi, or anything that could affect representativeness of water samples.
   - Above-ground caps must fit securely and vent hole must be clear.
   - Ground-flush caps must be water-tight to prevent surface water from entering well.

5. Inspect protective casing for the following conditions and repair or replace it as applicable.

   - Structural integrity - Casing must be free of corrosion and cracks.
   - Casing must be reasonably plumb with ground surface.
   - Paint must be bright orange.
   - Well identification number must be painted in white or welded to the top of lid.
   - Drain hole must be clear allowing water caught between protective casing and well casing to escape.
   - Structurally sound concrete surface seal and pad around protective casing must

be free of voids, cracks, and depressions where it contacts ground surface

6. Inspect well casing for the following conditions and repair as required.

   - Casing must be free of spider or insect debris.
   - Sharp edges - recondition edges as required.
   - Grout between well and protective casings must be free of cracks and structurally intact.

7. Inspect well and well records for the following conditions and remedy as appropriate.

   a. Well development and size of screen openings causing sediment accumulation at bottom of well - remove sediment that significantly affects well performance.

   NOTE

   For wells less than 25 feet deep, sediment may be removed using a centrifugal pump with an intake hose to suck sediment from well bottom. For deeper wells, a bailer or hose with a foot valve are suggested for sediment removal.

   b. Accumulation of chemical, physical, or biological incrustation on well screens. Remove incrustation or replace screen as appropriate. Do not use chemicals to remove incrustation.

8. Evaluate wells for reduced yield by comparing present yield to installation data, previous yield, and past pumping tests.

9. Inspect wells for blockage caused by sampling equipment lodged in well (e.g., purge pumps and bailers). Evaluate removal of such equipment on an individual basis.

10. Prior to performing maintenance at a designated location, develop a PSP that provides the following information.

    - Scope of maintenance activity
    - Work schedule and completion date
    - Manpower and materials required

- Decontamination procedures and other measures to ensure well integrity
- Decontamination procedures (Section 5) required for equipment that may enter the well casing or otherwise contaminate the well.
- Required documentation of field activities as follows:
  - Daily log (paragraph J.4.1) submitted to FEMP within one day of task conclusion
  - Weekly progress reports including photocopies of log entries
  - Well abandonment report documenting compliance with applicable EPA and Ohio Environmental Protection Agency regulations and FEMP Sitewide CERCLA Quality Assurance Project Plan
  - Final report in specified format documenting evaluation and maintenance activities and addressing plan objectives

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ATTACHMENT C2

SLUG TEST METHODS

THE SLUG-INJECTION TEST FOR ESTIMATING THE COEFFICIENT OF TRANSMISSIBILITY OF AN AQUIFER

By John G. Ferris and Doyle B. Knowles

ABSTRACT

If a comparatively small volume, or slug, of water is instantaneously injected into or withdrawn from a well, the well is considered to be an instantaneous vertical line source or line sink. For artesian aquifers, the coefficient of transmissibility of the material in the immediate vicinity of the well can be estimated by an equation developed by Theis (1935) for a vertical instantaneous line sink. The equation can be solved graphically from a straight-line plot of the data. For a slug-injection test, the well should tap the full thickness of the aquifer and be fully developed, and the water-level measurements should be made in rapid succession after the injection or withdrawal of the slug of water into or from the well.

EQUATION FOR DRAWDOWN IN AN INSTANTANEOUS VERTICAL LINE SOURCE OR LINE SINK

In the development of the nonequilibrium formula for drawdowns caused by the pumping of ground water from storage at a constant rate, Theis (1935) presented the equation for drawdown in an instantaneous vertical line source or line sink and obtained, by integration, the equation for a vertical line source or line sink that is continuous at constant strength. Many field tests evidence the applicability of the nonequilibrium formula to the problem of the discharging well that taps an artesian aquifer of infinite extent; however, the importance of the nonequilibrium formula to quantitative ground-water hydrology so over shadowed the initial step of the Theis development that little attention has been accorded the equation for an instantaneous vertical line source or line sink. Although of limited application, the equation provides a useful method for estimating the coefficient of transmissibility in the immediate vicinity of a well, which is a physical approximation of the theoretical vertical line source or line sink.

The slug-injection test for estimating the coefficient of transmissibility involves the instantaneous injection (or withdrawal) of a slug of water into or from a well; hence, the term "slug-injection test" seems appropriate. Use of the slug-injection test should be limited to fully developed wells that are open to the full thickness of an artesian aquifer of small or moderate transmissibility—less than 50,000 gpd per ft. The test probably cannot be used to determine the transmissibility of most water-table aquifers. Because the coefficient of transmissibility determined from this test generally applies only to the material close to the well, indiscriminate use of the results can

lead to erroneous conclusions. Great care must be exercised in conducting the tests, in analyzing the data and, most particularly, in applying the results to the solution of field problems. Nevertheless, the simplicity of the test justifies its use provided the assumptions upon which the formula is based are essentially fulfilled and the limitations of the test are fully recognized.

The equation for residual head in an instantaneous vertical line sink is written

$$s=\frac{qe^{\frac{-r^2S}{4Tt}}}{4\pi Tt} \tag{1}$$

where

s=the residual head after the injection of a slug of water,
r=the distance from the injection well to an observation well,
t=the time since the slug was injected, and
q=the volume of the slug.

Ordinarily, only a small volume of water can be injected into a well as a slug. For this reason, the reaction to the injected slug usually is not measurable in the aquifer beyond the immediate vicinity of the well. Therefore, the water-level measurements are made only in the injection well; the distance is then the radius, r_w, of the well. For values of r as small as r_w, especially where S is small (as for artesian aquifers), the exponent of e in equation 1 approaches zero as t becomes large and the value of the exponential terms approaches unity. Then, if q is expressed in gallons, T in gallons per day per foot, t in minutes, and s in feet, equation 1 can be written in the form

$$T=\frac{114.6q\,(1/t_m)}{s}, \tag{2}$$

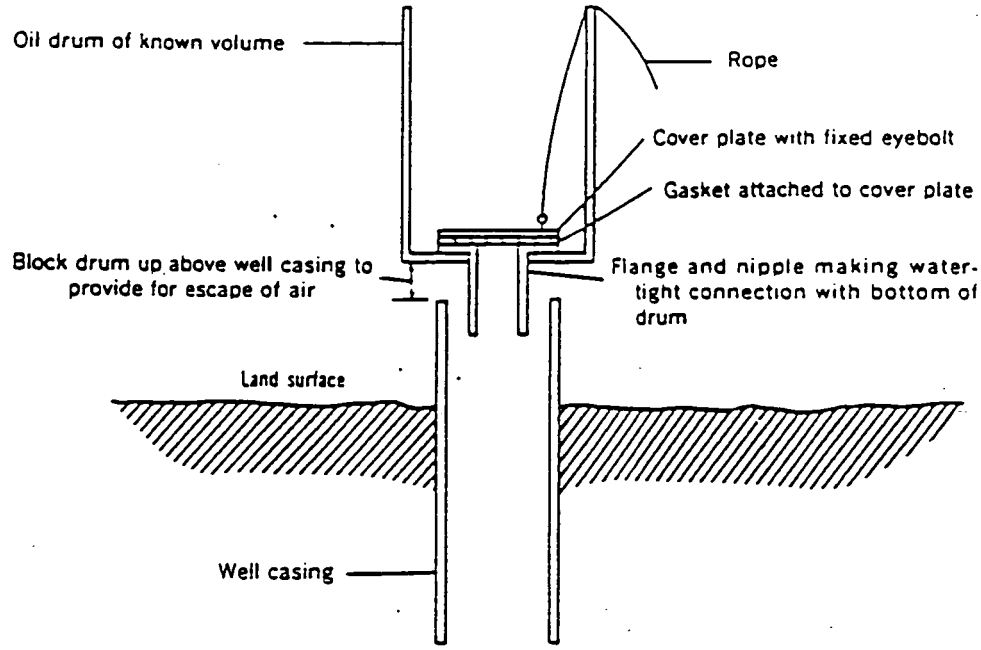
where

t_m=the time in minutes measured from the average of the times marking the beginning and cessation of the injection.

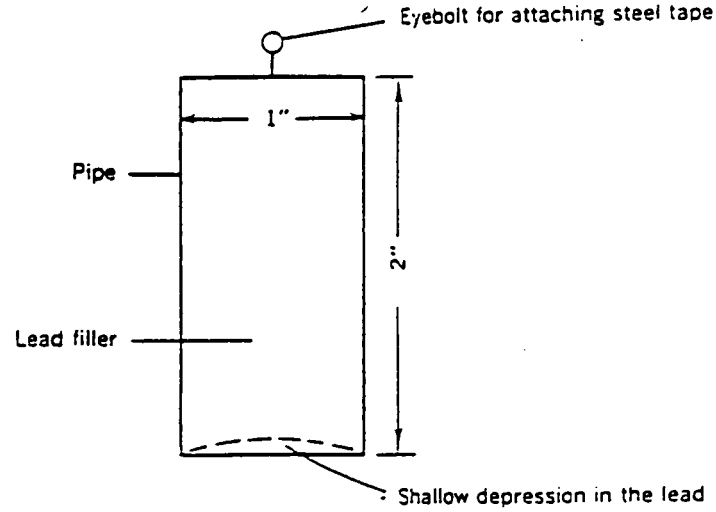
Equations 1 and 2 are equivalent to those derived by Skibitzke in the preceding paper for drawdowns near a vertical line source. The effects of instantaneously injecting a slug of water into a well are identical in the opposite direction to those of instantaneously withdrawing a slug of water of equal volume from the same well; that is, the rate of water-level decline following the injection of a slug equals the rate of water-level recovery following the withdrawal of a slug of equal volume.

EQUIPMENT AND PROCEDURE FOR A SLUG-INJECTION TEST

A convenient apparatus for instantaneously injecting water into a well is shown in figure 89*A*. An oil drum has been adapted for use



A. APPARATUS FOR INJECTING SLUG OF WATER INTO WELL



B. PERCUSSION INSTRUMENT FOR RAPID MEASUREMENT OF WATER LEVELS

FIGURE 89.—Equipment for making a slug-injection test.

690-185 O—63——5

as a container to hold the slug of water to be injected. An opening has been made in the bottom of the drum, and a nipple has been attached by using a flange connection. (The nipple could have been welded directly to the container.) A cover plate to which a gasket is attached has been placed over the opening inside the drum. When the rope attached to the cover plate is pulled, the cover plate is raised, thus allowing the slug of water to be introduced into the well almost instantaneously. The drum should be supported by blocks so it can be removed quickly and easily once the injection is completed and also to provide a vent for the escape of air from the well. Water-level measurements must be made rapidly after the slug of water has been introduced into the well. Because the wetted-tape method generally is too slow, a percussion instrument attached to the end of a steel tape or an electric tape should be used. A percussion instrument, such as shown in figure 89*B*, can be constructed easily by filling a short section of steel pipe with lead, carving a shallow, oval depression in the lead at one end of the pipe, and attaching the other end of the pipe to a steel tape. The instrument usually is referred to as a popper because the depression in the lead causes a popping noise upon sharp contact with the water surface in the well. Water-level measurements made with the popper are as accurate as those made by the wetted-tape method.

The residual head at any instant is the difference between the observed water level and the extrapolation of the antecedent water-level trend. In making a slug-injection test, the time at which the injection began and the time that it stopped should be recorded, and the average of these times should be used as the origin of time in analyzing the water-level measurements. The elapsed time during the injection must be small compared to the period of the water-level recession.

A slug-injection test is made as follows:

1. Before injecting the slug of water into the well, define the existing water-level trend by making water-level measurements at frequent intervals.
2. By means of a suitable apparatus, instantaneously (or nearly so) inject a known volume, q, of water into the well.
3. Remove the injection apparatus from the well and resume water-level measurements.
4. Calculate the values of the residual head and $1/t_m$.
5. Plot the corresponding values of s and $1/t_m$ on rectangular coordinate graph paper. The plotted values should define a straight line through the origin.
6. Calculate T from the coordinates of any point on the straight line.

If the observed data from a slug-injection test do not plot on a straight line, the well may be in need of additional development. The slug-injection test cannot be used to estimate transmissibilities that

are much in excess of 50,000 gpd per ft, because the water-level buildup produced by introducing water into the well disappears so rapidly that the data curve cannot be defined accurately.

A PRACTICAL APPLICATION OF THE SLUG-INJECTION TEST

A slug-injection test to estimate the coefficient of transmissibility of a water-bearing formation was made on a 6-inch test well at Speedway City, Ind. Measurements of the depth to water prior to and following the instantaneous injection of a 39-gallon slug of water, the residual head at the time of each water-level measurement, and the reciprocal of the time since the slug was injected, $1/t_m$, are given in table 7. The residual head, s, was plotted against the reciprocal of the time since the slug was injected, $1/t_m$, on rectangular coordinate graph paper, as shown in figure 90. A straight line drawn through points plotted from the observed data passes through the origin. Arbitrary selection of the point on the straight line where $1/t_m=0.5$ and $s=0.165$ foot and substitution of those values in equation 2 gives

$$T=\frac{114.6\times39\times0.5}{0.165}=13{,}500 \text{ gpd per ft.}$$

The well used for the slug-injection test was used later as a water-level observation well during an aquifer test made by pumping from a nearby well. The data from the second test were analyzed by the nonequilibrium formula and gave $T=16{,}000$ gpd per ft.

TABLE 7.—*Data for a slug-injection test at Speedway City, Ind.*

[39-gal slug of water injected into a well 6 in. in diam at time =0 min]

Time (min)	Depth to water below measuring point (ft)	Residual head (ft)	$1/t_m$ (1/min)	Time (min)	Depth to water below measuring point (ft)	Residual head (ft)	$1/t_m$ (1/min)
−20	42.39	--------	--------	3.67	42.31	0.09	0.272
−15	42.40	--------	--------	3.77	42.31	.09	.265
−10	42.40	--------	--------	3.87	42.32	.08	.258
1.25	42.14	0.26	0.800	4.10	42.32	.08	.244
1.33	42.15	.25	.750	4.33	42.32	.08	.231
1.50	42.20	.20	.667	4.52	42.33	.07	.221
1.92	42.23	.17	.521	4.58	42.33	.07	.218
2.17	42.24	.16	.461	4.72	42.33	.07	.212
2.30	42.25	.15	.435	5.17	42.34	.06	.193
2.37	42.26	.14	.422	5.28	42.34	.06	.189
2.42	42.26	.14	.413	5.45	42.34	.06	.183
2.67	42.28	.12	.375	6.10	42.35	.05	.164
2.72	42.28	.12	.368	6.40	42.35	.05	.156
2.77	42.28	.12	.361	6.83	42.35	.05	.146
2.92	42.29	.11	.342	7.17	42.36	.04	.139
3.00	42.29	.11	.333	7.75	42.36	.04	.129
3.22	42.30	.10	.311	8.58	43.36	.04	.117
3.28	42.30	.10	.305	9.37	42.37	.03	.107
3.33	42.30	.10	.300	10.12	42.37	.03	.099
3.40	42.31	.09	.294	11.00	42.37	.03	.091
3.47	42.31	.09	.288	12.5	42.37	.03	.080
3.55	42.31	.09	.282	13.0	42.37	.03	.077

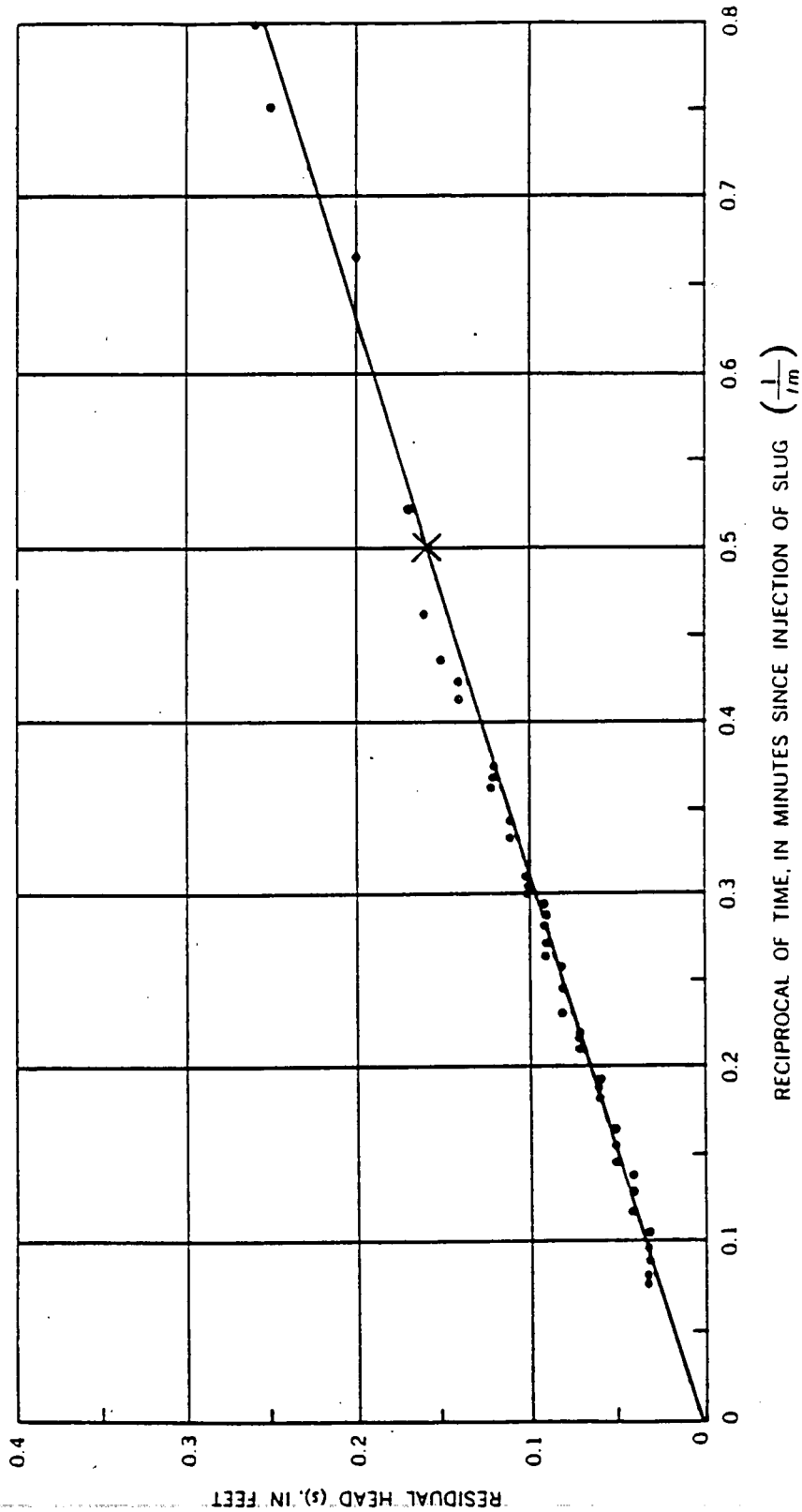


FIGURE 90.—Graph showing decline of residual head in a 6-inch well at Speedway City, Ind., following the instantaneous injection of a 30-gallon slug of water.

Water Level Measurements - Metal Tape

The steel tape method for measuring the depth to water is a simple and reliable method in observation wells between 1-1/2 and 6 inches in diameter. The steel tape method utilizes a steel tape with a popper. The popper is a metal cylinder 1 to 1-1/2 inches in diameter and 2 to 3 inches long with a concave undersurface and is fastened to the end of a steel tape. The steel tape with a popper is used in the following manner.

1) Chalk the steel tape with either carpenter's chalk or ordinary blackboard chalk which changes shade upon becoming wet.

2) Extend the chalked steel tape with a popper into the well. A few inches above the water the popper should be dropped to hit the water surface, where it will make a distinct "pop."

3) Adjust the length of the tape to determine the point at which the popper just hits the surface.

4) Extend a portion of the chalked tape below the water surface. Take a reading at a designated measuring point at the top of the casing. All water level measurements shall be taken from the same measuring point.

5) Retract the metal tape. The line of the color change of the chalked portion of the tape denotes the length of tape immersed in water.

6) Subtract the length of color change of the chalked portion of the tape from the reading at the measuring point for the depth to water.

Cascading water in a well may mask the mark of the true water level on the tape. In small-diameter wells, the volume of the weight may cause the water level to rise in the pipe, and the measurement may be somewhat inaccurate. Operating noises and lack of clearance may hinder the use of poppers.

Source: Bureau of Reclamation, 1981. *Groundwater Manual, Revised Edition, U.S. Department of the Interior.* Washington, D.C.: U.S. Government Printing Office.

Testing of Observation Wells

To determine the response to changing water stages, each observation well or piezometer should be tested as follows:

1) Inject a known volume of water into each well and measure subsequent decline of water level. The initial rise of water should be dissipated within a few minutes (to within about 0.01 of the initial rise) if the observation well is to reflect changes of head in the aquifer during the test.

2) Total depth, diameter, and screened interval should be known for each observation well and recorded in the field log book.

3) Radial distances from the control well to each observation well shall be measured.

Source: Bureau of Reclamation, 1981. *Groundwater Manual, Revised Edition*, U.S. Department of the Interior. Washington, D.C.: U.S. Government Printing Office.

Stallman, R.W., 1971. *Aquifer Test Design, Observation, and Data Analysis, Technicians of Water Resources Investigations of the U.S. Geological Survey*, Book 3, Chapter B1.

ATTACHMENT C3

CONSTANT HEAD PERMEABILITY

EPA 9100 - Constant Head Permeability Test Methods

2.7.3 Sample preparation:

1. Obtain sufficient representative soil sample. Air dry the sample at room temperature. Do not oven dry.

2. Thoroughly mix the selected representative sample with water to obtain a desired moisture content.

3. Compact the sample to the desired density within the mold using the method described as part of ASTM Method D698-70.

4. Level the surface of the compacted sample with straight edge, weigh and determine the density of the sample.

5. Measure the length and diameter of the sample.

6. Assemble the apparatus, make sure that there are no leaks, and then connect the pressure line to the apparatus.

2.7.4 Test procedure:

1. Place sufficient volume of water in the fluid chamber above the soil chamber.

2. Apply air pressure gradually to flush water through the sample until no air bubbles in the outflow are observed. For fine-grained soils, the saturation may take several hours to several days, depending on the applied pressure.

3. After the sample is saturated, measure and record the quantity of outflow versus time.

4. Record the pressure reading (h) on the top of the fluid chamber when each reading is made.

5. Plot the accumulated quantity of outflow versus time on rectangular coordinate paper.

6. Stop taking readings as soon as the linear position of the curve is defined.

2.7.5 Calculations: The hydraulic conductivity can be calculated using Equation (8).

2.8 Triaxial-cell method with back pressure:

2.8.1 Applicability: This method is applicable for all soil types, but especially for fine-grained, compacted, cohesive soils in which full fluid saturation of the sample is difficult to achieve. Normally, the test is run under constant-head conditions.

2.8.2 **Apparatus:** The apparatus is similar to conventional triaxial apparatus. The schematic diagram of this apparatus is shown in Figure 5.

2.8.3 **Sample preparation:** Disturbed or undisturbed samples can be tested. Undisturbed samples must be trimmed to the diameter of the top cap and base of the triaxial cell. Disturbed samples should be prepared in the mold using either kneading compaction for fine-grained soils, or by the pouring and vibrating method for coarse-grained soils, as discussed in Section 2.5.3.

2.8.4 **Test procedure:**

1. Measure the dimensions and weight of the prepared sample.

2. Place one of the prepared specimens on the base.

3. Place a rubber membrane in a membrane stretcher, turn both ends of the membrane over the ends of the stretcher, and apply a vacuum to the stretcher. Carefully lower the stretcher and membrane over the specimen. Place the specimen and release the vacuum on the membrane stretcher. Turn the ends of the membrane down around the base and up around the specimen cap and fasten the ends with O-rings.

4. Assemble the triaxial chamber and place it in position in the loading device. Connect the tube from the pressure reservoir to the base of the triaxial chamber. With valve C (see Figure 5) on the pressure reservoir closed and valves A and B open, increase the pressure inside the reservoir, and allow the pressure fluid to fill the triaxial chamber. Allow a few drops of the pressure fluid to escape through the vent valve (valve B) to insure complete filling of the chamber with fluid. Close valve A and the vent valve.

5. Place saturated filter paper disks having the same diameter as that of the specimen between the specimen and the base and cap; these disks will also facilitate removal of the specimen after the test. The drainage lines and the porous inserts should be completely saturated with deaired water. The drainage lines should be as short as possible and made of thick-walled, small-bore tubing to insure minimum elastic changes in volume due to changes in pressure. Valves in the drainage lines (valves E, F, and G in Figure 5) should preferably be of a type which will cause no discernible change of internal volume when operated. While mounting the specimen in the compression chamber, care should be exercised to avoid entrapping any air beneath the membrane or between the specimen and the base and cap.

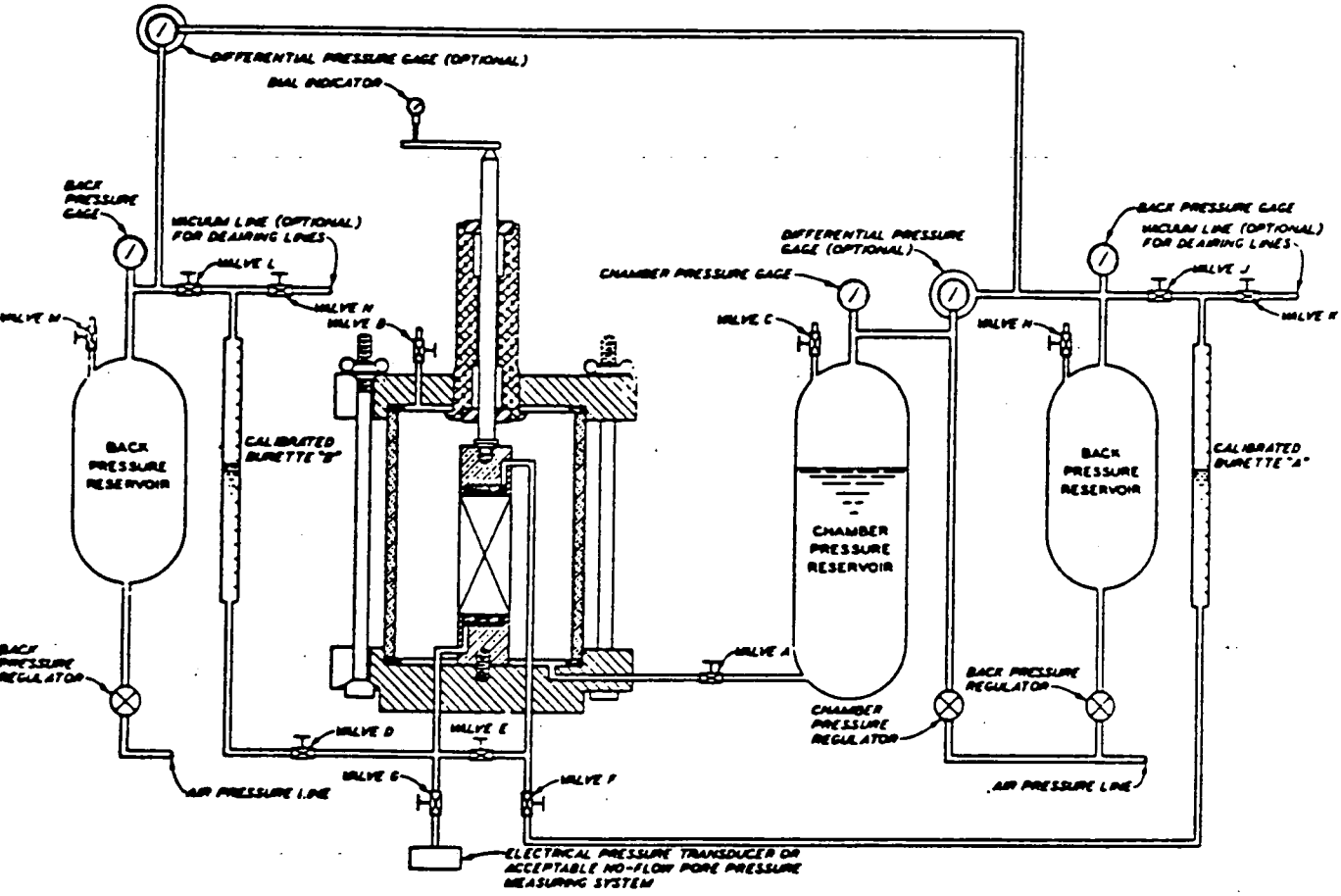


Figure 5.--Schematic diagram of typical triaxial compression apparatus for hydraulic conductivity tests with back pressure.
Source: U.S. Army Corps of Engineers, 1970

6. For ease and uniformity of saturation, as well as to allow volume changes during consolidation to be measured with the burette, specimens should be completely saturated before any appreciable consolidation is permitted; therefore, the difference between the chamber pressure and the back pressure should not exceed 5 psi during the saturation phase. To insure that a specimen is not prestressed during the saturation phase, the back pressure must be applied in small increments, with adequate time between increments to permit equalization of pore water pressure throughout the specimen.

7. With all valves closed, adjust the pressure regulators to a chamber pressure of about 7 psi and a back pressure of about 2 psi. Now open valve A to apply the preset pressure to the chamber fluid and simultaneously open valve F to apply the back pressure through the specimen cap. Immediately open valve G and read and record the pore pressure at the specimen base. When the measured pore pressure becomes essentially constant, close valves F and G and record the burette reading.

8. Using the technique described in Step 3, increase the chamber pressure and the back pressure in increments, maintaining the back pressure at about 5 psi less than the chamber pressure. The size of each increment might be 5, 10, or even 20 psi, depending on the compressibility of the soil specimen and the magnitude of the desired consolidation pressure. Open valve G and measure the pore pressure at the base immediately upon application of each increment of back pressure and observe the pore pressure until it becomes essentially constant. The time required for stabilization of the pore pressure may range from a few minutes to several hours depending on the permeability of the soil. Continue adding increments of chamber pressure and back pressure until, under any increment, the pore pressure reading equals the applied back pressure immediately upon opening valve G.

9. Verify the completeness of saturation by closing valve F and increasing the chamber pressure by about 5 psi. The specimen shall not be considered completely saturated unless the increase in pore pressure immediately equals the increase in chamber pressure.

10. When the specimen is completely saturated, increase the chamber pressure with the drainage valves closed to attain the desired effective consolidation pressure (chamber pressure minus back pressure). At zero elapsed time, open valves E and F.

11. Record time, dial indicator reading, and burette reading at elapsed times of 0, 15, and 30 sec, 1, 2, 4, 8, and 15 min, and 1, 2, 4, and 8 hr, etc. Plot the dial indicator readings and

burette readings on an arithmetic scale versus elapsed time on a log scale. When the consolidation curves indicate that primary consolidation is complete, close valves E and F.

12. Apply a pressure to burette B greater than that in burette A. The difference between the pressures in burettes B and A is equal to the head loss (h); h divided by the height of the specimen after consolidation (L) is the hydraulic gradient. The difference between the two pressures should be kept as small as practicable, consistent with the requirement that the rate of flow be large enough to make accurate measurements of the quantity of flow within a reasonable period of time. Because the difference in the two pressures may be very small in comparison to the pressures at the ends of the specimen, and because the head loss must be maintained constant throughout the test, the difference between the pressures within the burettes must be measured accurately; a differential pressure gage is very useful for this purpose. The difference between the elevations of the water within the burettes should also be considered (1 in. of water = 0.036 psi of pressure).

13. Open valves D and F. Record the burette readings at any zero elapsed time. Make readings of burettes A and B and of temperature at various elapsed times (the interval between successive readings depends upon the permeability of the soil and the dimensions of the specimen). Plot arithmetically the change in readings of both burettes versus time. Continue making readings until the two curves become parallel and straight over a sufficient length of time to determine accurately the rate of flow as indicated by the slope of the curves.

2.8.5 **Calculations:** The hydraulic conductivity can be calculated using Equation (8).

2.9 Pressure-chamber permeameter method:

2.9.1 **Applicability:** This method can be used to determine hydraulic conductivity of a wide range of soils. Undisturbed and disturbed samples can be tested under falling-head conditions using this method. This method is also applicable to both coarse- and fine-grained soils, including remolded, fine-grained materials.

2.9.2 **Apparatus:** The apparatus, shown in Figure 6, consists of

1. Pressure chamber;
2. Standpipe;
3. Specimen cap and base; and
4. Coarse porous plates.

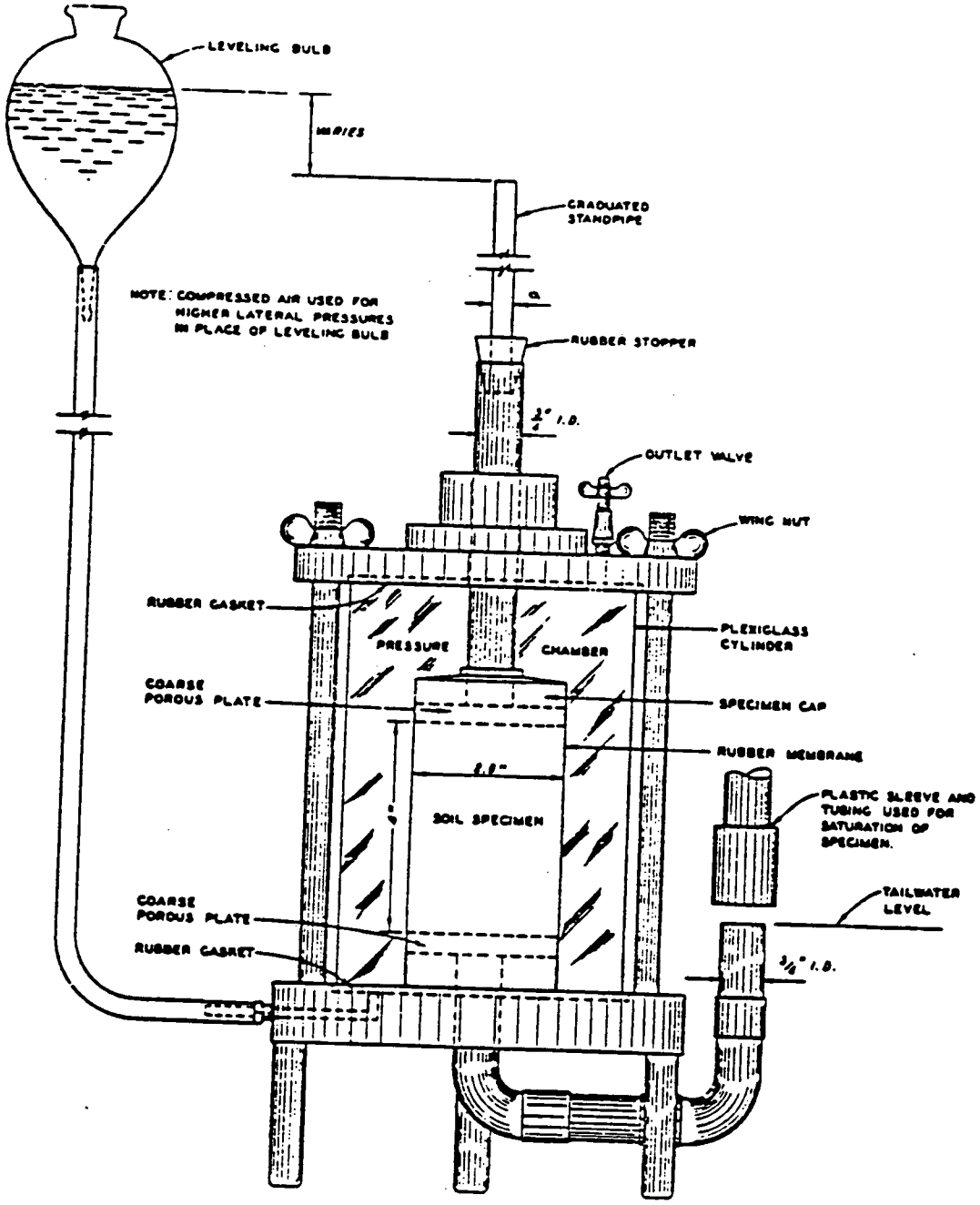


Figure 6.--Pressure chamber for hydraulic conductivity.
Source: U.S. Army Corps of Engineers, 1980.

The apparatus is capable of applying confining pressure to simulate field stress conditions.

2.9.3 **Sample preparation:** The sample preparation of disturbed and undisturbed conditions can be prepared in the chamber and enclosed within the rubber membrane, as discussed in Section 2.8.4.

2.9.4 **Test procedure:**

1. By adjusting the leveling bulb, a confining pressure is applied to the sample such that the stress conditions represent field conditions. For higher confining pressure, compressed air may be used.

2. Allow the sample to consolidate under the applied stress until the end of primary consolidation.

3. Flush water through the sample until no indication of air bubbles is observed. For higher head of water, compressed air may be used.

4. Adjust the head of water to attain a desired hydraulic gradient.

5. Measure and record the head drop in the standpipe along with elapsed time until the plot of logarithm of head versus time is linear for more than three consecutive readings.

2.9.5 **Calculations:** The hydraulic conductivity can be determined using Equation (9).

2.10 Sources of error for laboratory test for hydraulic conductivity: There are numerous potential sources of error in laboratory tests for hydraulic conductivity. Fixed-wall permeameters may have problems with sidewall leakage, causing higher values of hydraulic conductivity. Flexible-membrane permeameters may yield misleadingly low values for hydraulic conductivity when testing with a leachate that causes contraction and shrinkage cracks in the sample because the membrane shrinks with the sample. Table B summarizes some potential errors that can occur. Olsen and Daniel (1981) provide a more detailed explanation of sources of these errors and methods to minimize them. If the hydraulic conductivity does not fall within the expected range for the soil type, as given in Table C, the measurement should be repeated after checking the source of error in Table B.

TABLE B

SUMMARY OF PUBLISHED DATA ON POTENTIAL ERRORS
IN USING DATA FROM
LABORATORY PERMEABILITY TESTS ON SATURATED SOILS

Source of Error (References)	Measured K Too Low or Too High?
1. Voids formed in sample preparation (Olsen and Daniel, 1981).	High
2. Smear zone formed during trimming (Olsen and Daniel, 1981).	Low
3. Use of distilled water as a permeant (Fireman, 1944; and Wilkinson, 1969).	Low
4. Air in sample (Johnson, 1954)	Low
5. Growth of micro-organisms (Allison, 1947).	Low
6. Use of excessive hydraulic gradient (Schwartzendruber, 1968; and Mitchell and Younger, 1967).	Low or High
7. Use of temperature other than the test temperature.	Varies
8. Ignoring volume change due to stress change, with no confining pressure used.	High
9. Performing laboratory rather than in-situ tests (Olsen and Daniel, 1981).	Usually Low
10. Impedance caused by the test apparatus, including the resistance of the screen or porous stone used to support the sample.	Low

TABLE C

HYDRAULIC CONDUCTIVITIES ESTIMATED FROM GRAIN-SIZE DESCRIPTIONS
(In Feet Per Day)

Grain-Size Class or Range From Sample Description	Degree of Sorting Poor	Moderate	Well	Silt Content Slight	Moderate	High
Fine-Grained Materials						
Clay			Less than .001			
Silt, clayey			1 - 4			
Silt, slightly sandy			5			
Silt, moderately sandy			7 - 8			
Silt, very sandy			9 - 11			
Sandy silt			11			
Silty sand			13			
Sands and gravels(1)						
Very fine sand	13	20	27	23	19	13
Very fine to fine sand	27	27	-	24	20	13
Very fine to medium sand	36	41-47	-	32	27	21
Very fine to coarse sand	48	-	-	40	31	24
Very fine to very coarse sand	59	-	-	51	40	29
Very fine sand to fine gravel	76	-	-	67	52	38
Very fine sand to medium gravel	99	-	-	80	66	49
Very fine sand to coarse gravel	128	-	-	107	86	64
Fine sand	27	40	53	33	27	20
Fine to medium sand	53	67		48	39	30
Fine to coarse sand	57	65-72	-	53	43	32
Fine to very coarse sand	70	-	-	60	47	35
Fine sand to fine gravel	88	-	-	74	59	44
Fine sand to medium gravel	114	-	-	94	75	57
Fine sand to coarse gravel	145	-	-	107	87	72
Medium sand	67	80	94	64	51	40
Medium to coarse sand	74	94	-	72	57	42
Medium to very coarse sand	84	98-111	-	71	61	49
Medium sand to fine gravel	103	-	-	84	68	52
Medium sand to medium gravel	131	-	-	114	82	66
Medium sand to coarse gravel	164	-	-	134	108	82
Coarse sand	80	107	134	94	74	53
Coarse to very coarse sand	94	134	-	94	75	57
Coarse sand to fine gravel	116	136-156	-	107	88	68
Coarse sand to medium gravel	147	-	-	114	94	74
Coarse sand to coarse gravel	184	-	-	134	100	92

(1) Reduce by 10 percent if grains are subangular.
Source: Lappala (1978).

(continued)

TABLE C (Continued)

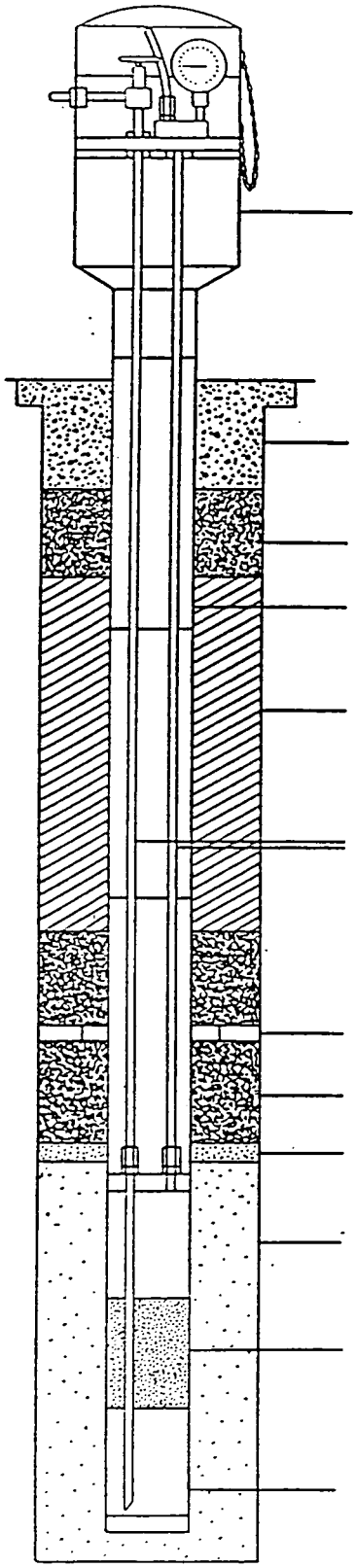
Grain-Size Class or Range From Sample Description	Degree of Sorting Poor	Moderate	Well	Silt Content Slight	Moderate	High
Sands and Gravels(1)						
Very coarse sand	107	147	187	114	94	74
Very coarse sand to fine gravel	134	214	-	120	104	87
Very coarse sand to medium gravel	1270	199-227	-	147	123	99
Very coarse sand to coarse gravel	207	-	-	160	132	104
Fine gravel	160	214	267	227	140	107
Fine to medium gravel	201	334	-	201	167	134
Fine to coarse gravel	245	289-334	-	234	189	144
Medium gravel	241	231	401	241	201	160
Medium to coarse gravel	294	468	-	294	243	191
Coarse gravel	334	468	602	334	284	234

(1) Reduce by 10 percent if grains are subangular.
Source: Lappala (1978).

ATTACHMENT C4

LYSIMETER INSTALLATION MANUAL

TIMCO™ LYSIMETER MANUAL



TIMCO™ Lysimeter Configuration

TIMCO™ HEAD ASSEMBLY
- Vacuum/pressure gauge
- Teflon® tap for sample line
- Teflon® tap for gauge & vacuum/pressure line

CONCRETE SURFACE SEAL

BENTONITE SEAL

TIMCO™ DEKA-SEAL™ CASING

BACKFILL

CONNECTING TUBES

TIMCO™ CENTRALIZER
- Solid Teflon®, PVC, or Stainless Steel

BENTONITE SEAL

GRANULAR SAND

TIMCO™ SELECT SILICA FLOUR
- 200 mesh, 99.88% pure
- Mixed with distilled water

TIMCO™ POROUS CERAMIC FILTER
- Threaded construction with O-ring seals.

TIMCO™ LYSIMETER

Timco Manufacturing Inc. P.O. Box 8 851 15th Street Prairie du Sac, Wisconsin
Toll Free 1-800-236-8534 608-643-8534 FAX 608-643-4275

TIMCO™ LYSIMETER MANUAL

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Teflon® is Dupont's Trademark for their fluorocarbon resin

TIMCO™ Porous Teflon® Lysimeters
are protected by U.S. Patent 4,692,287

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TIMCO™ LYSIMETER MANUAL

INTRODUCTION

TIMCO™ Manufacturing Inc. began manufacturing well screens in 1970. This was in response to expressed market needs for better quality materials to be used for water and monitoring wells. Associated geotechnical products were designed, evaluated and subsequently marketed.

Over the years TIMCO™ has led the industry with innovative products and manufacturing techniques. TIMCO™ was the first company to introduce flush threaded joints for well screens and casing. This provided the industry with a jointing system strong enough to allow placement of flush wells down to a depth of over 2,000 feet without the use of solvents.

Current developments in ground water monitoring techniques using the fluorocarbon Teflon® were originated by TIMCO™. TIMCO™ developed extruders for the casing material and special techniques to slot this totally inert man-made material. Later TIMCO™ developed and patented the process to manufacture Teflon® in a porous form. This material is used as a porous media in the TIMCO™ Lysimeter System, the subject of this application manual.

TIMCO™ has an active program of research and development. This is conducted at the principal facility in Prairie du Sac, Wisconsin. In addition, TIMCO™ continues to support research at leading institutions concerned with the development of techniques to monitor one of our most valuable resources —the groundwater.

If you have any suggestions or ideas you would like to share with us, please give us a call or write to us at the address below.

Robert Timmons
President

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TIMCO™ LYSIMETER MANUAL

OPERATING PRINCIPLES

The TIMCO™ Lysimeter System is designed for long term use in one location. Care must be taken with the installation to ensure correct operation for a long period. The assembled system should be checked for leaks prior to being put in the ground.

A tube or cup type Lysimeter has an outside diameter of 1.9" and should be placed in boreholes of at least 6" in diameter, this allows for an adequate silica slurry pack to surround the Lysimeter.

The Lysimeter has the vacuum/pressure outlet marked on the Lysimeter top plug. This connection leads to the vacuum gauge on the head assembly. It allows a vacuum to be applied to the system, thereby creating a vacuum gradient between the inside of the Lysimeter, the slurry pack, and the soil under investigation. The second marked connection is the sample evacuation tube. This is connected to the head assembly sample line.

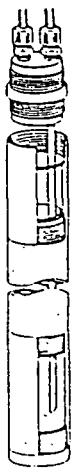
The specification of the silica flour used to surround the installed Lysimeter is optional and can be purchased from TIMCO™. If a 6" borehole is used, a single 50 lb. pail will be sufficient for each Lysimeter installation. The silica slurry is used to establish a continuum between the Lysimeter and the surrounding soil. Since the TIMCO™ silica is not water soluble, it immediately begins to separate itself from the distilled water. When placed in the ground the water migrates into the soil and establishes the continuity required for surface tension to be transmitted in an outward direction upon application of a vacuum. This allows any moisture attached to the soil particles to be drawn into the Lysimeter through the silica pack.

It must be mentioned here that TIMCO™ suggests that the use of silica flour in a Lysimeter installation is optional. Alternate materials can be used in establishing continuity between the porous filter and the soils under investigation. Sifted or filtered backfill can be used with TIMCO™ Lysimeters.

TIMCO™ manufactures a variety of Lysimeters for use in vadose zone investigations. The Ceramic Filter models and Telfon® Filter models have different applications and varied situations within an application. Typically the Teflon® Filter models are used in saturated vadose zone situations like golf courses or irrigated farmland, and the Ceramic Filter models are used in dry soil conditions. The cup-type models (filter media in cup form at the bottom of Lysimeter) will pull a sample from a larger area than the tube-type. The tube-type (filter media in the center of Lysimeter) insures the sample will not migrate back into the soil. The Shallow Sampling Lysimeter is designed for placement at 20 feet or less. For installations at depths of 20 feet to 300 feet a Deep Sampling Lysimeter is required. While all models are manufactured to the highest quality standards, TIMCO™ cautions the user to be careful in the choice of a Lysimeter, and to be certain the choice made is one that is compatible with the Lysimeter capability.

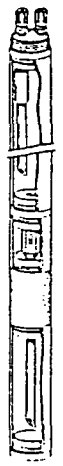
Ceramic Filters with PVC Bodies

TIMCO™
Cup Type Lysimeter



TIMCO™
Tube Type Lysimeter

TIMCO™
Deep Sampling Lysimeter
Cup Type



TIMCO™
Deep Sampling Lysimeter
Tube Type

TIMCO™ LYSIMETER MANUAL

SYSTEM REQUIREMENTS

The following items will be required for a typical TIMCO™ Lysimeter Installation up to 20 feet beneath the ground surface.

- A TIMCO™ Shallow Cup-Type or Tube-Type Lysimeter
- A TIMCO™ Lysimeter Head Assembly
- A 50 lb. Pail of TIMCO™ Silica Flour (200 mesh, 99.88% pure)
- Up to 40 feet of Teflon® or Polyethylene Tubing, and tube groover
- A TIMCO™ Vacuum/Pressure Hand Pump
- Up to 20 feet of TIMCO™ Deka-Seal™, Teflon®, or PVC flush threaded casing
- TIMCO™ Surface Protective Cover

Additional items not provided by TIMCO™ :

- Chemicals and distilled water for decontamination (optional)
- Distilled water for pressure testing, de-airing and prefilling
- Plastic gloves for handling the decontaminated system
- A latex membrane for vacuum testing the system
- Clean plastic bags to wrap the assembled system for transfer to the installation site
- 2 gallons of distilled water for each 50 lb. pail of TIMCO™ Silica Flour
- A large clean silica flour mixing container
- A large rigid spatula to mix the silica slurry
- A clean sample collection container with a 2 port stopper seal compatible with the TIMCO™ Teflon® tubing. The capacity should be greater than that of the Lysimeter.
- Bentonite to seal the borehole above the Lysimeter
- A padlock for the protective cover

TIMCO™ LYSIMETER MANUAL

ASSEMBLING THE LYSIMETER

If properly installed, the typical Lysimeter system will be expected to produce representative samples for several decades. It is therefore important to check out the system thoroughly before taking it to the installation site. Prior to installation the system should be pressure and/or vacuum tested to ensure it is leak free.

The Lysimeter system components supplied by TIMCO™ are cleaned and packed in plastic bags. They have not been subjected to the rigorous decontamination procedures required for equipment used to obtain samples for subsequent micro-analysis of trace pollutants. If complete decontamination is required, see the section titled "Decontamination Procedures" and/or follow those specified for the specific job. Note: If the Lysimeter body is decontaminated it will be necessary to pass at least 2 liters of distilled water through the porous section to ensure complete removal of liquids used for the decontamination. After this procedure is completed, the components should be bagged. Subsequent handling should be done in a clean area using sterile gloves.

The system components supplied are manufactured by TIMCO™ to satisfy the requirements of the order. Mixing these with components from other sources may lead to incompatibility problems resulting in leakage or failure of the Lysimeter system.

Assembly of Tubing to Fittings

Tubing, because of its slippery nature and rigidity, has to be specially grooved before a fitting is attached. Failure to do so will allow the tubing to slip out of the fitting and cause leakage. TIMCO™ normally grooves each end of the tubing supplied with the order. If the installation requires the tubing to be shortened the new end will need to be grooved using a special grooving tool available from TIMCO™. The tool not only cuts the groove but also places the groove at the correct distance from the end of the tube.

Assembling the System

1) As mentioned earlier, it is suggested the complete system be assembled away from the installation site. This will allow for the assembly and testing under clean conditions. The assembled Lysimeter may then be easily placed at the job site.

2) Attach the vacuum/pressure and sample evacuation lines to the Lysimeter top plug. If necessary cut each to length, making certain the cuts are clean and vertical to the horizontal length of the tubing.

3) Follow the previous instructions for the grooving. Note the vacuum/pressure outlet at the top of the Lysimeter plug is marked with a "V". Make certain the other end of the tube connected to this fitting is suitably marked or tagged. (A piece of tape works well.) This will assure the tubing is correctly connected to the TIMCO™ Head Assembly.

4) If the installation is to involve threaded casing, assemble it at this time.

5) Pass the two tubes from the Lysimeter through the casing string.

6) To complete the assembly attach the sample evacuation and vacuum/pressure lines to the bottom of the head assembly. The TIMCO™ vacuum/pressure hand pump is connected on the vacuum mode. The black female hose connector should be used to attach the end of the tubing to the hand pump (black end).

TIMCO™ LYSIMETER MANUAL

TESTING THE SYSTEM

Effective use of the Lysimeter Systems requires there be no air leaks. Two methods are described to check the assembled system for leaks.*

Pressure Testing

Completely immerse the Lysimeter and the tubing connections in distilled water. Connect the pressure outlet of the TIMCO™ hand pump to the vacuum/pressure line fitting on the head assembly. Close the sample port on the head assembly. Apply 15 psi of air pressure. Observe all connections for evidence of bubble leakage. The porous filter section should give off bubbles over its entire surface area. If leaks are observed in the tubing fittings, dissemble and check for correct assembly and retighten. Leaks at the fitting connections to the Lysimeter body or the head assembly may be wrapped with Teflon® tape prior to reassembly. Leaks involving the body components of the Lysimeter should be checked for cleanliness, particularly the surface that touches the O-rings.

Vacuum Testing

The porous filter media of the Lysimeter body is sealed off with a latex or flexible plastic membrane. Secure a seal by placing rubber bands over the membrane and securing it to the body of the Lysimeter above the porous filter. Shut off the sample valve. Connect the vacuum inlet of the pump to the vacuum/pressure port on the head assembly, and apply a vacuum in excess of 20 inches of mercury. Shut off the vacuum valve. Note the vacuum reading on the gauge. Leave the system for several hours and then recheck the vacuum reading. A small drop of up to 3 inches of mercury may be expected. If a large drop is noted, check and retighten all connections as described above.

Prewetting the Porous Filter Media

Finally, before taking the assembled Lysimeter system to the installation site, TIMCO™ recommends that the Lysimeter body be placed in distilled water and a vacuum of about 15 inches of mercury be applied for 1 hour. This procedure prevents all surfaces of the porous filter media, eliminating any entrapped air in the filter media. The Lysimeter should be installed with the body filled with distilled water if no riser casing is used. An empty, unsupported Lysimeter will float on the wet silica slurry when placed in the borehole.

*Note — All TIMCO™ Lysimeters are tested at TIMCO™ prior to shipping. Fittings may loosen during transit.

TIMCO™ LYSIMETER MANUAL

INSTALLATION AND EVACUATION OF THE SHALLOW LYSIMETER

The installation of a TIMCO™ Lysimeter System should be in accordance with the following procedure. It is suitable for depths of up to 20 feet. For greater depths a TIMCO™ Deep-Sampling Lysimeter should be used.

1.) Borehole Preparation

The borehole must provide adequate space to allow the Lysimeter body to be surrounded by the silica slurry pack. For a 1.9" diameter Lysimeter use a 6" or larger borehole. The borehole must allow for at least a 1.5" thickness of silica slurry all around the porous filter of the Lysimeter. If difficulties are anticipated in maintaining an open borehole, use casing to hold back the material. Immediately after installation of the silica pack and Lysimeter, pull back the casing and install a bentonite plug.

2.) Mixing the Silica Flour Slurry

The TIMCO™ 200 mesh, 99.88% pure crystalline silica flour is mixed with distilled water using a ratio of 150 mls. water to 450 grams of silica flour. The TIMCO™ Silica Flour is supplied in a 50 lb. sealed pail. This will require about 2 gallons of distilled water to make the slurry and will be sufficient for a single Lysimeter installation on a 6" borehole. Add the flour slowly to the distilled water with constant stirring. The mix must be completely blended and lumpfree. Constant stirring is essential as the silica is not water soluble and will settle if not agitated.

3.) Placing the Silica Slurry Pack

Pour part of the silica slurry into the borehole to provide a bed for the Lysimeter. A minimum of 4" depth for the cup-type Lysimeter and 2" for the tube-type Lysimeter. Depending upon the borehole diameter, between a quarter and a third of the total mix is usually sufficient.

The TIMCO™ Lysimeter System should now be lowered into the borehole. Take particular care to make certain that the Lysimeter body is centrally located within the borehole diameter. A minimum of 1.5" of silica slurry around the annular area of the unit is essential. TIMCO™ suggests Deka-Seal® casing be used for support and accurate placement. Centralizers will also assure correct placement.

The balance of the silica slurry should now be poured into the borehole to completely cover and surround the Lysimeter body. Note that you must have the Lysimeter in intimate contact with the silica slurry and the slurry must fill all voids in the bottom of the borehole. The Lysimeter should be supported at the surface with stakes for at least 2 hours until the silica sets.

A bentonite seal should be installed next, followed by tamped backfill. A second bentonite seal is suggested near the surface. Protection at the surface can be achieved with the TIMCO™ Lysimeter Head Assembly and a TIMCO™ Protective Cover set in concrete.

4.) Activating the Lysimeter

If the Lysimeter was filled with distilled water before installation, this should now be removed and discarded. TIMCO™ recommends the use of a two port rubber stopper in a collection flask. The flask should be of adequate size to hold the sample from a full Lysimeter. This method is unlikely to disturb the silica pack and break the seal between the pack and the porous section of the Lysimeter which would result in a Lysimeter system failure.

TIMCO™ LYSIMETER MANUAL

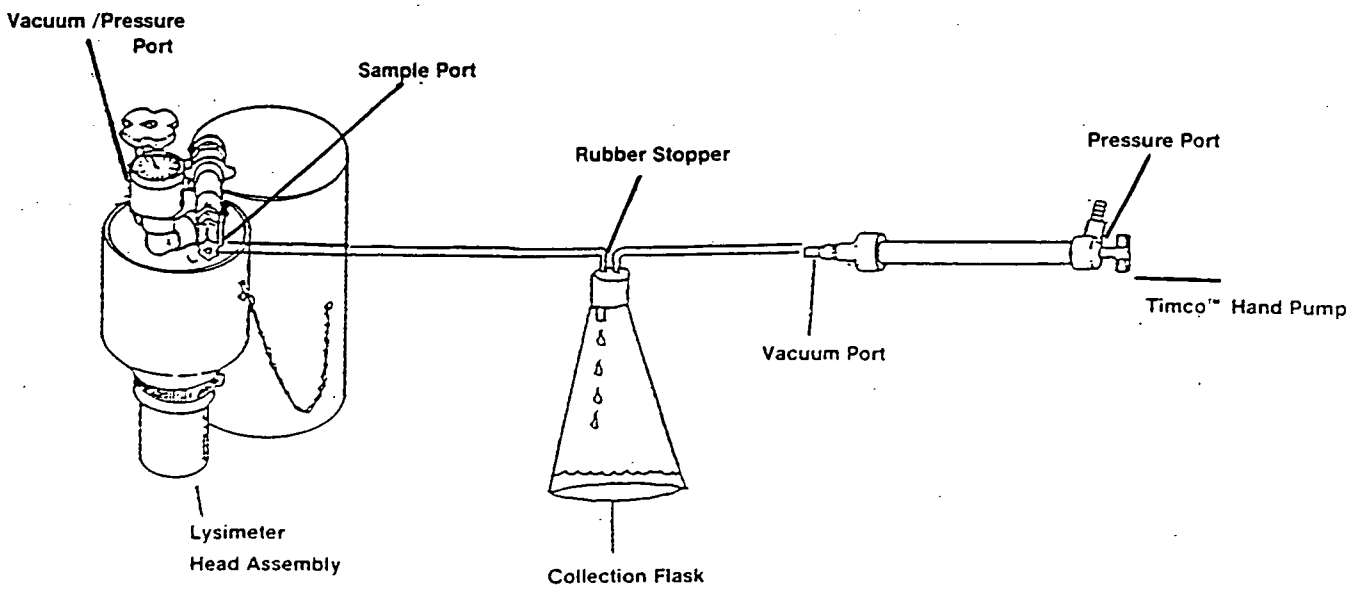
1. Close the vacuum/pressure valve and open the sample valve on the head assembly.
2. Attach the tube from the sample port on the head assembly to the hole in the rubber stopper. (Tube to protube about 1" into the flask.)
3. Attach the second tube from the flask to the vacuum/pressure inlet on the TIMCO™ Hand Pump. (Tube to be flush with the bottom of the rubber stopper.)
4. Apply a gentle vacuum to the system, the distilled water will flow into the collection flask. (See illustration)

5.) Evacuating the Lysimeter

After removing the distilled water from the Lysimeter you are ready to charge the Lysimeter to obtain a sample. If you start the charging procedure immediately after installation, it will be neccesary to discard the distilled water used to make up the silica pack. (*Remove a water volume equivalent to approximately one third of that used to make up the slurry.) If the installation is left for a few days, the water in the silica pack will migrate into the surrounding soil and establish the continuity needed between the porous filter media and the soil. Samples collected in this situation should be considered representative.

1. Close the vacuum/pressure valve and open the sample valve on the head assembly.
2. Continue applying a gentle vacuum to the Lysimeter until a reading of 18-21 inches of mercury is reached. Quickly close the sample port.
3. When the gauge reads 10 inches of mercury or less, evacuation of water should be attempted. (Up to 24 hours may be needed.)

*Example: Using 2 gallons (7570 mld.) to mix the silica slurry would mean that the first .6 gallons (2271 mls.) of distilled water should be discarded.



Sample capacity:		
	1.9" Cup-Type	400 MLS
	1.9" Tube-Type	550 MLS

TIMCO™ LYSIMETER MANUAL

TIMCO™ Deep-Sampling Cup and Tube Type Lysimeters

The TIMCO™ Deep-Sampling Lysimeters are used when the area to be investigated is deeper than 20 feet. The maximum operational depth is 300 feet. This system is operated exactly the same as a shallow installation except that pressure must be used to evacuate the sample. All instructions for installation, and activating the system are the same as the shallow installation.

If sampling deeper than 100 feet, the pressure supplied by the hand pump may not be sufficent to remove the sample. A pressure of .44 psi is required for each foot of depth. A portable mitrogen tank of air compressor may be used as an alternate pressure source.

Evacuating the Deep-Sampling Lysimeter

1) Open the sample evacuation valve and the vacuum/pressure valve.
2) Connect the pressure outlet of the TIMCO™ Hand Pump to the vacuum/pressure port of the head assembly.
3) Gently increase pressure until 9 psi is achieved to lift the sample into the holding chamber of the Deep-Sampling Lysimeter. (If 9 psi were applied instantly, it is possible the silica pack would be damaged resulting in a Lysimeter system failure.)
4) Apply the correct amount of pressure required to lift the sample to the surface and into a collection flask. (Example: 100 feet x .44 psi = 44 psi of lift to evacuate the Lysimeter.)

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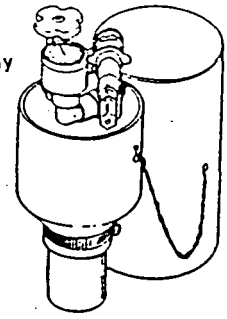
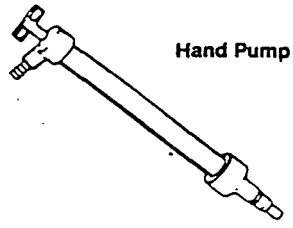
LYSIMETER ACCESSORIES



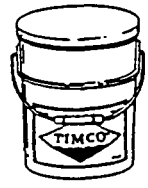
Lysimeter Head Assembly

Designed to fit the top of the casing string. It includes a vacuum/pressure gauge, a valve for the sample evacuation line and a valve for the vacuum/pressure line. All are inclosed in a protective slip cap.



Vacuum/Pressure Hand Pump

The pump is used to apply a vacuum to the Lysimeter during extraction phase and pressure to deliver the sample to the surface.



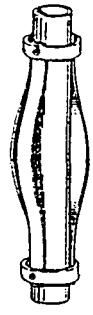
Silica Flour

TIMCO™ Silica Flour

TIMCO™ Silica Flour has been found to be the best for use with TIMCO™ Lysimeters. It is 200 mesh, 99.88% pure silica flour, available in 50 lb. sealed pails.

Tubing

For connection of vacuum/pressure and sample evacuation lines. Teflon® or polyethylene tubing is recommended.



PVC

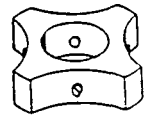
TIMCO™ Deka-Seal Casing

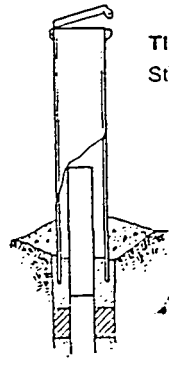
Available in PVC or Teflon® . Will thread directly on to the Lysimeter to direct casing string within the center of borehole. Conduit for vacuum/pressure and sample tubing.

TIMCO™ Centralizers

Varisize for PVC installations. Cloverleaf for Teflon® installations. Recommended for depths greater than 20 feet.

Cloverleaf
(Specify Borehole)





TIMCO™ Protective Cover
Steel Construction/Painted

Steel Protective Cover

A locking cover for protection against weather and vandalism.

Tube Groover

If the installation requires the tubing to be cut, the new end will need to be grooved. The tool cuts and places the groove at the correct distance from the end of the tubing.

TIMCO™ LYSIMETER MANUAL

CLEANING AND DECONTAMINATION

The following advice is provided by TIMCO™. TIMCO™ can assume no liability and provides no guarantee the procedures will ensure that a TIMCO™ product has been 100% cleaned. TIMCO™ does however believe the procedures will give the proper purity characteristic required under state of the art conditions.

Teflon® & Ceramic Components

Step 1 - Disassemble all components.

Step 2 - Prepare a normal solution of Hydrochloric Acid.
(120 g. concentrated HCL diluted in 1 liter distilled water).

Step 3 - Rinse all components in distilled water.

Step 4 - Submerge all components in this solution for 30 minutes minimum. Use a tool to remove from the solution. Soak in distilled water.

Step 5 - Resubmerge the components in clean water at least 2 more times to remove all traces of Hydrochloric Acid.

Step 6 - TIMCO™ believes an additional step of an Isopropyl Alcohol (IPA) bath and then another bath of Hydrogen Peroxide should render the equipment clean.

Step 7 - In all cases a final rinse in distilled, deionized water should ensure that the device is then suitable for representative sampling.

PVC Components

Step 1 - All products must be thoroughly cleaned of loose PVC particles, machining burrs and any other loose materials both inside and out.
(Timco normally does this with all products shipped, but occasionally mistakes happen).

Step 2 - Prepare a suitable Isopropyl Alcohol (IPA) bath which will allow total immersion of the product to be decomtaminated.

Step 3 - Allow products to remain fully immersed for a period of no less than 10 minutes.

Step 4 - Remove products with clean surgical gloves to reduce chances of new contamination. Allow excess IPA to drain off.

ATTACHMENT C5

WATER LEVEL MEASUREMENTS

Water Level Measurements - Metal Tape

The steel tape method for measuring the depth to water is a simple and reliable method in observation wells between 1-1/2 and 6 inches in diameter. The steel tape method utilizes a steel tape with a popper. The popper is a metal cylinder 1 to 1-1/2 inches in diameter and 2 to 3 inches long with a concave undersurface and is fastened to the end of a steel tape. The steel tape with a popper is used in the following manner.

1) Chalk the steel tape with either carpenter's chalk or ordinary blackboard chalk which changes shade upon becoming wet.

2) Extend the chalked steel tape with a popper into the well. A few inches above the water the popper should be dropped to hit the water surface, where it will make a distinct "pop."

3) Adjust the length of the tape to determine the point at which the popper just hits the surface.

4) Extend a portion of the chalked tape below the water surface. Take a reading at a designated measuring point at the top of the casing. All water level measurements shall be taken from the same measuring point.

5) Retract the metal tape. The line of the color change of the chalked portion of the tape denotes the length of tape immersed in water.

6) Subtract the length of color change of the chalked portion of the tape from the reading at the measuring point for the depth to water.

Cascading water in a well may mask the mark of the true water level on the tape. In small-diameter wells, the volume of the weight may cause the water level to rise in the pipe, and the measurement may be somewhat inaccurate. Operating noises and lack of clearance may hinder the use of poppers.

Source: Bureau of Reclamation, 1981. *Groundwater Manual, Revised Edition, U.S. Department of the Interior.* Washington, D.C.: U.S. Government Printing Office.

Testing of Observation Wells

To determine the response to changing water stages, each observation well or piezometer should be tested as follows:

1) Inject a known volume of water into each well and measure subsequent decline of water level. The initial rise of water should be dissipated within a few minutes (to within about 0.01 of the initial rise) if the observation well is to reflect changes of head in the aquifer during the test.

2) Total depth, diameter, and screened interval should be known for each observation well and recorded in the field log book.

3) Radial distances from the control well to each observation well shall be measured.

Source: Bureau of Reclamation, 1981. *Groundwater Manual, Revised Edition*, U.S. Department of the Interior. Washington, D.C.: U.S. Government Printing Office.

Stallman, R.W., 1971. *Aquifer Test Design, Observation, and Data Analysis, Technicians of Water Resources Investigations of the U.S. Geological Survey*, Book 3, Chapter B1.

ATTACHMENT C6

PACKER TEST METHODS

4333

EARTH MANUAL

PART 2

Third Edition

Materials Engineering Branch
Research and Laboratory Services Division
Denver Office
1990

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

208

Mission: As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally-owned public lands and natural and cultural resources. This includes fostering wise use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also promotes the goals of the Take Pride in America campaign by encouraging stewardship and citizen responsibility for the public lands and promoting citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U.S. Administration.

Mission of the Bureau of Reclamation

The Bureau of Reclamation of the U.S. Department of the Interior is responsible for the development and conservation of the Nation's water resources in the Western United States.

The Bureau's original purpose "to provide for the reclamation of arid and semiarid lands in the West" today covers a wide range of interrelated functions. These include providing municipal and industrial water supplies; hydroelectric power generation; irrigation water for agriculture; water quality improvement; flood control; river navigation; river regulation and control; fish and wildlife enhancement; outdoor recreation; and research on water-related design, construction, materials, atmospheric management, and wind and solar power.

Bureau programs most frequently are the result of close cooperation with the U.S. Congress, other Federal agencies, States, local governments, academic institutions, water-user organizations, and other concerned groups.

Any use of trade names and trademarks in this publication is for descriptive purposes only and does not constitute endorsement by the Bureau of Reclamation.

SI METRIC

The information contained in this report regarding commercial products or firms may not be used for advertising or promotional purposes and is not to be construed as an endorsement of any product or firm by the Bureau of Reclamation.

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 7310-89

PROCEDURE FOR

CONSTANT HEAD HYDRAULIC CONDUCTIVITY TESTS IN SINGLE DRILL HOLES

INTRODUCTION

This procedure is under the jurisdiction of the Geotechnical Services Branch, code D-3760, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 7310. The number immediately following the designation indicates the year of acceptance or the year of last revision.

Although the term "permeability" was used in all other procedures in this manual pertaining to the capacity of rock or soil to conduct a liquid, the similar term "hydraulic conductivity," is used throughout this procedure. (See designation USBR 3900 for differences in meaning of the two terms.)

Since geologic and hydrologic conditions encountered during drilling are not always predictable and may not be ideal, variations from this procedure may be necessary to suit the particular purpose of the test, and conditions at the test site. Much of the information for this procedure was taken from references [1] through [5],[1] which contain additional information on field hydraulic conductivity testing.

1. Scope

1.1 This designation outlines the procedure for performing tests to determine an approximate value of hydraulic conductivity (permeability) of soil or rock in an isolated vertical or inclined interval of a drill hole (borehole), either above or below the water table. Usually, the tests are performed as a part of the drilling program. This procedure can be used in holes of various diameters if suitable equipment is available, but N-size [3-in (76-mm)] nominal diameter drill holes are most commonly used.[2]

1.2 The constant head, single drill hole test is based on the same theories as the steady-state or Theim-type aquifer test; and the same assumptions are made. These assumptions are: (1) the aquifer is homogeneous, isotropic, and of uniform thickness; (2) the well (test interval) fully penetrates the aquifer and receives or delivers water to the entire thickness; (3) discharge or inflow is constant and has continued for a sufficient duration for the hydraulic system to reach a steady state; and (4) flow to or from the well is horizontal, radial, and laminar. Field conditions may not meet all of these assumptions. Equations and other factors affecting the test are given in paragraph 14., *Calculations*. This procedure should not be used for testing toxic waste containment that requires a very low loss of liquid.

1.3 Constant head hydraulic conductivity tests should be considered scientific tests. Great care should be exercised by those conducting the tests to eliminate as much error as possible.

[1] Number in brackets refers to the reference.
[2] Hereafter referred to as N-size holes.

2. Auxiliary Tests

2.1 The soil or rock penetrated by the drill hole should be identified, described, and classified from samples taken during the drilling operation. Soil can be sampled in accordance with USBR 7010, 7015, or 7105 and classified in accordance with USBR 5000. Rock cores or cuttings should be examined and appropriate description and classification made. Data obtained from the drill hole should be entered on appropriate log forms.

3. Applicable Documents

3.1 *USBR Procedures*:

USBR 1040 Calibrating Pressure Gauges
USBR 1050 Calibrating Pressure Transducers
USBR 3900 Standard Definitions of Terms and Symbols Relating to Soil Mechanics
USBR 5000 Determining Unified Soil Classification (Laboratory Method)
USBR 5005 Determining Unified Soil Classification (Visual Method)
USBR 5600 Determining Permeability and Settlement of Soils [8-in (203-mm) Diameter Cylinder]
USBR 5605 Determining Permeability and Settlement of Soils Containing Gravel
USBR 7010 Performing Disturbed Soil Sampling Using Auger Boring Method
USBR 7015 Performing Penetration Resistance Testing and Sampling of Soil
USBR 7105 Performing Undisturbed Soil Sampling by Mechanical Drilling Methods
USBR 7300 Performing Field Permeability Testing by the Well Permeameter Method

3.2 *USBR Document:*

3.2.1 Geology for Designs and Specifications by the Bureau of Reclamation. (This document covers both soil and rock.)

4. Summary of Method

4.1 *Pump-In Test.*-Water is injected into an isolated interval of a drill hole in soil or rock, and the volume of water injected is determined for a measured period of time. The injection pressure is a constant gravity head, with or without added pressure head provided by a hydraulic pump. The hydraulic conductivity is calculated from the flow rate, length and radius of test interval in the drill hole, and effective head.

4.2 *Artesian Test.*-Where water under artesian pressure flows out of the drill hole, the effective (shut-in) head at the test interval is measured and the hydraulic conductivity calculated from the flow rate, the length and radius of the well, and the effective head.

5. Significance and Use

5.1 Hydraulic conductivity tests are made to obtain data related to (a) identifying seepage potential and dewatering requirements, (b) drainage problems, (c) ground-water supply investigations, and (d) grouting requirements. The tests yield approximate values of hydraulic conductivity that are suitable for many engineering purposes. Reliability of the values obtained depends primarily on (a) homogeneity of the strata tested, (b) suitability of test equipment used for a given condition, (c) care taken in performing the test, and (d) adherence to requirements for proper use of the equations. The test is also used in formulating geologic descriptions and interpretation of material properties, particularly where there is poor sample recovery.

5.2 Where tests are performed in fractured rock, results could reflect secondary conductivity rates which would not represent primary conductivity of the intact mass. When the test is performed in fractured, brittle, swelling clay or rock, or where fractures contain loose material, hydraulic conductivity may be reduced and judgment should be used in applying results.

5.3 Generally, this procedure is suitable for materials in which the hydraulic conductivity ranges between 5 and 100,000 ft/yr (5×10^{-6} and 1×10^{-1} cm/s) and where results are to be used for engineering purposes. The procedure is not applicable in materials of lower permeability, particularly for purposes such as investigations for containment of toxic wastes.

6. Terminology

6.1 Definitions are in accordance with USBR 3900. Some definitions are from *Glossary of Geology* [6].

6.2 Terms not included in USBR 3900 specific to this designation are:

6.2.1 *Drill Hole.*-A circular hole made by drilling.

6.2.2 *Feed Pipe* (conductor pipe, injection pipe, rise pipe, drop pipe).-The main pipe (or rod) which conducts water from the collar of the hole into the test interval in the drill hole for the hydraulic conductivity test.

6.2.3 *Bailer.*-A cylindrical container with a valve on the bottom for admission of fluid, attached to a line and used for recovering and removing water, cuttings, and mud from a drill hole.

6.2.4 *Walking Beam.*-An oscillating rigid lever balanced on a fulcrum used to activate the cable in cable-tool drilling by alternating up and down motion.

6.2.5 *Aquifer.*-A water-bearing bed or stratum of earth, gravel, or porous rock with interconnected openings or pores through which water can move.

6.2.6 *Packer.*-A short expansible device deliberately set in a drill hole to prevent upward or downward fluid movement; generally for temporary use. The expansible part of the packer is called the gland. Straddle packers are two packers separated by a length of perforated pipe to span or straddle a test interval.

6.2.7 *Artesian.*-An adjective referring to ground water under hydrostatic pressure; i.e., an artesian aquifer is a confined aquifer. Artesian ground water rises above the confining layer in the drill hole and may or may not flow at ground surface.

6.2.8 *Ground Water.*-That part of the subsurface water that is in the zone of saturation.

6.2.9 *Water Table.*-The surface between the zone of saturation and the zone of aeration; that surface of a body of unconfined ground water at which the pressure is equal to that of the atmosphere.

6.2.10 *Perched Water Table.*-A water table, usually of limited area, maintained above the normal free water elevation by the presence of an intervening relatively impervious confining stratum.

6.2.11 *Gauge Saver.*-A vessel, with a pressure gauge, filled with glycerin or oil to protect the gauge from direct contact with fluid in the pressure line (see fig. 1).

6.2.12 *Holding Pressure* (applicable primarily for grouting).-The gauge pressure after the water-pumping system has been shut off at the valve ahead of the gauge and backflow is prevented.

6.2.13 *Back Pressure* (applicable primarily for grouting).-The gauge pressure in the system after the holding pressure has dissipated as determined by opening a valve and allowing the gauge to drop to zero, and then reclosing the valve.

6.2.14 *Backflow* (applicable primarily for grouting).-The reverse movement of water out of the drill hole when the holding and/or back pressure below the packers exceeds the pressure of the water column in the hole.

7. Interferences

7.1 During drilling, it is important to minimize movement of fines [minus No. 200 sieve-size material (75 μm)] into the material being tested and to remove any accumulation of fines from the wall of the drill hole during preparation for the test, so as to avoid obtaining test values

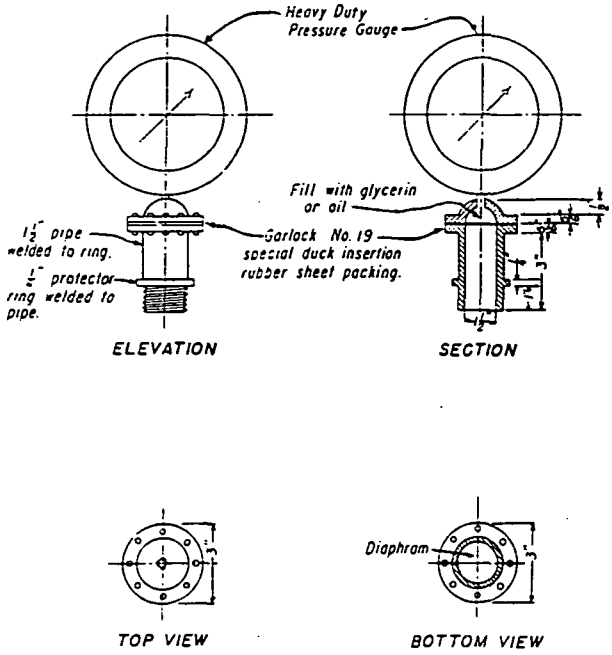


Figure 1. - Gauge saver device for protecting pressure gauge. 40-D-4287

lower than the actual hydraulic conductivity of the material being tested. Drilling using clear water without additives is preferred. Bentonitic muds should not be used in holes where hydraulic conductivity testing is to be performed. Biodegradable additives may be used if necessary, but only if the test interval is adequately cleaned before testing. The drilling procedure should be documented on the log form.

7.2 Test results can be adversely affected by injecting water containing sediment which would tend to plug voids in the material being tested.

7.3 The temperature of the injected water should be equal to or warmer than that of the ground or ground water. This reduces the tendency of air dissolved in the water to become entrapped in the voids of the material being tested and to cause low values of hydraulic conductivity. In most areas not affected by artesian conditions, the temperature at a depth of about 25 feet (8 m) below the ground surface remains relatively constant at the annual mean air temperature for the region. At significantly greater depths, temperature rises about 1 °F (0.6 °C) for each 500 to 1,000 feet (150 to 300 m) of depth. The temperature of the injected water, especially if it is known to be colder than the ground-water temperature, should be recorded on a geologic log, or the hydraulic conductivity test data forms (see subpar. 8.12 for suitable temperature measuring devices).

7.4 It is possible that dissolved minerals in the water used for a test may react chemically with substances in the material being tested to cause a change in the hydraulic conductivity. Therefore, it is desirable to use water for the test that is similar in quality to that expected to permeate the ground when the project is in operation.

8. Apparatus

8.1 *Drill Rigs* (see fig. 2):

8.1.1 *Rotary Drilling.*-A drilling method resulting in grinding a hole with a hard-toothed drill bit at the end of a rotating drill rod (pipe). The equipment consists essentially of a power unit, hoisting or tugging unit, controlled-feed rotary drill head and mounting frame, mast or tripod, and circulating pump. The rig should have various accessory drilling and sampling equipment (rods, bits, core barrels, augers), as required for drill hole advancement, sampling, and testing.

8.1.2 *Cable Tool Drilling.*-A method of drilling in which the material at the bottom of the hole is broken up by a steel bit with a blunt, chisel-shaped cutting edge. The drilling equipment consists essentially of a mast, a string of drill tools (casing, tubing, or pipe, of one size) that is alternately lifted and dropped by a hoist with a power unit, and a walking beam. A bailer is always used with a cable tool rig. Normally, a cable tool drilled hole is not satisfactory for hydraulic conductivity testing with packers.

8.2 *Injection Pump.*-A centrifugal or helical screw type pump providing a constant water flow is required. This may require a special pump separate from that used for drilling operations. Although there may be conditions where a larger or smaller pump may be required, high-quality pumps having a capacity of 40 gal/min (150 L/min) at a pressure of 120 lb/in² (830 kPa) (such as Monyo model 3L-8 manufactured by the Robbins and Myers Company, Springfield, Ohio, or equivalent) are adequate for most hydraulic conductivity tests. The pump should provide the required flow at the required constant pressure with maximum allowable pressure fluctuation—due to pumping pulsations—of ±5 percent of the test gauge pressure. A surge chamber is required for all testing; this minimizes pulsations which can affect the injection rate in the test interval. Also, it makes readings more accurate and protects the pressure gauges against damage from sudden pressure changes.

8.3 *Feed Pipe.*-The feed pipe should be of adequate diameter to minimize head losses and have adequate tensile strength to withstand pumping pressures and stresses during hoisting or tugging. The feed pipe is commonly a threaded and coupled assembly of pipe or tubing having a uniform inside diameter. Drill rods, generally of N-size, can be used without seriously affecting reliability of test data if the flow rate to the test interval does not exceed about 15 gal/min (57 L/min) and the depth to the top of the interval does not exceed 50 feet (15 m).

NOTE 1.-Use of drill rods as feed pipe should be permitted only after the assembled drill rod string has been pressure tested to calibrate head losses at anticipated flows. If seals or sealing materials are used during calibration, the same type of seals or sealing materials (not oils or wax) should be used during hydraulic conductivity testing.

8.4 *Flowmeters.*-One or more calibrated flowmeters are required; the capacity of each meter should be specified.

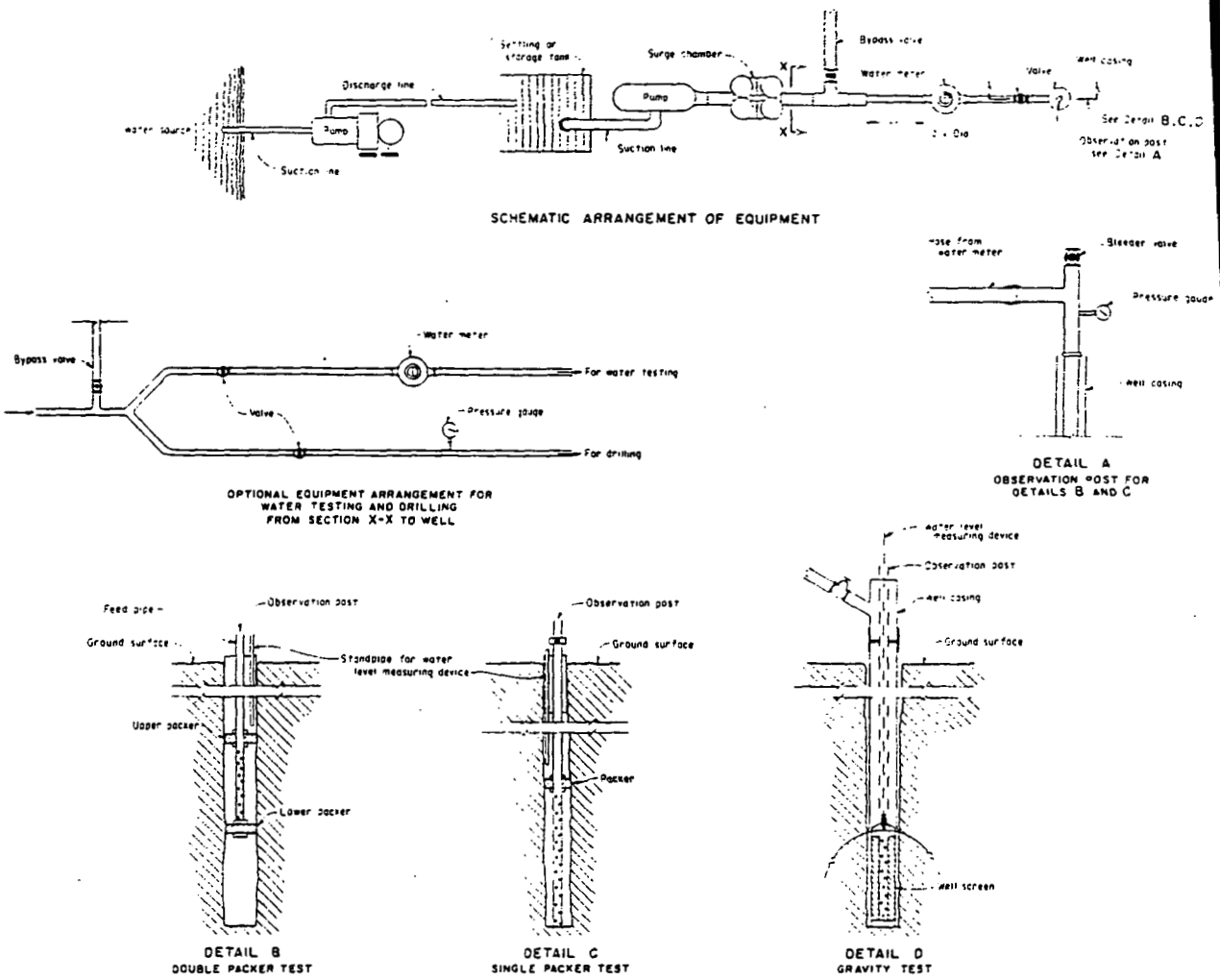


Figure 2. - Schematic arrangement of hydraulic conductivity equipment. 801-D-111

For flows up to 50 gal/min (200 L/min), a 1-inch (25-mm) diameter disk-type meter may be used. For higher flows, a 2- or 2-1/2-inch (50- or 65-mm) diameter impeller-type meter is recommended.

8.4.1 A straight uninterrupted section of pipe having an inside diameter equal to the rated size of the meter and a minimum length 10 times the inside diameter of the pipe should be provided upstream of the meter. Manufacturers commonly recommend pipe lengths of one to two times the inside diameter of straight pipe downstream from the meter.

8.5 *Pressure Sensors.*-Where required, calibrated pneumatic piezometers or electrical transducers can be used as down-hole sensors to measure pressures at the test interval during a hydraulic conductivity test. Down-hole sensors are preferred over the method of calibrating the piping system for head loss between a pressure gauge on the surface and the test interval. However, an above-ground pressure measurement can provide a check of the pressure sensor.

8.5.1 *Pneumatic Piezometers.*-A down-hole pneumatic piezometer system has been developed [7]. Descriptions of the equipment and procedure, as used at two damsites, are presented in appendix X1.

8.5.2 *Electrical Transducers.*-Electrical transducers have been used as down-hole pressure sensors by other agencies [8], particularly for very low hydraulic conductivities [below 1 ft/yr (1×10^{-6} cm/s)]. The USBR has used electrical down-hole sensors in preliminary trials. Electrical transducers measure pressures more accurately than pneumatic piezometers and can be connected to a strip-chart recorder for a continuous record. However, transducers are considered less rugged for field use and require more maintenance and experienced personnel to operate than do pneumatic piezometers.

8.6 *Pressure Gauges.*-When down-hole pressure sensors are not available or sensors are not working properly, calibrated pressure gauges can be used to estimate effective pressure in the test interval after correcting for friction loss through the feed pipe and packer. All pressure

gauges used in water testing should be high-quality, stainless steel, glycerin or oil filled, with pressure indicated in both lbf/in² and kPa (such as manufactured by Marsh Instrument Company, a unit of General Signal, P O Box 1011, Skokie, Illinois; or equal). Pressure gauge ranges should be compatible with testing requirements; they should be sized so that the gauge capacity does not exceed two to three times the maximum desired pumping pressure for each respective pumping stage. Gauges should have the smallest graduations possible and an accuracy of ±2.5 percent over the total range of the gauge. If a gauge saver is used with the gauge, calibration should be made with the gauge saver in place. Accuracy of the gauges should be checked before use and periodically during the testing program (see subpar. 11.2 for additional information).

8.6.1 One or more pressure gauges should be located downstream of the flowmeter and downstream of any valves at the top of the feed pipe. This location for pressure measurement can be used by inserting a sub (adaptor, or short piece of pipe) with the gauge — installed on the top of the feed pipe.

8.6.2 At least one additional calibrated replacement gauge should be available at the test site.

8.7 *Swivel.*-During the hydraulic conductivity test, it is preferable to eliminate the swivel and use a direct connection to the feed pipe. If a swivel must be used in the water line during testing, it should be of the nonconstricting type and calibrated for head loss. Significant friction loss can result from use of the constricting type.

8.8 *Packers.*-One or two (straddle) packers are required for the test. Packers may be either bottom-set mechanical, screw set mechanical, pneumatic inflatable, or liquid inflatable. The pneumatic inflatable packer is the preferable type for general use and is usually the only one suitable for use in soft rock and soil. The gland of this packer is longer and more flexible than the other types and will form a tighter seal in an irregular drill hole. A leather cup type of packer should not be used. To ensure a tight water seal, the length of contact between each expanded packer and the drill hole wall should not be less than three times the drill hole diameter.

NOTE 2.-More than one type of packer may be required to test the complete length of a drill hole. The type of packer used depends upon many factors, e.g., rock type, drill hole roughness, spacing and width of rock joints, and test pressures.

8.8.1 *Inflatable Packers.*-Inflatable packers with an expansible gland and a floating head (see app. fig. X1.2) should be designed for anticipated drill hole diameters and pressure conditions. For normal hydraulic conductivity testing, a reasonable maximum recommended working pressure inside and outside of the packer is 300 lbf/in² (2070 kPa) [8]. Inside pressure should be increased in water-filled holes, proportionally to the static head. For drill holes with sharp projections in the walls, a wire-reinforced packer gland having a higher working pressure [7] may be required. The pressure in the packer should not be high enough to fracture the material being tested. The pressure required to form a tight seal at the ends of a test interval depends on the flexibility of the gland, the friction of the floating head, and the drill hole roughness. The minimum differential pressure between the packer and the test interval can be determined by testing packers in a pipe slightly larger than the nominal diameter of the drill hole, in order to simulate possible enlargement of the drill hole during drilling. For a given test interval pressure, the packer pressure is increased until it provides a watertight seal between the packer and the material with which it is in contact. The pressure in the packer should range approximately between 30 and 300 lbf/in² (210 to 2100 kPa) greater than that in the test interval, with 100 lbf/in² (690 kPa) being normal. Pneumatic inflatable packers can be inflated with compressed air or compressed nitrogen.

8.8.2 Special pneumatic packers are available for use in wireline drilling operations. Because the packers must be able to pass through the wireline bit and then expand to completely seal the hole at the test interval, special materials are needed for the packer gland. A special packer assembly—consisting of two packers in tandem—is used with the upper packer being expanded inside the drill rod, just above the bit, and the lower packer expanded against the wall of the hole just below the bit. The two packers on the assembly can be positioned properly—relative to the bit—by a set of lugs or a ring located on the assembly. Special seals or connections are needed to attach the water supply to the wire-line drill pipe at the surface.

8.8.3 A minimum of two sets of replacement packers and/or spare glands should be available at the test site.

8.9 *Perforated Pipe Sections.*-Lengths of perforated steel pipe corresponding to the lengths of test intervals, are required between packers to admit water into the test intervals. The total area of all perforations should be greater than five times the inside cross-sectional area of the pipe. These perforated pipe sections should be calibrated for head loss.

8.10 *Well Screen.*-Well screen or slotted pipe may be required for testing in granular, unstable materials that require support [9]. As a general rule, the maximum size of slot width should be approximately equal to the 50-percent size of the particles around the drill hole (see subpar. 11.4).

8.11 *Water Level Measuring Device*:

8.11.1 Although there are other types of water level indicators, the electrical probe indicator is most commonly used. Essentially it consists of (1) a flexible, insulated conduit marked in linear units and enclosing two wires, each insulated except at the tips; (2) a low-voltage electrical source; and (3) a light or other means of indicating a closed circuit which occurs when the tips contact the water surface. Different brands of electric water level indicators and even different models of the same brand often have their own unique operating characteristics. Before using any electric water level indicator, it should first be tested at the surface in a bucket of water.

8.11.2 For approximate measurements of the water level when it is within about 100 feet (30 m) of the ground

surface, a cloth tape with a "popper" can be used. A "popper" can be made from a short pipe nipple (or length of tubing) by screwing a plug attached to a graduated tape into one end of the nipple and leaving the other end of the nipple open. When the "popper" is lowered in the drill hole and the open end of the pipe nipple strikes a water surface, it makes a popping sound, and the depth to water can be measured by the tape.

8.11.3 An accurate measurement of the water level can be made by chalking the lower end of the steel tape. After contacting the water level, the tape should be lowered about 1 more foot before retrieving it. Measurement is then made to the "wet line" on the tape.

8.12 *Temperature Measuring Device.*-Equipment for measuring ground-water temperature is available from commercial sources or can be made from a thermistor, two-conductor cable, reel, Wheatstone bridge, and a low-voltage electrical source. A maximum-minimum type thermometer is acceptable.

9. Regents and Materials

9.1 *Water* (See subpars. 7.2, 7.3, and 7.4.).-The clear water supply should be sufficient to perform the hydraulic conductivity test without interrruption and to maintain the required pressure throughout the test period.

9.2 *Sand or Gravel Backfill.*-Where a granular backfill is used to prevent sloughing of the drill hole wall, it should be a clean coarse sand or fine gravel. Laboratory permeability tests (USBR 5600 or 5605) should be made on the backfill material to make sure that it has a coefficient of permeability greater than one order of magnitude higher than that expected of the in situ material being tested.

10. Precautions

10.1 *Safety Precautions*:

10.1.1 This procedure may involve hazardous materials, operations, and equipment.

10.1.2 Use normal precautions for drilling [10, 11].

10.1.3 Precautions should be taken during calibration pressure testing of equipment, particularly testing of packers with compressed air or nitrogen (never use oxygen) to avoid injuries from a sudden packer or hose rupture.

10.2 *Technical Precautions*:

10.2.1 As a general rule, total pressure (static head plus gauge pressure) applied in the drill hole should not exceed 1 lbf/in² per foot (22.6 kPa/m) of rock and soil overburden at the center of the test interval, if the test interval is 10 feet (3 m) long or less. If the test interval exceeds 10 feet, pressure should not exceed 1 lbf/in² per foot of overburden at the top of the interval. In layered or fractured material, or for drill holes near steep abutments or slopes, 0.5 lbf/in² per foot (11.3 kPa/m) of material to the nearest free surface is an appropriate maximum pressure. Higher pressures than these may fracture the materials.

10.2.2 If there is excessive or complete loss of water when the hole is being drilled, drilling should be stopped before cuttings fill the voids, and a hydraulic conductivity test completed on a shorter than normal length test interval.

10.2.3 Hydraulic conductivity test equipment should be considered and treated as precision testing equipment. Gauges, thermometers, etc., should have their own protective cases; they should not be carried with drill tools or be tossed around. They should be calibrated frequently. It is recommended that all test equipment needed for hydraulic conductivity testing be kept separate from drilling equipment.

11. Calibration

11.1 *For Measurment of Effective Head*:

11.1.1 *Pressure Sensors.*-Calibrate down-hole pressure sensors by the methods and at frequencies prescribed by USBR 1050.

11.1.2 *Friction Loss Estimates.*-Where down-hole pressure sensors are not used, estimates of effective head at the test interval are made by subtracting friction loss from the applied head measured at the ground surface. The friction loss should be determined for all components of the piping system, from the pressure gauge to the test interval.

11.1.2.1 Calibrate friction loss in parts or sections of the piping systems including (1) the swivel (if used); (2) feed pipe (per unit length); and (3) the packer assembly. Record the data, with references to the particular parts calibrated, in tabular or graphical form so the accumulative friction loss can be totaled for determination of effective head at the test interval. The calibration procedure is as follows:

11.1.2.1.1 Lay out the individual or joined parts to be calibrated on a horizontal surface with calibrated pressure gauges at each end.

11.1.2.1.2 Pump water through the system at incremental, increasing flow rates to the maximum flow rate expected to be used in the test; allow the flow to stabilize between incremental flows.

11.1.2.1.3 Record the pressure at each gauge for each incremental flow rate.

11.1.2.1.4 Calculate the friction head loss for each incremental flow rate.

$$f = 2.31\left(\frac{P_1 - P_2}{d}\right) \qquad (1)$$

where:

f = friction head loss in feet of head per linear foot of pipe, ft/ft or m/m
P_1 = upstream pressure, lbf/in² or kPa
P_2 = downstream pressure, lbf/in² or kPa
d = pipe length, ft or m (d = 1 for swivel or packer assembly)
2.31 = converts from pressure in lbf/in² to head in feet or 0.102 converts from pressure in kPa to head in meters

Example, assume

P_1 = 18.6 lbf/in² or 128 kPa
P_2 = 13.2 lbf/in² or 91.0 kPa
d = 10.0 ft or 3.05 m

Inch-pound application:

$$f = 2.31\left(\frac{18.6 - 13.2}{10.0}\right) = 1.25 \text{ ft/ft}$$

SI application:

$$f = 0.102\left(\frac{128 - 91.0}{3.05}\right) = 1.24 \text{ m/m}$$

11.1.2.1.5 Plot friction head loss versus flow rate. Figure 3 is an example of a plot of friction head loss (f) at relatively low flow rates for a 10-foot (3.3-m) length of 1-1/4-inch (32-mm) diameter pipe. Since head loss in pipe at turbulent flow is approximately related to velocity squared, a plot of friction head loss versus the square of the flow rate is nearly a straight line (see fig. 4).

NOTE 3.-There are standard tables and charts which provide unit friction losses for various sizes of pipe, elbows, tees, reducers, etc., for clean and rusty conditions. Although such information is sometimes used, it is preferable to determine friction losses in the piping system and packers actually used for the hydraulic conductivity test.

11.1.2.1.6 To calibrate a packer, inflate the packer in a short length of casing or pipe in which a valve and pressure gauge have been installed. A pressure gauge is also installed in the rods immediately ahead of the packer assembly. Pump water into the rods at incremental increases (or decreases) of flow rate—allowing the system to stabilize after each incremental change—until the highest anticipated flow rate is reached.

NOTE 4.-For packers smaller than N-size, such as the B-size used in wireline equipment, there are significant head losses, and relatively low flow rates must be maintained. This requires water meters and pressure gauges capable of accurately measuring the low flows and small changes in pressures.

11.2 *Pressure Gauges.*-Calibrate each pressure gauge (see USBR 1040) by comparing it with a test or master gauge. The master gauge should not be used during drilling or hydraulic conductivity testing. Calibrate each gauge at the start of a testing program plus one additional calibration per week during tests of long duration.

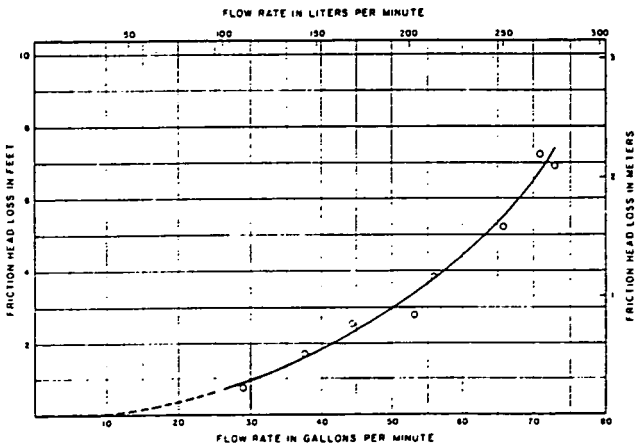


Figure 3. - Head loss due to friction at increasing flow rates for a 10-foot (3-m) 1-1/4-inch (32-mm) diameter iron pipe.

11.3 *Flowmeters.*-Calibrate a flowmeter by flowing water into a container of known volume; the container used for the volume check should be commensurate in size with the flowmeter size and graduations. From these data, flow rates can be calculated for comparison with meter readings. All flowmeters should be calibrated to an accuracy of ±1 percent. Calibration should be done at the start of the testing program plus one additional calibration per week during tests of long duration.

NOTE 5.-Some impeller-type flowmeters have an accuracy range significantly less than indicated by the dial. Minimum and maximum rates should be established.

11.4 *Well Screens and Perforated or Slotted Pipe Sections.*-From manufacturers' data or by calibration, determine the head losses in expected flow ranges to ensure there is no restriction of flow into the material being tested.

12. Conditioning

12.1 Not applicable, special conditioning requirements are not needed for this procedure.

13. Procedure

13.1 *Cleaning of Drill Hole*:

13.1.1 Remove any accumulation of fine particles (smear, mud cake, compaction caused by driving casing, etc.) from the drill hole wall. Such accumulation significantly restricts the flow of water into or from the hole. Exercise good judgment in cleaning the hole, since excess cleaning may be detrimental. If there is a question as to whether or not drill holes in particular materials need cleaning, hydraulic conductivity tests can be performed in holes with cleaning and others without cleaning. If cleaning does not significantly change test results at a site, cleaning of additional intervals in the same materials may not be necessary.

13.1.1.1 When the test interval is above the water table, it may be possible to brush or scratch the drill hole wall to break up accumulated fines. For unstable materials which require use of a well screen, materials which cave against the screen may break up the accumulation of fines on the wall. Mild surging with a bailer, while adding water, also may help break up a disturbed or compacted zone, but this may stir up fines which then plug the voids in the material to be tested. Mild jetting—followed immediately by bailing or pumping—also is a possibility.

13.1.1.2 When the test interval is below the water table—in materials that are rock-like and self-supporting—use of a water jet in the hole (preferably accompanied with pumping to induce flow into the borehole) is one of the best methods to clean the hole. After jetting, bail or pump the sediment-laden water from the test interval. Jetting can also be used through a screen below the water

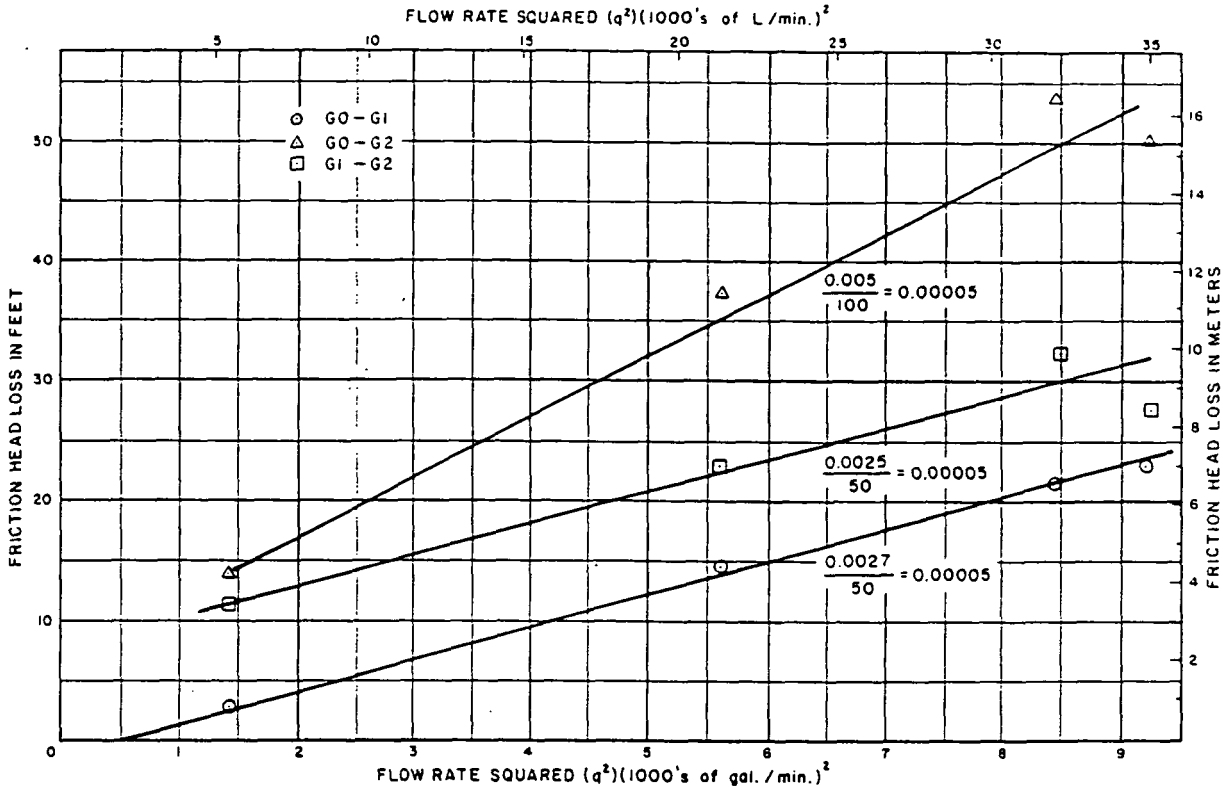


Figure 4. - Plot of feed pipe calibration data — example.

table in unstable materials. For soft rock, flushing the sides of the drill hole by running the bit or a bailer up and down the hole may enlarge the hole by erosion or otherwise change the characteristics of the fracture systems.

13.1.1.3 Finally, clean the drill hole by pumping or bailing water from the bottom upward, with the pumping continued until the return fluid is clear without cuttings or sediment. Record the method used in cleaning the hole on the log of drill hole or on a special testing form.

13.2 *Length of Test Interval*:

13.2.1 The length of the test interval depends on (1) purpose of the test, (2) stratigraphic interval, and (3) flow rate. Where materials are relatively uniform, use a test interval of about 10 feet (3 m). Where flow rates are high, shorten the test interval to locate high flow rate zones; where rates are very low, the interval may be lengthened if desired.

13.3 *Ground-Water Level Determination*:

13.3.1 Depth to ground-water level must be determined before calculating hydraulic conductivity. Measure depths to water levels with an electrical probe or other suitable equipment (see subpar. 8.11).

13.3.2 *Auger Holes.*-In power auger or other types of holes to which water is not added as part of the drilling process, report the presence or absence of a water level, depth to water level, and date of initial and final water level measurement. In materials of low hydraulic conductivity, several days to several weeks may be required for a water level to stabilize in the hole. Report evidence of moisture in the cuttings and if a perched water level was observed.

13.3.3 *Rotary or Cable Tool Holes.*-For drill holes in which addition of water to the hole is an integral part of the drilling process:

13.3.3.1 Bail or pump the hole dry or to a stable water level at the close of the last shift each day and record level.

13.3.3.2 Report the presence or absence of water and depth to water at the beginning of the first shift each day. Additional readings are desirable whenever water level in the hole has not been disturbed for an appreciable period of time.

13.3.3.3 Report changes in water level detected as the hole is drilled deeper. Record factors that affect the water level such as depth of casing, and/or cemented intervals. These data may be helpful in recognizing perched or confined (artesian) conditions.

13.3.3.4 Upon completion of the hole, the water must be bailed down to the extent practicable, the water level measured, and the date recorded of hole completion. Measure the water level for a period of days or weeks until equilibrium is reached.

NOTE 6.-At times, exceptions must be made to the requirement for continuation of water level readings. Such is the case when

state or local laws require that the hole be filled continuously from bottom to top immediately upon hole completion and before the drill crew leaves the site. In other instances, landowners may allow right-of-entry for only a limited time for measurements.

13.3.4 *Perched and Artesian Aquifers.*-It is important to recognize perched and artesian aquifers, especially those under sufficient pressure to raise the water level above the confining layer but not to the ground surface (see [5]). They must be distinguished from water table aquifers (those which continue in depth). If perched water table or artesian aquifers—separated by dry or less permeable strata—are encountered in the same drill hole, the resulting water level in the hole is a composite; therefore, conclusions and interpretations based on such data are misleading. If a perched water table is recognized (or suspected) during drilling, water levels must be determined for each zone for calculation of hydraulic conductivity. This might require completion of the drill hole with a watertight seal set at a suitable horizon to separate two water table conditions. In this type installation, two strings of pipe or conduit are required: one extending down to the portion of the hole immediately above the packer, and a second string extending through the packer to a point near the bottom of the hole. Water-level measurements provide the basis for determining a perched condition or if the lower water table is under artesian pressure.

13.3.5 *Multiple Water-Level Measurements.*-In some instances, it is desirable to install multiple conduits and packers or plugs in a drill hole so that ground-water levels (or pressure-heads) in several water-bearing horizons can be measured over an extended period of time (see [5], pp. 7-14).

13.4 *Pressure Tests With Packers*:

13.4.1 The recommended arrangement of typical equipment for packer pressure tests, without a pressure sensor is shown on figure 2. (See app. fig. X1.1 for equipment with a pressure sensor.) Beginning at the source of water, the general arrangement is clean water source, suction line, pump, discharge line to storage and/or settling tank, suction line, water-supply pump, surge chamber, line to bypass valve junction, water meter, gate or plug valve, tee with sub for pressure gauge, short length of pipe on which the pressure gauge is attached, tee and off-line bleeder valve for evaluating back and/or holding pressure, flexible 1-1/4-inch (32-mm) diameter hose, and 1-1/4-inch-diameter feed pipe to packer or packers in drill hole, which isolate the test interval. All connections should be tight and as short and straight as possible with minimum change in diameter of hose and pipe. Friction loss decreases as the pipe diameter is increased.

13.4.2 When the material is subject to caving, and casing and/or grout is needed to support the walls of the drill hole, the hole should be water tested as it is advanced. Other hole conditions may make this procedure desirable or necessary. The following procedure is commonly used:

13.4.2.1 After the hole has been drilled to the top of the interval to be tested, it may be desirable to remove the drill string from the hole and advance casing or grout to the bottom of the hole.

13.4.2.2 Advance the hole 5 to 10 feet (1.5 to 3 m) into the material to be tested.

13.4.2.3 Remove the drill string from the hole.

13.4.2.4 Clean the interval to be tested, and record the depth to the water table, if present. If a composite water level is suspected, the water level affecting the test should be determined by measurements through the feed pipe after the packer has been seated and the water level has stabilized.

13.4.2.5 If the hole will stand open, seat a single packer at the top of the test interval. Record the type of packer, its depth, and packer pressure if it is the inflatable type.

13.4.2.6 Pump water into the interval at a rate to develop a suitable pressure. The pressure to be used depends upon testing depths and ground water levels or pressures. Materials subject to deformation or heaving, such as by separation of bedding planes or joints, or materials at shallow depths, must not be subjected to high pressures (see subpar. 10.2.1). For comparison of flow rates in different parts of a single foundation and with results from other foundations, some of the following pressures are commonly used: 25, 50, 75, and 100 lbf/in² (170, 350, 520, and 690 kPa).

NOTE 7.-At test pressures less than 25 lbf/in², errors in measurement of pressure and volume of water may increase unless special low pressure gauges are used. Gravity tests provide more accurate results under these conditions. At pressures higher than 10 lbf/in², difficulties in securing a tight packer seal and the likelihood of leakage increase rapidly. However, under artesian pressures or in deep holes the water pressure—as registered on a surface gauge—will need to be sufficient to overcome the effective head at the test interval and firmly seal the packer.

NOTE 8.-Where the hole is subject to caving, a pump-down wire-line system has been developed that can be used to eliminate removal of the drill string from the hole. With this system, the hole is drilled to the bottom of the interval to be tested, and the drill rod is raised so the end of the rod is at the top of the test interval. The tandem packer (see subpar. 8.8.2) is then lowered through the drill rod and expanded to seal both inside the rod and against the wall of the hole at the top of the test interval. Models of this equipment are available which have transducers below the packer for measuring water pressures at the test interval.

13.4.2.7 For determining effective head, artesian heads encountered in the drill hole are treated the same as water table conditions: i.e., the depth from the pressure gauge, or the water level maintained during the test, to the stabilized water level is used as the gravity head. If the artesian head stabilizes above the ground surface, the gravity component of the effective head is negative and is measured between the stabilized level and the pressure gauge height. If a flow-type test is used, the effective head is the difference between the stabilized water level and the level maintained during the flow period.

13.4.2.8 After pressures are selected, based on ground-water conditions and the purpose of the test, perform a test at each pressure. Usually, a 5-cycle procedure is used, three increasing steps to the maximum pressure and then two decreasing steps to the starting pressure. This cycling allows a more detailed evaluation of test results than testing at a single pressure and commonly allows extrapolation to ascertain at what pressures the following may occur (1) laminar flow, (2) turbulent flow, (3) dilation of fractures, (4) washouts, (5) void filling, or (6) hydraulic fracturing. However, the equations normally used to calculate hydraulic conductivity are based on laminar flow conditions.

NOTE 9.–In some instances, only a single water pressure test at a given interval in the drill hole may be required. For example, if geologic conditions are known, and there is no need to perform the steps in subparagraphs 13.4.2.2 through 13.4.2.6, a single value of hydraulic conductivity with a relatively low application of pressure may suffice.

13.4.2.9 During each test, continue pumping water to the test interval at the required pressure until the flow rate becomes stable. As a general guide, maintain flow rates during three or more 5-minute intervals during which 1-minute readings of flow are made and recorded. In tests above the water table, water should be applied to the test interval until the flow rate stabilizes before starting the 5-minute measurement intervals. Where tests are below the water table, flow rates usually stabilize faster than for the tests above the water table, and the time period before the 5-minute test intervals may be shorter. These time periods may need to be varied, particularly when tests to determine grouting requirements are made

13.4.2.10 Determine and record the presence of back pressure and decay of holding pressure. After the test, deflate the packer and remove it from the drill hole.

13.4.2.11 Advance the drill hole and, if necessary, the casing; repeat the procedure in subparagraphs 13.4.2.3 through 13.4.2.10 until the required depth of drill hole is reached. When casing is used in a drill hole, always set the packer in the material below the casing.

13.4.3 If the hole will stay open without casing, it can be drilled to final depth, and after cleaning the hole, hydraulic conductivity tests can be performed from the bottom of the hole upward using straddle (double) packers. Although a single packer can be used to test the bottom interval of the hole, starting at the bottom with double packers will cause loss of borehole testing of only about the length of the bottom packer and will save one complete trip in and out of the hole with the drill string assembly to change the packers. After the test for the bottom interval is completed, straddle packers are used for successive test intervals up the drill hole. See subparagraph 13.4.2, where caving or other hole conditions will not allow this procedure.

13.5 *Gravity Tests*:

13.5.1 Constant-head gravity tests are usually performed without packers above or below the water table with drill holes of N-size or larger (see fig. 2, detail D). This type of test is often made in reasonably stable-walled drill holes up to 25 feet (7.6 m) depth where water pressure at the test interval needs to be kept low. The test is usually performed in successive 5- or 10-foot (1.5- or 3-m) intervals as the drill hole is advanced. The upper end of each test interval is normally determined by the bottom depth of tightly reamed or driven casing. If the casing is not believed to be tight, appropriate entries should be recorded on the log form. If the wall of the drill hole is stable, the test can be performed in the unsupported hole. If the wall needs to be supported, use a well screen (see subpar. 11.4 for calibration) inserted through the casing. It may be necessary to ream or drive the casing to the bottom of the interval, set the screen, and then pull back the casing to expose the screen. After the test, the screen is removed and the casing reamed or driven to the bottom of the hole.

NOTE 10.–Clean coarse sand or fine gravel backfill (see subpar. 9.2) may be used instead of a well screen. Ream or drive the casing to the bottom of the interval, clean it out, and add the backfill as the casing is pulled back to expose the test interval. Record use of this procedure on the log form.

13.5.1.1 If the drill hole is self-supporting, clean and prepare it in the normal manner (see subpar. 13.1).

13.5.1.2 If the drill hole is not self-supporting, lower the well screen and casing into the hole.

13.5.1.3 For test intervals above the water table, maintain a constant head of water [within 0.2 foot (60 mm)] at the top of the test interval by injecting water through a small diameter tube extending below the water level maintained during the test. For test intervals below the water table or influenced by artesian conditions, maintain a constant head a short distance above the measured static water level.

Monitor the water level with a water-level indicator. If the water-level indicator is inserted in a small diameter pipe in the casing, the wave or ripple action on the water surface will be dampened and permit more accurate water-level measurements.

NOTE 11.–When the flow rate is very low, the constant water level can be maintained by pouring water in the hole from a graduated container.

13.5.1.4 Record the flow rate at time intervals until a constant flow rate is reached.

13.5.1.5 Repeat the procedure of subparagraphs 13.5.1.3 and 13.5.1.4 at one or more different water levels.

13.5.1.6 This test is essentially the same as designation USBR 7300 (see also [3], p. 74); the instructions in USBR 7300 for performing the test and calculating hydraulic conductivity apply to this procedure also.

14. Calculations

14.1 For pressure or constant gravity head hydraulic conductivity tests, calculate the hydraulic conductivity of

the soil or rock by the following equation (expressed in consistent units) [4]:

$$k = \frac{q}{2\pi LH} \ln \frac{L}{r}, \text{ where } L \geqq 10r \qquad (2)$$

or

$$k = \frac{q}{2\pi LH} \sinh^{-1} \frac{L}{2r}, \text{ where } 10r \geqq L \geqq r \qquad (3)$$

where:

k = hydraulic conductivity, ft/yr or cm/s
q = constant rate of flow into the test interval, ft^3/yr or cm^3/s
L = length of the test interval, ft or cm
H = differential head of water at test interval, ft or cm
r = radius of the borehole, ft or cm
ln = natural logarithm, $\log_e$
$\sinh^{-1}$ = inverse hyperbolic sine, $\sinh^{-1} x \ln (x + \sqrt{x^2 + 1})$

14.2 An example calculation for a single packer test in the bottom of a borehole below the water table follows:

Example, assume:

r = 1.8 in or 0.15 ft = 4.6 cm
q = 2.2 gal/min or 8.3 L/min
$q = 1.5 \times 10^5$ ft^3/yr = 140 cm^3/s
L = 3.0 ft = 91 cm
H_g, gravity = distance from ground-water level to pressure gauge = 10.2 ft = 311 cm
H_p, pressure = 5 $lbf/in^2 \times 2.31$ $ft_{water}/(lbf/in^2)$
= 11.6 ft = 354 cm of water
$H = H_g + H_p$ = 21.8 ft = 664 cm

$$\frac{L}{r} = \frac{3.0}{0.15} = 20, \text{ hence use equation (2):}$$

$$k = \frac{q}{2\pi LH} \ln \frac{L}{r}$$

$$k = \frac{1.5 \times 10^5 \text{ ft}^3/\text{yr}}{2\pi\,(3.0 \text{ ft})\,21.8 \text{ ft}} \ln \frac{3.0 \text{ ft}}{0.15 \text{ ft}}$$

$$k = 1.1 \times 10^3 \text{ ft/yr} = 1.1 \times 10^{-3} \text{ cm/s}$$

NOTE 12.–These equations are most applicable and reliable where the length of test interval is at least $5r$, and the interval is below the water table. The equations are based on laminar flow of fluid through porous media. Flow rates, high enough to cause turbulent flow, invalidate the results in all types of material. In fractured material, the calculated value should be considered an apparent hydraulic conductivity even under laminar flow conditions.

14.3 For pressure tests, when the test interval is below the water table, H is the distance from the water table to the elevation of the pressure gauge plus applied pressure converted to linear units of water head.

Where the test interval is above the water table, H is the distance from the midpoint of the isolated test interval to the elevation of the pressure gauge plus the applied pressure converted to linear units of water head.

For gravity tests above the water table, H is the distance between the bottom of the test interval and the water level maintained during the test.

For gravity tests below the water table, H is the distance between the pretest stabilized water level in the drill hole and the water level maintained during the test.

14.4 If there is artesian pressure, an additional pressure must be applied to overcome the artesian pressure to provide an effective test pressure. For example, if there is an artesian pressure of 5 lbf/in^2 (34 kPa) at the pressure gauge, 15 lbf/in^2 (103 kPa) could be applied, then the effective pressure would be 15 lbf/in^2 minus 5 lbf/in^2 which equals 10 lbf/in^2 (69 kPa).

14.5 The calculations can be done conveniently by (1) a nomograph [12], (2) a hand calculator with the proper functions, or (3) a computer. For repeated tests, it is convenient to prepare a table for one or more diameter drill holes and lengths of test intervals and combine the terms on the right side of the equations, other than q and H, into a coefficient.

NOTE 13.–The lugeon (lugeon unit, lugeon coefficient) [13, 14, 15, 16], has been used as an index of hydraulic conductivity, in connection with cyclic tests, and for grouting purposes.

15. Report

15.1 Record field test data on a daily driller's report, and/or on the log of the drill hole or on a special reporting form designed for the specific project. Record the following:

15.1.1 Log of the drill hole.

15.1.2 Elevations of the ground surface, the water table, and the top and bottom of the test interval.

15.1.3 Diameter of the drill hole at test interval.

15.1.4 Method of cleaning the drill hole.

15.1.5 Size of the feed pipe and any well screen.

15.1.6 Water pressure and/or gravity head, and flow rate for each time interval.

15.1.7 Total amount of water used per test.

15.1.8 Average temperature of ground water and water used in the test.

15.1.9 Packer inflation pressures.

15.1.10 Capacity of pump supplying water to the test interval.

15.1.11 All head loss calibration data.

15.1.12 Note any comments considered necessary to help evaluate the test results.

15. References

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APPENDIX

X1. PROCEDURE USING A PNEUMATIC PIEZOMETER WITH TWO PACKERS ISOLATING THE TEST INTERVAL

X1.1 Equipment Assembly (Refer to figs. X1.1 and X1.2).–A complete straddle packer unit is assembled as follows.

X1.1.1 Connect a predetermined length of perforated injection (feed) pipe to the lower packer. (The length of perforated pipe is determined by the thickness of the zone to be tested.) Connect the inflation tubing to the lower packer, and lower the sliding head end of the packer into the drill hole. (See subpar. 11.1.2.1.6 for calibration of packers.)

X1.1.2 Clamp the top of the perforated injection pipe at the hole collar, and connect the upper packer with the sliding head already down the hole.

X1.1.3 Provide approximately 12 inches (300 mm) of slack in the inflation tubing between the two packers to allow for retraction of the upper packer sliding head. Connect the tubing to the upper packer.

X1.1.4 Install the pneumatic piezometer, piezometer tubing, packer inflation tubing, and sealed lengths of injection pipe to the head adaptor.

X1.1.5 Lower the entire unit into the drill hole adding lengths of sealed injection pipe as necessary to reach the interval to be tested. As the unit is lowered, the packer inflation tubing and the piezometer tubing is unreeled into the hole and taped to the sealed injection pipe at approximately 10-foot intervals.

X1.1.6 Upon reaching the test depth, lock both the inflation tubing reel and the piezometer tubing reel; connect the inflation tubing by quick-connect couplings to a nitrogen or compressed air bottle equipped with a high pressure regulator; connect the piezometer tubing by quick-connect couplings to the readout box; and connect the injection pipe to the water pressure source. The test is now ready to begin.

X1.2 Test Procedure

X1.2.1 After the unit has been lowered to the test interval and before inflating the packers, any water head above the test interval must be determined. This head will show as pressure on the pneumatic piezometer gauge and can be verified by running a water level indicator into the hole to measure the depth to the water table. The piezometer will register water pressure that can be converted to head of water. This water head should be

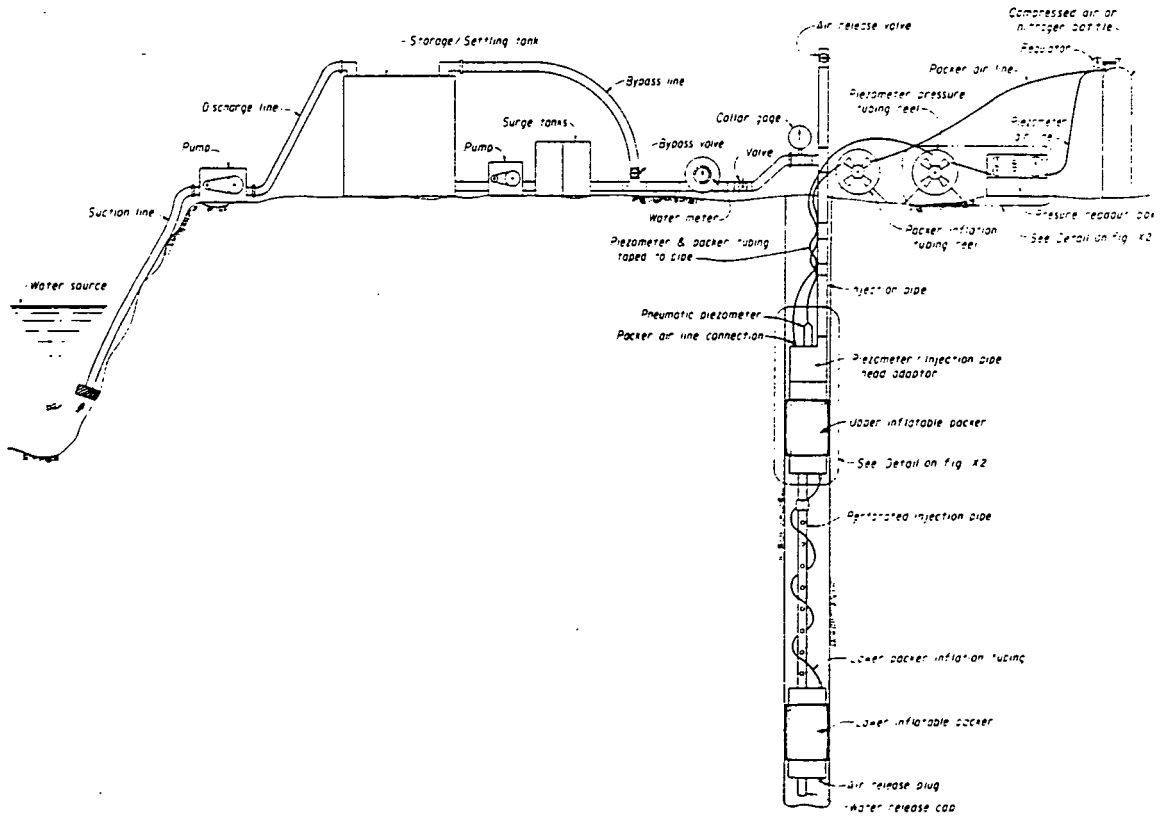

Figure X1.1. - Schematic arrangement of drill hole packer and pressure monitoring equipment. 801-D-180

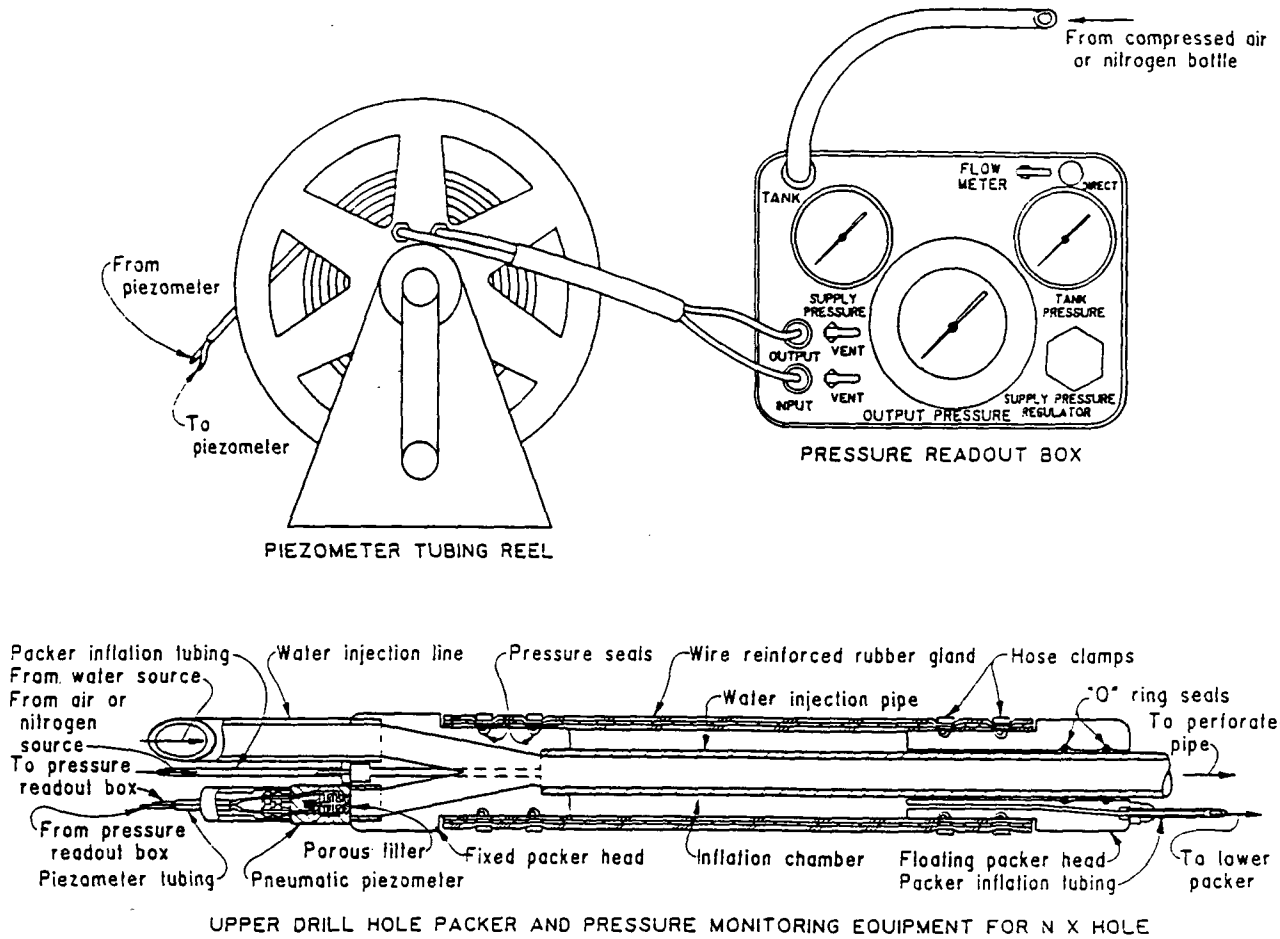

Figure X1.2. - Upper drill hole packer and pressure monitoring equipment for NX hole.

used to determine the minimum inflation pressure to be applied to the packers by the following equation:

$$SH + PP + PE = \text{minimum inflation pressure}$$

where:

SH = static pressure at the midpoint elevation of the test interval, lbf/in² or kPa

PP = gauge pressure to be maintained during the test, lbf/in² or kPa

PE = pressure needed to expand packer to hole diameter as determined before insertion in the drill hole by expanding the packer in a length of pipe having a diameter similar to the hole diameter, lbf/in² or kPa

Inflation pressure gauge is in units of lbf/in² (kPa).

The static water level measured before the packers are inflated might be a composite water level (see subpar. 13.3.4).

X1.2.2 Inflate the packers, and determine water head for the test interval. This is the static head to be used for calculation of hydraulic conductivity. If the static head is significantly different from the composite measured before the packers were inflated, recalculation of packer inflation pressure may be required. The final packer inflation pressure should be the lowest practical pressure to seal the test interval against the maximum injection pressure to avoid fracturing of the material being tested.

X1.2.3 After the inflation pressures have been determined, deflate the packers; fill and flush the system with water until all entrapped air has been removed. This is accomplished by filling the injection pipe under a gravity head and leaving the air-release valve open at the top of the injection pipe tee at an elevation higher than the injection hose. The valve must remain open until all air has been removed and water runs freely, indicating a filled system. At this point, water is flowing around the deflated packer system and is completely filling the annulus between the drillhole and the packers. In the case of an interval with a high injection rate, it may be necessary to keep the air valve closed to keep from entraining air into the test interval.

X1.2.4 Close the air release valve at the top of the injection pipe and slowly inflate the packers to the predetermined inflation pressure.

X1.2.5 Lock in the inflation pressure by closing the pressure valve in the packer tubing. If the pressure gauge

on the closed system remains steady, it verifies a sealed system. At this point, water injected under gravity head approaches a constant flow rate.

X1.2.6 Record the piezometer pressure after packer inflation. For an interval of very low injection rate, this is equal to the height of the injection standpipe plus the pressure recorded at the hole collar gauge. For a test interval with a high injection rate, the readout would show the same value less any friction from water flow through the injection pipe.

X1.2.7 Proceed with the test by applying the selected pressures at the test interval and monitoring the flow rate and pressure on the pneumatic piezometer.

X1.2.8 To accurately compute hydraulic conductivity, the down-hole pressure must remain constant. A zone with a high injection rate must be monitored more closely than a zone with a small injection rate, and adjustments made to hold the down-hole pressure constant. To accomplish this, the injection pressure shown on the collar gauge must be adjusted in order to maintain the down-hole pressure constant.

NOTE X1.–For example, a pressure stage is started with the collar gauge reading 35 lbf/in^2 (241 kPa) and the down-hole piezometer reading 200 lbf/in^2 (1380 kPa). As the flow increases, the down-hole pressure may drop to 150 lbf/in^2 (1034 kPa) because friction loss in the injection pipe and the collar gauge would have to be adjusted to bring the down-hole pressure gauge back up to 200 lbf/in^2. When the flow decreases from a fast to a slow rate, the collar gauge pressure would have to be decreased.

X1.2.9 The test is completed following one or more stages of pressure increases and pressure decreases. Following the last stage, deflate the packers and close the injection line. The system is now ready to move to the next test interval for repetition of this procedure.

ATTACHMENT C7

PRESSURE PULSE HYDRAULIC CONDUCTIVITY TEST METHODS AND ANALYSIS

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A Method for Determining the Hydraulic Properties of Tight Formations

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A method for testing formations of very low permeability is presented. The method is based on an analytical solution that describes the decay of a head change caused by pressurizing the volume of water stored in a shut-in well. Type curves prepared from this solution are matched with observed data to determine the hydraulic properties of the formation tested. The test is similar to the conventional slug test; however, its much shorter duration makes the testing of extremely tight formations feasible.

INTRODUCTION

Geohydrologists are showing an increasing interest in the hydraulic properties of so-called 'tight formations,' those units that are usually considered to be almost impermeable, for example, tightly compacted clays, rock units in which fractures, if they exist, are essentially closed or filled, or matrix rock between fractures. As the subsurface geologic units are being considered for the disposal of a variety of wastes, some of which are quite hazardous, the need often arises for quantitatively evaluating the ability of these tight units to restrict the transport of wastes by ground water. The problem is how to conduct field tests for determining their hydraulic properties. Pumping tests in adjacent, more permeable units, if any, would have to be conducted for inordinately long periods of time to reflect the properties of such tight confining beds; therefore such tests are generally not feasible. The 'slug test' as presented by *Cooper et al.* [1967] has been suggested as a possible means for testing formations with low transmissivity [*Papadopulos et al.*, 1973]. The duration of this test can be shortened by utilizing a standpipe of small radius. However, as will be shown later, when the transmissivity of the formation to be tested is extremely low, the standpipe radius needed to conduct this test within a reasonable period of time is too small to be practical.

In this paper we present an alternative method for evaluating tight formations in which the field test can be conducted within a relatively short period of time. The method is essentially a modification of the conventional slug test. Instead of causing an instantaneous water level change and observing its decay in an open standpipe, the well is filled with water to the surface and suddenly pressurized with an additional amount of water. The well is then shut-in and the decay of pressure, or of the additional head change caused by the pressurization, is observed. Possible arrangements for conducting a test of this type are shown in Figure 1. The theory for analyzing pressure or head decay data from the test and a comparison of the method to the conventional slug test are presented below.

THEORY

Consider a well system similar to one of those shown in Figure 1. The initial head in the interval to be tested may or may not be known, depending on the time that has elapsed since the well has been drilled. Thus prior to the test the water level in the well could be stable, or it could be rising or falling. However, because of the low hydraulic conductivity of the formation any rise or fall of the water level is at a very slow rate. To conduct the test, the system is filled with water, and after a period of observation of the water level the system is suddenly pressurized by injecting an additional amount of water with a high-pressure pump. The system is then shut-in, and the head change H_0 caused by the pressurization is allowed to decay. The head variation in the system is schematically shown in Figure 2.

We are interested in obtaining a relation between (1) the head change H in the system (see Figure 2) at any time t after pressurization and (2) the hydraulic properties of the tested interval. It is assumed that the water level decline which follows the filling of the system with water is at such a slow rate that it is either negligible for the duration of the pressurization period or it can be projected to the end of this period without significant errors. The head change H_0 is superimposed on this water level decline, and both H_0 and H are measured above it or its projection (see Figure 2). It is further assumed that the flow in the tested interval is primarily radial and that the hydraulic properties of the formation remain constant throughout the test.

Under these assumptions the boundary value problem describing the flow system can be expressed as

$$\frac{\partial^2 h}{\partial r^2} + \frac{1}{r}\frac{\partial h}{\partial r} = \frac{S}{T}\frac{\partial h}{\partial t} \tag{1}$$

$$h(r, 0) = 0 \tag{2}$$

$$h(\infty, t) = 0 \tag{3}$$

$$h(r_s, t) = H(t) \tag{4}$$

$$H(0) = H_0 \tag{5}$$

$$2\pi r_s T \frac{\partial h}{\partial r}(r_s, t) = V_w C_w \rho_w g \frac{\partial H}{\partial t}(t) \tag{6}$$

where

- h head change in the tested interval of the formation due to the pressurization, dimension L;
- r radial distance from the center of the well, L;
- S storage coefficient of the tested interval, dimensionless;
- T transmissivity of the tested interval, L^2/T;
- r_s radius of well in the tested interval, L;
- V_w volume of water within the pressurized section of the system, L^3;

[1] Now at S. S. Papadopulos and Associates, Inc., Potomac, Maryland 20854.

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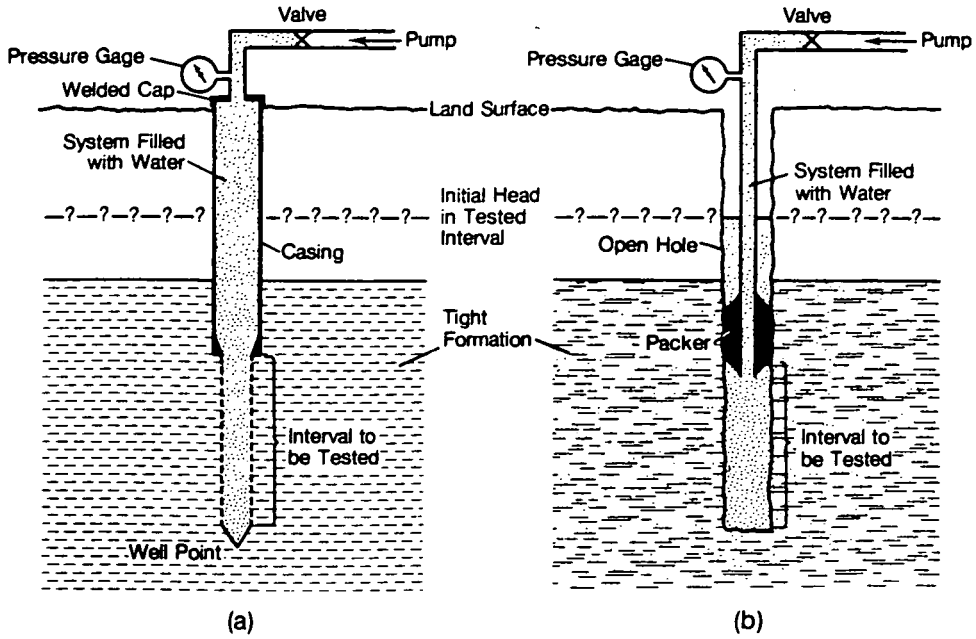

Fig. 1. Possible arrangements for conducting pressurized test (*a*) in unconsolidated formations and (*b*) in consolidated formations.

C_w compressibility of water, LT^2/M;
ρ_w density of water, M/L^3;
g gravitational acceleration, L/T^2.

And H_0, H, and t are as previously defined. Equation (1) is the differential equation of nonsteady radial groundwater flow in a confined formation [*Jacob*, 1950]. Equations (2) and (3) state that the head change due to the pressurization of the system is initially zero everywhere in the formation, and that at infinity, that is, at very large distances from the well, the head change remains equal to zero at all times. Equation (4) states that at the well face the head change in the formation is equal to the head change in the well, and (5) states that the initial he change in the well is equal to H_0. Finally, (6) states that t rate at which water flows from the well into the formation, expressed by applying Darcy's law at the well face, is equal the rate at which the volume of water stored within the pre surized system expands as the head, or the pressure, within t system declines. It is assumed that volumetric changes due the expansion and contraction of other components of the sy tem are negligible.

With the exception of the form of (6), the boundary valu problem presented above is identical to that describing a co ventional slug test [*Cooper et al.*, 1967]. In a conventional slu test the rate at which water flows from the well into the forma tion is equal to the rate at which the volume of water stored i the well changes as the water level declines in the well. Th equivalent of (6) is therefore expressed by *Cooper et al.* [196 p. 264, equation (5*c*)] as

$$2\pi r_s T \frac{\partial h}{\partial r}(r_s, t) = \pi r_c^2 \frac{\partial H}{\partial t}(t) \quad (7$$

where r_c is the radius of the well casing, or of the standpipe, i the interval over which the water level decline takes plac Note that (7) becomes identical to (6) if r_c^2 is replaced b $V_w C_w \rho_w g/\pi$. Therefore the solutions for a conventional slu test presented by *Cooper et al.* [1967, p. 264, equation (8), an p. 265, equation (9)] become solutions to the problem de scribed above if $V_w C_w \rho_w g/\pi$ replaces r_c^2 everywhere in the so lutions. The resulting solution for the head change in the wel is

$$\frac{H}{H_0} = F\left(\frac{\pi r_s^2 S}{V_w C_w \rho_w g}, \frac{\pi T t}{V_w C_w \rho_w g}\right) \quad (8$$

From *Cooper et al.* [1967, p. 265, equation (9)] the functio $F(\alpha, \beta)$, α and β being dummy variables corresponding to th first and second parameters of the function, can be defined as

$$F(\alpha, \beta) = \frac{8\alpha}{\pi^2} \int_0^\infty \frac{\exp(-\beta u^2/\alpha)}{u f(u, \alpha)} du \quad (9$$

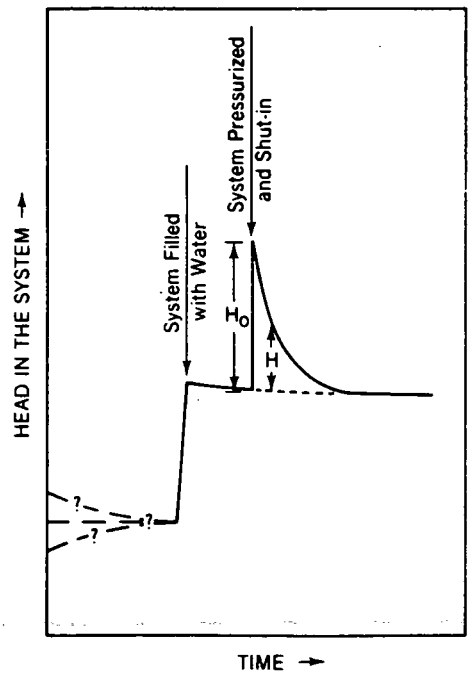

Fig. 2. Schematic variation of head in well system prior to and after pressurization.

TABLE 1. Values of the Function $F(\alpha, \beta)$

β	$\alpha=0.1$	$\alpha=0.2$	$\alpha=0.5$	$\alpha=1$	$\alpha=2$	$\alpha=5$	$\alpha=10$
0.000001	0.9993	0.9990	0.9984	0.9977	0.9968	0.9948	0.9923
0.000002	0.9990	0.9986	0.9977	0.9968	0.9955	0.9927	0.9894
0.000004	0.9986	0.9980	0.9968	0.9955	0.9936	0.9898	0.9853
0.000006	0.9982	0.9975	0.9961	0.9945	0.9922	0.9876	0.9822
0.000008	0.9980	0.9971	0.9955	0.9936	0.9910	0.9857	0.9796
0.00001	0.9977	0.9968	0.9945	0.9929	0.9900	0.9841	0.9773
0.00002	0.9968	0.9955	0.9929	0.9900	0.9858	0.9776	0.9683
0.00004	0.9955	0.9936	0.9899	0.9858	0.9801	0.9687	0.9558
0.00006	0.9944	0.9922	0.9877	0.9827	0.9757	0.9619	0.9464
0.00008	0.9936	0.9909	0.9858	0.9800	0.9720	0.9562	0.9387
0.0001	0.9929	0.9899	0.9841	0.9777	0.9688	0.9512	0.9318
0.0002	0.9898	0.9857	0.9776	0.9687	0.9562	0.9321	0.9059
0.0004	0.9855	0.9797	0.9685	0.9560	0.9389	0.9061	0.8711
0.0006	0.9822	0.9752	0.9615	0.9465	0.9258	0.8869	0.8458
0.0008	0.9794	0.9713	0.9557	0.9385	0.9151	0.8711	0.8253
0.001	0.9769	0.9679	0.9505	0.9315	0.9057	0.8576	0.8079
0.002	0.9670	0.9546	0.9307	0.9048	0.8702	0.8075	0.7450
0.004	0.9528	0.9357	0.9031	0.8686	0.8232	0.7439	0.6684
0.006	0.9417	0.9211	0.8825	0.8419	0.7896	0.7001	0.6178
0.008	0.9322	0.9089	0.8654	0.8202	0.7626	0.6662	0.5797
0.01	0.9238	0.8982	0.8505	0.8017	0.7400	0.6384	0.5492
0.02	0.8904	0.8562	0.7947	0.7336	0.6595	0.5450	0.4517
0.04	0.8421	0.7980	0.7214	0.6489	0.5654	0.4454	0.3556
0.06	0.8048	0.7546	0.6697	0.5919	0.5055	0.3872	0.3030
0.08	0.7734	0.7150	0.6289	0.5486	0.4618	0.3469	0.2682
0.1	0.7459	0.6885	0.5951	0.5137	0.4276	0.3168	0.2428
0.2	0.6418	0.5774	0.4799	0.4010	0.3234	0.2313	0.1740
0.4	0.5095	0.4458	0.3566	0.2902	0.2292	0.1612	0.1207
0.6	0.4227	0.3642	0.2864	0.2311	0.1817	0.1280	0.09616
0.8	0.3598	0.3072	0.2397	0.1931	0.1521	0.1077	0.08134
1.	0.3117	0.2648	0.2061	0.1663	0.1315	0.09375	0.07120
2.	0.1786	0.1519	0.1202	0.09912	0.08044	0.05940	0.04620
4.	0.08761	0.07698	0.06420	0.05521	0.04668	0.03621	0.02908
6.	0.05527	0.04599	0.04331	0.03830	0.03326	0.02663	0.02185
8.	0.03963	0.03658	0.03254	0.02933	0.02594	0.02125	0.01771
10.	0.03065	0.02870	0.02600	0.02376	0.02130	0.01776	0.01499
20.	0.01408	0.01361	0.01288	0.01219	0.01133	0.009943	0.008716
40.	0.006680	0.006568	0.006374	0.006171	0.005897	0.005395	0.004898
60.	0.004367	0.004318	0.004229	0.004132	0.003994	0.003726	0.003445
80.	0.003242	0.003214	0.003163	0.003105	0.003022	0.002853	0.002668
100.	0.002577	0.002559	0.002526	0.002487	0.002431	0.002313	0.002181
200.	0.001271	0.001266	0.001258	0.001247	0.001230	0.001194	0.001149
400.	0.0006307	0.0006295	0.0006272	0.0006242	0.0006195	0.0006085	0.0005944
600.	0.0004193	0.0004188	0.0004177	0.0004163	0.0004141	0.0004087	0.0004016
800.	0.0003140	0.0003137	0.0003131	0.0003123	0.0003110	0.0003078	0.0003035
1000.	0.0002510	0.0002508	0.0002504	0.0002495	0.0002490	0.0002469	0.0002440

where

$$f(u, \alpha) = [uJ_0(u) - 2\alpha J_1(u)]^2 + [uY_0(u) - 2\alpha Y_1(u)]^2$$

and $J_0(u)$, $J_1(u)$, $Y_0(u)$, and $Y_1(u)$ are the zero and first-order Bessel functions of the first and second kind.

Tables of function $F(\alpha, \beta)$ against β are given by *Cooper et al.* [1967] and *Papadopulos et al.* [1973] for 10 orders of α, $\alpha = 10^{-10}$ to $\alpha = 10^{-1}$. However, the first parameter of the function in (8) could often have values that are much larger than 10^{-1}; therefore additional values of the function for several α, in the range $10^{-1} \leq \alpha \leq 10$, were computed and are given in Table 1. It can be shown that for small values of the ratio β/α, that is, for small β or large α, the function can be approximated by

$$F(\alpha, \beta) \cong e^{4\alpha\beta} \operatorname{erfc}(2(\alpha\beta)^{1/2}) \qquad (10)$$

When this approximation is valid, the function ceases to be dependent on both α and β and depends only on the product $\alpha\beta$. Values of the approximation are given in Table 2. Plots of $F(\alpha, \beta)$, as defined by (9), and of the approximation given by (10) against the product parameter $\alpha\beta$, as shown in Figure 3, indicate that for the practical purpose of analyzing test data the approximation can be used whenever α is larger than 10.

TABLE 2. Values of the Approximation to $F(\alpha, \beta)$ Given by (10)

$\alpha\beta$	Eq.10	$\alpha\beta$	Eq.10
0.000001	0.9977	0.6	0.3137
0.000002	0.9968	0.8	0.2800
0.000004	0.9955	1.	0.2554
0.000006	0.9945	2.	0.1888
0.000008	0.9936	4.	0.1370
0.00001	0.9929	6.	0.1129
0.00002	0.9900	8.	0.09825
0.00004	0.9859	10.	0.08813
0.00006	0.9828	20.	0.06269
0.00008	0.9801	40.	0.04446
0.0001	0.9778	60.	0.03634
0.0002	0.9689	80.	0.03149
0.0004	0.9564	100.	0.02817
0.0006	0.9470	200.	0.01993
0.0008	0.9392	400.	0.01410
0.001	0.9325	600.	0.01151
0.002	0.9066	800.	0.009972
0.004	0.8719	1000.	0.008920
0.006	0.8467	2000.	0.006307
0.008	0.8263	4000.	0.004460
0.01	0.8090	6000.	0.003642
0.02	0.7466	8000.	0.003154
0.04	0.6708	10000.	0.002821
0.06	0.6209	20000.	0.001995
0.08	0.5835	40000.	0.001410
0.1	0.5536	60000.	0.001152
0.2	0.4582	80000.	0.0009974
0.4	0.3647	100000.	0.0008921

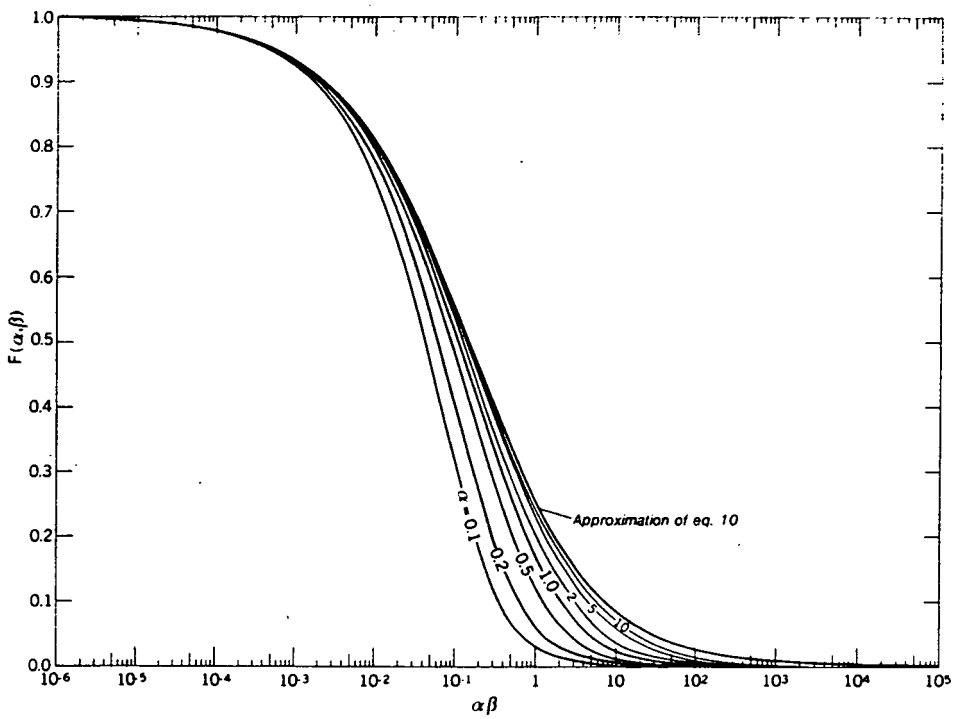

Fig. 3. Type curves of the function $F(\alpha, \beta)$ against the product parameter $\alpha\beta$.

METHOD OF ANALYSIS

The method of analyzing pressure or head decay data collected during the test depends on whether the parameter α, that is, $\pi r_s^2 S/V_w C_w \rho_w g$, is larger or smaller than 0.1. The methods applicable for $\alpha \leq 0.1$ and for $\alpha > 0.1$ are described below. Since the magnitude of α would not be known in advance, an attempt should be made to analyze test data by the method applicable for $\alpha \leq 0.1$. If this attempt indicates that α is larger than 0.1, then the method applicable for $\alpha > 0.1$ is used.

For $\alpha \leq 0.1$ the data are analyzed in a manner similar to that explained by *Cooper et al.* [1967] for the analysis of conventional slug test data. Briefly, the method consists of preparing a family of type curves, one for each α, of $F(\alpha, \beta)$ against β on semilogarithmic paper. Observed values of H/H_0 are plotted against time t on semilogarithmic paper of the same scale and are matched with a type curve by keeping the β and t axes coincident and moving the plots horizontally. The expressions corresponding to α and β in (8), the α value of the matched type curve, and the β and t values from a match point are used to determine the transmissivity and the storage coefficient of the tested interval.

In this range of α, that is, for $\alpha \leq 0.1$, the type curves of $F(\alpha, \beta)$ against β are somewhat similar in shape, but the horizontal shift from one type curve to the next is small and becomes smaller as α becomes smaller. Thus if the accuracy of the test data is such that a clear distinction cannot be made between adjacent type curves and the data are matched with the incorrect type curve, the error in the determined storage coefficient would be as large as the error in α; however, because of the small horizontal shift in the type curves the error in the determined transmissivity would be small. Analyses show that even an error of 2 orders of magnitude in α would result in an error of less than 30% in the value of the determined transmissivity [*Papadopulos et al.*, 1973]. Therefore the use of type curves prepared as described above yields good estimates of the transmissivity when $\alpha \leq 0.1$; but the storage coefficient could be of questionable reliability, as also stated by *Cooper et al.* [1967] and *Papadopulos et al.* [1973] in their discussion of the conventional slug test.

The method of analysis described above is not suitable for $\alpha \leq 0.1$. As α becomes large both (1) the similarity in the shape of type curves prepared by plotting $F(\alpha, \beta)$ against β and (2) the horizontal shift from one curve to the next increase; the type curves tend to plot parallel to each other, and curves for α values that differ by 1 order of magnitude plot one log cycle apart. Thus not only the probability of matching test data with the incorrect type curve increases, but also the error in the determined transmissivity, caused by the incorrect choice of type curve, becomes as large as that in the storage coefficient. This is due to the fact that for large α a major part of the type curve is defined by the approximation of (10) and is dependent on the product $\alpha\beta$. In Figure 3, note that the upper part of the curves for different α coincides with the curve for the approximation; the larger the α the greater the portion of the curve that coincides with the approximation. Since

$$\alpha\beta = \frac{\pi^2 r_s^2 TSt}{(V_w C_w \rho_w g)^2} \tag{11}$$

the analysis of test data that fall in the range of the approximation would yield only TS, the product of transmissivity and storage coefficient. Therefore for $\alpha > 0.1$ type curves of $F(\alpha, \beta)$ against $\alpha\beta$, as shown in Figure 3, are more suitable for analyzing the test data. Analysis with these type curves provides insight as to whether the data are adequate for identifying both α and β and hence determining both T and S, or whether the data fall in the range where only the product TS can be determined.

COMPARISON TO CONVENTIONAL SLUG TEST

We stated earlier that the test described in this paper can be conducted within a relatively short period of time. Figure 4

was prepared to illustrate this point. It compares the decay of the head change caused by the pressurization of a system similar to that shown in Figure 1*b* with the decay of the water level after a conventional slug test in the same system. It is assumed that the conventional slug test was conducted by instantaneously changing the water level within the packer standpipe with the valve and pump disconnected. The following parameters and system dimensions were used in calculating the curves shown in Figure 4:

Parameter	Dimension
Transmissivity of tested interval	10^{-11} m²/s
Storage coefficient of tested interval	4×10^{-4}
Thickness of tested interval	10 m
Radius of well in tested interval	0.1 m
Radius of stand pipe	0.02 m
Length of stand pipe (bottom of packer to valve)	90 m
Compressibility of water	4.6×10^{-10} m²/N
Density of water	1000 kg/m³

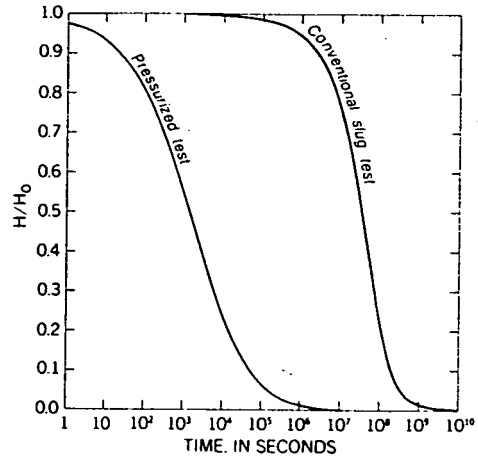

Fig. 4. Head or water level decay in well system during pressurized and conventional slug tests.

The response to pressurization was calculated using (8), and that to the conventional test by the applicable equation [*Cooper et al.*, 1967, p. 265, equation (9)], which can be expressed as

$$\frac{H}{H_0} = F\left(\frac{r_s^2 S}{r_c^2}, \frac{Tt}{r_c^2}\right) \tag{12}$$

Note that complete decay of the head change requires a very long time, about 10^7 s (116 days) for the pressurized test and 10^{10} s (116,000 days or 320 years) for the conventional test. However, in an actual field test, data collected during 50% decay of the head change ($H/H_0 = 0.5$), or at most an 80% decay ($H/H_0 = 0.2$) would be sufficient for analyzing the test. For the pressurized test the time required for 50% decay is about 1400 s (24 min), and for 80% decay about 14,000 s (4 hours). The corresponding times for the conventional test are 3.5×10^7 s (410 days or 1.1 years) and 1.1×10^8 s (1300 days or 3.5 years), respectively. Obviously, for a conventional test the duration of even the 50% decay is too long to be reasonable for practical applications.

DISCUSSION

The comparison presented above clearly demonstrates the advantage of using the method described in this paper for testing tight formations. The assumed transmissivity corresponds to a hydraulic conductivity of 10^{-12} m/s. Some shales, basalts, and salt formations that are being considered for the disposal of hazardous wastes are expected to have an even lower hydraulic conductivity. For example, permeabilities corresponding to hydraulic conductivities of 10^{-13}–10^{-16} m/s and of 10^{-9}–10^{-14} m/s have been reported for intact and fractured specimens, respectively, of an argillite from the Eleana Formation at the Nevada Test Site [*Lin*, 1978]. The method presented here could be the only possible method for in situ evaluation of such formations.

As in any other test method, this method is valid only if the underlying assumptions are satisfied in the field. Two critical assumptions are that (1) the flow in the tested interval is primarily radial and (2) the hydraulic properties of the tested interval remain constant throughout the test. In most instances the first of these assumption would be valid because (1) the length of the tested interval is usually much larger than the diameter of the well and (2) most natural formations have a vertical-to-horizontal anisotropy with the largest principal hydraulic conductivity in the horizontal direction. To assure that the second assumption is satisfied, especially in fractured rocks, care should be taken during pressurization to keep the fluid pressure in the tested interval well below the least principal rock stress to avoid either modifying the local permeability or opening fractures. Unfortunately, in most instances the least principal stress is unknown; therefore it is advisable to limit the initial head change H_0 to a magnitude only sufficiently large to be adequately measured. With modern pressure transducers head changes of 0.01 m of water are easily measured. Initial pulses of 1–10 m (10–100 kPa) are quite sufficient in most instances; such changes in stress are almost always too small to cause significant changes in rock properties.

We stated earlier that the duration of a conventional slug test could be shortened by reducing the radius of the standpipe r_c over the interval that the water level change takes place. Actually, for a given transmissivity and storage coefficient the duration of a test, regardless of whether it is pressurized or conventional, depends on the volume of water that flows into the formation per unit decline of head, or water level, in the well. This volume per unit decline is $V_w C_w \rho_w g$ in the case of a pressurized test and πr_c^2 in the case of a conventional test. Note that the solution for the pressurized test, equation (8), was obtained by substituting the first of these quantities for the second in the solution for the conventional slug test, equation (12). If these two quantities are equal to each other, the durations of both tests would be the same. In other words, if the conventional test is conducted with a standpipe that has a radius

$$r_c = (V_w C_w \rho_w g/\pi)^{1/2} \tag{13}$$

the duration of the test would be the same as that of a pressurized test. Of course, this may not be always possible. For instance, in the example used for the comparison of Figure 4 the radius required to reduce the duration of the conventional test to that of the pressurized test would have been 0.00078 m, too small a radius to be practical.

Equation (13) can be used as a criterion (in conjunction with other factors pertaining to the convenience of conducting a test of one type or other) to select between the pressurized or the conventional slug test for testing a tight formation. In terms of duration the test that involves the smaller volume per unit decline of head would be the shortest.

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Designation: D 4631 – 86

Standard Test Method for Determining Transmissivity and Storativity of Low Permeability Rocks by In-Situ Measurements Using the Pressure Pulse Technique[1]

This standard is issued under the fixed designation D 4631; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers a field procedure for determining the transmissivity and storativity of geological formations having permeabilities lower than 10^{-3} μm^2 (1 millidarcy) using the pressure pulse technique.

1.2 The transmissivity and storativity values determined by this test method provide a good approximation of the capacity of the zone of interest to transmit water, if the test intervals are representative of the entire zone and the surrounding rock is fully water saturated.

1.3 The values stated in SI units are to be regarded as the standard.

1.4 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Terminology

2.1 *Descriptions of Terms Specific to This Standard:*

2.1.1 *transmissivity, T*—the transmissivity of a formation of thickness, *b*, is defined as follows:

$$T = K \cdot b$$

where:

K = equivalent formation hydraulic conductivity (efhc).

The efhc is the hydraulic conductivity of a material if it were homogeneous and porous over the entire interval. The hydraulic conductivity, K, is related to the equivalent formation, k, as follows:

$$K = k\rho g/\mu$$

where:

ρ = fluid density,
μ = fluid viscosity, and
g = acceleration due to gravity.

2.1.2 *storativity, S*—the storativity (or storage coefficient) of a formation of thickness, *b*, is defined as follows:

$$S = S_s \cdot b$$

where:

S_s = equivalent bulk rock specific storage (ebrss).

The ebrss is defined as the specific storage of a material if it were homogeneous and porous over the entire interval. The specific storage is given as follows:

$$S_s = \rho g\,(C_b + nC_w)$$

where:

C_b = bulk rock compressibility,
C_w = fluid compressibility, and
n = formation porosity.

2.2 *Symbols:*

2.2.1 C_b—bulk rock compressibility ($M^{-1}LT^2$).
2.2.2 C_w—compressibility of water ($M^{-1}LT^2$).
2.2.3 K—hydraulic conductivity (LT^{-1}).
2.2.4 L—length of packed-off zone (L).
2.2.5 P—excess test hole pressure ($ML^{-1}T^{-2}$).
2.2.6 P_o—initial pressure pulse ($ML^{-1}T^{-2}$).
2.2.7 S—storativity (or storage coefficient) (dimensionless).
2.2.8 S_s—specific storage (L^{-1}).
2.2.9 T—transmissivity (L^2T^{-1}).
2.2.10 V_w—volume of water pulsed (L^3).
2.2.11 b—formation thickness (L).
2.2.12 e—fracture aperture (L).
2.2.13 g—acceleration due to gravity (LT^{-2}).
2.2.14 k—permeability (L^2).
2.2.15 n—porosity (dimensionless).
2.2.16 r_w—radius of test hole (L).
2.2.17 t—time elapsed from pulse initiation (T).
2.2.18 α—dimensionless parameter.
2.2.19 β—dimensionless parameter.
2.2.20 μ—viscosity of water ($ML^{-1}T^{-1}$).
2.2.21 ρ—density of water (ML^{-3}).

3. Summary of Test Method

3.1 A borehole is first drilled into the rock mass, intersecting the geological formations for which the transmissivity and storativity are desired. The borehole is cored through potential zones of interest, and is later subjected to geophysical borehole logging over these intervals. During the test, each interval of interest is packed off at top and bottom with inflatable rubber packers attached to high-pressure steel tubing. After inflating the packers, the tubing string is completely filled with water.

3.2 The test itself involves applying a pressure pulse to the water in the packed-off interval and tubing string, and recording the resulting pressure transient. A pressure transducer, located either in the packed-off zone or in the tubing at the surface, measures the transient as a function of time. The decay characteristics of the pressure pulse are dependent

[1] This test method is under the jurisdiction of ASTM Committee D-18 on Soil and Rock and is the direct responsibility of Subcommittee D18.12 on Rock Mechanics.

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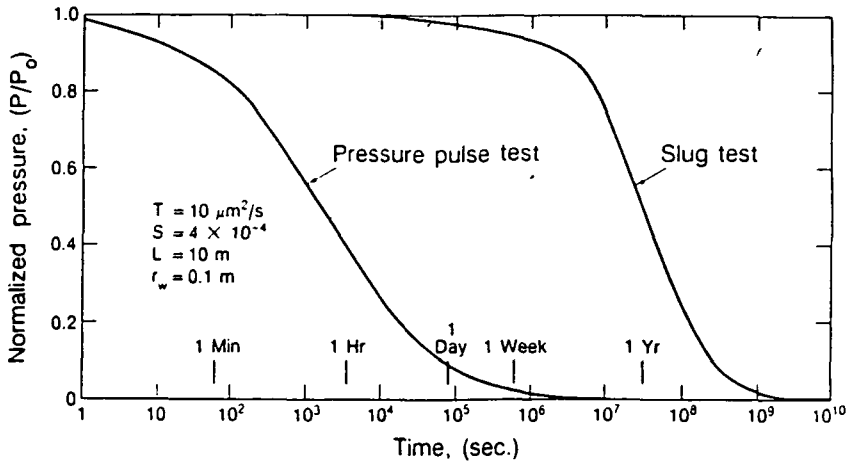

FIG. 1 Comparative Times for Pressure Pulse and Slug Tests

on the transmissivity and storativity of the rock surrounding the interval being pulsed and on the volume of water being pulsed. Alternatively, under non-artesian conditions, the pulse test may be performed by releasing the pressure on a shut-in well, thereby subjecting the well to a negative pressure pulse. Interpretation of this test method is similar to that described for the positive pressure pulse.

4. Significance and Use

4.1 *Test Method*—The pulse test method is used to determine the transmissivity and storativity of low-permeability formations surrounding the packed-off intervals. The test method is considerably shorter in duration than the pump and slug tests used in more permeable rocks. To obtain results to the desired accuracy, pump and slug tests in low-permeability formations are too time consuming, as indicated in Fig. 1 (from Bredehoeft and Papadopulos **(1)**).[2]

4.2 *Analysis*—The transient pressure data obtained using the suggested method are evaluated by the curve-matching technique described by Bredehoeft and Papadopulos **(1)**, or by an analytical technique proposed by Wang *et al* **(2)**. The latter is particularly useful for interpreting pulse tests when only the early-time transient pressure decay data are available.

4.3 *Units:*

4.3.1 *Conversions*—The permeability of a formation is often expressed in terms of the unit darcy. A porous medium has a permeability of 1 darcy when a fluid of viscosity 1 cP (1 mPa·s) flows through it at a rate of 1 cm^3/s (10^{-6} m^3/s)/1 cm^2 (10^{-4} m^2) cross-sectional area at a pressure differential of 1 atm (101.4 kPa)/1 cm (10 mm) of length. One darcy corresponds to 0.987 μm^2. For water as the flowing fluid at 20°C, a hydraulic conductivity of 9.66 μm/s corresponds to a permeability of 1 darcy.

4.3.2 *Viscosity of Water*—Table 1 shows the viscosity of water as a function of temperature.

5. Apparatus

NOTE—A schematic of the test equipment is shown in Fig. 2.

5.1 *Source of Pressure Pulse*—A pump or pressure intensifier shall be capable of injecting an additional amount of water to the water-filled tubing string and packed-off test interval to produce a sharp pressure pulse of up to 1 MPa (145 psi) in magnitude, preferably with a rise time of less than 1 % of one half of the pressure decay ($P/P_o = 0.5$).

5.2 *Packers*—Hydraulically actuated packers are recommended because they produce a positive seal on the borehole wall and because of the low compressibility of water they are also comparatively rigid. Each packer shall seal a portion of the borehole wall at least 0.5 m in length, with an applied pressure at least equal to the excess maximum pulse pressure to be applied to the packed-off interval and less than the formation fracture pressure at that depth.

5.3 *Pressure Transducers*—The test pressure may be measured directly in the packed-off test interval or at the surface with an electronic pressure transducer. In either case the pressure shall be recorded at the surface as a function of time. The pressure transducer shall have an accuracy of at least ±3 kPa (±0.4 psi), including errors introduced by the

TABLE 1 Viscosity of Water as a Function of Temperature

Temperature, °C	Absolute Viscosity, mPa · s
0	1.79
2	1.67
4	1.57
6	1.47
8	1.39
10	1.31
12	1.24
14	1.17
16	1.11
18	1.06
20	1.00
22	0.96
24	0.91
26	0.87
28	0.84
30	0.80
32	0.77
34	0.74
36	0.71
38	0.68
40	0.66

[2] The boldface numbers in parentheses refer to the list of references at the end of this standard.

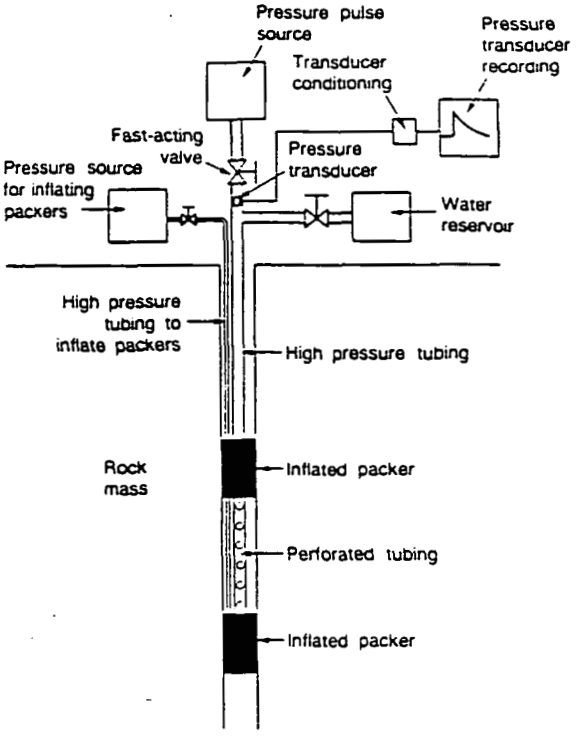

FIG. 2 Schematic of Test Equipment

recording system, and a resolution of at least 1 kPa (0.15 psi).

5.4 *Hydraulic Systems*—The inflatable rubber packers shall be attached to high-pressure steel tubing reaching to the surface. The packers themselves shall be inflated with water using a separate hydraulic system. The pump or pressure intensifier providing the pressure pulse shall be attached to the steel tubing at the surface. If the pump is used, a fast-operating valve shall be mounted in the tubing at the surface near the pressure pump.

6. Procedure

6.1 *Drilling Test Holes:*

6.1.1 *Number and Orientation*—The number of test holes shall be sufficient to supply the detail required by the scope of the project. The test holes shall be directed to intersect major fracture sets, preferable at right angles.

6.1.2 *Test Hole Quality*—The drilling procedure shall provide a borehole sufficiently smooth for packer seating, shall contain no rapid changes in direction, and shall minimize formation damage.

6.1.3 *Test Holes Cored*—Core the test holes through zones of potential interest to provide information for locating test intervals.

6.1.4 *Core Description*—Describe the rock core from the test holes with particular emphasis on the lithology and natural discontinuities.

6.1.5 *Geophysical Borehole Logging*—Log geophysically the zones of potential interest. In particular, run electrical-induction and gamma-gamma density logs. Run other logs as required.

6.1.6 *Washing Test Holes*—The test holes must not contain any material that could be washed into the permeable zones during testing, thereby changing the transmissivity and storativity. Flush the test holes with clean water until the return is free from cuttings and other dispersed solids.

6.2 *Test Intervals:*

6.2.1 *Selection of Test Intervals*—Test intervals are determined from the core descriptions, geophysical borehole logs, and, if necessary, from visual inspection of the borehole with a borescope or TV camera.

6.2.2 *Changes in Lithology*—Test each major change in lithology that can be isolated between packers.

6.2.3 *Sampling Discontinuities*—Discontinuities are often the major permeable features in hard rock. Test jointed zones, fault zones, bedding planes, and the like, both by isolating individual features and by evaluating the combined effects of several features.

6.2.4 *Redundancy of Tests*—To evaluate variability in transmissivity and storativity, conduct several tests in each rock type, if homogeneous. If the rock is not homogeneous, each set of tests should encompass similar types of discontinuities.

6.3 *Test Water:*

6.3.1 *Quality*—Water used for pressure pulse tests shall be clean, and compatible with the formation. Even small amounts of dispersed solids in the injection water could plug the rock face of the test interval and result in a measured transmissivity value that is erroneously low.

6.3.2 *Temperature*—The lower limit of the test water temperature shall be 5°C below that of the rock mass to be tested. Cold water injected into a warm rock mass causes air to come out of solution, and the resulting bubbles will radically modify the pressure transient characteristics.

6.4 *Testing:*

6.4.1 *Filling and Purging System*—Allow sufficient time after washing the test hole for any induced formation pressures to dissipate. Once the packers have been set, slowly fill the tubing string and packed-off interval with water to ensure that no air bubbles will be trapped in the test interval and tubing.

6.4.2 *Pressure Pulse Test*—Rapidly pressurize the tubing, typically to between 300 and 600 kPa (50 to 100 psi), and then shut in. This range of pressures is in most cases sufficiently low to minimize distortion of fractures adjacent to the test hole, but in no case should the pressure exceed the minimum principal ground stress. Record the resulting pressure pulse and decay transient detected by the pressure transducer as a function of time. A typical record is shown in Fig. 3.

7. Calculation and Interpretation of Test Data

7.1 The type of matching technique developed by Bredehoeft and Papadopulos (1) involves plotting normalized pressure (the ratio of the excess borehole pressure, P, at a given time to the initial pressure pulse, P_o) against the logarithm of time, as indicated in Figs. 2 and 3. The pulse decay is given as follows:

$$\frac{P}{P_o} = F(\alpha,\beta) \tag{1}$$

where:

α and β = dimensionless parameters given by:

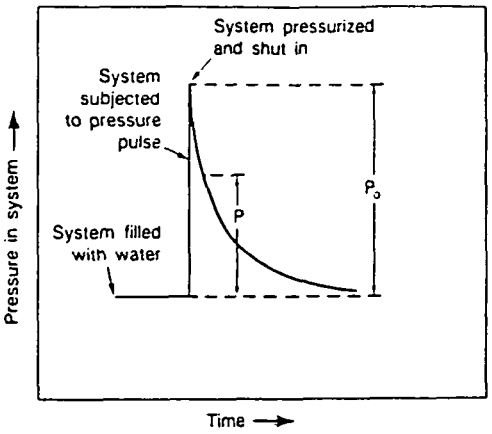

FIG. 3 Typical Pressure Record

$$\alpha = \pi r_w^2 S / V_w C_w \rho g \quad (2)$$

$$\beta = \beta T t / V_w C_w \rho g \quad (3)$$

where:

V_w = volume of water being pulsed,
r_w = well radius,
t = time elapsed from pulse initiation,
C_w = compressibility of water,
T = transmissivity, and
S = storativity.

7.1.1 In Fig. 3, the pressure of the packed-off interval and tubing filled with water is considered constant. In those cases where the response of the system to filling is time dependent, interpretation of the pressure pulse test is unaffected, provided the time dependency is linear. Neuzil (3) has proposed a modification to the Bredehoeft and Papadopulos procedure for interpreting test data when the response of the system to filling is non-time dependent and when the compressibility of the shut-in well is significantly larger than that of water. Tables of the function $F(\alpha, \beta)$ have been provided by Cooper *et al* (4), Papadopulos (5), and Bredehoeft and Papadopulos (1).

7.2 The method for analyzing pulse decay data depends on whether the parameter α is larger or smaller than 0.1. Since the value of α is not known *a priori*, the test data are first analyzed by the method applicable to $\alpha < 0.1$. If this analysis indicates that $\alpha > 0.1$, then that method is used.

7.2.1 For $\alpha < 0.1$, the data are analyzed by the method described by Cooper *et al* (4), in which the family of curves shown in Fig. 4 for $F(\alpha, \beta)$ as a function of β for various values of α are used. Observed values of P/P_o are plotted as a function of time, t, on semilogarithmic paper of the same scale, and are matched with a type curve by keeping the β and t axes coincident and moving the plots horizontally.

7.2.2 The expressions corresponding to α and β in Eqs 1 and 2, the α value of the matched type curve, and the β and t values from a match point are used to determine the transmissivity, T, and the storage coefficient, S, of the tested interval. Bredehoeft and Papadopulos (1) indicate that this procedure yields good estimates of the transmissivity when $\alpha \leq 0.1$, but that the storage coefficient could be of questionable reliability for values of $\alpha < 10^{-5}$.

7.2.3 For $\alpha > 0.1$, Bredehoeft and Papadopulos (1) recommend the use of the family of curves shown in Fig. 5 for $F(\alpha, \beta)$ as a function of the product $\alpha\beta = \left(\frac{\pi^2 r_w^2 TSt}{(V_w C_w \rho g)^2}\right)$ to interpret the data. Matching of the observed values of P/P_o plotted as a function of t with a type curve is performed in the same manner as indicated previously for $\alpha \leq 0.1$. In this

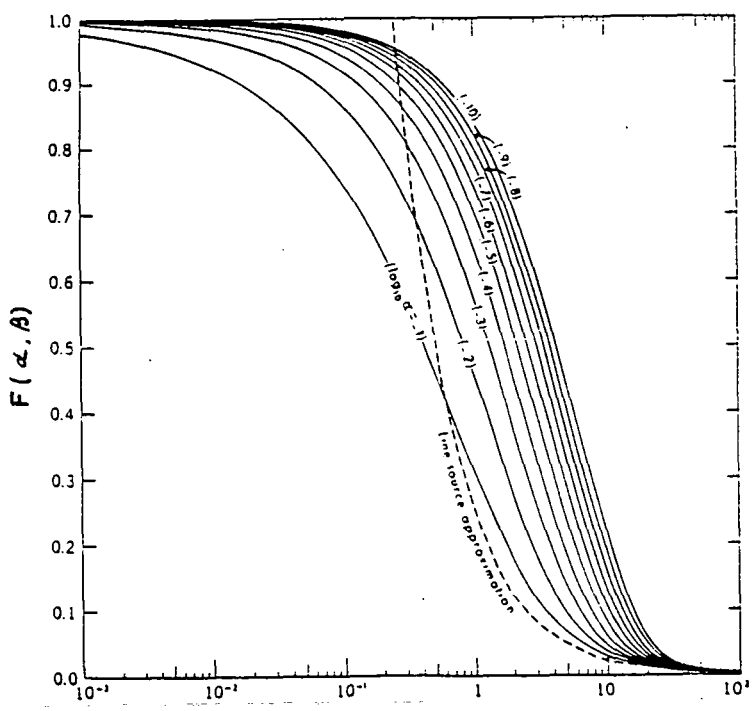

FIG. 4 Type Curves of the Function $F(\alpha, \beta)$ Against the Parameter β for Different Values of α

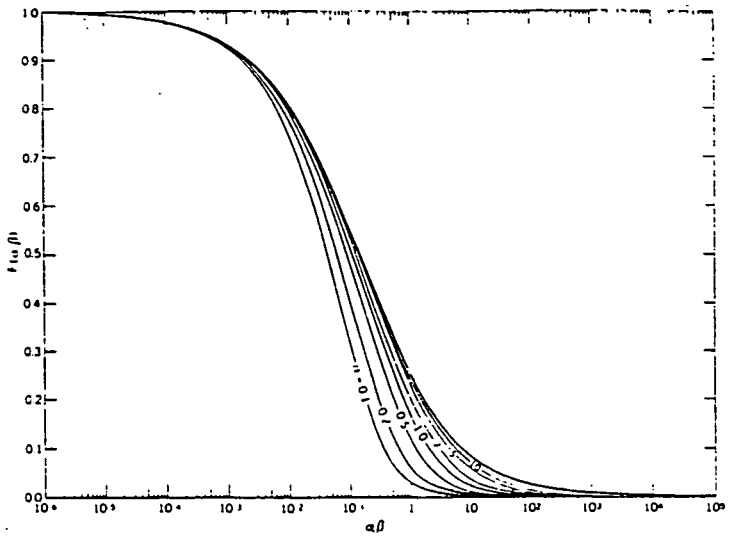

FIG. 5 Type Curves of the Function $F(\alpha, \beta)$ Against the Product Parameter $\alpha\beta$

way, the product TS and S are determined. Analysis with the type curves shown in Fig. 5 provides an indication as to whether the data are adequate for identifying both α and β and hence, determining both S and T, or whether the data fall in the range where only the product TS can be determined.

7.3 Wang *et al* (2) present an alternative method of analyzing pressure pulse data involving analytical solutions for pulse decay in single fractures of both infinite and finite extent. Recognizing that finite fracture geometry introduces errors in the interpretation of the pulse decay data, Wang suggests a method that uses data from elapsed times before the fracture boundaries begin to influence the pressure data. Wang found by linear regression of calculated decay pressure versus time an empirical expression for the fracture aperture of the following form:

$$\begin{aligned}\log(e/10^6) &= -0.32 \log(t) + C \\ &+ 0.32\,[2 \log(r_w/0.04) \\ &+ \log(2.394\mu C_w \times 10^{12})] \\ &+ 0.333 \log(L/2).\end{aligned} \tag{4}$$

where:

e = parallel-plate equivalent aperture, m,
t = time, s,
r_w = borehole radius, m,
μ = water viscosity, mPa·s,
C_w = water compressibility, 1/Pa,
L = length of the packed-off interval, m, and
C = a constant that depends on the fraction of pulse decay, as follows:

Fraction of pulse decay, $(P_o - P)/P_o$	0.05	0.10	0.15
Wang constant, C:	1.09	1.20	1.27

7.3.1 Wang shows that in test zones containing two fractures of different apertures, the wider fracture dominates the early time behavior. The early pressure pulse decay therefore reflects the major fracture only. Doe, *et al* (6) view individual fractures as confined aquifers whose transmissivities are given by the cubic relationship:

$$T = \rho g e^3/12\mu \tag{5}$$

Thus, Eq 5 provides transmissivity in terms of a parallel-plate equivalent fracture aperture calculated from Eq 4.

7.3.2 Eqs 4 and 5 can be solved for the early-time pressure pulse decay data to provide a transmissivity value for the test interval from the calculated parallel-plate equivalent aperture.

8. Report

8.1 The report shall include the following:

8.1.1 *Introduction*—The introductory section is intended to present the scope and purpose of the pressure pulse test program, and the characteristics of the rock mass tested.

8.1.1.1 *Scope of Testing Program:*

8.1.1.1.1 Report the location and orientation of the boreholes and test intervals. For tests in many boreholes or in a variety of rock types, present the test matrix in tabular form.

8.1.1.1.2 Rationale for test location selection, including the reasons for the number, location, and size of test intervals.

8.1.1.1.3 Discuss in general terms the limitations of the testing program, stating the areas of interest which are not covered by the testing program and the limitations of the data within the areas of application.

8.1.1.2 *Brief Description of the Test Intervals*—Describe rock type, structure, fabric, grain or crystal size, discontinuities, voids, and weathering of the rock mass in the test intervals. A more detailed description may be needed for certain applications. In a heterogeneous rock mass or for several rock types, many intervals may be described; a tabular presentation is then recommended for clarity.

8.1.2 *Test Method:*

8.1.2.1 *Equipment and Apparatus*—Include a list of the equipment used for the test, the manufacturer's name, model number, and basic specifications for each major item, and the date of last calibration, if applicable.

8.1.2.2 *Procedure*—State the steps actually followed in the procedure for the test.

8.1.2.3 *Variations*—If the actual equipment or procedure deviates from this test method, note each variation and the reasons. Discuss the effects of the deviations upon the test results.

8.1.3 *Theoretical Background:*

8.1.3.1 *Data Reduction Equations*—Clearly present and fully define all equations and type curves used to reduce the data. Note any assumptions inherent in the equations and type curves and any limitations in their applications and discuss their effects on the results.

8.1.3.2 *Site Specific Influences*—Discuss the degree to which the assumptions contained in the data reduction equations pertain to the actual test location and fully explain any factors or methods applied to the data to correct for departures from the assumptions of the data reduction equations.

8.1.4 *Results:*

8.1.4.1 *Summary Table*—Present a table of results, including the types of rock and discontinuities, the average values of the transmissivity and storativity, and their ranges and uncertainties.

8.1.4.2 *Individual Results*—Present a table of results for individual tests, including test number, interval length, rock types, transmissivity and storativity, and pressure pulse amplitude and decay time (or recording time, if the decay is incomplete).

8.1.4.3 *Graphic Data*—Present pressure pulse decay versus time curves for each test, together with the appropriate type curves used for their interpretation.

8.1.4.4 *Other*—Other analysis or presentations may be included as appropriate, for example: (*1*) discussion of the characteristics of the permeable zones, (*2*) histograms of results, and (*3*) comparison of results to other studies or previous work.

8.1.5 *Appended Data*—Include in an appendix a completed data form (Fig. 6) for each test.

9. Precision and Bias

9.1 *Error Estimmte:*

9.1.1 Analyze the results using standard statistical methods. Calculate all uncertainties using a 95 % confidence interval.

9.1.2 *Measurement Error*—Evaluate the errors in transmissivity and storativity associated with a single test. This includes the combined effects of pressure determination, measurement of time, and type curve matching or early decay time analysis.

9.1.3 *Sample Variability*—For each rock or discontinuity type, calculate, as a minimum, the mean transmissivity and storativity and their ranges, standard deviations, and 95 % confidence limits for the means. Compare the uncertainty associated with the transmissivity and storativity for each

Data Sheet

Project _____ Test No. _____

Test Location _____ Borehole No. _____

Rock Type _____ Borehole Dip and Dip Direction _____

Date _____ Measured Depth of Test to Top Packer, m _____

Testing by _____ Borehole Diameter, mm _____

Rock Temperature, °C _____

Equipment Description	Serial No.	Date of last Calibration

Length of Packed-off Interval, m _____ Packer Pressure, kPa _____

Length of Tubing Above Top Packer, m _____ Tubing ID, mm _____

Water Temperature, °C _____ Maximum Pulse Pressure, kPa _____

Pulse Decay Time, s _____

FIG. 6 Data Sheet for in Situ Measurement of Transmissivity and Storativity Using the Pressure Pulse Technique

rock type with the measurement uncertainty to determine whether measurement error or sample variability is the dominant factor in the results.

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(1) Bredehoeft, J. D., and Papadopulos, S. S. "A Method for Determining the Hydraulic Properties of Tight Formations," *Water Resources Research*, Vol 16, 1980, pp. 233–238.

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(3) Neuzil, C. E., "On Conducting the Modified 'Slug Test' in Tight Formations," *Water Resources Research*, Vol 18, 1982, pp. 439–441.

(4) Cooper, H. H., Bredehoeft, J. D., and Papadopulos, S. S., "Response of a Finite Diameter Well to an Instantaneous Charge of Water," *Water Resources Research*, Vol 3, 1967, pp. 263–269.

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(9) Shuri, F. S., Feves, M. L., Peterson, G. L., Foster, K. M., and Kienle, C. F., Public Draft: "Field and In Situ Rock Mechanics Testing Manual," Office of Nuclear Waste Isolation, Document ONWI-310, Section F: "In Situ Fluid Properties," GT-F.1 In Situ Permeability Measurement of Rock Using Borehole Packers, 1981.

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ATTACHMENT D

GROUNDWATER QUALITY DATA

WELL NO.:1018

03/11/93

PARAMETER ...	A90	B90	C90	D90	A91	B91	C91	D91	A92	B92	C92	MIN	MAX	AVG	UNITS
1,1,1-Trichloroethane	<	1.000	<	1.000								1.000	1.000	1.000	ug/l
1,1,2,2-Tetrachloroethane	<	1.000	<	1.000								1.000	1.000	1.000	ug/l
1,1,2-Trichloroethane	<	1.000	<	1.000								1.000	1.000	1.000	ug/l
1,1-Dichloroethane	<	1.000	<	1.000								1.000	1.000	1.000	ug/l
1,1-Dichloroethene	<	1.000	<	1.000								1.000	1.000	1.000	ug/l
1,2-Dichloroethane	<	1.000	<	1.000								1.000	1.000	1.000	ug/l
1,2-Dichloroethene			<	1.000								1.000	1.000	1.000	ug/l
1,2-Dichloropropane	<	1.000	<	1.000								1.000	1.000	1.000	ug/l
2-Chloroethyl vinyl ether	<	60.000	<	10.000								10.000	60.000	35.000	ug/l
2-Hexanone			<	2.000								2.000	2.000	2.000	ug/l
4-Methyl-2-pentanone			<	2.000								2.000	2.000	2.000	ug/l
Acetone			<	2.000								2.000	2.000	2.000	ug/l
Alkalinity at CaCO3				270.000								270.000	270.000	270.000	mg/l
Ammonia, as nitrogen			<	0.020								0.020	0.020	0.020	mg/l
Benzene	<	1.000	<	1.000								1.000	1.000	1.000	ug/l
Bromodichloromethane	<	1.000	<	1.000								1.000	1.000	1.000	ug/l
Bromoform	<	1.000	<	1.000								1.000	1.000	1.000	ug/l
Bromomethane	<	1.000	<	1.000								1.000	1.000	1.000	ug/l
Carbon disulfide			<	1.000								1.000	1.000	1.000	ug/l
Carbon tetrachloride	<	1.000	<	1.000								1.000	1.000	1.000	ug/l
Chloride		6.000		3.000								3.000	6.000	4.500	mg/l
Chlorobenzene	<	1.000	<	1.000								1.000	1.000	1.000	ug/l
Chloroethane			<	1.000								1.000	1.000	1.000	ug/l
Chloroform	<	1.000	<	1.000								1.000	1.000	1.000	ug/l
Chloromethane	<	1.000	<	1.000								1.000	1.000	1.000	ug/l
Cyanide			<	0.005								0.005	0.005	0.005	mg/l
Dibromochloromethane	<	1.000	<	1.000								1.000	1.000	1.000	ug/l
Ethyl benzene	<	1.000	<	1.000								1.000	1.000	1.000	ug/l
Fluoride				0.410								0.410	0.410	0.410	mg/l
Methyl ethyl ketone			<	2.000								2.000	2.000	2.000	ug/l
Methylene chloride	<	1.000	<	1.000								1.000	1.000	1.000	ug/l
Nitrogen, Nitrate		0.060										0.060	0.060	0.060	mg/l
Nitrogen, Nitrate+Nitrite				0.060								0.060	0.060	0.060	mg/l
Phenols			<	0.005								0.005	0.005	0.005	mg/l
Phosphorus, Total				0.210								0.210	0.210	0.210	mg/l
RA-226		0.451										0.451	0.451	0.451	pCi/l
RA-228	<	0.890										0.890	0.890	0.890	pCi/l

* Average for this Quarter

WELL NO.:1018

03/11/93

PARAMETER	...	A90	B90	C90	D90	A91	B91	C91	D91	A92	B92	C92	MIN	MAX	AVG	UNITS
Specific conductance					635.000								635.000	635.000	635.000	umhos/c
Styrene				<	1.000								1.000	1.000	1.000	ug/l
Sulfate			53.000		72.000								53.000	72.000	62.500	mg/l
TH-228		<	0.290										0.290	0.290	0.290	pCi/l
TH-230			0.405										0.405	0.405	0.405	pCi/l
TH-232		<	0.290										0.290	0.290	0.290	pCi/l
TH-TOTAL		<	2.600										2.600	2.600	2.600	ug/l
TOC			1.000	<	1.000								1.000	1.000	1.000	mg/l
TOX		<	10.000	<	10.000								10.000	10.000	10.000	ug/l Cl
Tetrachloroethene		<	1.000	<	1.000								1.000	1.000	1.000	ug/l
Toluene		<	1.000	<	1.000								1.000	1.000	1.000	ug/l
Total dissolved solids					520.000								520.000	520.000	520.000	mg/l
Trichloroethene		<	1.000	<	1.000								1.000	1.000	1.000	ug/l
Trichlorofluoromethane		<	1.000										1.000	1.000	1.000	ug/l
U-234			1.090										1.090	1.090	1.090	pCi/l
U-235/236		<	0.220										0.220	0.220	0.220	pCi/l
U-238			1.010										1.010	1.010	1.010	pCi/l
U-TOTAL			3.050										3.050	3.050	3.050	ug/l
Vinyl acetate				<	2.000								2.000	2.000	2.000	ug/l
Vinyl chloride		<	1.000	<	1.000								1.000	1.000	1.000	ug/l
Xylenes, Total				<	1.000								1.000	1.000	1.000	ug/l
cis-1,3-Dichloropropene		<	1.000	<	1.000								1.000	1.000	1.000	ug/l
m-Dichlorobenzene		<	1.000										1.000	1.000	1.000	ug/l
o-Dichlorobenzene		<	1.000										1.000	1.000	1.000	ug/l
p-Dichlorobenzene		<	1.000										1.000	1.000	1.000	ug/l
pH					6.950								6.950	6.950	6.950	S.U.
trans-1,2-Dichloroethene		<	1.000	<	1.000								1.000	1.000	1.000	ug/l
trans-1,3-Dichloropropene		<	1.000	<	1.000								1.000	1.000	1.000	ug/l

4333

* Average for this Quarter

WELL NO.:1019

03/11/93

PARAMETER ...	A90	B90	C90	D90	A91	B91	C91	D91	A92	B92	C92	MIN	MAX	AVG	UNITS
1,1,1-Trichloroethane					< 1.000	< 1.000						1.000	1.000	1.000	ug/l
1,1,2,2-Tetrachloroethane					< 1.000	< 1.000						1.000	1.000	1.000	ug/l
1,1,2-Trichloroethane					< 1.000	< 1.000						1.000	1.000	1.000	ug/l
1,1-Dichloroethane					2.300	1.900						1.900	2.300	2.100	ug/l
1,1-Dichloroethene					< 1.000	< 1.000						1.000	1.000	1.000	ug/l
1,2-Dichloroethane					< 1.000	< 1.000						1.000	1.000	1.000	ug/l
1,2-Dichloroethene (Total)					8.500	14.500						8.500	14.500	11.500	ug/l
1,2-Dichloropropane					< 1.000	< 1.000						1.000	1.000	1.000	ug/l
2-Chloroethyl vinyl ether					< 10.000	< 10.000						10.000	10.000	10.000	ug/l
2-Hexanone					< 2.000	< 2.000						2.000	2.000	2.000	ug/l
4-Methyl-2-pentanone					< 2.000	< 2.000						2.000	2.000	2.000	ug/l
Acetone					< 2.000	< 2.000						2.000	2.000	2.000	ug/l
Alkalinity at CaCO3					433.000	425.000						425.000	433.000	429.000	mg/l
Aluminum					0.790	< 0.500						0.500	0.790	0.645	mg/l
Aluminum, (Dissd.)					< 0.500	< 0.500						0.500	0.500	0.500	mg/l
Ammonia, as nitrogen					0.080	0.180						0.080	0.180	0.130	mg/l
Antimony					< 0.025	< 0.020						0.020	0.025	0.023	mg/l
Antimony, (Dissd.)					< 0.025	< 0.020						0.020	0.025	0.023	mg/l
Arsenic					0.005	< 0.005						0.005	0.005	0.005	mg/l
Arsenic, (Dissd.)					< 0.003	< 0.005						0.003	0.005	0.004	mg/l
Barium					< 0.200	< 0.500						0.200	0.500	0.350	mg/l
Barium, (Dissd.)					< 0.200	< 0.500						0.200	0.500	0.350	mg/l
Benzene					< 1.000	< 1.000						1.000	1.000	1.000	ug/l
Beryllium					< 0.010	< 0.050						0.010	0.050	0.030	mg/l
Beryllium, (Dissd.)					< 0.010	< 0.050						0.010	0.050	0.030	mg/l
Bromodichloromethane					< 1.000	< 1.000						1.000	1.000	1.000	ug/l
Bromoform					< 1.000	< 1.000						1.000	1.000	1.000	ug/l
Bromomethane					< 1.000	< 1.000						1.000	1.000	1.000	ug/l
CS-137					< 7.700							7.700	7.700	7.700	pCi/l
Cadmium					< 0.001	< 0.001						0.001	0.001	0.001	mg/l
Cadmium, (Dissd.)					< 0.001	< 0.001						0.001	0.001	0.001	mg/l
Calcium					168.000	188.000						168.000	188.000	178.000	mg/l
Calcium, (Dissd.)					130.000	108.000						108.000	130.000	119.000	mg/l
Carbon disulfide					< 1.000	< 1.000						1.000	1.000	1.000	ug/l
Carbon tetrachloride					< 1.000	< 1.000						1.000	1.000	1.000	ug/l
Chloride					64.000	88.000						64.000	88.000	76.000	mg/l
Chlorobenzene					< 1.000	< 1.000						1.000	1.000	1.000	ug/l

*Average for this Quarter

03/11/93

WELL NO.:1019

PARAMETER	...	A90	B90	C90	D90	A91	B91	C91	D91	A92	B92	C92	MIN	MAX	AVG	UNITS
Chloroethane						< 1.000	< 1.000						1.000	1.000	1.000	ug/l
Chloroform						< 1.000	< 1.000						1.000	1.000	1.000	ug/l
Chloromethane						< 1.000	< 1.000						1.000	1.000	1.000	ug/l
Chromium, Total						0.008	< 0.003						0.003	0.008	0.006	mg/l
Chromium, Total (Dissd.)						< 0.005	< 0.002						0.002	0.005	0.004	mg/l
Cobalt						< 0.025	< 0.005						0.005	0.025	0.015	mg/l
Cobalt, (Dissd.)						< 0.025	< 0.005						0.005	0.025	0.015	mg/l
Copper						< 0.025	0.024						0.024	0.025	0.025	mg/l
Copper, (Dissd.)						< 0.025	< 0.020						0.020	0.025	0.023	mg/l
Cyanide						< 0.005	< 0.005						0.005	0.005	0.005	mg/l
Dibromochloromethane						< 1.000	< 1.000						1.000	1.000	1.000	ug/l
Ethyl benzene						< 1.000	< 1.000						1.000	1.000	1.000	ug/l
Fluoride						0.440	0.390						0.390	0.440	0.415	mg/l
GROSS ALPHA						460.000							460.000	460.000	460.000	pCi/l
GROSS BETA						426.000							426.000	426.000	426.000	pCi/l
Iron						3.260	0.770						0.770	3.260	2.015	mg/l
Iron, (Dissd.)						< 0.050	1.590						0.050	1.590	0.820	mg/l
Lead						0.006	< 0.005						0.005	0.006	0.006	mg/l
Lead, (Dissd.)						< 0.005	< 0.005						0.005	0.005	0.005	mg/l
Magnesium						54.000	59.000						54.000	59.000	56.500	mg/l
Magnesium, (Dissd.)						60.000	49.000						49.000	60.000	54.500	mg/l
Manganese						0.962	0.699						0.699	0.962	0.831	mg/l
Manganese, (Dissd.)						< 0.020	0.980						0.020	0.980	0.500	mg/l
Mercury						<*,***.***	<*,***.***						*,***.***	*,***.***	0.000	mg/l
Mercury, (Dissd.)						<*,***.***	<*,***.***						*,***.***	*,***.***	0.000	mg/l
Methyl ethyl ketone						< 2.000	< 2.000						2.000	2.000	2.000	ug/l
Methylene chloride						< 1.000	< 1.000						1.000	1.000	1.000	ug/l
Molybdenum						< 0.025	< 0.010						0.010	0.025	0.018	mg/l
Molybdenum, (Dissd.)						< 0.025	< 0.010						0.010	0.025	0.018	mg/l
NP-237						< 0.100							0.100	0.100	0.100	pCi/l
Nickel						< 0.005	< 0.010						0.005	0.010	0.008	mg/l
Nickel, (Dissd.)						< 0.005	< 0.010						0.005	0.010	0.008	mg/l
Nitrogen, Nitrate						0.040	0.030						0.030	0.040	0.035	mg/l
PU-238						< 0.059							0.059	0.059	0.059	pCi/l
PU-239/240						< 0.110							0.110	0.110	0.110	pCi/l
Phenols						< 0.005	< 0.005						0.005	0.005	0.005	mg/l
Phosphorus, Total						< 0.100	< 0.100						0.100	0.100	0.100	mg/l

* Average for this Quarter

PARAMETER ...	A90	B90	C90	D90	A91	B91	C91	D91	A92	B92	C92	MIN	MAX	AVG	UNITS
Potassium					< 1.000	1.400						1.000	1.400	1.200	mg/l
Potassium, (Dissd.)					< 1.000	< 1.000						1.000	1.000	1.000	mg/l
RA-226					< 0.220							0.220	0.220	0.220	pCi/l
RA-228					< 2.400							2.400	2.400	2.400	pCi/l
RU-106					< 65.000							65.000	65.000	65.000	pCi/l
Selenium					< 0.003	< 0.005						0.003	0.005	0.004	mg/l
Selenium, (Dissd.)					< 0.003	< 0.005						0.003	0.005	0.004	mg/l
Silver					< 0.001	< 0.001						0.001	0.001	0.001	mg/l
Silver, (Dissd.)					< 0.001	< 0.001						0.001	0.001	0.001	mg/l
Sodium					82.200	65.000						65.000	82.200	73.600	mg/l
Sodium, (Dissd.)					70.900	91.000						70.900	91.000	80.950	mg/l
Specific conductance					1,230.000	1,480.000						1,230.000	1,480.000	1,355.000	umhos/c
Styrene					< 1.000	< 1.000						1.000	1.000	1.000	ug/l
Sulfate					250.000	497.000						250.000	497.000	373.500	mg/l
TC-99					< 23.000							23.000	23.000	23.000	pCi/l
TH-228					0.293							0.293	0.293	0.293	pCi/l
TH-230					0.421							0.421	0.421	0.421	pCi/l
TH-232					< 0.240							0.240	0.240	0.240	pCi/l
TH-TOTAL					< 2.200							2.200	2.200	2.200	ug/l
TOC					20.000	45.000						20.000	45.000	32.500	mg/l
TOX					88.000	63.000						63.000	88.000	75.500	ug/l Cl
Tetrachloroethene					< 1.000	< 1.000						1.000	1.000	1.000	ug/l
Thallium					< 0.010	< 0.010						0.010	0.010	0.010	mg/l
Thallium, (Dissd.)					< 0.010	< 0.010						0.010	0.010	0.010	mg/l
Toluene					< 1.000	< 1.000						1.000	1.000	1.000	ug/l
Total dissolved solids					808.000	1,020.000						808.000	1,020.000	914.000	mg/l
Trichloroethene					< 1.000	< 1.000						1.000	1.000	1.000	ug/l
U-234	83.200				79.500							79.500	83.200	81.350	pCi/l
U-235/236	10.400				8.930							8.930	10.400	9.665	pCi/l
U-238	350.000				326.000							326.000	350.000	338.000	pCi/l
U-TOTAL	1,040.000				907.000	755.000						755.000	1,040.000	900.667	ug/l
Vanadium					< 0.050	< 0.050						0.050	0.050	0.050	mg/l
Vanadium, (Dissd.)					< 0.050	< 0.050						0.050	0.050	0.050	mg/l
Vinyl acetate					< 2.000	< 2.000						2.000	2.000	2.000	ug/l
Vinyl chloride					< 1.000	< 1.000						1.000	1.000	1.000	ug/l
Xylenes, Total					< 1.000	< 1.000						1.000	1.000	1.000	ug/l
Zinc					< 0.020	0.054						0.020	0.054	0.037	mg/l

* Average for this Quarter

433

WELL NO.:1019

PARAMETER	...	A90	B90	C90	D90		A91		B91	C91	D91	A92	B92	C92	MIN	MAX	AVG	UNITS
Zinc, (Dissd.)						<	0.020	<	0.050						0.020	0.050	0.035	mg/l
cis-1,3-Dichloropropene						<	1.000	<	1.000						1.000	1.000	1.000	ug/l
pH							6.900		6.750						6.750	6.900	6.825	S.U.
trans-1,2-Dichloroethene						<	1.000	<	1.000						1.000	1.000	1.000	ug/l
trans-1,3-Dichloropropene						<	1.000	<	1.000						1.000	1.000	1.000	ug/l

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4333

* Average for this Quarter

WELL NO.:1020

03/11/93

PARAMETER ...	A90	B90	C90	D90	A91	B91	C91	D91	A92	B92	C92	MIN	MAX	AVG	UNITS
1,1,1-Trichloroethane		1.000 <	1.000 <	1.000								1.000	1.000	1.000	ug/l
1,1,2,2-Tetrachloroethane		1.000 <	1.000 <	1.000								1.000	1.000	1.000	ug/l
1,1,2-Trichloroethane		1.000 <	1.000 <	1.000								1.000	1.000	1.000	ug/l
1,1-Dichloroethane		1.000 <	1.000 <	1.000								1.000	1.000	1.000	ug/l
1,1-Dichloroethene		1.000 <	1.000 <	1.000								1.000	1.000	1.000	ug/l
1,2-Dichloroethane		1.000 <	1.000 <	1.000								1.000	1.000	1.000	ug/l
1,2-Dichloroethene (Total)		1.000 <	1.000 <	1.000								1.000	1.000	1.000	ug/l
1,2-Dichloropropane		1.000 <	1.000 <	1.000								1.000	1.000	1.000	ug/l
2-Chloroethyl vinyl ether		<	60.000 <	10.000								10.000	60.000	35.000	ug/l
2-Hexanone		2.000 <	2.000 <	2.000								2.000	2.000	2.000	ug/l
4-Methyl-2-pentanone		2.000 <	2.000 <	2.000								2.000	2.000	2.000	ug/l
Acetone		2.000 <	2.000 <	2.000								2.000	2.000	2.000	ug/l
Alkalinity at CaCO3			291.000	259.000								259.000	291.000	275.000	mg/l
Ammonia, as nitrogen				0.040								0.040	0.040	0.040	mg/l
Benzene		1.000 <	1.000 <	1.000								1.000	1.000	1.000	ug/l
Bromodichloromethane		1.000 <	1.000 <	1.000								1.000	1.000	1.000	ug/l
Bromoform		1.000 <	1.000 <	1.000								1.000	1.000	1.000	ug/l
Bromomethane		1.000 <	1.000 <	1.000								1.000	1.000	1.000	ug/l
Carbon disulfide		1.000 <	1.000 <	1.000								1.000	1.000	1.000	ug/l
Carbon tetrachloride		1.000 <	1.000 <	1.000								1.000	1.000	1.000	ug/l
Chloride		3.000	4.000	4.000								3.000	4.000	3.667	mg/l
Chlorobenzene		1.000 <	1.000 <	1.000								1.000	1.000	1.000	ug/l
Chloroethane		<	1.000 <	1.000								1.000	1.000	1.000	ug/l
Chloroform		1.000 <	1.000 <	1.000								1.000	1.000	1.000	ug/l
Chloromethane		1.000 <	1.000 <	1.000								1.000	1.000	1.000	ug/l
Cyanide			<	0.005								0.005	0.005	0.005	mg/l
Dibromochloromethane		1.000 <	1.000 <	1.000								1.000	1.000	1.000	ug/l
Ethyl benzene		1.000 <	1.000 <	1.000								1.000	1.000	1.000	ug/l
Fluoride			0.220	0.180								0.180	0.220	0.200	mg/l
GROSS ALPHA		136.500 <	11.000	19.500								11.000	136.500	55.667	pCi/l
GROSS BETA		75.000	6.600	20.900								6.600	75.000	34.167	pCi/l
Methyl ethyl ketone		2.000 <	2.000 <	2.000								2.000	2.000	2.000	ug/l
Methylene chloride		1.000 <	1.000 <	1.000								1.000	1.000	1.000	ug/l
Nitrogen, Nitrate		0.020 <	0.020									0.020	0.020	0.020	mg/l
Nitrogen, Nitrate+Nitrite				1.680								1.680	1.680	1.680	mg/l
Phenols			0.006	0.007								0.006	0.007	0.007	mg/l
Phosphorus, Total				0.280								0.280	0.280	0.280	mg/l

* Average for this Quarter

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4333

WELL NO.:1020

PARAMETER	...	A90	B90	C90	D90	A91	B91	C91	D91	A92	B92	C92	MIN	MAX	AVG	UNITS
RA-226			0.310	0.150	0.468								0.150	0.468	0.309	pCi/l
RA-228			0.885 <	0.980 <	3.300								0.885	3.300	1.722	pCi/l
Specific conductance				571.000	520.000								520.000	571.000	545.500	umhos/c
Styrene			1.000 <	1.000 <	1.000								1.000	1.000	1.000	ug/l
Sulfate			47.500	53.000	55.000								47.500	55.000	51.833	mg/l
TH-228			0.825 <	0.370	1.360								0.370	1.360	0.851	pCi/l
TH-230			0.391	0.766 <	0.670								0.391	0.766	0.609	pCi/l
TH-232			0.320 <	0.370 <	0.670								0.320	0.670	0.453	pCi/l
TH-TOTAL			2.900 <	3.300 <	6.100								2.900	6.100	4.100	ug/l
TOC			7.000	4.000	7.000								4.000	7.000	6.000	mg/l
TOX			10.000 <	10.000 <	10.000								10.000	10.000	10.000	ug/l Cl
Tetrachloroethene			1.000 <	1.000 <	1.000								1.000	1.000	1.000	ug/l
Toluene			1.000 <	1.000 <	1.000								1.000	1.000	1.000	ug/l
Total dissolved solids				385.000	326.000								326.000	385.000	355.500	mg/l
Trichloroethene			1.000 <	1.000 <	1.000								1.000	1.000	1.000	ug/l
U-234			3.665	1.870	8.850								1.870	8.850	4.795	pCi/l
U-235/236			0.434 <	0.370	0.868								0.370	0.868	0.557	pCi/l
U-238			5.190	2.680	8.990								2.680	8.990	5.620	pCi/l
U-TOTAL			15.250	8.040									8.040	15.250	11.645	ug/l
Vinyl acetate			2.000 <	2.000 <	2.000								2.000	2.000	2.000	ug/l
Vinyl chloride			1.000 <	1.000 <	1.000								1.000	1.000	1.000	ug/l
Xylenes, Total			1.000 <	1.000 <	1.000								1.000	1.000	1.000	ug/l
cis-1,3-Dichloropropene			1.000 <	1.000 <	1.000								1.000	1.000	1.000	ug/l
pH				6.920	6.930								6.920	6.930	6.925	S.U.
trans-1,2-Dichloroethene			<	1.000 <	1.000								1.000	1.000	1.000	ug/l
trans-1,3-Dichloropropene			1.000 <	1.000 <	1.000								1.000	1.000	1.000	ug/l

4333

* Average for this Quarter

WELL NO.:1024

03/11/93

PARAMETER ...	A90	B90	C90	D90	A91	B91	C91	D91	A92	B92	C92	MIN	MAX	AVG	UNITS
1,1,1-Trichloroethane	<	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000		1.000	1.000	1.000	ug/l
1,1,2,2-Tetrachloroethane	<	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000		1.000	1.000	1.000	ug/l
1,1,2-Trichloroethane	<	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000		1.000	1.000	1.000	ug/l
1,1-Dichloroethane	< 1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000		1.000	1.000	1.000	ug/l
1,1-Dichloroethene	<	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000		1.000	1.000	1.000	ug/l
1,2,4-Trichlorobenzene	<	4.000										4.000	4.000	4.000	ug/l
1,2-Dichloroethane	< 1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000		1.000	1.000	1.000	ug/l
1,2-Dichloroethene (Total)	<	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000		1.000	1.000	1.000	ug/l
1,2-Dichloropropane	<	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000		1.000	1.000	1.000	ug/l
2,4,5-Trichlorophenol	<	4.000										4.000	4.000	4.000	ug/l
2,4,6-Trichlorophenol	<	4.000										4.000	4.000	4.000	ug/l
2,4-Dichlorophenol	<	4.000										4.000	4.000	4.000	ug/l
2,4-Dimethylphenol	<	4.000										4.000	4.000	4.000	ug/l
2,4-Dinitrophenol	<	4.000										4.000	4.000	4.000	ug/l
2,4-Dinitrotoluene	<	15.000										15.000	15.000	15.000	ug/l
2,6-Dinitrotoluene	<	15.000										15.000	15.000	15.000	ug/l
2-Chloroethyl vinyl ether			<	10.000 <	10.000 <	10.000 <	10.000 <	10.000 <	10.000 <	10.000		10.000	10.000	10.000	ug/l
2-Chloronaphthalene	<	4.000										4.000	4.000	4.000	ug/l
2-Chlorophenol	<	4.000										4.000	4.000	4.000	ug/l
2-Hexanone	<	2.000 <	2.000 <	2.000 <	2.000 <	2.000 <	2.000 <	2.000 <	2.000 <	2.000		2.000	2.000	2.000	ug/l
2-Nitroaniline	<	15.000										15.000	15.000	15.000	ug/l
2-Nitrophenol	<	4.000										4.000	4.000	4.000	ug/l
3,3'-Dichlorobenzidine	<	15.000										15.000	15.000	15.000	ug/l
3-Nitroaniline	<	15.000										15.000	15.000	15.000	ug/l
4,4'-DDD	<	0.200										0.200	0.200	0.200	ug/l
4,4'-DDE	<	0.200										0.200	0.200	0.200	ug/l
4,4'-DDT	<	0.200										0.200	0.200	0.200	ug/l
4,6-Dinitro-2-methylphenol	<	4.000										4.000	4.000	4.000	ug/l
4-Bromophenyl phenyl ether	<	15.000										15.000	15.000	15.000	ug/l
4-Chloro-3-methylphenol	<	4.000										4.000	4.000	4.000	ug/l
4-Chlorophenylphenyl ether	<	15.000										15.000	15.000	15.000	ug/l
4-Methyl-2-pentanone	<	2.000 <	2.000 <	2.000 <	2.000 <	2.000 <	2.000 <	2.000 <	2.000 <	2.000		2.000	2.000	2.000	ug/l
4-Nitroaniline	<	15.000										15.000	15.000	15.000	ug/l
4-Nitrophenol	<	4.000										4.000	4.000	4.000	ug/l
Acenaphthylene	<	4.000										4.000	4.000	4.000	ug/l
Acetone	< 2.000 <	2.000 <	2.000 <	2.000 <	2.000 <	2.000 <	2.000 <	2.000 <	2.000 <	2.000		2.000	2.000	2.000	ug/l
Aldrin	<	0.200										0.200	0.200	0.200	ug/l

* Average for this Quarter

WELL NO.:1024

PARAMETER	...	A90	B90	C90	D90	A91	B91	C91	D91	A92	B92	C92	MIN	MAX	AVG	UNITS
Alkalinity at CaCO3					347.000	389.000	278.000	392.000	383.000	377.000	400.000		278.000	400.000	366.571	mg/l
Aluminum		0.261	2.290	2.540	15.800	0.800 <	0.500	0.720 <	0.200	0.570	0.490		0.200	15.800	2.417	mg/l
Aluminum, (Dissd.)	<	0.050 <	0.050 <	0.500 <	0.500 <	0.500 <	0.500 <	0.200 <	0.200 <	0.200 <	0.200		0.050	0.500	0.290	mg/l
Ammonia, as nitrogen					0.570	0.480	0.470	0.340	0.410	0.450	0.450		0.340	0.570	0.453	mg/l
Anthracene		<	4.000										4.000	4.000	4.000	ug/l
Antimony		<	0.025 <	0.025 <	0.025 <	0.025 <	0.020 <	0.020 <	0.020 <	0.020 <	0.020		0.020	0.025	0.022	mg/l
Antimony, (Dissd.)		<	0.025 <	0.025 <	0.025 <	0.025 <	0.020 <	0.020 <	0.020 <	0.020 <	0.020		0.020	0.025	0.022	mg/l
Aroclor 1016		<	0.200										0.200	0.200	0.200	ug/l
Aroclor 1221		<	0.200										0.200	0.200	0.200	ug/l
Aroclor 1232		<	0.200										0.200	0.200	0.200	ug/l
Aroclor 1242		<	0.200										0.200	0.200	0.200	ug/l
Aroclor 1248		<	0.200										0.200	0.200	0.200	ug/l
Aroclor 1254		<	0.200										0.200	0.200	0.200	ug/l
Aroclor 1260		<	0.200										0.200	0.200	0.200	ug/l
Arsenic		0.006	0.006	0.009	0.035	0.007 <	0.005 <	0.005	0.005	0.005	0.006		0.005	0.035	0.009	mg/l
Arsenic, (Dissd.)		0.005	0.005	0.004	0.005	0.005 <	0.005 <	0.005	0.005 <	0.005 <	0.005		0.004	0.005	0.005	mg/l
Barium		0.253 <	0.200 <	0.020	0.342 <	0.200 <	0.500 <	0.200 <	0.200 <	0.200	0.157		0.020	0.500	0.227	mg/l
Barium, (Dissd.)	<	0.200 <	0.200 <	0.200 <	0.200 <	0.200 <	0.500 <	0.200 <	0.200	0.230	0.209		0.200	0.500	0.234	mg/l
Benzene		<	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000		1.000	1.000	1.000	ug/l
Benzo(a)anthracene		<	4.000										4.000	4.000	4.000	ug/l
Benzo(a)pyrene		<	4.000										4.000	4.000	4.000	ug/l
Benzo(b)fluoranthene		<	4.000										4.000	4.000	4.000	ug/l
Benzo(ghi)perylene		<	4.000										4.000	4.000	4.000	ug/l
Benzo(k)fluoranthene		<	4.000										4.000	4.000	4.000	ug/l
Benzoic acid		<	4.000										4.000	4.000	4.000	ug/l
Benzyl alcohol		<	40.000										40.000	40.000	40.000	ug/l
Beryllium	<	0.010 <	0.010 <	0.010 <	0.010 <	0.010 <	0.050 <	0.050 <	0.005 <	0.005 <	0.005		0.005	0.050	0.017	mg/l
Beryllium, (Dissd.)	<	0.010 <	0.010 <	0.010 <	0.010 <	0.010 <	0.050 <	0.050 <	0.005 <	0.005 <	0.005		0.005	0.050	0.017	mg/l
Bromodichloromethane		<	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000		1.000	1.000	1.000	ug/l
Bromoform		<	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000		1.000	1.000	1.000	ug/l
Bromomethane		<	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000		1.000	1.000	1.000	ug/l
Butyl benzyl phthalate		<	4.000										4.000	4.000	4.000	ug/l
CS-137		<	12.000		<	6.200							6.200	12.000	9.100	pCi/l
Cadmium		<	0.001 <	0.001	0.002 <	0.001 <	0.001 <	0.001 <	0.001 <	0.001 <	0.001		0.001	0.002	0.001	mg/l
Cadmium, (Dissd.)		<	0.001 <	0.001 <	0.001 <	0.001 <	0.001 <	0.001 <	0.001 <	0.001 <	0.001		0.001	0.001	0.001	mg/l
Calcium		95.800	104.000	99.600	146.000	74.400	87.000	89.000	90.000	96.600	83.900		74.400	146.000	96.630	mg/l
Calcium, (Dissd.)		88.900	95.200	74.000	78.400	71.600	78.000	84.000	84.000	84.300	97.000		71.600	97.000	83.540	mg/l

* Average for this Quarter

PARAMETER ...	A90	B90	C90	D90	A91	B91	C91	D91	A92	B92	C92	MIN	MAX	AVG	UNITS
Carbon disulfide	<	1.000 <	1.000 <	1.000 <	1.000	1.400 <	1.000 <	1.000 <	1.000 <	1.000		1.000	1.400	1.044	ug/l
Carbon tetrachloride	<	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000		1.000	1.000	1.000	ug/l
Chlordane	<	0.200										0.200	0.200	0.200	ug/l
Chloride	2.000	2.000	3.000	2.000	2.000	1.000	2.000 <	1.000	2.000	3.000		1.000	3.000	2.000	mg/l
Chlorobenzene	<	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000		1.000	1.000	1.000	ug/l
Chloroethane			<	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000		1.000	1.000	1.000	ug/l
Chloroform	<	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000		1.000	1.000	1.000	ug/l
Chloromethane	<	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000		1.000	1.000	1.000	ug/l
Chromium, Total <	0.005	0.008	0.008 <	0.005	0.007	0.005	0.008	0.003	0.003	0.004		0.003	0.008	0.006	mg/l
Chromium, Total (Dissd.)	0.005 <	0.005 <	0.005 <	0.005 <	0.005 <	0.002 <	0.002 <	0.002 <	0.002 <	0.002		0.002	0.005	0.004	mg/l
Chrysene	<	4.000										4.000	4.000	4.000	ug/l
Cobalt <	0.025 <	0.025 <	0.025 <	0.025 <	0.025 <	0.005 <	0.005 <	0.005 <	0.005 <	0.005		0.005	0.025	0.015	mg/l
Cobalt, (Dissd.) <	0.025 <	0.025 <	0.025 <	0.025 <	0.025 <	0.005 <	0.005 <	0.005 <	0.005 <	0.005		0.005	0.025	0.015	mg/l
Copper <	0.025 <	0.025 <	0.025	0.085 <	0.025 <	0.020 <	0.020 <	0.020 <	0.020	0.029		0.020	0.085	0.029	mg/l
Copper, (Dissd.) <	0.025 <	0.025 <	0.025 <	0.025 <	0.025 <	0.020 <	0.020 <	0.020 <	0.020 <	0.020		0.020	0.025	0.023	mg/l
Cyanide	<	0.005	<	0.005 <	0.005 <	0.005 <	0.005 <	0.005	<	0.005		0.005	0.005	0.005	mg/l
Cyanide, Total								<	0.005			0.005	0.005	0.005	mg/l
Di-n-butylphthalate	<	4.000										4.000	4.000	4.000	ug/l
Dibenzo(a,h)anthracene	<	4.000										4.000	4.000	4.000	ug/l
Dibenzofuran	<	4.000										4.000	4.000	4.000	ug/l
Dibromochloromethane	<	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000		1.000	1.000	1.000	ug/l
Dieldrin	<	0.200										0.200	0.200	0.200	ug/l
Diethyl phthalate	<	4.000										4.000	4.000	4.000	ug/l
Dimethyl phthalate	<	4.000										4.000	4.000	4.000	ug/l
Diphenylamine	<	15.000										15.000	15.000	15.000	ug/l
Endosulfan I	<	0.200										0.200	0.200	0.200	ug/l
Endosulfan II	<	0.200										0.200	0.200	0.200	ug/l
Endosulfan sulfate	<	0.200										0.200	0.200	0.200	ug/l
Endrin	<	0.080										0.080	0.080	0.080	ug/l
Endrin aldehyde	<	0.200										0.200	0.200	0.200	ug/l
Ethyl benzene	<	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000		1.000	1.000	1.000	ug/l
Fluoranthene	<	4.000										4.000	4.000	4.000	ug/l
Fluorene	<	4.000										4.000	4.000	4.000	ug/l
Fluoride	0.680	0.620	0.920	0.820	0.870	0.990	0.930	0.950	1.040	0.940		0.620	1.040	0.876	mg/l
GROSS ALPHA	<	11.000		<	8.500							8.500	11.000	9.750	pCi/l
GROSS BETA	<	28.000		<	5.100							5.100	28.000	16.550	pCi/l
Heptachlor	<	0.200										0.200	0.200	0.200	ug/l

* Average for this Quarter

250

333

WELL NO.:1024

PARAMETER ...	A90	B90	C90	D90	A91	B91	C91	D91	A92	B92	C92	MIN	MAX	AVG	UNITS
Heptachlor epoxide	<	0.200										0.200	0.200	0.200	ug/l
Hexachlorobenzene	<	4.000										4.000	4.000	4.000	ug/l
Hexachlorobutadiene	<	4.000										4.000	4.000	4.000	ug/l
Hexachlorocyclopentadiene	<	4.000										4.000	4.000	4.000	ug/l
Hexachloroethane	<	4.000										4.000	4.000	4.000	ug/l
Indeno(1,2,3-cd)pyrene	<	4.000										4.000	4.000	4.000	ug/l
Iron	2.120	5.050	7.900	78.300	3.540	0.540	2.320	1.600	3.100	2.330		0.540	78.300	10.680	mg/l
Iron, (Dissd.)	1.480	1.480	1.620	1.310	1.500	0.250	0.910	1.500	1.130	1.020		0.250	1.620	1.220	mg/l
Isophorone	<	4.000										4.000	4.000	4.000	ug/l
Lead	< 0.005	< 0.005	< 0.005	0.046	< 0.005	< 0.005	< 0.005	< 0.003	< 0.003	< 0.003		0.003	0.046	0.009	mg/l
Lead, (Dissd.)	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.003	< 0.003	< 0.003		0.003	0.005	0.004	mg/l
Magnesium	43.400	58.000	53.600	41.000	44.000	43.000	40.000	48.000	39.100	43.000		39.100	58.000	45.310	mg/l
Magnesium, (Dissd.)	43.300	28.000	43.200	38.000	35.000	27.000	22.000	43.000	41.200	41.100		22.000	43.300	36.180	mg/l
Manganese	0.115	0.150	0.174	1.050	0.119	0.092	0.103	0.078	0.113	0.056		0.056	1.050	0.205	mg/l
Manganese, (Dissd.)	0.080	0.063	0.068	0.063	0.058	0.085	0.079	0.080	0.062	0.036		0.036	0.085	0.067	mg/l
Mercury		<*,***.***	<*,***.***	<*,***.***	<*,***.***	<*,***.***	<*,***.***	<*,***.***	<*,***.***	<*,***.***		*,***.***	*,***.***	0.000	mg/l
Mercury, (Dissd.)		<*,***.***	<*,***.***	<*,***.***	<*,***.***	<*,***.***	<*,***.***	<*,***.***	<*,***.***	<*,***.***		*,***.***	*,***.***	0.000	mg/l
Methyl ethyl ketone	<	2.000	< 2.000	< 2.000	< 2.000	< 2.000	< 2.000	< 2.000	< 2.000	< 2.000		2.000	2.000	2.000	ug/l
Methylene chloride	< 1.000	< 1.000	< 1.000	< 1.000	< 1.000	< 1.000	< 1.000	< 1.000	< 1.000	< 1.000		1.000	1.000	1.000	ug/l
Molybdenum	<	0.025	< 0.025	0.039	< 0.025	< 0.010	0.014	0.010	< 0.010	< 0.010		0.010	0.039	0.019	mg/l
Molybdenum, (Dissd.)	<	0.025	< 0.025	< 0.025	< 0.025	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010		0.010	0.025	0.017	mg/l
N-Nitrosodi-n-propylamine	<	4.000										4.000	4.000	4.000	ug/l
N-Nitrosodiphenylamine	<	4.000										4.000	4.000	4.000	ug/l
NP-237	<	0.120		<	0.120							0.120	0.120	0.120	pCi/l
Naphthalene	<	4.000										4.000	4.000	4.000	ug/l
Nickel	< 0.005	< 0.005	< 0.005	0.083	< 0.005	0.049	< 0.010	0.011	< 0.010	< 0.010		0.005	0.083	0.019	mg/l
Nickel, (Dissd.)	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010		0.005	0.010	0.008	mg/l
Nitrobenzene	<	4.000										4.000	4.000	4.000	ug/l
Nitrogen, Nitrate	0.020	0.070	0.050	<	0.020	< 0.020	< 0.020	0.030	< 0.020	< 0.020		0.020	0.070	0.030	mg/l
Nitrogen, Nitrate+Nitrite			<	0.020								0.020	0.020	0.020	mg/l
PU-238	<	0.140										0.140	0.140	0.140	pCi/l
PU-239/240	<	0.180										0.180	0.180	0.180	pCi/l
Pentachlorophenol	<	4.000										4.000	4.000	4.000	ug/l
Phenanthrene	<	4.000										4.000	4.000	4.000	ug/l
Phenol	<	4.000										4.000	4.000	4.000	ug/l
Phenols	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005		0.005	0.005	0.005	mg/l
Phosphorus, Total				0.060	0.180	0.100	< 0.100	< 0.100	0.110	0.250		0.060	0.250	0.129	mg/l

* Average for this Quarter

PARAMETER ...	A90	B90	C90	D90	A91	B91	C91	D91	A92	B92	C92	MIN	MAX	AVG	UNITS
Potassium		1.820	2.260	4.840	1.430	1.400	1.700	1.300	1.600	1.300		1.300	4.840	1.961	mg/l
Potassium, (Dissd.)		1.350	1.380	1.480 <	1.000	1.400	1.500	1.200	1.300	1.300		1.000	1.500	1.323	mg/l
Pyrene	<	4.000										4.000	4.000	4.000	ug/l
Pyridine	<	4.000										4.000	4.000	4.000	ug/l
RA-226	<	0.160 <	0.130	<	0.120							0.120	0.160	0.137	pCi/l
RA-228	<	0.130 <	1.300	<	0.870							0.130	1.300	0.767	pCi/l
RU-106	<	88.000		<	74.000							74.000	88.000	81.000	pCi/l
SR-90		1.390										1.390	1.390	1.390	pCi/l
Selenium	<	0.003 <	0.003 <	0.003 <	0.003 <	0.005 <	0.005 <	0.005 <	0.005 <	0.005		0.003	0.005	0.004	mg/l
Selenium, (Dissd.)	<	0.003 <	0.003 <	0.003 <	0.003 <	0.005 <	0.005 <	0.005 <	0.005 <	0.005		0.003	0.005	0.004	mg/l
Silver	< 0.001 <	0.001 <	0.001 <	0.001	0.002 <	0.001 <	0.001 <	0.001 <	0.001 <	0.001		0.001	0.002	0.001	mg/l
Silver, (Dissd.)	< 0.001 <	0.001 <	0.001 <	0.001 <	0.001 <	0.001 <	0.001 <	0.001 <	0.001 <	0.001		0.001	0.001	0.001	mg/l
Sodium	25.700	15.900	14.900	13.000	11.600	12.000	18.000	16.000	12.600	12.100		11.600	25.700	15.180	mg/l
Sodium, (Dissd.)	26.300	11.800	16.100	8.200	10.700	12.000	15.000	12.000	13.000	16.800		8.200	26.300	14.190	mg/l
Specific conductance				712.000	733.000	750.000	743.000	731.000	748.000	799.000		712.000	799.000	745.143	umhos/c
Styrene	<	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000		1.000	1.000	1.000	ug/l
Sulfate	43.000	46.000	50.000	44.000	61.000	57.000	67.000	54.000	43.000	47.000		43.000	67.000	51.200	mg/l
TC-99	< 15.000 <	26.000		<	19.000							15.000	26.000	20.000	pCi/l
TH-228	<	0.340 <	0.310	<	0.190							0.190	0.340	0.280	pCi/l
TH-230		0.604	0.366		0.202							0.202	0.604	0.391	pCi/l
TH-232	<	0.340 <	0.310	<	0.190							0.190	0.340	0.280	pCi/l
TH-TOTAL	<	3.000 <	2.800	<	1.800							1.800	3.000	2.533	ug/l
TOC	< 1.000	2.000	50.000	3.000	4.000	21.000	8.000	7.000	19.000	15.000		1.000	50.000	13.000	mg/l
TOX	< 10.000 <	10.000	26.000	614.000 <	10.000 <	10.000 <	10.000 <	10.000 <	10.000 <	10.000		10.000	614.000	72.000	ug/l Cl
Tetrachloroethene	< 1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000		1.000	1.000	1.000	ug/l
Thallium	<	0.010 <	0.010 <	0.010 <	0.010 <	0.010 <	0.010 <	0.010 <	0.010 <	0.010		0.010	0.010	0.010	mg/l
Thallium, (Dissd.)	<	0.010 <	0.010 <	0.010 <	0.010 <	0.010 <	0.010 <	0.010 <	0.010 <	0.010		0.010	0.010	0.010	mg/l
Toluene	< 1.000 <	1.000 <	1.000 <	1.000 <	1.000	1.300 <	1.000 <	1.000 <	1.000 <	1.000		1.000	1.300	1.030	ug/l
Total dissolved solids				508.000	418.000	336.000	372.000	430.000	416.000	403.000		336.000	508.000	411.857	mg/l
Toxaphene	<	0.500										0.500	0.500	0.500	ug/l
Trichloroethene	2.700 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000		1.000	2.700	1.170	ug/l
U-234	< 1.000	0.396	1.040		0.282							0.282	1.040	0.680	pCi/l
U-235/236	<	0.200	0.351	<	0.180							0.180	0.351	0.244	pCi/l
U-238	< 1.000 <	0.200	0.979		0.188							0.188	1.000	0.592	pCi/l
U-TOTAL	2.200 <	1.000	1.090		0.529	0.600	0.800	0.800	0.700	0.400		0.400	2.200	0.902	ug/l
Vanadium	< 0.050 <	0.050 <	0.050	0.178 <	0.050 <	0.050 <	0.050 <	0.050 <	0.050 <	0.050		0.050	0.178	0.063	mg/l
Vanadium, (Dissd.)	< 0.050 <	0.050 <	0.050 <	0.050 <	0.050 <	0.050 <	0.050 <	0.050 <	0.050 <	0.050		0.050	0.050	0.050	mg/l

* Average for this Quarter

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4333

WELL NO.:1024

PARAMETER	...	A90	B90	C90	D90	A91	B91	C91	D91	A92	B92	C92	MIN	MAX	AVG	UNITS
Vinyl acetate		<	2.000 <	2.000 <	2.000 <	2.000 <	2.000 <	2.000 <	2.000 <	2.000 <	2.000		2.000	2.000	2.000	ug/l
Vinyl chloride		<	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000		1.000	1.000	1.000	ug/l
Xylenes, Total		<	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000		1.000	1.000	1.000	ug/l
Zinc	<	0.020 <	0.020 <	0.020	0.147 <	0.020	0.088	0.048	0.039 <	0.020 <	0.020		0.020	0.147	0.044	mg/l
Zinc, (Dissd.)	<	0.020 <	0.020 <	0.020 <	0.020 <	0.020	0.090	0.032	0.039 <	0.020 <	0.020		0.020	0.090	0.030	mg/l
alpha-BHC		<	0.200										0.200	0.200	0.200	ug/l
beta-BHC		<	0.200										0.200	0.200	0.200	ug/l
bis(2-Chloroethoxy)methane		<	15.000										15.000	15.000	15.000	ug/l
bis(2-Chloroethyl)ether		<	15.000										15.000	15.000	15.000	ug/l
bis(2-Chloroisopropyl)ether		<	15.000										15.000	15.000	15.000	ug/l
bis(2-Ethylhexyl)phthalate		<	4.000										4.000	4.000	4.000	ug/l
cis-1,3-Dichloropropene		<	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000		1.000	1.000	1.000	ug/l
delta-BHC		<	0.200										0.200	0.200	0.200	ug/l
gamma-BHC (Lindane)		<	0.200										0.200	0.200	0.200	ug/l
m-Dichlorobenzene		<	4.000										4.000	4.000	4.000	ug/l
m-Methylphenol (Cresol)		<	4.000										4.000	4.000	4.000	ug/l
o-Dichlorobenzene		<	4.000										4.000	4.000	4.000	ug/l
o-Methylphenol (Cresol)		<	4.000										4.000	4.000	4.000	ug/l
p-Chloroaniline		<	4.000										4.000	4.000	4.000	ug/l
p-Dichlorobenzene		<	4.000										4.000	4.000	4.000	ug/l
pH					7.080	7.180	7.300	7.340	7.200	7.160	7.210		7.080	7.340	7.210	S.U.
trans-1,2-Dichloroethene				<	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000		1.000	1.000	1.000	ug/l
trans-1,3-Dichloropropene		<	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000		1.000	1.000	1.000	ug/l

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4333

* Average for this Quarter

WELL NO.:1029

03/11/93

PARAMETER ...	A90	B90	C90	D90	A91	B91	C91	D91	A92	B92	C92	MIN	MAX	AVG	UNITS
1,1,1-Trichloroethane		< 1.000		< 1.000								1.000	1.000	1.000	ug/l
1,1,2,2-Tetrachloroethane		< 1.000		< 1.000								1.000	1.000	1.000	ug/l
1,1,2-Trichloroethane		< 1.000		< 1.000								1.000	1.000	1.000	ug/l
1,1-Dichloroethane		< 1.000		< 1.000								1.000	1.000	1.000	ug/l
1,1-Dichloroethene		< 1.000		< 1.000								1.000	1.000	1.000	ug/l
1,2-Dichloroethane		< 1.000		< 1.000								1.000	1.000	1.000	ug/l
1,2-Dichloroethene				< 1.000								1.000	1.000	1.000	ug/l
1,2-Dichloropropane		< 1.000		< 1.000								1.000	1.000	1.000	ug/l
2-Chloroethyl vinyl ether		< 60.000		< 10.000								10.000	60.000	35.000	ug/l
2-Hexanone				< 2.000								2.000	2.000	2.000	ug/l
4-Methyl-2-pentanone				< 2.000								2.000	2.000	2.000	ug/l
Acetone				< 2.000								2.000	2.000	2.000	ug/l
Alkalinity at CaCO3				345.000								345.000	345.000	345.000	mg/l
Ammonia, as nitrogen				0.050								0.050	0.050	0.050	mg/l
Benzene		< 1.000		< 1.000								1.000	1.000	1.000	ug/l
Bromodichloromethane		< 1.000		< 1.000								1.000	1.000	1.000	ug/l
Bromoform		< 1.000		< 1.000								1.000	1.000	1.000	ug/l
Bromomethane		< 1.000		< 1.000								1.000	1.000	1.000	ug/l
Carbon disulfide				< 1.000								1.000	1.000	1.000	ug/l
Carbon tetrachloride		< 1.000		< 1.000								1.000	1.000	1.000	ug/l
Chloride		3.000		3.000								3.000	3.000	3.000	mg/l
Chlorobenzene		< 1.000		< 1.000								1.000	1.000	1.000	ug/l
Chloroethane				< 1.000								1.000	1.000	1.000	ug/l
Chloroform		< 1.000		< 1.000								1.000	1.000	1.000	ug/l
Chloromethane		< 1.000		< 1.000								1.000	1.000	1.000	ug/l
Cyanide				< 0.005								0.005	0.005	0.005	mg/l
Dibromochloromethane		< 1.000		< 1.000								1.000	1.000	1.000	ug/l
Ethyl benzene		< 1.000		< 1.000								1.000	1.000	1.000	ug/l
Fluoride				0.860								0.860	0.860	0.860	mg/l
GROSS ALPHA		29.900										29.900	29.900	29.900	pCi/l
GROSS BETA		28.000										28.000	28.000	28.000	pCi/l
Methyl ethyl ketone				< 2.000								2.000	2.000	2.000	ug/l
Methylene chloride		< 1.000		< 1.000								1.000	1.000	1.000	ug/l
Nitrogen, Nitrate		0.080										0.080	0.080	0.080	mg/l
Nitrogen, Nitrate+Nitrite				0.030								0.030	0.030	0.030	mg/l
Phenols				< 0.005								0.005	0.005	0.005	mg/l
Phosphorus, Total				2.530								2.530	2.530	2.530	mg/l

* Average for this Quarter

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4333

WELL NO.:1029

PARAMETER	...	A90	B90	C90	D90	A91	B91	C91	D91	A92	B92	C92	MIN	MAX	AVG	UNITS
RA-226			0.755										0.755	0.755	0.755	pCi/l
RA-228			< 0.370										0.370	0.370	0.370	pCi/l
Specific conductance					723.000								723.000	723.000	723.000	umhos/c
Styrene					< 1.000								1.000	1.000	1.000	ug/l
Sulfate			64.000		56.000								56.000	64.000	60.000	mg/l
TH-228			< 0.670										0.670	0.670	0.670	pCi/l
TH-230			< 0.670										0.670	0.670	0.670	pCi/l
TH-232			< 0.670										0.670	0.670	0.670	pCi/l
TH-TOTAL			< 6.000										6.000	6.000	6.000	ug/l
TOC			1.000		3.000								1.000	3.000	2.000	mg/l
TOX			15.000		< 10.000								10.000	15.000	12.500	ug/l Cl
Tetrachloroethene			< 1.000		< 1.000								1.000	1.000	1.000	ug/l
Toluene			< 1.000		< 1.000								1.000	1.000	1.000	ug/l
Total dissolved solids					462.000								462.000	462.000	462.000	mg/l
Trichloroethene			< 1.000		< 1.000								1.000	1.000	1.000	ug/l
Trichlorofluoromethane			< 1.000										1.000	1.000	1.000	ug/l
U-234			2.320										2.320	2.320	2.320	pCi/l
U-235/236			0.529										0.529	0.529	0.529	pCi/l
U-238			1.730										1.730	1.730	1.730	pCi/l
U-TOTAL			3.640										3.640	3.640	3.640	ug/l
Vinyl acetate					< 2.000								2.000	2.000	2.000	ug/l
Vinyl chloride			< 1.000		< 1.000								1.000	1.000	1.000	ug/l
Xylenes, Total					< 1.000								1.000	1.000	1.000	ug/l
cis-1,3-Dichloropropene			< 1.000		< 1.000								1.000	1.000	1.000	ug/l
m-Dichlorobenzene			< 1.000										1.000	1.000	1.000	ug/l
o-Dichlorobenzene			< 1.000										1.000	1.000	1.000	ug/l
p-Dichlorobenzene			< 1.000										1.000	1.000	1.000	ug/l
pH					7.310								7.310	7.310	7.310	S.U.
trans-1,2-Dichloroethene			< 1.000		< 1.000								1.000	1.000	1.000	ug/l
trans-1,3-Dichloropropene			< 1.000		< 1.000								1.000	1.000	1.000	ug/l

4333

* Average for this Quarter

WELL NO.:1033

03/11/93

PARAMETER ...	A90	B90	C90	D90	A91	B91	C91	D91	A92	B92	C92	MIN	MAX	AVG	UNITS
1,1,1-Trichloroethane	<	1.000										1.000	1.000	1.000	ug/l
1,1,2,2-Tetrachloroethane	<	1.000										1.000	1.000	1.000	ug/l
1,1,2-Trichloroethane	<	1.000										1.000	1.000	1.000	ug/l
1,1-Dichloroethane	<	1.000										1.000	1.000	1.000	ug/l
1,1-Dichloroethene	<	1.000										1.000	1.000	1.000	ug/l
1,2-Dichloroethane	<	1.000										1.000	1.000	1.000	ug/l
1,2-Dichloropropane	<	1.000										1.000	1.000	1.000	ug/l
2-Chloroethyl vinyl ether	<	60.000										60.000	60.000	60.000	ug/l
Benzene	<	1.000										1.000	1.000	1.000	ug/l
Bromodichloromethane	<	1.000										1.000	1.000	1.000	ug/l
Bromoform	<	1.000										1.000	1.000	1.000	ug/l
Bromomethane	<	1.000										1.000	1.000	1.000	ug/l
Carbon tetrachloride	<	1.000										1.000	1.000	1.000	ug/l
Chloride		6.000										6.000	6.000	6.000	mg/l
Chlorobenzene	<	1.000										1.000	1.000	1.000	ug/l
Chloroform	<	1.000										1.000	1.000	1.000	ug/l
Chloromethane	<	1.000										1.000	1.000	1.000	ug/l
Dibromochloromethane	<	1.000										1.000	1.000	1.000	ug/l
Ethyl benzene	<	1.000										1.000	1.000	1.000	ug/l
GROSS ALPHA		54.400										54.400	54.400	54.400	pCi/l
GROSS BETA		45.400										45.400	45.400	45.400	pCi/l
Methylene chloride	<	1.000										1.000	1.000	1.000	ug/l
Nitrogen, Nitrate		0.240										0.240	0.240	0.240	mg/l
RA-226		0.474										0.474	0.474	0.474	pCi/l
RA-228	<	0.610										0.610	0.610	0.610	pCi/l
Sulfate		113.000										113.000	113.000	113.000	mg/l
TH-228		0.654										0.654	0.654	0.654	pCi/l
TH-230		0.872										0.872	0.872	0.872	pCi/l
TH-232	<	0.330										0.330	0.330	0.330	pCi/l
TH-TOTAL	<	2.900										2.900	2.900	2.900	ug/l
TOC		2.000										2.000	2.000	2.000	mg/l
TOX	<	10.000										10.000	10.000	10.000	ug/l Cl
Tetrachloroethene	<	1.000										1.000	1.000	1.000	ug/l
Toluene	<	1.000										1.000	1.000	1.000	ug/l
Trichloroethene	<	1.000										1.000	1.000	1.000	ug/l
Trichlorofluoromethane	<	1.000										1.000	1.000	1.000	ug/l
U-234		6.080										6.080	6.080	6.080	pCi/l

* Average for this Quarter

03/11/93

WELL NO.:1033

PARAMETER	...	A90	B90	C90	D90	A91	B91	C91	D91	A92	B92	C92	MIN	MAX	AVG	UNITS
U-235/236			0.610										0.610	0.610	0.610	pCi/l
U-238			7.540										7.540	7.540	7.540	pCi/l
U-TOTAL			21.500										21.500	21.500	21.500	ug/l
Vinyl chloride		<	1.000										1.000	1.000	1.000	ug/l
cis-1,3-Dichloropropene		<	1.000										1.000	1.000	1.000	ug/l
m-Dichlorobenzene		<	1.000										1.000	1.000	1.000	ug/l
o-Dichlorobenzene		<	1.000										1.000	1.000	1.000	ug/l
p-Dichlorobenzene		<	1.000										1.000	1.000	1.000	ug/l
trans-1,2-Dichloroethene		<	1.000										1.000	1.000	1.000	ug/l
trans-1,3-Dichloropropene		<	1.000										1.000	1.000	1.000	ug/l

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4333

* Average for this Quarter

WELL NO.:1045

03/11/93

PARAMETER ...	A90	B90	C90	D90	A91	B91	C91	D91	A92	B92	C92	MIN	MAX	AVG	UNITS
1,1,1-Trichloroethane		< 1.000		< 1.000								1.000	1.000	1.000	ug/l
1,1,2,2-Tetrachloroethane		< 1.000		< 1.000								1.000	1.000	1.000	ug/l
1,1,2-Trichloroethane		< 1.000		< 1.000								1.000	1.000	1.000	ug/l
1,1-Dichloroethane		< 1.000		< 1.000								1.000	1.000	1.000	ug/l
1,1-Dichloroethene		< 1.000		< 1.000								1.000	1.000	1.000	ug/l
1,2-Dichloroethane		< 1.000		< 1.000								1.000	1.000	1.000	ug/l
1,2-Dichloroethene				< 1.000								1.000	1.000	1.000	ug/l
1,2-Dichloropropane		< 1.000		< 1.000								1.000	1.000	1.000	ug/l
2-Chloroethyl vinyl ether		< 60.000		< 10.000								10.000	60.000	35.000	ug/l
2-Hexanone				< 2.000								2.000	2.000	2.000	ug/l
4-Methyl-2-pentanone				< 2.000								2.000	2.000	2.000	ug/l
Acetone				< 2.000								2.000	2.000	2.000	ug/l
Alkalinity at CaCO3				258.000								258.000	258.000	258.000	mg/l
Ammonia, as nitrogen				< 0.020								0.020	0.020	0.020	mg/l
Benzene		< 1.000		< 1.000								1.000	1.000	1.000	ug/l
Bromodichloromethane		< 1.000		< 1.000								1.000	1.000	1.000	ug/l
Bromoform		< 1.000		< 1.000								1.000	1.000	1.000	ug/l
Bromomethane		< 1.000		< 1.000								1.000	1.000	1.000	ug/l
Carbon disulfide				< 1.000								1.000	1.000	1.000	ug/l
Carbon tetrachloride		< 1.000		< 1.000								1.000	1.000	1.000	ug/l
Chloride		4.000		3.000								3.000	4.000	3.500	mg/l
Chlorobenzene		< 1.000		< 1.000								1.000	1.000	1.000	ug/l
Chloroethane				< 1.000								1.000	1.000	1.000	ug/l
Chloroform		< 1.000		< 1.000								1.000	1.000	1.000	ug/l
Chloromethane		< 1.000		< 1.000								1.000	1.000	1.000	ug/l
Cyanide				< 0.005								0.005	0.005	0.005	mg/l
Dibromochloromethane		< 1.000		< 1.000								1.000	1.000	1.000	ug/l
Ethyl benzene		< 1.000		< 1.000								1.000	1.000	1.000	ug/l
Fluoride				0.210								0.210	0.210	0.210	mg/l
Methyl ethyl ketone				< 2.000								2.000	2.000	2.000	ug/l
Methylene chloride		< 1.000		< 1.000								1.000	1.000	1.000	ug/l
Nitrogen, Nitrate		0.100										0.100	0.100	0.100	mg/l
Nitrogen, Nitrate+Nitrite				0.020								0.020	0.020	0.020	mg/l
Phenols				< 0.005								0.005	0.005	0.005	mg/l
Phosphorus, Total				0.270								0.270	0.270	0.270	mg/l
RA-226		< 0.230										0.230	0.230	0.230	pCi/l
RA-228		< 1.300										1.300	1.300	1.300	pCi/l

* Average for this Quarter

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4333

WELL NO.:1045

PARAMETER	...	A90	B90	C90	D90	A91	B91	C91	D91	A92	B92	C92	MIN	MAX	AVG	UNITS
Specific conductance					536.000								536.000	536.000	536.000	umhos/c
Styrene				<	1.000								1.000	1.000	1.000	ug/l
Sulfate			55.000		48.000								48.000	55.000	51.500	mg/l
TH-228		<	0.490										0.490	0.490	0.490	pCi/l
TH-230			0.875										0.875	0.875	0.875	pCi/l
TH-232		<	0.490										0.490	0.490	0.490	pCi/l
TH-TOTAL		<	4.400										4.400	4.400	4.400	ug/l
TOC			3.000		3.000								3.000	3.000	3.000	mg/l
TOX		<	10.000	<	10.000								10.000	10.000	10.000	ug/l Cl
Tetrachloroethene		<	1.000	<	1.000								1.000	1.000	1.000	ug/l
Toluene		<	1.000	<	1.000								1.000	1.000	1.000	ug/l
Total dissolved solids					345.000								345.000	345.000	345.000	mg/l
Trichloroethene		<	1.000	<	1.000								1.000	1.000	1.000	ug/l
Trichlorofluoromethane		<	1.000										1.000	1.000	1.000	ug/l
U-234			2.490										2.490	2.490	2.490	pCi/l
U-235/236			0.369										0.369	0.369	0.369	pCi/l
U-238			2.930										2.930	2.930	2.930	pCi/l
U-TOTAL			8.890										8.890	8.890	8.890	ug/l
Vinyl acetate				<	2.000								2.000	2.000	2.000	ug/l
Vinyl chloride		<	1.000	<	1.000								1.000	1.000	1.000	ug/l
Xylenes, Total				<	1.000								1.000	1.000	1.000	ug/l
cis-1,3-Dichloropropene		<	1.000	<	1.000								1.000	1.000	1.000	ug/l
m-Dichlorobenzene		<	1.000										1.000	1.000	1.000	ug/l
o-Dichlorobenzene		<	1.000										1.000	1.000	1.000	ug/l
p-Dichlorobenzene		<	1.000										1.000	1.000	1.000	ug/l
pH					6.900								6.900	6.900	6.900	S.U.
trans-1,2-Dichloroethene		<	1.000	<	1.000								1.000	1.000	1.000	ug/l
trans-1,3-Dichloropropene		<	1.000	<	1.000								1.000	1.000	1.000	ug/l

OR 259

* Average for this Quarter

WELL NO.:1048

03/11/93

PARAMETER ...	A90	B90	C90	D90	A91	B91	C91	D91	A92	B92	C92	MIN	MAX	AVG	UNITS
1,1,1-Trichloroethane	<	1.000	<	1.000								1.000	1.000	1.000	ug/l
1,1,2,2-Tetrachloroethane	<	1.000	<	1.000								1.000	1.000	1.000	ug/l
1,1,2-Trichloroethane	<	1.000	<	1.000								1.000	1.000	1.000	ug/l
1,1-Dichloroethane	<	1.000	<	1.000								1.000	1.000	1.000	ug/l
1,1-Dichloroethene	<	1.000	<	1.000								1.000	1.000	1.000	ug/l
1,2-Dichloroethane	<	1.000	<	1.000								1.000	1.000	1.000	ug/l
1,2-Dichloroethene			<	1.000								1.000	1.000	1.000	ug/l
1,2-Dichloropropane	<	1.000	<	1.000								1.000	1.000	1.000	ug/l
2-Chloroethyl vinyl ether	<	60.000	<	10.000								10.000	60.000	35.000	ug/l
2-Hexanone			<	2.000								2.000	2.000	2.000	ug/l
4-Methyl-2-pentanone			<	2.000								2.000	2.000	2.000	ug/l
Acetone			<	2.000								2.000	2.000	2.000	ug/l
Alkalinity at CaCO3				586.000								586.000	586.000	586.000	mg/l
Ammonia, as nitrogen			<	0.020								0.020	0.020	0.020	mg/l
Benzene	<	1.000	<	1.000								1.000	1.000	1.000	ug/l
Bromodichloromethane	<	1.000	<	1.000								1.000	1.000	1.000	ug/l
Bromoform	<	1.000	<	1.000								1.000	1.000	1.000	ug/l
Bromomethane	<	1.000	<	1.000								1.000	1.000	1.000	ug/l
Carbon disulfide			<	1.000								1.000	1.000	1.000	ug/l
Carbon tetrachloride	<	1.000	<	1.000								1.000	1.000	1.000	ug/l
Chloride		9.000		13.000								9.000	13.000	11.000	mg/l
Chlorobenzene	<	1.000	<	1.000								1.000	1.000	1.000	ug/l
Chloroethane			<	1.000								1.000	1.000	1.000	ug/l
Chloroform	<	1.000	<	1.000								1.000	1.000	1.000	ug/l
Chloromethane	<	1.000	<	1.000								1.000	1.000	1.000	ug/l
Cyanide			<	0.005								0.005	0.005	0.005	mg/l
Dibromochloromethane	<	1.000	<	1.000								1.000	1.000	1.000	ug/l
Ethyl benzene	<	1.000	<	1.000								1.000	1.000	1.000	ug/l
Fluoride				0.130								0.130	0.130	0.130	mg/l
Methyl ethyl ketone			<	2.000								2.000	2.000	2.000	ug/l
Methylene chloride	<	1.000	<	1.000								1.000	1.000	1.000	ug/l
Nitrogen, Nitrate		0.040										0.040	0.040	0.040	mg/l
Nitrogen, Nitrate+Nitrite				0.030								0.030	0.030	0.030	mg/l
Phenols			<	0.005								0.005	0.005	0.005	mg/l
Phosphorus, Total				2.060								2.060	2.060	2.060	mg/l
RA-226		1.040										1.040	1.040	1.040	pCi/l
RA-228	<	0.720										0.720	0.720	0.720	pCi/l

* Average for this Quarter

260

4333

WELL NO.:1048

PARAMETER	...	A90	B90	C90	D90	A91	B91	C91	D91	A92	B92	C92	MIN	MAX	AVG	UNITS
Specific conductance					1,540.000								1,540.000	1,540.000	1,540.000	umhos/c
Styrene					< 1.000								1.000	1.000	1.000	ug/l
Sulfate			97.000		82.000								82.000	97.000	89.500	mg/l
TH-228			1.270										1.270	1.270	1.270	pCi/l
TH-230			< 1.000										1.000	1.000	1.000	pCi/l
TH-232			< 1.000										1.000	1.000	1.000	pCi/l
TH-TOTAL			6.390										6.390	6.390	6.390	ug/l
TOC			4.000		6.000								4.000	6.000	5.000	mg/l
TOX			15.000		119.000								15.000	119.000	67.000	ug/l Cl
Tetrachloroethene			< 1.000		< 1.000								1.000	1.000	1.000	ug/l
Toluene			< 1.000		< 1.000								1.000	1.000	1.000	ug/l
Total dissolved solids					1,230.000								1,230.000	1,230.000	1,230.000	mg/l
Trichloroethene			< 1.000		< 1.000								1.000	1.000	1.000	ug/l
Trichlorofluoromethane			< 1.000										1.000	1.000	1.000	ug/l
U-234			13.800										13.800	13.800	13.800	pCi/l
U-235/236			< 1.000										1.000	1.000	1.000	pCi/l
U-238			13.500										13.500	13.500	13.500	pCi/l
U-TOTAL			40.600										40.600	40.600	40.600	ug/l
Vinyl acetate					< 2.000								2.000	2.000	2.000	ug/l
Vinyl chloride			< 1.000		< 1.000								1.000	1.000	1.000	ug/l
Xylenes, Total					< 1.000								1.000	1.000	1.000	ug/l
cis-1,3-Dichloropropene			< 1.000		< 1.000								1.000	1.000	1.000	ug/l
m-Dichlorobenzene			< 1.000										1.000	1.000	1.000	ug/l
o-Dichlorobenzene			< 1.000										1.000	1.000	1.000	ug/l
p-Dichlorobenzene			< 1.000										1.000	1.000	1.000	ug/l
pH					6.680								6.680	6.680	6.680	S.U.
trans-1,2-Dichloroethene			< 1.000		< 1.000								1.000	1.000	1.000	ug/l
trans-1,3-Dichloropropene			< 1.000		< 1.000								1.000	1.000	1.000	ug/l

* Average for this Quarter

PARAMETER ...	A90	B90	C90	D90	A91	B91	C91	D91	A92	B92	C92	MIN	MAX	AVG	UNITS
1,1,1-Trichloroethane	<	1.000	<	1.000				<	1.000			1.000	1.000	1.000	ug/l
1,1,2,2-Tetrachloroethane	<	1.000	<	1.000				<	1.000			1.000	1.000	1.000	ug/l
1,1,2-Trichloroethane	<	1.000	<	1.000				<	1.000			1.000	1.000	1.000	ug/l
1,1-Dichloroethane	<	1.000	<	1.000				<	1.000			1.000	1.000	1.000	ug/l
1,1-Dichloroethene	<	1.000	<	1.000				<	1.000			1.000	1.000	1.000	ug/l
1,2-Dichloroethane	<	1.000	<	1.000				<	1.000			1.000	1.000	1.000	ug/l
1,2-Dichloroethene			<	1.000								1.000	1.000	1.000	ug/l
1,2-Dichloroethene (Total)								<	1.000			1.000	1.000	1.000	ug/l
1,2-Dichloropropane	<	1.000	<	1.000				<	1.000			1.000	1.000	1.000	ug/l
2-Chloroethyl vinyl ether	<	60.000	<	10.000				<	10.000			10.000	60.000	26.667	ug/l
2-Hexanone			<	2.000				<	2.000			2.000	2.000	2.000	ug/l
4-Methyl-2-pentanone			<	2.000				<	2.000			2.000	2.000	2.000	ug/l
Acetone			<	2.000				<	2.000			2.000	2.000	2.000	ug/l
Alkalinity at CaCO3				358.000					372.000			358.000	372.000	365.000	mg/l
Aluminum									4.300			4.300	4.300	4.300	mg/l
Aluminum, (Dissd.)								<	0.200			0.200	0.200	0.200	mg/l
Ammonia, as nitrogen			<	0.020				<	0.020			0.020	0.020	0.020	mg/l
Antimony								<	0.020			0.020	0.020	0.020	mg/l
Antimony, (Dissd.)								<	0.020			0.020	0.020	0.020	mg/l
Arsenic								<	0.005			0.005	0.005	0.005	mg/l
Arsenic, (Dissd.)								<	0.005			0.005	0.005	0.005	mg/l
Barium								<	0.200			0.200	0.200	0.200	mg/l
Barium, (Dissd.)								<	0.200			0.200	0.200	0.200	mg/l
Benzene	<	1.000	<	1.000				<	1.000			1.000	1.000	1.000	ug/l
Beryllium								<	0.005			0.005	0.005	0.005	mg/l
Beryllium, (Dissd.)								<	0.005			0.005	0.005	0.005	mg/l
Bromodichloromethane	<	1.000	<	1.000				<	1.000			1.000	1.000	1.000	ug/l
Bromoform	<	1.000	<	1.000				<	1.000			1.000	1.000	1.000	ug/l
Bromomethane	<	1.000	<	1.000				<	1.000			1.000	1.000	1.000	ug/l
Cadmium								<	0.001			0.001	0.001	0.001	mg/l
Cadmium, (Dissd.)								<	0.001			0.001	0.001	0.001	mg/l
Calcium									101.000			101.000	101.000	101.000	mg/l
Calcium, (Dissd.)									94.600			94.600	94.600	94.600	mg/l
Carbon disulfide			<	1.000				<	1.000			1.000	1.000	1.000	ug/l
Carbon tetrachloride	<	1.000	<	1.000				<	1.000			1.000	1.000	1.000	ug/l
Chloride		4.000		5.000					7.000			4.000	7.000	5.333	mg/l
Chlorobenzene	<	1.000	<	1.000				<	1.000			1.000	1.000	1.000	ug/l

* Average for this Quarter

263

WELL NO.:1064

PARAMETER	...	A90	B90	C90	D90	A91	B91	C91	D91	A92	B92	C92	MIN	MAX	AVG	UNITS
Chloroethane				<	1.000				<	1.000			1.000	1.000	1.000	ug/l
Chloroform		<	1.000	<	1.000				<	1.000			1.000	1.000	1.000	ug/l
Chloromethane		<	1.000	<	1.000				<	1.000			1.000	1.000	1.000	ug/l
Chromium, Total										0.024			0.024	0.024	0.024	mg/l
Chromium, Total (Dissd.)										0.009			0.009	0.009	0.009	mg/l
Cobalt									<	0.005			0.005	0.005	0.005	mg/l
Cobalt, (Dissd.)									<	0.005			0.005	0.005	0.005	mg/l
Copper									<	0.020			0.020	0.020	0.020	mg/l
Copper, (Dissd.)									<	0.020			0.020	0.020	0.020	mg/l
Cyanide				<	0.005				<	0.005			0.005	0.005	0.005	mg/l
Dibromochloromethane		<	1.000	<	1.000				<	1.000			1.000	1.000	1.000	ug/l
Ethyl benzene		<	1.000	<	1.000				<	1.000			1.000	1.000	1.000	ug/l
Fluoride					0.570					0.680			0.570	0.680	0.625	mg/l
GROSS ALPHA		<	15.000										15.000	15.000	15.000	pCi/l
GROSS BETA		<	27.000										27.000	27.000	27.000	pCi/l
Iron										6.440			6.440	6.440	6.440	mg/l
Iron, (Dissd.)									<	0.100			0.100	0.100	0.100	mg/l
Lead									<	0.003			0.003	0.003	0.003	mg/l
Lead, (Dissd.)									<	0.003			0.003	0.003	0.003	mg/l
Magnesium										38.000			38.000	38.000	38.000	mg/l
Magnesium, (Dissd.)										36.300			36.300	36.300	36.300	mg/l
Manganese										0.264			0.264	0.264	0.264	mg/l
Manganese, (Dissd.)										0.064			0.064	0.064	0.064	mg/l
Mercury									<*,***.***				*,***.***	*,***.***	0.000	mg/l
Mercury, (Dissd.)									<*,***.***				*,***.***	*,***.***	0.000	mg/l
Methyl ethyl ketone				<	2.000				<	2.000			2.000	2.000	2.000	ug/l
Methylene chloride		<	1.000	<	1.000				<	1.000			1.000	1.000	1.000	ug/l
Molybdenum									<	0.010			0.010	0.010	0.010	mg/l
Molybdenum, (Dissd.)									<	0.010			0.010	0.010	0.010	mg/l
Nickel										0.018			0.018	0.018	0.018	mg/l
Nickel, (Dissd.)									<	0.010			0.010	0.010	0.010	mg/l
Nitrogen, Nitrate			0.050							0.040			0.040	0.050	0.045	mg/l
Nitrogen, Nitrate+Nitrite					0.040								0.040	0.040	0.040	mg/l
Phenols				<	0.005				<	0.005			0.005	0.005	0.005	mg/l
Phosphorus, Total					0.860					0.310			0.310	0.860	0.585	mg/l
Potassium										2.800			2.800	2.800	2.800	mg/l
Potassium, (Dissd.)										1.700			1.700	1.700	1.700	mg/l

* Average for this Quarter

4333

PARAMETER ...	A90	B90	C90	D90	A91	B91	C91	D91	A92	B92	C92	MIN	MAX	AVG	UNITS
RA-226		0.179										0.179	0.179	0.179	pCi/l
RA-228		< 1.500										1.500	1.500	1.500	pCi/l
Selenium									< 0.005			0.005	0.005	0.005	mg/l
Selenium, (Dissd.)									< 0.005			0.005	0.005	0.005	mg/l
Silver									< 0.001			0.001	0.001	0.001	mg/l
Silver, (Dissd.)									< 0.001			0.001	0.001	0.001	mg/l
Sodium									21.700			21.700	21.700	21.700	mg/l
Sodium, (Dissd.)									21.700			21.700	21.700	21.700	mg/l
Specific conductance				865.000					871.000			865.000	871.000	868.000	umhos/c
Styrene			<	1.000					< 1.000			1.000	1.000	1.000	ug/l
Sulfate		174.000		112.000					120.000			112.000	174.000	135.333	mg/l
TH-228		0.574										0.574	0.574	0.574	pCi/l
TH-230		0.728										0.728	0.728	0.728	pCi/l
TH-232		< 0.500										0.500	0.500	0.500	pCi/l
TH-TOTAL		< 4.600										4.600	4.600	4.600	ug/l
TOC		2.000		2.000					17.000			2.000	17.000	7.000	mg/l
TOX		< 10.000	<	10.000					< 10.000			10.000	10.000	10.000	ug/l Cl
Tetrachloroethene		< 1.000	<	1.000					< 1.000			1.000	1.000	1.000	ug/l
Thallium									< 0.010			0.010	0.010	0.010	mg/l
Thallium, (Dissd.)									< 0.010			0.010	0.010	0.010	mg/l
Toluene		< 1.000	<	1.000					< 1.000			1.000	1.000	1.000	ug/l
Total dissolved solids				540.000					552.000			540.000	552.000	546.000	mg/l
Trichloroethene		< 1.000	<	1.000					< 1.000			1.000	1.000	1.000	ug/l
Trichlorofluoromethane		< 1.000										1.000	1.000	1.000	ug/l
U-234		3.170										3.170	3.170	3.170	pCi/l
U-235/236		< 0.220										0.220	0.220	0.220	pCi/l
U-238		2.260										2.260	2.260	2.260	pCi/l
U-TOTAL		5.200							6.000	5.000		5.000	6.000	5.400	ug/l
Vanadium									< 0.050			0.050	0.050	0.050	mg/l
Vanadium, (Dissd.)									< 0.050			0.050	0.050	0.050	mg/l
Vinyl acetate			<	2.000					< 2.000			2.000	2.000	2.000	ug/l
Vinyl chloride		< 1.000	<	1.000					< 1.000			1.000	1.000	1.000	ug/l
Xylenes, Total			<	1.000					< 1.000			1.000	1.000	1.000	ug/l
Zinc									< 0.020			0.020	0.020	0.020	mg/l
Zinc, (Dissd.)									0.041			0.041	0.041	0.041	mg/l
cis-1,3-Dichloropropene		< 1.000	<	1.000					< 1.000			1.000	1.000	1.000	ug/l
m-Dichlorobenzene		< 1.000										1.000	1.000	1.000	ug/l

* Average for this Quarter

264

4333

WELL NO.:1064

03/11/93

PARAMETER ...	A90	B90	C90	D90	A91	B91	C91	D91	A92	B92	C92	MIN	MAX	AVG	UNITS
o-Dichlorobenzene	<	1.000										1.000	1.000	1.000	ug/l
p-Dichlorobenzene	<	1.000										1.000	1.000	1.000	ug/l
pH				6.780					7.210			6.780	7.210	6.995	S.U.
trans-1,2-Dichloroethene	<	1.000	<	1.000				<	1.000			1.000	1.000	1.000	ug/l
trans-1,3-Dichloropropene	<	1.000	<	1.000				<	1.000			1.000	1.000	1.000	ug/l

* Average for this Quarter

WELL NO.:1075

03/11/93

PARAMETER	...	A90	B90	C90	D90	A91	B91	C91	D91	A92	B92	C92	MIN	MAX	AVG	UNITS
U-234		289.000											289.000	289.000	289.000	pCi/l
U-235/236		13.900											13.900	13.900	13.900	pCi/l
U-238		304.000											304.000	304.000	304.000	pCi/l
U-TOTAL		910.000											910.000	910.000	910.000	ug/l

266

4333

* Average for this Quarter

03/11/93

WELL NO.:1077

PARAMETER ...	A90	B90	C90	D90	A91	B91	C91	D91	A92	B92	C92	MIN	MAX	AVG	UNITS
1,1,1-Trichloroethane										< 1.000		1.000	1.000	1.000	ug/l
1,1,2,2-Tetrachloroethane										< 1.000		1.000	1.000	1.000	ug/l
1,1,2-Trichloroethane										< 1.000		1.000	1.000	1.000	ug/l
1,1-Dichloroethane										< 1.000		1.000	1.000	1.000	ug/l
1,1-Dichloroethene										< 1.000		1.000	1.000	1.000	ug/l
1,2-Dichloroethane										< 1.000		1.000	1.000	1.000	ug/l
1,2-Dichloroethene (Total)										< 1.000		1.000	1.000	1.000	ug/l
1,2-Dichloropropane										< 1.000		1.000	1.000	1.000	ug/l
2-Chloroethyl vinyl ether										< 10.000		10.000	10.000	10.000	ug/l
2-Hexanone										< 2.000		2.000	2.000	2.000	ug/l
4-Methyl-2-pentanone										< 2.000		2.000	2.000	2.000	ug/l
Acetone										< 2.000		2.000	2.000	2.000	ug/l
Alkalinity at CaCO3										404.000		404.000	404.000	404.000	mg/l
Aluminum										43.600		43.600	43.600	43.600	mg/l
Aluminum, (Dissd.)										< 0.200		0.200	0.200	0.200	mg/l
Ammonia, as nitrogen										0.030		0.030	0.030	0.030	mg/l
Antimony										< 0.020		0.020	0.020	0.020	mg/l
Antimony, (Dissd.)										< 0.020		0.020	0.020	0.020	mg/l
Arsenic										0.215		0.215	0.215	0.215	mg/l
Arsenic, (Dissd.)										< 0.005		0.005	0.005	0.005	mg/l
Barium										1.360		1.360	1.360	1.360	mg/l
Barium, (Dissd.)										< 0.200		0.200	0.200	0.200	mg/l
Benzene										< 1.000		1.000	1.000	1.000	ug/l
Beryllium										< 0.005		0.005	0.005	0.005	mg/l
Beryllium, (Dissd.)										< 0.005		0.005	0.005	0.005	mg/l
Bromodichloromethane										< 1.000		1.000	1.000	1.000	ug/l
Bromoform										<* 1.000		1.000	1.000	1.000	ug/l
Bromomethane										< 1.000		1.000	1.000	1.000	ug/l
Cadmium										0.002		0.002	0.002	0.002	mg/l
Cadmium, (Dissd.)										< 0.001		0.001	0.001	0.001	mg/l
Calcium										769.000		769.000	769.000	769.000	mg/l
Calcium, (Dissd.)										124.000		124.000	124.000	124.000	mg/l
Carbon disulfide										< 1.000		1.000	1.000	1.000	ug/l
Carbon tetrachloride										< 1.000		1.000	1.000	1.000	ug/l
Chloride										5.000		5.000	5.000	5.000	mg/l
Chlorobenzene										< 1.000		1.000	1.000	1.000	ug/l
Chloroethane										< 1.000		1.000	1.000	1.000	ug/l

* Average for this Quarter

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WELL NO.:1077

PARAMETER	...	A90	B90	C90	D90	A91	B91	C91	D91	A92	B92	C92	MIN	MAX	AVG	UNITS
Chloroform											< 1.000		1.000	1.000	1.000	ug/l
Chloromethane											< 1.000		1.000	1.000	1.000	ug/l
Chromium, Total											0.206		0.206	0.206	0.206	mg/l
Chromium, Total (Dissd.)											< 0.002		0.002	0.002	0.002	mg/l
Cobalt											0.160		0.160	0.160	0.160	mg/l
Cobalt, (Dissd.)											0.007		0.007	0.007	0.007	mg/l
Copper											0.175		0.175	0.175	0.175	mg/l
Copper, (Dissd.)											< 0.020		0.020	0.020	0.020	mg/l
Cyanide											< 0.005		0.005	0.005	0.005	mg/l
Dibromochloromethane											< 1.000		1.000	1.000	1.000	ug/l
Ethyl benzene											< 1.000		1.000	1.000	1.000	ug/l
Fluoride											0.520		0.520	0.520	0.520	mg/l
Iron											233.000		233.000	233.000	233.000	mg/l
Iron, (Dissd.)											0.990		0.990	0.990	0.990	mg/l
Lead											0.108		0.108	0.108	0.108	mg/l
Lead, (Dissd.)											< 0.003		0.003	0.003	0.003	mg/l
Magnesium											291.000		291.000	291.000	291.000	mg/l
Magnesium, (Dissd.)											57.200		57.200	57.200	57.200	mg/l
Manganese											10.300		10.300	10.300	10.300	mg/l
Manganese, (Dissd.)											0.371		0.371	0.371	0.371	mg/l
Mercury											<*,***.***		*,***.***	*,***.***	0.000	mg/l
Mercury, (Dissd.)											<*,***.***		*,***.***	*,***.***	0.000	mg/l
Methyl ethyl ketone											< 2.000		2.000	2.000	2.000	ug/l
Methylene chloride											< 1.000		1.000	1.000	1.000	ug/l
Molybdenum											0.040		0.040	0.040	0.040	mg/l
Molybdenum, (Dissd.)											< 0.010		0.010	0.010	0.010	mg/l
Nickel											0.200		0.200	0.200	0.200	mg/l
Nickel, (Dissd.)											< 0.010		0.010	0.010	0.010	mg/l
Nitrogen, Nitrate											< 0.020		0.020	0.020	0.020	mg/l
Phenols											< 0.005		0.005	0.005	0.005	mg/l
Phosphorus, Total											< 0.100		0.100	0.100	0.100	mg/l
Potassium											18.200		18.200	18.200	18.200	mg/l
Potassium, (Dissd.)											1.800		1.800	1.800	1.800	mg/l
Selenium											< 0.005		0.005	0.005	0.005	mg/l
Selenium, (Dissd.)											< 0.005		0.005	0.005	0.005	mg/l
Silver											< 0.001		0.001	0.001	0.001	mg/l
Silver, (Dissd.)											< 0.001		0.001	0.001	0.001	mg/l

* Average for this Quarter

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PARAMETER ...	A90	B90	C90	D90	A91	B91	C91	D91	A92	B92	C92	MIN	MAX	AVG	UNITS
Sodium										18.500		18.500	18.500	18.500	mg/l
Sodium, (Dissd.)										19.100		19.100	19.100	19.100	mg/l
Specific conductance										1,020.000		1,020.000	1,020.000	1,020.000	umhos/c
Styrene										< 1.000		1.000	1.000	1.000	ug/l
Sulfate										130.000		130.000	130.000	130.000	mg/l
TOC										58.000		58.000	58.000	58.000	mg/l
TOX										< 10.000		10.000	10.000	10.000	ug/l Cl
Tetrachloroethene										< 1.000		1.000	1.000	1.000	ug/l
Thallium										< 0.010		0.010	0.010	0.010	mg/l
Thallium, (Dissd.)										< 0.010		0.010	0.010	0.010	mg/l
Toluene										< 1.000		1.000	1.000	1.000	ug/l
Total dissolved solids										766.000		766.000	766.000	766.000	mg/l
Trichloroethene										< 1.000		1.000	1.000	1.000	ug/l
U-234	2.890											2.890	2.890	2.890	pCi/l
U-235/236	< 0.160											0.160	0.160	0.160	pCi/l
U-238	3.200											3.200	3.200	3.200	pCi/l
U-TOTAL	9.570									6.400		6.400	9.570	7.985	ug/l
Vanadium										0.205		0.205	0.205	0.205	mg/l
Vanadium, (Dissd.)										< 0.050		0.050	0.050	0.050	mg/l
Vinyl acetate										< 2.000		2.000	2.000	2.000	ug/l
Vinyl chloride										< 1.000		1.000	1.000	1.000	ug/l
Xylenes, Total										< 1.000		1.000	1.000	1.000	ug/l
Zinc										0.440		0.440	0.440	0.440	mg/l
Zinc, (Dissd.)										< 0.020		0.020	0.020	0.020	mg/l
cis-1,3-Dichloropropene										< 1.000		1.000	1.000	1.000	ug/l
pH										7.160		7.160	7.160	7.160	S.U.
trans-1,2-Dichloroethene										< 1.000		1.000	1.000	1.000	ug/l
trans-1,3-Dichloropropene										< 1.000		1.000	1.000	1.000	ug/l

* Average for this Quarter

WELL NO.:1081

03/11/93

PARAMETER ...	A90	B90	C90	D90	A91	B91	C91	D91	A92	B92	C92	MIN	MAX	AVG	UNITS
1,1,1-Trichloroethane	<	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000		1.000	1.000	1.000	ug/l
1,1,2,2-Tetrachloroethane	<	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000		1.000	1.000	1.000	ug/l
1,1,2-Trichloroethane	<	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000		1.000	1.000	1.000	ug/l
1,1-Dichloroethane	< 1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000		1.000	1.000	1.000	ug/l
1,1-Dichloroethene	<	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000		1.000	1.000	1.000	ug/l
1,1-Dichloroethene (Total)		<	1.000									1.000	1.000	1.000	ug/l
1,2,4-Trichlorobenzene	<	4.000										4.000	4.000	4.000	ug/l
1,2-Dichloroethane	< 1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000		1.000	1.000	1.000	ug/l
1,2-Dichloroethene (Total)	<	1.000	<	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000		1.000	1.000	1.000	ug/l
1,2-Dichloropropane	<	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000		1.000	1.000	1.000	ug/l
2,4,5-Trichlorophenol	<	4.000										4.000	4.000	4.000	ug/l
2,4,6-Trichlorophenol	<	4.000										4.000	4.000	4.000	ug/l
2,4-Dichlorophenol	<	4.000										4.000	4.000	4.000	ug/l
2,4-Dimethylphenol	<	4.000										4.000	4.000	4.000	ug/l
2,4-Dinitrophenol	<	4.000										4.000	4.000	4.000	ug/l
2,4-Dinitrotoluene	<	15.000										15.000	15.000	15.000	ug/l
2,6-Dinitrotoluene	<	15.000										15.000	15.000	15.000	ug/l
2-Chloroethyl vinyl ether			<	10.000 <	10.000 <	10.000 <	10.000 <	10.000 <	10.000 <	10.000		10.000	10.000	10.000	ug/l
2-Chloronaphthalene	<	4.000										4.000	4.000	4.000	ug/l
2-Chlorophenol	<	4.000										4.000	4.000	4.000	ug/l
2-Hexanone	<	2.000 <	2.000 <	2.000 <	2.000 <	2.000 <	2.000 <	2.000 <	2.000 <	2.000		2.000	2.000	2.000	ug/l
2-Nitroaniline	<	15.000										15.000	15.000	15.000	ug/l
2-Nitrophenol	<	4.000										4.000	4.000	4.000	ug/l
3,3'-Dichlorobenzidine	<	15.000										15.000	15.000	15.000	ug/l
3-Nitroaniline	<	15.000										15.000	15.000	15.000	ug/l
4,4'-DDD	<	0.200										0.200	0.200	0.200	ug/l
4,4'-DDE	<	0.200										0.200	0.200	0.200	ug/l
4,4'-DDT	<	0.200										0.200	0.200	0.200	ug/l
4,6-Dinitro-2-methylphenol	<	4.000										4.000	4.000	4.000	ug/l
4-Bromophenyl phenyl ether	<	15.000										15.000	15.000	15.000	ug/l
4-Chloro-3-methylphenol	<	4.000										4.000	4.000	4.000	ug/l
4-Chlorophenylphenyl ether	<	15.000										15.000	15.000	15.000	ug/l
4-Methyl-2-pentanone	<	2.000 <	2.000 <	2.000 <	2.000 <	2.000 <	2.000 <	2.000 <	2.000 <	2.000		2.000	2.000	2.000	ug/l
4-Nitroaniline	<	15.000										15.000	15.000	15.000	ug/l
4-Nitrophenol	<	4.000										4.000	4.000	4.000	ug/l
Acenaphthylene	<	4.000										4.000	4.000	4.000	ug/l
Acetone	< 2.000	2.100 <	2.000 <	2.000 <	2.000 <	2.000 <	2.000 <	2.000 <	2.000 <	2.000		2.000	2.100	2.010	ug/l

* Average for this Quarter

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WELL NO.:1081

PARAMETER	...	A90	B90	C90	D90	A91	B91	C91	D91	A92	B92	C92	MIN	MAX	AVG	UNITS
Aldrin		<	0.200										0.200	0.200	0.200	ug/l
Alkalinity at CaCO3					295.000	662.000	680.000	708.000	552.000	622.000	607.000		295.000	708.000	589.429	mg/l
Aluminum		2.130	4.350	3.390 <	0.500	1.310	2.800	0.260	0.450	1.480	0.890		0.260	4.350	1.756	mg/l
Aluminum, (Dissd.)		0.096	0.138 <	0.500 <	0.500 <	0.500 <	0.500 <	0.200 <	0.200 <	0.200 <	0.200		0.096	0.500	0.303	mg/l
Ammonia, as nitrogen				<	0.020	0.070	0.050 <	0.020	0.040	0.060	0.050		0.020	0.070	0.044	mg/l
Anthracene		<	4.000										4.000	4.000	4.000	ug/l
Antimony		<	0.025 <	0.025 <	0.025 <	0.025 <	0.020 <	0.020 <	0.020 <	0.020 <	0.020		0.020	0.025	0.022	mg/l
Antimony, (Dissd.)		<	0.025 <	0.025 <	0.025 <	0.025 <	0.020 <	0.020 <	0.020 <	0.020 <	0.020		0.020	0.025	0.022	mg/l
Aroclor 1016		<	0.200										0.200	0.200	0.200	ug/l
Aroclor 1221		<	0.200										0.200	0.200	0.200	ug/l
Aroclor 1232		<	0.200										0.200	0.200	0.200	ug/l
Aroclor 1242		<	0.200										0.200	0.200	0.200	ug/l
Aroclor 1248		<	0.200										0.200	0.200	0.200	ug/l
Aroclor 1254		<	0.200										0.200	0.200	0.200	ug/l
Aroclor 1260		<	0.200										0.200	0.200	0.200	ug/l
Arsenic	<	0.003 <	0.003 <	0.003 <	0.003 <	0.003 <	0.005 <	0.005 <	0.005 <	0.005 <	0.005		0.003	0.005	0.004	mg/l
Arsenic, (Dissd.)	<	0.003 <	0.003 <	0.003 <	0.003 <	0.003 <	0.005 <	0.005 <	0.005 <	0.005 <	0.005		0.003	0.005	0.004	mg/l
Barium	<	0.200 <	0.200 <	0.200 <	0.200 <	0.400 <	0.500 <	0.200 <	0.200 <	0.200 <	0.200		0.200	0.500	0.250	mg/l
Barium, (Dissd.)	<	0.200 <	0.200 <	0.200 <	0.200 <	0.400 <	0.500 <	0.200 <	0.200 <	0.200 <	0.200		0.200	0.500	0.250	mg/l
Benzene		<	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000		1.000	1.000	1.000	ug/l
Benzo(a)anthracene		<	4.000										4.000	4.000	4.000	ug/l
Benzo(a)pyrene		<	4.000										4.000	4.000	4.000	ug/l
Benzo(b)fluoranthene		<	4.000										4.000	4.000	4.000	ug/l
Benzo(ghi)perylene		<	4.000										4.000	4.000	4.000	ug/l
Benzo(k)fluoranthene		<	4.000										4.000	4.000	4.000	ug/l
Benzoic acid		<	4.000										4.000	4.000	4.000	ug/l
Benzyl alcohol		<	40.000										40.000	40.000	40.000	ug/l
Beryllium	<	0.010 <	0.010 <	0.010 <	0.010 <	0.010 <	0.050 <	0.050 <	0.005 <	0.005 <	0.005		0.005	0.050	0.017	mg/l
Beryllium, (Dissd.)	<	0.010 <	0.010 <	0.010 <	0.010 <	0.010 <	0.050 <	0.050 <	0.005 <	0.005 <	0.005		0.005	0.050	0.017	mg/l
Bromodichloromethane		<	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000		1.000	1.000	1.000	ug/l
Bromoform		<	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000		1.000	1.000	1.000	ug/l
Bromomethane		<	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000		1.000	1.000	1.000	ug/l
Butyl benzyl phthalate		<	4.000										4.000	4.000	4.000	ug/l
CS-137				<	7.300 <	8.100							7.300	8.100	7.700	pCi/l
Cadmium		<	0.001 <	0.001 <	0.001 <	0.001 <	0.001 <	0.001 <	0.001 <	0.001 <	0.001		0.001	0.001	0.001	mg/l
Cadmium, (Dissd.)		<	0.001 <	0.001 <	0.001 <	0.001 <	0.001 <	0.001 <	0.001 <	0.001 <	0.001		0.001	0.001	0.001	mg/l
Calcium		294.000	304.000	319.000	193.000	261.000	334.000	260.000	280.000	244.000	274.000		193.000	334.000	276.300	mg/l

* Average for this Quarter

PARAMETER ...	A90	B90	C90	D90	A91	B91	C91	D91	A92	B92	C92	MIN	MAX	AVG	UNITS
Calcium, (Dissd.)	250.000	162.000	250.000	166.000	167.000	203.000	230.000	160.000	202.000	270.000		160.000	270.000	206.000	mg/l
Carbon disulfide	<	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000		1.000	1.000	1.000	ug/l
Carbon tetrachloride	<	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000		1.000	1.000	1.000	ug/l
Chlordane	<	0.200										0.200	0.200	0.200	ug/l
Chloride	34.000	34.000	37.000	36.000	37.000	39.000	40.000	37.000	34.000	35.000		34.000	40.000	36.300	mg/l
Chlorobenzene	<	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000		1.000	1.000	1.000	ug/l
Chloroethane			<	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000		1.000	1.000	1.000	ug/l
Chloroform	<	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000		1.000	1.000	1.000	ug/l
Chloromethane	<	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000		1.000	1.000	1.000	ug/l
Chromium, Total	0.012	0.015	0.012	0.079	0.010	0.020	0.012	0.026	0.011	0.033		0.010	0.079	0.023	mg/l
Chromium, Total (Dissd.)	0.005 <	0.005	0.009 <	0.005 <	0.005 <	0.002 <	0.002	0.005	0.004	0.005		0.002	0.009	0.005	mg/l
Chrysene	<	4.000										4.000	4.000	4.000	ug/l
Cobalt	< 0.025 <	0.025 <	0.025 <	0.025 <	0.025 <	0.005 <	0.005 <	0.005 <	0.005 <	0.005		0.005	0.025	0.015	mg/l
Cobalt, (Dissd.)	< 0.025 <	0.025 <	0.025 <	0.025 <	0.025 <	0.005 <	0.005 <	0.005 <	0.005 <	0.005		0.005	0.025	0.015	mg/l
Copper	0.028	0.033 <	0.025 <	0.025 <	0.025	0.065	0.020	0.020	0.025 <	0.020		0.020	0.065	0.029	mg/l
Copper, (Dissd.)	< 0.025	0.029 <	0.025 <	0.025 <	0.025 <	0.020 <	0.020 <	0.020 <	0.020 <	0.020		0.020	0.029	0.023	mg/l
Cyanide	<	0.005	<	0.005 <	0.005 <	0.005 <	0.005 <	0.005 <	0.005 <	0.005		0.005	0.005	0.005	mg/l
Di-n-butylphthalate	<	4.000										4.000	4.000	4.000	ug/l
Dibenzo(a,h)anthracene	<	4.000										4.000	4.000	4.000	ug/l
Dibenzofuran	<	4.000										4.000	4.000	4.000	ug/l
Dibromochloromethane	<	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000		1.000	1.000	1.000	ug/l
Dieldrin	<	0.200										0.200	0.200	0.200	ug/l
Diethyl phthalate	<	4.000										4.000	4.000	4.000	ug/l
Dimethyl phthalate	<	4.000										4.000	4.000	4.000	ug/l
Diphenylamine	<	15.000										15.000	15.000	15.000	ug/l
Endosulfan I	<	0.200										0.200	0.200	0.200	ug/l
Endosulfan II	<	0.200										0.200	0.200	0.200	ug/l
Endosulfan sulfate	<	0.200										0.200	0.200	0.200	ug/l
Endrin	<	0.080										0.080	0.080	0.080	ug/l
Endrin aldehyde	<	0.200										0.200	0.200	0.200	ug/l
Ethyl benzene	<	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000		1.000	1.000	1.000	ug/l
Fluoranthene	<	4.000										4.000	4.000	4.000	ug/l
Fluorene	<	4.000										4.000	4.000	4.000	ug/l
Fluoride	0.790	0.530	0.380	0.380	0.280	0.370	0.250	0.350	0.360	0.440		0.250	0.790	0.413	mg/l
GROSS ALPHA		565.000	18.200 <	20.000	37.100							18.200	565.000	160.075	pCi/l
GROSS BETA		490.000 <	12.000	27.200	15.600							12.000	490.000	136.200	pCi/l
Heptachlor	<	0.200										0.200	0.200	0.200	ug/l

* Average for this Quarter

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PARAMETER	A90	B90	C90	D90	A91	B91	C91	D91	A92	B92	C92	MIN	MAX	AVG	UNITS
Heptachlor epoxide	<	0.200										0.200	0.200	0.200	ug/l
Hexachlorobenzene	<	4.000										4.000	4.000	4.000	ug/l
Hexachlorobutadiene	<	4.000										4.000	4.000	4.000	ug/l
Hexachlorocyclopentadiene	<	4.000										4.000	4.000	4.000	ug/l
Hexachloroethane	<	4.000										4.000	4.000	4.000	ug/l
Indeno(1,2,3-cd)pyrene	<	4.000										4.000	4.000	4.000	ug/l
Iron	4.190	5.760	2.940	1.770	3.830	4.940	0.400	0.822	2.850	1.940		0.400	5.760	2.944	mg/l
Iron, (Dissd.)	0.101	< 0.050	< 0.050	0.056	< 0.050	< 0.100	< 0.100	< 0.100	0.190	< 0.100		0.050	0.190	0.090	mg/l
Isophorone	<	4.000										4.000	4.000	4.000	ug/l
Lead	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	0.003	< 0.003	< 0.003		0.003	0.005	0.004	mg/l
Lead, (Dissd.)	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.003	< 0.003	< 0.003		0.003	0.005	0.004	mg/l
Magnesium	95.000	102.000	111.000	66.000	102.000	99.000	110.000	102.000	92.000	113.000		66.000	113.000	99.200	mg/l
Magnesium, (Dissd.)	100.000	26.000	82.800	26.000	60.000	72.000	83.000	62.000	71.000	92.000		26.000	100.000	67.480	mg/l
Manganese	0.165	0.109	0.062	0.054	0.116	0.150	0.046	0.029	0.108	0.054		0.029	0.165	0.089	mg/l
Manganese, (Dissd.)	< 0.020	< 0.020	< 0.020	< 0.020	0.075	< 0.040	0.027	< 0.015	< 0.015	< 0.015		0.015	0.075	0.027	mg/l
Mercury		<*,***.***	<*,***.***	<*,***.***	<*,***.***	<*,***.***	<*,***.***	<*,***.***	<*,***.***	<*,***.***		*,***.***	*,***.***	0.000	mg/l
Mercury, (Dissd.)		<*,***.***	<*,***.***	<*,***.***	<*,***.***	<*,***.***	<*,***.***	<*,***.***	<*,***.***	<*,***.***		*,***.***	*,***.***	0.000	mg/l
Methyl ethyl ketone	<	2.000	< 2.000	< 2.000	< 2.000	< 2.000	< 2.000	< 2.000	< 2.000	< 2.000		2.000	2.000	2.000	ug/l
Methylene chloride	< 1.000	< 1.000	< 1.000	< 1.000	< 1.000	< 1.000	< 1.000	< 1.000	< 1.000	< 1.000		1.000	1.000	1.000	ug/l
Molybdenum	<	0.025	< 0.025	< 0.025	< 0.025	< 0.010	< 0.010	0.010	< 0.010	< 0.010		0.010	0.025	0.017	mg/l
Molybdenum, (Dissd.)	<	0.025	< 0.025	< 0.025	< 0.025	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010		0.010	0.025	0.017	mg/l
N-Nitrosodi-n-propylamine	<	4.000										4.000	4.000	4.000	ug/l
N-Nitrosodiphenylamine	<	4.000										4.000	4.000	4.000	ug/l
NP-237			<	0.096	< 0.170							0.096	0.170	0.133	pCi/l
Naphthalene	<	4.000										4.000	4.000	4.000	ug/l
Nickel	0.014	0.007	< 0.005	< 0.005	0.012	< 0.010	< 0.010	0.012	< 0.010	< 0.010		0.005	0.014	0.010	mg/l
Nickel, (Dissd.)	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.010	< 0.010	< 0.012	< 0.010	< 0.010		0.005	0.012	0.008	mg/l
Nitrobenzene	<	4.000										4.000	4.000	4.000	ug/l
Nitrogen, Nitrate	8.840	9.310	14.900		11.100	10.500	10.100	7.400	5.800	5.900		5.800	14.900	9.317	mg/l
Nitrogen, Nitrate+Nitrite				11.400								11.400	11.400	11.400	mg/l
PU-238				0.819	< 0.048							0.048	0.819	0.434	pCi/l
PU-239/240				0.178	0.080							0.080	0.178	0.129	pCi/l
Pentachlorophenol	<	4.000										4.000	4.000	4.000	ug/l
Phenanthrene	<	4.000										4.000	4.000	4.000	ug/l
Phenol	<	4.000										4.000	4.000	4.000	ug/l
Phenols	< 0.005	< 0.005	0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005		0.005	0.005	0.005	mg/l
Phosphorus, Total				0.260	0.260	0.290	0.130	0.290	0.510	0.260		0.130	0.510	0.286	mg/l

* Average for this Quarter

PARAMETER ...	A90	B90	C90	D90	A91	B91	C91	D91	A92	B92	C92	MIN	MAX	AVG	UNITS
Potassium		4.040	3.320	2.910	4.760	3.500	2.600	2.800	4.210	3.700		2.600	4.760	3.538	mg/l
Potassium, (Dissd.)		2.410	2.740	2.870	3.300	2.400	2.500	2.700	3.900	3.400		2.400	3.900	2.913	mg/l
Pyrene	<	4.000										4.000	4.000	4.000	ug/l
Pyridine	<	4.000										4.000	4.000	4.000	ug/l
RA-226	<	0.230	< 0.240	< 0.100	< 0.098							0.098	0.240	0.167	pCi/l
RA-228	<	2.000	< 1.400	< 1.600	< 0.960							0.960	2.000	1.490	pCi/l
RU-106			<	64.000	< 63.000							63.000	64.000	63.500	pCi/l
Selenium	<	0.003	< 0.003	< 0.003	< 0.003	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005		0.003	0.005	0.004	mg/l
Selenium, (Dissd.)	<	0.003	< 0.003	< 0.003	< 0.003	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005		0.003	0.005	0.004	mg/l
Silver	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001		0.001	0.001	0.001	mg/l
Silver, (Dissd.)	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001		0.001	0.001	0.001	mg/l
Sodium	89.300	51.900	46.100	50.100	58.900	74.000	55.000	48.000	81.300	53.800		46.100	89.300	60.840	mg/l
Sodium, (Dissd.)	70.200	13.400	43.900	36.000	58.600	56.000	52.000	45.000	85.400	52.700		13.400	85.400	51.320	mg/l
Specific conductance				1,890.000	1,870.000	1,610.000	1,850.000	1,790.000	2,000.000	2,000.000		1,610.000	2,000.000	1,858.571	umhos/c
Styrene	<	1.000	< 1.000	< 1.000	< 1.000	< 1.000	< 1.000	< 1.000	< 1.000	< 1.000		1.000	1.000	1.000	ug/l
Sulfate	412.000	403.000	637.000	396.000	588.000	633.000	642.000	521.000	506.000	532.000		396.000	642.000	527.000	mg/l
TC-99	< 17.000		<	17.000	< 15.000							15.000	17.000	16.333	pCi/l
TH-228	< 1.000	< 0.580	0.522	2.110	0.811							0.522	2.110	1.005	pCi/l
TH-230	< 1.000	3.340	< 0.320	0.750	< 0.780							0.320	3.340	1.238	pCi/l
TH-232	<	0.580	< 0.320	< 0.480	< 0.780							0.320	0.780	0.540	pCi/l
TH-TOTAL	<	5.300	< 2.900	< 4.300	< 7.000							2.900	7.000	4.875	ug/l
TOC	2.000	35.000	5.000	7.000	23.000	22.000	21.000	44.000	20.000	27.000		2.000	44.000	20.600	mg/l
TOX	< 10.000	25.000	< 10.000	29.000	70.000	98.000	49.000	34.000	22.000	32.000		10.000	98.000	37.900	ug/l Cl
Tetrachloroethene	< 1.000	< 1.000	< 1.000	< 1.000	< 1.000	< 1.000	< 1.000	< 1.000	< 1.000	< 1.000		1.000	1.000	1.000	ug/l
Thallium	<	0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010		0.010	0.010	0.010	mg/l
Thallium, (Dissd.)	<	0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010		0.010	0.010	0.010	mg/l
Toluene	< 1.000	< 1.000	< 1.000	< 1.000	< 1.000	< 1.000	< 1.000	< 1.000	< 1.000	< 1.000		1.000	1.000	1.000	ug/l
Total dissolved solids				1,500.000	1,470.000	1,320.000	1,360.000	1,260.000	1,000.000	1,530.000		1,000.000	1,530.000	1,348.571	mg/l
Toxaphene	<	0.500										0.500	0.500	0.500	ug/l
Trichloroethene	< 1.000	< 1.000	< 1.000	< 1.000	< 1.000	< 1.000	< 1.000	< 1.000	< 1.000	< 1.000		1.000	1.000	1.000	ug/l
U-234	10.500	8.090	7.400	23.500	5.270							5.270	23.500	10.952	pCi/l
U-235	< 1.000											1.000	1.000	1.000	pCi/l
U-235/236		0.555	< 0.340	1.120	0.266							0.266	1.120	0.570	pCi/l
U-238	13.500	9.300	6.230	34.400	7.290							6.230	34.400	14.144	pCi/l
U-TOTAL	40.500	27.900	17.300	18.100	16.700	16.000	16.000	17.000	39.000	23.800		16.000	40.500	23.230	ug/l
Vanadium	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050		0.050	0.050	0.050	mg/l
Vanadium, (Dissd.)	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050		0.050	0.050	0.050	mg/l

* Average for this Quarter

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PARAMETER	A90	B90	C90	D90	A91	B91	C91	D91	A92	B92	C92	MIN	MAX	AVG	UNITS
Vinyl acetate	<	2.000 <	2.000 <	2.000 <	2.000 <	2.000 <	2.000 <	2.000 <	2.000 <	2.000		2.000	2.000	2.000	ug/l
Vinyl chloride	<	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000		1.000	1.000	1.000	ug/l
Xylenes, Total	<	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000		1.000	1.000	1.000	ug/l
Zinc	< 0.020	< 0.020 <	0.020	0.025	0.021	0.099	0.038	0.071	0.043	0.033		0.020	0.099	0.039	mg/l
Zinc, (Dissd.)	< 0.020	< 0.020 <	0.020	0.020 <	0.020 <	0.050	0.027	0.072	0.024 <	0.020		0.020	0.072	0.029	mg/l
alpha-BHC	<	0.200										0.200	0.200	0.200	ug/l
beta-BHC	<	0.200										0.200	0.200	0.200	ug/l
bis(2-Chloroethoxy)methane	<	15.000										15.000	15.000	15.000	ug/l
bis(2-Chloroethyl)ether	<	15.000										15.000	15.000	15.000	ug/l
bis(2-Chloroisopropyl)ether	<	15.000										15.000	15.000	15.000	ug/l
bis(2-Ethylhexyl)phthalate	<	4.000										4.000	4.000	4.000	ug/l
cis-1,3-Dichloropropene	<	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000		1.000	1.000	1.000	ug/l
delta-BHC	<	0.200										0.200	0.200	0.200	ug/l
gamma-BHC (Lindane)	<	0.200										0.200	0.200	0.200	ug/l
m-Dichlorobenzene	<	4.000										4.000	4.000	4.000	ug/l
m-Methylphenol (Cresol)	<	4.000										4.000	4.000	4.000	ug/l
o-Dichlorobenzene	<	4.000										4.000	4.000	4.000	ug/l
o-Methylphenol (Cresol)	<	4.000										4.000	4.000	4.000	ug/l
p-Chloroaniline	<	4.000										4.000	4.000	4.000	ug/l
p-Dichlorobenzene	<	4.000										4.000	4.000	4.000	ug/l
pH				6.520	7.020	7.090	6.980	6.790	6.990	6.990		6.520	7.090	6.911	S.U.
trans-1,2-Dichloroethene			<	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000		1.000	1.000	1.000	ug/l
trans-1,3-Dichloropropene	<	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000		1.000	1.000	1.000	ug/l

WELL NO.:1082

03/11/93

PARAMETER ...	A90	B90	C90	D90	A91	B91	C91	D91	A92	B92	C92	MIN	MAX	AVG	UNITS
1,1,1-Trichloroethane	<	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000		1.000	1.000	1.000	ug/l
1,1,2,2-Tetrachloroethane	<	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000		1.000	1.000	1.000	ug/l
1,1,2-Trichloroethane	<	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000		1.000	1.000	1.000	ug/l
1,1-Dichloroethane	< 1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000		1.000	1.000	1.000	ug/l
1,1-Dichloroethene	<	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000		1.000	1.000	1.000	ug/l
1,1-Dichloroethene (Total)		<	1.000									1.000	1.000	1.000	ug/l
1,2,4-Trichlorobenzene	<	4.000										4.000	4.000	4.000	ug/l
1,2-Dichloroethane	< 1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000		1.000	1.000	1.000	ug/l
1,2-Dichloroethene (Total)	<	1.000	<	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000		1.000	1.000	1.000	ug/l
1,2-Dichloropropane	<	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000		1.000	1.000	1.000	ug/l
2,4,5-Trichlorophenol	<	4.000										4.000	4.000	4.000	ug/l
2,4,6-Trichlorophenol	<	4.000										4.000	4.000	4.000	ug/l
2,4-Dichlorophenol	<	4.000										4.000	4.000	4.000	ug/l
2,4-Dimethylphenol	<	4.000										4.000	4.000	4.000	ug/l
2,4-Dinitrophenol	<	4.000										4.000	4.000	4.000	ug/l
2,4-Dinitrotoluene	<	15.000										15.000	15.000	15.000	ug/l
2,6-Dinitrotoluene	<	15.000										15.000	15.000	15.000	ug/l
2-Chloroethyl vinyl ether			<	10.000 <	10.000 <	10.000 <	10.000 <	10.000 <	10.000 <	10.000		10.000	10.000	10.000	ug/l
2-Chloronaphthalene	<	4.000										4.000	4.000	4.000	ug/l
2-Chlorophenol	<	4.000										4.000	4.000	4.000	ug/l
2-Hexanone	<	2.000 <	2.000 <	2.000 <	2.000 <	2.000 <	2.000 <	2.000 <	2.000 <	2.000		2.000	2.000	2.000	ug/l
2-Nitroaniline	<	15.000										15.000	15.000	15.000	ug/l
2-Nitrophenol	<	4.000										4.000	4.000	4.000	ug/l
3,3'-Dichlorobenzidine	<	15.000										15.000	15.000	15.000	ug/l
3-Nitroaniline	<	15.000										15.000	15.000	15.000	ug/l
4,4'-DDD	<	0.200										0.200	0.200	0.200	ug/l
4,4'-DDE	<	0.200										0.200	0.200	0.200	ug/l
4,4'-DDT	<	0.200										0.200	0.200	0.200	ug/l
4,6-Dinitro-2-methylphenol	<	4.000										4.000	4.000	4.000	ug/l
4-Bromophenyl phenyl ether	<	15.000										15.000	15.000	15.000	ug/l
4-Chloro-3-methylphenol	<	4.000										4.000	4.000	4.000	ug/l
4-Chlorophenylphenyl ether	<	15.000										15.000	15.000	15.000	ug/l
4-Methyl-2-pentanone	<	2.000 <	2.000 <	2.000 <	2.000 <	2.000 <	2.000 <	2.000 <	2.000 <	2.000		2.000	2.000	2.000	ug/l
4-Nitroaniline	<	15.000										15.000	15.000	15.000	ug/l
4-Nitrophenol	<	4.000										4.000	4.000	4.000	ug/l
Acenaphthylene	<	4.000										4.000	4.000	4.000	ug/l
Acetone	< 2.000 <	2.000 <	2.000 <	2.000 <	2.000 <	2.000 <	2.000 <	2.000 <	2.000 <	2.000		2.000	2.000	2.000	ug/l

* Average for this Quarter

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WELL NO.:1082

PARAMETER	...	A90	B90	C90	D90	A91	B91	C91	D91	A92	B92	C92	MIN	MAX	AVG	UNITS
Aldrin		<	0.200										0.200	0.200	0.200	ug/l
Alkalinity at CaCO3					327.000	461.000	510.000	550.000	479.000	468.000	447.000		327.000	550.000	463.143	mg/l
Aluminum		0.936	36.800	0.920	1.710	4.960	0.550	0.310	4.980	3.620	1.210		0.310	36.800	5.600	mg/l
Aluminum, (Dissd.)		0.108	0.194 <	0.500 <	0.500 <	0.500 <	0.500 <	0.200	0.460 <	0.200 <	0.200		0.108	0.500	0.336	mg/l
Ammonia, as nitrogen					0.120	0.030	0.070 <	0.020	0.370	0.020 <	0.020		0.020	0.370	0.093	mg/l
Anthracene		<	4.000										4.000	4.000	4.000	ug/l
Antimony		<	0.025 <	0.025 <	0.025 <	0.025 <	0.020 <	0.020 <	0.020 <	0.020 <	0.020		0.020	0.025	0.022	mg/l
Antimony, (Dissd.)		<	0.025 <	0.025 <	0.025 <	0.025 <	0.020 <	0.020 <	0.020 <	0.020 <	0.020		0.020	0.025	0.022	mg/l
Aroclor 1016		<	0.200										0.200	0.200	0.200	ug/l
Aroclor 1221		<	0.200										0.200	0.200	0.200	ug/l
Aroclor 1232		<	0.200										0.200	0.200	0.200	ug/l
Aroclor 1242		<	0.200										0.200	0.200	0.200	ug/l
Aroclor 1248		<	0.200										0.200	0.200	0.200	ug/l
Aroclor 1254		<	0.200										0.200	0.200	0.200	ug/l
Aroclor 1260		<	0.200										0.200	0.200	0.200	ug/l
Arsenic	<	0.003	0.011 <	0.003 <	0.003	0.005 <	0.005 <	0.005 <	0.005 <	0.005 <	0.005		0.003	0.011	0.005	mg/l
Arsenic, (Dissd.)	<	0.003 <	0.003 <	0.003 <	0.003 <	0.003 <	0.005 <	0.005 <	0.005 <	0.005 <	0.005		0.003	0.005	0.004	mg/l
Barium	<	0.200	0.356 <	0.200 <	0.200	0.339 <	0.500 <	0.200 <	0.200 <	0.200 <	0.200		0.200	0.500	0.260	mg/l
Barium, (Dissd.)	<	0.200 <	0.200 <	0.200 <	0.200	0.274 <	0.500 <	0.200 <	0.200 <	0.200 <	0.200		0.200	0.500	0.237	mg/l
Benzene		<	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000		1.000	1.000	1.000	ug/l
Benzo(a)anthracene		<	4.000										4.000	4.000	4.000	ug/l
Benzo(a)pyrene		<	4.000										4.000	4.000	4.000	ug/l
Benzo(b)fluoranthene		<	4.000										4.000	4.000	4.000	ug/l
Benzo(ghi)perylene		<	4.000										4.000	4.000	4.000	ug/l
Benzo(k)fluoranthene		<	4.000										4.000	4.000	4.000	ug/l
Benzoic acid		<	4.000										4.000	4.000	4.000	ug/l
Benzyl alcohol		<	40.000										40.000	40.000	40.000	ug/l
Beryllium	<	0.010 <	0.010 <	0.010 <	0.010 <	0.010 <	0.050 <	0.050 <	0.005 <	0.005 <	0.005		0.005	0.050	0.017	mg/l
Beryllium, (Dissd.)	<	0.010 <	0.010 <	0.010 <	0.010 <	0.010 <	0.050 <	0.050 <	0.005 <	0.005 <	0.005		0.005	0.050	0.017	mg/l
Bromodichloromethane		<	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000		1.000	1.000	1.000	ug/l
Bromoform		<	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000		1.000	1.000	1.000	ug/l
Bromomethane		<	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000		1.000	1.000	1.000	ug/l
Butyl benzyl phthalate		<	4.000										4.000	4.000	4.000	ug/l
CS-137				<	6.600 <	8.100							6.600	8.100	7.350	pCi/l
Cadmium		<	0.001 <	0.001 <	0.001 <	0.001 <	0.001 <	0.001 <	0.001 <	0.001 <	0.001		0.001	0.001	0.001	mg/l
Cadmium, (Dissd.)		<	0.001 <	0.001 <	0.001 <	0.001 <	0.001 <	0.001 <	0.001 <	0.001 <	0.001		0.001	0.001	0.001	mg/l
Calcium		143.000	300.000	181.000	95.100	181.000	194.000	140.000	209.000	151.000	158.000		95.100	300.000	175.210	mg/l

* Average for this Quarter

4333

PARAMETER ...	A90	B90	C90	D90	A91	B91	C91	D91	A92	B92	C92	MIN	MAX	AVG	UNITS
Calcium, (Dissd.)	163.000	165.000	157.000	92.300	153.000	122.000	168.000	149.000	137.000	139.000		92.300	168.000	144.530	mg/l
Carbon disulfide	<	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000		1.000	1.000	1.000	ug/l
Carbon tetrachloride	<	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000		1.000	1.000	1.000	ug/l
Chlordane	<	0.200										0.200	0.200	0.200	ug/l
Chloride	33.000	31.000	34.000	37.000	47.000	46.000	41.000	40.000	38.000	44.000		31.000	47.000	39.100	mg/l
Chlorobenzene	<	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000		1.000	1.000	1.000	ug/l
Chloroethane			<	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000		1.000	1.000	1.000	ug/l
Chloroform	<	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000		1.000	1.000	1.000	ug/l
Chloromethane	<	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000		1.000	1.000	1.000	ug/l
Chromium, Total	0.008	0.055	0.007	0.024	0.020	0.008	0.006	0.058	0.004	0.038		0.004	0.058	0.023	mg/l
Chromium, Total (Dissd.)	0.005 <	0.005	0.006 <	0.005 <	0.005 <	0.002 <	0.002	0.003	0.003	0.004		0.002	0.006	0.004	mg/l
Chrysene	<	4.000										4.000	4.000	4.000	ug/l
Cobalt <	0.025 <	0.025 <	0.025 <	0.025 <	0.025 <	0.005 <	0.005	0.009 <	0.005 <	0.005		0.005	0.025	0.015	mg/l
Cobalt, (Dissd.) <	0.025 <	0.025 <	0.025 <	0.025 <	0.025 <	0.005 <	0.005 <	0.005 <	0.005 <	0.005		0.005	0.025	0.015	mg/l
Copper <	0.025	0.064 <	0.025 <	0.025 <	0.025	0.020 <	0.020	0.027	0.024 <	0.020		0.020	0.064	0.028	mg/l
Copper, (Dissd.) <	0.025	0.027 <	0.025 <	0.025 <	0.025 <	0.020 <	0.020 <	0.020 <	0.020 <	0.020		0.020	0.027	0.023	mg/l
Cyanide	<	0.005	<	0.005 <	0.005 <	0.005 <	0.005 <	0.005 <	0.005 <	0.005		0.005	0.005	0.005	mg/l
Di-n-butylphthalate	<	4.000										4.000	4.000	4.000	ug/l
Dibenzo(a,h)anthracene	<	4.000										4.000	4.000	4.000	ug/l
Dibenzofuran	<	4.000										4.000	4.000	4.000	ug/l
Dibromochloromethane	<	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000		1.000	1.000	1.000	ug/l
Dieldrin	<	0.200										0.200	0.200	0.200	ug/l
Diethyl phthalate	<	4.000										4.000	4.000	4.000	ug/l
Dimethyl phthalate	<	4.000										4.000	4.000	4.000	ug/l
Diphenylamine	<	15.000										15.000	15.000	15.000	ug/l
Endosulfan I	<	0.200										0.200	0.200	0.200	ug/l
Endosulfan II	<	0.200										0.200	0.200	0.200	ug/l
Endosulfan sulfate	<	0.200										0.200	0.200	0.200	ug/l
Endrin	<	0.080										0.080	0.080	0.080	ug/l
Endrin aldehyde	<	0.200										0.200	0.200	0.200	ug/l
Ethyl benzene	<	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000		1.000	1.000	1.000	ug/l
Fluoranthene	<	4.000										4.000	4.000	4.000	ug/l
Fluorene	<	4.000										4.000	4.000	4.000	ug/l
Fluoride	0.870	0.920	0.700	0.610	0.690	0.620	0.470	0.720	0.680	0.590		0.470	0.920	0.687	mg/l
GROSS ALPHA		301.000	320.000	140.000	251.000							140.000	320.000	253.000	pCi/l
GROSS BETA		303.000	295.000	251.000	300.000							251.000	303.000	287.250	pCi/l
Heptachlor	<	0.200										0.200	0.200	0.200	ug/l

* Average for this Quarter

WELL NO.:1082

PARAMETER ...	A90	B90	C90	D90	A91	B91	C91	D91	A92	B92	C92	MIN	MAX	AVG	UNITS
Heptachlor epoxide	<	0.200										0.200	0.200	0.200	ug/l
Hexachlorobenzene	<	4.000										4.000	4.000	4.000	ug/l
Hexachlorobutadiene	<	4.000										4.000	4.000	4.000	ug/l
Hexachlorocyclopentadiene	<	4.000										4.000	4.000	4.000	ug/l
Hexachloroethane	<	4.000										4.000	4.000	4.000	ug/l
Indeno(1,2,3-cd)pyrene	<	4.000										4.000	4.000	4.000	ug/l
Iron	0.911	29.700	1.150	3.900	14.100	0.990	0.360	8.410	6.140	2.670		0.360	29.700	6.833	mg/l
Iron, (Dissd.)	0.062	0.109	< 0.050	< 0.050	< 0.050	< 0.100	< 0.100	0.880	< 0.100	< 0.100		0.050	0.880	0.160	mg/l
Isophorone	<	4.000										4.000	4.000	4.000	ug/l
Lead	< 0.005	0.010	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	0.006	< 0.003	< 0.003		0.003	0.010	0.005	mg/l
Lead, (Dissd.)	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.003	< 0.003	< 0.003		0.003	0.005	0.004	mg/l
Magnesium	69.000	101.000	81.600	53.000	86.000	73.000	84.000	97.000	80.000	74.000		53.000	101.000	79.860	mg/l
Magnesium, (Dissd.)	71.000	52.000	66.800	15.000	51.000	54.000	61.000	62.000	50.000	46.000		15.000	71.000	52.880	mg/l
Manganese	0.031	0.537	0.033	0.106	0.246	< 0.040	0.015	0.208	0.016	0.057		0.015	0.537	0.129	mg/l
Manganese, (Dissd.)	< 0.020	< 0.020	< 0.020	< 0.020	< 0.020	< 0.040	< 0.015	0.035	< 0.015	< 0.015		0.015	0.040	0.022	mg/l
Mercury		<*,***.***	<*,***.***	<*,***.***	<*,***.***	<*,***.***	<*,***.***	<*,***.***	<*,***.***	<*,***.***		*,***.***	*,***.***	0.000	mg/l
Mercury, (Dissd.)		<*,***.***	<*,***.***	<*,***.***	<*,***.***	<*,***.***	<*,***.***	<*,***.***	<*,***.***	<*,***.***		*,***.***	*,***.***	0.000	mg/l
Methyl ethyl ketone	<	2.000	< 2.000	< 2.000	< 2.000	< 2.000	< 2.000	< 2.000	< 2.000	< 2.000		2.000	2.000	2.000	ug/l
Methylene chloride	< 1.000	< 1.000	< 1.000	< 1.000	< 1.000	< 1.000	< 1.000	< 1.000	< 1.000	< 1.000		1.000	1.000	1.000	ug/l
Molybdenum	<	0.025	< 0.025	< 0.025	< 0.025	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010		0.010	0.025	0.017	mg/l
Molybdenum, (Dissd.)	<	0.025	< 0.025	< 0.025	< 0.025	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010		0.010	0.025	0.017	mg/l
N-Nitrosodi-n-propylamine	<	4.000										4.000	4.000	4.000	ug/l
N-Nitrosodiphenylamine	<	4.000										4.000	4.000	4.000	ug/l
NP-237			<	0.160	< 0.042							0.042	0.160	0.101	pCi/l
Naphthalene	<	4.000										4.000	4.000	4.000	ug/l
Nickel	0.005	0.058	< 0.005	0.006	0.023	< 0.010	< 0.010	0.064	< 0.010	< 0.010		0.005	0.064	0.020	mg/l
Nickel, (Dissd.)	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010		0.005	0.010	0.008	mg/l
Nitrobenzene	<	4.000										4.000	4.000	4.000	ug/l
Nitrogen, Nitrate	0.050	0.020	< 0.020	<	0.020	0.030	< 0.020	0.030	0.030	0.020		0.020	0.050	0.027	mg/l
Nitrogen, Nitrate+Nitrite			<	0.020								0.020	0.020	0.020	mg/l
PU-238				0.047	< 0.036							0.036	0.047	0.041	pCi/l
PU-239/240			<	0.089	< 0.036							0.036	0.089	0.063	pCi/l
Pentachlorophenol	<	4.000										4.000	4.000	4.000	ug/l
Phenanthrene	<	4.000										4.000	4.000	4.000	ug/l
Phenol	<	4.000										4.000	4.000	4.000	ug/l
Phenols	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005		0.005	0.005	0.005	mg/l
Phosphorus, Total				0.160	0.460	< 0.100	< 0.100	2.140	0.660	< 0.100		0.100	2.140	0.531	mg/l

* Average for this Quarter

PARAMETER ...	A90	B90	C90	D90	A91	B91	C91	D91	A92	B92	C92	MIN	MAX	AVG	UNITS
Potassium		25.500	2.480	2.710	3.660	2.200	1.900	4.300	4.000	2.300		1.900	25.500	5.450	mg/l
Potassium, (Dissd.)		5.900	2.420	2.340	2.320	1.800	1.900	2.900	2.400	1.700		1.700	5.900	2.631	mg/l
Pyrene	<	4.000										4.000	4.000	4.000	ug/l
Pyridine	<	4.000										4.000	4.000	4.000	ug/l
RA-226	<	0.160	0.130	0.087	< 0.190							0.087	0.190	0.142	pCi/l
RA-228	<	2.000	2.860	1.760	2.360							1.760	2.860	2.245	pCi/l
RU-106			<	75.000	< 49.000							49.000	75.000	62.000	pCi/l
Selenium	<	0.003	< 0.003	< 0.003	< 0.003	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005		0.003	0.005	0.004	mg/l
Selenium, (Dissd.)	<	0.003	< 0.003	< 0.003	< 0.003	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005		0.003	0.005	0.004	mg/l
Silver	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001		0.001	0.001	0.001	mg/l
Silver, (Dissd.)	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001		0.001	0.001	0.001	mg/l
Sodium	26.800	18.400	19.000	18.900	21.600	26.000	23.000	20.000	18.700	22.000		18.400	26.800	21.440	mg/l
Sodium, (Dissd.)	31.400	18.600	17.300	8.800	21.300	26.000	22.000	19.000	18.700	18.400		8.800	31.400	20.150	mg/l
Specific conductance				1,310.000	1,240.000	1,220.000	1,210.000	1,230.000	1,200.000	1,270.000		1,200.000	1,310.000	1,240.000	umhos/c
Styrene	<	1.000	< 1.000	< 1.000	< 1.000	< 1.000	< 1.000	< 1.000	< 1.000	< 1.000		1.000	1.000	1.000	ug/l
Sulfate	166.000	19.000	240.000	191.000	255.000	248.000	263.000	297.000	173.000	179.000		19.000	297.000	203.100	mg/l
TC-99	< 16.000			53.900	< 12.000							12.000	53.900	27.300	pCi/l
TH-228	< 1.000	1.420	0.500	< 0.830	< 0.570							0.500	1.420	0.864	pCi/l
TH-230	< 1.000	4.310	0.756	< 0.830	0.762							0.756	4.310	1.532	pCi/l
TH-232		1.610	0.285	< 0.830	1.690							0.285	1.690	1.104	pCi/l
TH-TOTAL		14.500	2.850	< 7.500	15.300							2.850	15.300	10.038	ug/l
TOC	2.000	33.000	5.000	11.000	17.000	15.000	19.000	39.000	18.000	17.000		2.000	39.000	17.600	mg/l
TOX	< 10.000	31.000	< 10.000	23.000	34.000	27.000	13.000	35.000	11.000	< 10.000		10.000	35.000	20.400	ug/l Cl
Tetrachloroethene	< 1.000	< 1.000	< 1.000	< 1.000	< 1.000	< 1.000	< 1.000	< 1.000	< 1.000	< 1.000		1.000	1.000	1.000	ug/l
Thallium	<	0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010		0.010	0.010	0.010	mg/l
Thallium, (Dissd.)	<	0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010		0.010	0.010	0.010	mg/l
Toluene	< 1.000	< 1.000	< 1.000	< 1.000	< 1.000	< 1.000	< 1.000	< 1.000	< 1.000	< 1.000		1.000	1.000	1.000	ug/l
Total dissolved solids				1,140.000	972.000	844.000	866.000	646.000	698.000	820.000		646.000	1,140.000	855.143	mg/l
Toxaphene	<	0.500										0.500	0.500	0.500	ug/l
Trichloroethene	< 1.000	< 1.000	< 1.000	< 1.000	< 1.000	< 1.000	< 1.000	< 1.000	< 1.000	< 1.000		1.000	1.000	1.000	ug/l
U-234	49.200	0.256	37.700	38.400	46.400							0.256	49.200	34.391	pCi/l
U-235	4.800											4.800	4.800	4.800	pCi/l
U-235/236	<	0.160	3.610	3.010	4.970							0.160	4.970	2.938	pCi/l
U-238	207.000	< 0.160	187.000	181.000	213.000							0.160	213.000	157.632	pCi/l
U-TOTAL	617.000	< 0.540	632.000	687.000	553.000	533.000	660.000	660.000	675.000	640.400		0.540	687.000	565.794	ug/l
Vanadium	< 0.050	0.136	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050		0.050	0.136	0.059	mg/l
Vanadium, (Dissd.)	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050		0.050	0.050	0.050	mg/l

* Average for this Quarter

280

4333

PARAMETER	A90	B90	C90	D90	A91	B91	C91	D91	A92	B92	C92	MIN	MAX	AVG	UNITS
Vinyl acetate	<	2.000 <	2.000 <	2.000 <	2.000 <	2.000 <	2.000 <	2.000 <	2.000 <	2.000		2.000	2.000	2.000	ug/l
Vinyl chloride	<	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000		1.000	1.000	1.000	ug/l
Xylenes, Total	<	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000		1.000	1.000	1.000	ug/l
Zinc	< 0.020	0.089 <	0.020	0.029	0.043	0.057	0.035	0.085	0.035	0.033		0.020	0.089	0.045	mg/l
Zinc, (Dissd.)	< 0.020 <	0.020 <	0.020	0.024 <	0.020 <	0.050	0.033	0.051	0.024 <	0.020		0.020	0.051	0.028	mg/l
alpha-BHC	<	0.200										0.200	0.200	0.200	ug/l
beta-BHC	<	0.200										0.200	0.200	0.200	ug/l
bis(2-Chloroethoxy)methane	<	15.000										15.000	15.000	15.000	ug/l
bis(2-Chloroethyl)ether	<	15.000										15.000	15.000	15.000	ug/l
bis(2-Chloroisopropyl)ether	<	15.000										15.000	15.000	15.000	ug/l
bis(2-Ethylhexyl)phthalate	<	4.000										4.000	4.000	4.000	ug/l
cis-1,3-Dichloropropene	<	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000		1.000	1.000	1.000	ug/l
delta-BHC	<	0.200										0.200	0.200	0.200	ug/l
gamma-BHC (Lindane)	<	0.200										0.200	0.200	0.200	ug/l
m-Dichlorobenzene	<	4.000										4.000	4.000	4.000	ug/l
m-Methylphenol (Cresol)	<	4.000										4.000	4.000	4.000	ug/l
o-Dichlorobenzene	<	4.000										4.000	4.000	4.000	ug/l
o-Methylphenol (Cresol)	<	4.000										4.000	4.000	4.000	ug/l
p-Chloroaniline	<	4.000										4.000	4.000	4.000	ug/l
p-Dichlorobenzene	<	4.000										4.000	4.000	4.000	ug/l
pH				6.630	7.380	7.250	7.170	7.100	7.260	7.290		6.630	7.380	7.154	S.U.
trans-1,2-Dichloroethene			<	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000		1.000	1.000	1.000	ug/l
trans-1,3-Dichloropropene	<	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000 <	1.000		1.000	1.000	1.000	ug/l

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* Average for this Quarter

WELL NO.:1084

03/11/93

PARAMETER	...	A90	B90	C90	D90	A91	B91	C91	D91	A92	B92	C92	MIN	MAX	AVG	UNITS
U-234		19.400											19.400	19.400	19.400	pCi/l
U-235/236		1.900											1.900	1.900	1.900	pCi/l
U-238		78.100											78.100	78.100	78.100	pCi/l
U-TOTAL		233.000											233.000	233.000	233.000	ug/l

* Average for this Quarter

WELL NO.:1087

03/11/93

PARAMETER ...	A90	B90	C90	D90	A91	B91	C91	D91	A92	B92	C92	MIN	MAX	AVG	UNITS
1,1,1-Trichloroethane	<	1.000	<	1.000	< 1.000							1.000	1.000	1.000	ug/l
1,1,2,2-Tetrachloroethane	<	1.000	<	1.000	< 1.000							1.000	1.000	1.000	ug/l
1,1,2-Trichloroethane	<	1.000	<	1.000	< 1.000							1.000	1.000	1.000	ug/l
1,1-Dichloroethane	<	1.000	<	1.000	< 1.000							1.000	1.000	1.000	ug/l
1,1-Dichloroethene	<	1.000	<	1.000	< 1.000							1.000	1.000	1.000	ug/l
1,2-Dichloroethane	<	1.000	<	1.000	< 1.000							1.000	1.000	1.000	ug/l
1,2-Dichloroethene (Total)	<	1.000	<	1.000	< 1.000							1.000	1.000	1.000	ug/l
1,2-Dichloropropane	<	1.000	<	1.000	< 1.000							1.000	1.000	1.000	ug/l
2-Chloroethyl vinyl ether			<	10.000	< 10.000							10.000	10.000	10.000	ug/l
2-Hexanone	<	2.000	<	2.000	< 2.000							2.000	2.000	2.000	ug/l
4-Methyl-2-pentanone	<	2.000	<	2.000	< 2.000							2.000	2.000	2.000	ug/l
Acetone	<	2.000	<	2.000	< 2.000							2.000	2.000	2.000	ug/l
Alkalinity at CaCO3			378.000	378.000	385.000							378.000	385.000	380.333	mg/l
Aluminum					1.890							1.890	1.890	1.890	mg/l
Ammonia, as nitrogen				0.030	< 0.020							0.020	0.030	0.025	mg/l
Antimony					< 0.025							0.025	0.025	0.025	mg/l
Arsenic					< 0.003							0.003	0.003	0.003	mg/l
Barium					< 0.200							0.200	0.200	0.200	mg/l
Benzene	<	1.000	<	1.000	< 1.000							1.000	1.000	1.000	ug/l
Beryllium					< 0.010							0.010	0.010	0.010	mg/l
Bromodichloromethane	<	1.000	<	1.000	< 1.000							1.000	1.000	1.000	ug/l
Bromoform	<	1.000	<	1.000	< 1.000							1.000	1.000	1.000	ug/l
Bromomethane	<	1.000	<	1.000	< 1.000							1.000	1.000	1.000	ug/l
CS-137					< 7.300							7.300	7.300	7.300	pCi/l
Cadmium					< 0.001							0.001	0.001	0.001	mg/l
Calcium					78.800							78.800	78.800	78.800	mg/l
Carbon disulfide	<	1.000	<	1.000	< 1.000							1.000	1.000	1.000	ug/l
Carbon tetrachloride	<	1.000	<	1.000	< 1.000							1.000	1.000	1.000	ug/l
Chloride		10.000	15.000	11.000	11.000							10.000	15.000	11.750	mg/l
Chlorobenzene	<	1.000	<	1.000	< 1.000							1.000	1.000	1.000	ug/l
Chloroethane			<	1.000	< 1.000							1.000	1.000	1.000	ug/l
Chloroform	<	1.000	<	1.000	< 1.000							1.000	1.000	1.000	ug/l
Chloromethane	<	1.000	<	1.000	< 1.000							1.000	1.000	1.000	ug/l
Chromium, Total					0.023							0.023	0.023	0.023	mg/l
Cobalt					< 0.025							0.025	0.025	0.025	mg/l
Copper					< 0.025							0.025	0.025	0.025	mg/l
Cyanide			<	0.005	< 0.020							0.005	0.020	0.013	mg/l

* Average for this Quarter

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4333

WELL NO.:1087

PARAMETER ...	A90	B90	C90	D90	A91	B91	C91	D91	A92	B92	C92	MIN	MAX	AVG	UNITS
Dibromochloromethane	<	1.000		< 1.000	< 1.000							1.000	1.000	1.000	ug/l
Ethyl benzene	<	1.000		< 1.000	< 1.000							1.000	1.000	1.000	ug/l
Fluoride			1.220	1.180	0.970							0.970	1.220	1.123	mg/l
GROSS ALPHA		20.800		19.800	26.100							19.800	26.100	22.233	pCi/l
GROSS BETA		20.800		15.300	12.500							12.500	20.800	16.200	pCi/l
Iron					4.510							4.510	4.510	4.510	mg/l
Lead					< 0.005							0.005	0.005	0.005	mg/l
Magnesium					55.000							55.000	55.000	55.000	mg/l
Manganese					0.094							0.094	0.094	0.094	mg/l
Mercury					<*,***.***							*,***.***	*,***.***	0.000	mg/l
Methyl ethyl ketone	<	2.000		< 2.000	< 2.000							2.000	2.000	2.000	ug/l
Methylene chloride	<	1.000		< 1.000	< 1.000							1.000	1.000	1.000	ug/l
Molybdenum					< 0.025							0.025	0.025	0.025	mg/l
NP-237					< 0.240							0.240	0.240	0.240	pCi/l
Nickel					0.014							0.014	0.014	0.014	mg/l
Nitrogen, Nitrate	<	0.020	0.070		< 0.020							0.020	0.070	0.037	mg/l
Nitrogen, Nitrate+Nitrite				0.050								0.050	0.050	0.050	mg/l
PU-238					< 0.110							0.110	0.110	0.110	pCi/l
PU-239/240					< 0.042							0.042	0.042	0.042	pCi/l
Phenols		<	0.005	0.006	< 0.005							0.005	0.006	0.005	mg/l
Phosphorus, Total				0.150	0.380							0.150	0.380	0.265	mg/l
Potassium					2.670							2.670	2.670	2.670	mg/l
RA-226		1.820		< 0.150	0.175							0.150	1.820	0.715	pCi/l
RA-228	<	1.300		< 1.000	< 2.000							1.000	2.000	1.433	pCi/l
RU-106					< 52.000							52.000	52.000	52.000	pCi/l
Selenium					< 0.003							0.003	0.003	0.003	mg/l
Silver					< 0.001							0.001	0.001	0.001	mg/l
Sodium					16.400							16.400	16.400	16.400	mg/l
Specific conductance			861.000	995.000	883.000							861.000	995.000	913.000	umhos/c
Styrene	<	1.000		< 1.000	< 1.000							1.000	1.000	1.000	ug/l
Sulfate		118.000	116.000	119.000	155.000							116.000	155.000	127.000	mg/l
TC-99					< 21.000							21.000	21.000	21.000	pCi/l
TH-228		1.690		< 0.230	0.581							0.230	1.690	0.834	pCi/l
TH-230		3.330		0.252	0.341							0.252	3.330	1.308	pCi/l
TH-232	<	0.710		< 0.230	< 0.270							0.230	0.710	0.403	pCi/l
TH-TOTAL	<	6.400		< 2.000	< 2.400							2.000	6.400	3.600	ug/l
TOC		2.000	4.000	3.000	5.000							2.000	5.000	3.500	mg/l

* Average for this Quarter

WELL NO.:1087

03/11/93

PARAMETER	...	A90	B90	C90	D90	A91	B91	C91	D91	A92	B92	C92	MIN	MAX	AVG	UNITS
TOX			12.000 <	10.000 <	10.000 <	10.000							10.000	12.000	10.500	ug/l
Tetrachloroethene		<	1.000	<	1.000 <	1.000							1.000	1.000	1.000	ug/l
Thallium					<	0.010							0.010	0.010	0.010	mg/l
Toluene		<	1.000	<	1.000 <	1.000							1.000	1.000	1.000	ug/l
Total dissolved solids				505.000	612.000	428.000							428.000	612.000	515.000	mg/l
Trichloroethene		<	1.000	<	1.000 <	1.000							1.000	1.000	1.000	ug/l
U-234			11.500		14.700 <	0.200							0.200	14.700	8.800	pCi/l
U-235/236			0.459		2.530 <	0.200							0.200	2.530	1.063	pCi/l
U-238			11.300		13.900 <	0.200							0.200	13.900	8.467	pCi/l
U-TOTAL			33.600			16.800							16.800	33.600	25.200	ug/l
Vanadium					<	0.050							0.050	0.050	0.050	mg/l
Vinyl acetate		<	2.000	<	2.000 <	2.000							2.000	2.000	2.000	ug/l
Vinyl chloride		<	1.000	<	1.000 <	1.000							1.000	1.000	1.000	ug/l
Xylenes, Total		<	1.000	<	1.000 <	1.000							1.000	1.000	1.000	ug/l
Zinc					<	0.020							0.020	0.020	0.020	mg/l
cis-1,3-Dichloropropene		<	1.000	<	1.000 <	1.000							1.000	1.000	1.000	ug/l
pH				7.450	7.320	7.670							7.320	7.670	7.480	S.U.
trans-1,2-Dichloroethene				<	1.000 <	1.000							1.000	1.000	1.000	ug/l
trans-1,3-Dichloropropene		<	1.000	<	1.000 <	1.000							1.000	1.000	1.000	ug/l

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* Average for this Quarter

WELL NO.:1111

03/11/93

PARAMETER ...	A90	B90	C90	D90	A91	B91	C91	D91	A92	B92	C92	MIN	MAX	AVG	UNITS
1,1,1-Trichloroethane	<	1.000 <	1.000 <	1.000 <	1.000							1.000	1.000	1.000	ug/l
1,1,2,2-Tetrachloroethane	<	1.000 <	1.000 <	1.000 <	1.000							1.000	1.000	1.000	ug/l
1,1,2-Trichloroethane	<	1.000 <	1.000 <	1.000 <	1.000							1.000	1.000	1.000	ug/l
1,1-Dichloroethane	<	1.000 <	1.000 <	1.000 <	1.000							1.000	1.000	1.000	ug/l
1,1-Dichloroethene	<	1.000 <	1.000 <	1.000 <	1.000							1.000	1.000	1.000	ug/l
1,2-Dichloroethane	<	1.000 <	1.000 <	1.000 <	1.000							1.000	1.000	1.000	ug/l
1,2-Dichloroethene (Total)	<	1.000 <	1.000 <	1.000 <	1.000							1.000	1.000	1.000	ug/l
1,2-Dichloropropane	<	1.000 <	1.000 <	1.000 <	1.000							1.000	1.000	1.000	ug/l
2-Chloroethyl vinyl ether		<	10.000 <	10.000 <	10.000							10.000	10.000	10.000	ug/l
2-Hexanone	<	2.000 <	2.000 <	2.000 <	2.000							2.000	2.000	2.000	ug/l
4-Methyl-2-pentanone	<	2.000 <	2.000 <	2.000 <	2.000							2.000	2.000	2.000	ug/l
Acetone	<	2.000 <	2.000 <	2.000 <	2.000							2.000	2.000	2.000	ug/l
Alkalinity at CaCO3			255.000	256.000	222.000							222.000	256.000	244.333	mg/l
Aluminum					49.600							49.600	49.600	49.600	mg/l
Ammonia, as nitrogen				0.040	0.060							0.040	0.060	0.050	mg/l
Antimony				<	0.025							0.025	0.025	0.025	mg/l
Arsenic					0.027							0.027	0.027	0.027	mg/l
Barium					0.463							0.463	0.463	0.463	mg/l
Benzene	<	1.000 <	1.000 <	1.000 <	1.000							1.000	1.000	1.000	ug/l
Beryllium				<	0.010							0.010	0.010	0.010	mg/l
Bromodichloromethane	<	1.000 <	1.000 <	1.000 <	1.000							1.000	1.000	1.000	ug/l
Bromoform	<	1.000 <	1.000 <	1.000 <	1.000							1.000	1.000	1.000	ug/l
Bromomethane	<	1.000 <	1.000 <	1.000 <	1.000							1.000	1.000	1.000	ug/l
CS-137				<	7.100							7.100	7.100	7.100	pCi/l
Cadmium				<	0.001							0.001	0.001	0.001	mg/l
Calcium					370.000							370.000	370.000	370.000	mg/l
Carbon disulfide	<	1.000 <	1.000 <	1.000 <	1.000							1.000	1.000	1.000	ug/l
Carbon tetrachloride	<	1.000 <	1.000 <	1.000 <	1.000							1.000	1.000	1.000	ug/l
Chloride		9.000	8.000	8.000	6.000							6.000	9.000	7.750	mg/l
Chlorobenzene	<	1.000 <	1.000 <	1.000 <	1.000							1.000	1.000	1.000	ug/l
Chloroethane		<	1.000 <	1.000 <	1.000							1.000	1.000	1.000	ug/l
Chloroform	<	1.000 <	1.000 <	1.000 <	1.000							1.000	1.000	1.000	ug/l
Chloromethane	<	1.000 <	1.000 <	1.000 <	1.000							1.000	1.000	1.000	ug/l
Chromium, Total				<	0.005							0.005	0.005	0.005	mg/l
Cobalt				<	0.025							0.025	0.025	0.025	mg/l
Copper					0.097							0.097	0.097	0.097	mg/l
Cyanide			<	0.005 <	0.005							0.005	0.005	0.005	mg/l

* Average for this Quarter

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4333

03/11/93

WELL NO.:1111

PARAMETER	A90	B90	C90	D90	A91	B91	C91	D91	A92	B92	C92	MIN	MAX	AVG	UNITS
Dibromochloromethane	<	1.000	< 1.000	< 1.000	< 1.000							1.000	1.000	1.000	ug/l
Ethyl benzene	<	1.000	< 1.000	< 1.000	< 1.000							1.000	1.000	1.000	ug/l
Fluoride			1.990	0.160	0.240							0.160	1.990	0.797	mg/l
GROSS ALPHA	<	21.000		30.000	72.400							21.000	72.400	41.133	pCi/l
GROSS BETA		54.300		51.200	156.000							51.200	156.000	87.167	pCi/l
Iron					92.800							92.800	92.800	92.800	mg/l
Lead					< 0.005							0.005	0.005	0.005	mg/l
Magnesium					158.000							158.000	158.000	158.000	mg/l
Manganese					1.640							1.640	1.640	1.640	mg/l
Mercury					<*,***.***							*,***.***	*,***.***	0.000	mg/l
Methyl ethyl ketone	<	2.000	< 2.000	< 2.000	< 2.000							2.000	2.000	2.000	ug/l
Methylene chloride	<	1.000	< 1.000	< 1.000	< 1.000							1.000	1.000	1.000	ug/l
Molybdenum					< 0.025							0.025	0.025	0.025	mg/l
NP-237					< 0.130							0.130	0.130	0.130	pCi/l
Nickel					< 0.005							0.005	0.005	0.005	mg/l
Nitrogen, Nitrate		2.380	2.040		1.720							1.720	2.380	2.047	mg/l
Nitrogen, Nitrate+Nitrite				1.490								1.490	1.490	1.490	mg/l
PU-238					< 0.039							0.039	0.039	0.039	pCi/l
PU-239/240					< 0.039							0.039	0.039	0.039	pCi/l
Phenols		<	0.005	< 0.005	< 0.005							0.005	0.005	0.005	mg/l
Phosphorus, Total				0.440	3.130							0.440	3.130	1.785	mg/l
Potassium					12.800							12.800	12.800	12.800	mg/l
RA-226		2.490		0.209	0.530							0.209	2.490	1.076	pCi/l
RA-228		2.650	<	1.200	1.370							1.200	2.650	1.740	pCi/l
RU-106					< 79.000							79.000	79.000	79.000	pCi/l
Selenium					< 0.003							0.003	0.003	0.003	mg/l
Silver					< 0.001							0.001	0.001	0.001	mg/l
Sodium					6.400							6.400	6.400	6.400	mg/l
Specific conductance			597.000	638.000	510.000							510.000	638.000	581.667	umhos/
Styrene	<	1.000	< 1.000	< 1.000	< 1.000							1.000	1.000	1.000	ug/l
Sulfate		56.000	63.000	61.000	68.000							56.000	68.000	62.000	mg/l
TC-99					< 24.000							24.000	24.000	24.000	pCi/l
TH-228		1.190		1.870	3.230							1.190	3.230	2.097	pCi/l
TH-230		1.660	<	0.580	1.650							0.580	1.660	1.297	pCi/l
TH-232		1.020	<	0.580	1.360							0.580	1.360	0.987	pCi/l
TH-TOTAL		9.180	<	5.300	12.300							5.300	12.300	8.927	ug/l
TOC		3.000	5.000	< 1.000	14.000							1.000	14.000	5.750	mg/l

* Average for this Quarter

4333

WELL NO.:1111

03/11/93

PARAMETER	A90	B90	C90	D90	A91	B91	C91	D91	A92	B92	C92	MIN	MAX	AVG	UNITS
TOX		89.000	14.000 <	10.000 <	10.000							10.000	89.000	30.750	ug/l
Tetrachloroethene	<	1.000 <	1.000 <	1.000 <	1.000							1.000	1.000	1.000	ug/l
Thallium				<	0.010							0.010	0.010	0.010	mg/l
Toluene	<	1.000 <	1.000 <	1.000 <	1.000							1.000	1.000	1.000	ug/l
Total dissolved solids			480.000	384.000	324.000							324.000	480.000	396.000	mg/l
Trichloroethene	<	1.000 <	1.000 <	1.000 <	1.000							1.000	1.000	1.000	ug/l
U-234		12.700		11.000	11.700							11.000	12.700	11.800	pCi/l
U-235/236		0.761		0.753	0.807							0.753	0.807	0.774	pCi/l
U-238		12.400		10.800	13.100							10.800	13.100	12.100	pCi/l
U-TOTAL		37.300		20.900	26.000							20.900	37.300	28.067	ug/l
Vanadium				<	0.050							0.050	0.050	0.050	mg/l
Vinyl acetate	<	2.000 <	2.000 <	2.000 <	2.000							2.000	2.000	2.000	ug/l
Vinyl chloride	<	1.000 <	1.000 <	1.000 <	1.000							1.000	1.000	1.000	ug/l
Xylenes, Total	<	1.000 <	1.000 <	1.000 <	1.000							1.000	1.000	1.000	ug/l
Zinc					0.412							0.412	0.412	0.412	mg/l
cis-1,3-Dichloropropene	<	1.000 <	1.000 <	1.000 <	1.000							1.000	1.000	1.000	ug/l
pH			6.900	6.520	7.200							6.520	7.200	6.873	S.U.
trans-1,2-Dichloroethene			<	1.000 <	1.000							1.000	1.000	1.000	ug/l
trans-1,3-Dichloropropene	<	1.000 <	1.000 <	1.000 <	1.000							1.000	1.000	1.000	ug/l

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4333

* Average for this Quarter

WELL NO.:1113

03/11/93

PARAMETER ...	A90	B90	C90	D90	A91	B91	C91	D91	A92	B92	C92	MIN	MAX	AVG	UNITS
1,1,1-Trichloroethane	<	1.000 <	1.000 <	1.000 <	1.000							1.000	1.000	1.000	ug/l
1,1,2,2-Tetrachloroethane	<	1.000 <	1.000 <	1.000 <	1.000							1.000	1.000	1.000	ug/l
1,1,2-Trichloroethane	<	1.000 <	1.000 <	1.000 <	1.000							1.000	1.000	1.000	ug/l
1,1-Dichloroethane	<	1.000 <	1.000 <	1.000 <	1.000							1.000	1.000	1.000	ug/l
1,1-Dichloroethene	<	1.000 <	1.000 <	1.000 <	1.000							1.000	1.000	1.000	ug/l
1,2-Dichloroethane	<	1.000 <	1.000 <	1.000 <	1.000							1.000	1.000	1.000	ug/l
1,2-Dichloroethene (Total)	<	1.000 <	1.000 <	1.000 <	1.000							1.000	1.000	1.000	ug/l
1,2-Dichloropropane	<	1.000 <	1.000 <	1.000 <	1.000							1.000	1.000	1.000	ug/l
2-Chloroethyl vinyl ether		<	10.000 <	10.000 <	10.000							10.000	10.000	10.000	ug/l
2-Hexanone	<	2.000 <	2.000 <	2.000 <	2.000							2.000	2.000	2.000	ug/l
4-Methyl-2-pentanone	<	2.000 <	2.000 <	2.000 <	2.000							2.000	2.000	2.000	ug/l
Acetone	<	2.000 <	2.000 <	2.000 <	2.000							2.000	2.000	2.000	ug/l
Alkalinity at CaCO3			291.000	320.000	350.000							291.000	350.000	320.333	mg/l
Aluminum					5.920							5.920	5.920	5.920	mg/l
Ammonia, as nitrogen				0.040	0.040							0.040	0.040	0.040	mg/l
Antimony				<	0.025							0.025	0.025	0.025	mg/l
Arsenic					0.006							0.006	0.006	0.006	mg/l
Barium				<	0.200							0.200	0.200	0.200	mg/l
Benzene	< 1.000 <	1.000 <	1.000	0.750 <	1.000							0.750	1.000	0.950	ug/l
Beryllium				<	0.010							0.010	0.010	0.010	mg/l
Bromodichloromethane	<	1.000 <	1.000 <	1.000 <	1.000							1.000	1.000	1.000	ug/l
Bromoform	<	1.000 <	1.000 <	1.000 <	1.000							1.000	1.000	1.000	ug/l
Bromomethane	<	1.000 <	1.000 <	1.000 <	1.000							1.000	1.000	1.000	ug/l
CS-137				<	5.800							5.800	5.800	5.800	pCi/l
Cadmium				<	0.001							0.001	0.001	0.001	mg/l
Calcium					119.000							119.000	119.000	119.000	mg/l
Carbon disulfide	<	1.000 <	1.000 <	1.000 <	1.000							1.000	1.000	1.000	ug/l
Carbon tetrachloride	<	1.000 <	1.000 <	1.000 <	1.000							1.000	1.000	1.000	ug/l
Chloride		84.000	82.000	72.000	69.000							69.000	84.000	76.750	mg/l
Chlorobenzene	<	1.000 <	1.000 <	1.000 <	1.000							1.000	1.000	1.000	ug/l
Chloroethane		<	1.000 <	1.000 <	1.000							1.000	1.000	1.000	ug/l
Chloroform	<	1.000 <	1.000 <	1.000 <	1.000							1.000	1.000	1.000	ug/l
Chloromethane	<	1.000 <	1.000 <	1.000 <	1.000							1.000	1.000	1.000	ug/l
Chromium, Total					0.007							0.007	0.007	0.007	mg/l
Cobalt				<	0.025							0.025	0.025	0.025	mg/l
Copper				<	0.025							0.025	0.025	0.025	mg/l
Cyanide			<	0.005 <	0.005							0.005	0.005	0.005	mg/l

* Average for this Quarter

289

433

WELL NO.:1113

PARAMETER ...	A90	B90	C90	D90	A91	B91	C91	D91	A92	B92	C92	MIN	MAX	AVG	UNITS
Dibromochloromethane		< 1.000	< 1.000	< 1.000	< 1.000							1.000	1.000	1.000	ug/l
Ethyl benzene		< 1.000	< 1.000	0.750	< 1.000							0.750	1.000	0.938	ug/l
Fluoride			1.190	0.420	0.500							0.420	1.190	0.703	mg/l
GROSS ALPHA		787.000		1,130.000	1,340.000							787.000	1,340.000	1,085.667	pCi/l
GROSS BETA		633.000		850.000	679.000							633.000	850.000	720.667	pCi/l
Iron					13.700							13.700	13.700	13.700	mg/l
Lead	0.016			0.011	0.006							0.006	0.016	0.011	mg/l
Lead, (Dissd.)	< 0.005											0.005	0.005	0.005	mg/l
Magnesium					54.000							54.000	54.000	54.000	mg/l
Manganese					0.414							0.414	0.414	0.414	mg/l
Mercury					<*,***.***							*,***.***	*,***.***	0.000	mg/l
Methyl ethyl ketone		< 2.000	< 2.000	< 2.000	< 2.000							2.000	2.000	2.000	ug/l
Methylene chloride		< 1.000	< 1.000	< 1.000	< 1.000							1.000	1.000	1.000	ug/l
Molybdenum					< 0.025							0.025	0.025	0.025	mg/l
NP-237					< 0.054							0.054	0.054	0.054	pCi/l
Nickel					< 0.005							0.005	0.005	0.005	mg/l
Nitrogen, Nitrate		0.100	0.070		0.580							0.070	0.580	0.250	mg/l
Nitrogen, Nitrate+Nitrite				0.890								0.890	0.890	0.890	mg/l
PU-238					< 0.041							0.041	0.041	0.041	pCi/l
PU-239/240					< 0.100							0.100	0.100	0.100	pCi/l
Phenols			< 0.005	< 0.005	< 0.005							0.005	0.005	0.005	mg/l
Phosphorus, Total				0.250	0.590							0.250	0.590	0.420	mg/l
Potassium					3.050							3.050	3.050	3.050	mg/l
RA-226		1.410		0.224	0.213							0.213	1.410	0.616	pCi/l
RA-228		< 1.900		< 1.700	0.945							0.945	1.900	1.515	pCi/l
RU-106					< 61.000							61.000	61.000	61.000	pCi/l
Selenium					< 0.003							0.003	0.003	0.003	mg/l
Silver					< 0.001							0.001	0.001	0.001	mg/l
Sodium					69.700							69.700	69.700	69.700	mg/l
Specific conductance			960.000	1,030.000	934.000							934.000	1,030.000	974.667	umhos/cm
Styrene		< 1.000	< 1.000	< 1.000	< 1.000							1.000	1.000	1.000	ug/l
Sulfate		73.000	64.000	69.000	72.000							64.000	73.000	69.500	mg/l
TC-99					< 25.000							25.000	25.000	25.000	pCi/l
TH-228		< 0.710		0.169	1.270							0.169	1.270	0.716	pCi/l
TH-230		0.793		0.215	0.242							0.215	0.793	0.417	pCi/l
TH-232		4.020		< 0.210	< 0.150							0.150	4.020	1.460	pCi/l
TH-TOTAL		36.300		< 1.900	< 1.400							1.400	36.300	13.200	ug/l

* Average for this Quarter

PARAMETER ...	A90	B90	C90	D90	A91	B91	C91	D91	A92	B92	C92	MIN	MAX	AVG	UNITS
TOC		2.000	10.000 <	1.000	11.000							1.000	11.000	6.000	mg/l
TOX		20.000	44.000	16.000 <	10.000							10.000	44.000	22.500	ug/l Cl
Tetrachloroethene		< 1.000	< 1.000	< 1.000	< 1.000							1.000	1.000	1.000	ug/l
Thallium					< 0.010							0.010	0.010	0.010	mg/l
Toluene	< 1.000	< 1.000	< 1.000	0.750	< 1.000							0.750	1.000	0.950	ug/l
Total Petroleum Hydrocarbon				< 1.000								1.000	1.000	1.000	mg/l
Total dissolved solids			645.000	624.000	574.000							574.000	645.000	614.333	mg/l
Trichloroethene		< 1.000	< 1.000	< 1.000	< 1.000							1.000	1.000	1.000	ug/l
U-234	390.000	543.000		0.051	564.000							0.051	564.000	374.263	pCi/l
U-235	19.000											19.000	19.000	19.000	pCi/l
U-235/236		80.100		30.600	46.100							30.600	80.100	52.267	pCi/l
U-236	2.400											2.400	2.400	2.400	pCi/l
U-238	420.000	547.000		551.000	591.000							420.000	591.000	527.250	pCi/l
U-TOTAL	1,250.000	1,660.000		1,700.000	1,460.000							1,250.000	1,700.000	1,517.500	ug/l
Vanadium					< 0.050							0.050	0.050	0.050	mg/l
Vinyl acetate		< 2.000	< 2.000	< 2.000	< 2.000							2.000	2.000	2.000	ug/l
Vinyl chloride		< 1.000	< 1.000	< 1.000	< 1.000							1.000	1.000	1.000	ug/l
Xylenes, Total	< 1.000	< 1.000	< 1.000	1.000	< 1.000							1.000	1.000	1.000	ug/l
Zinc					0.047							0.047	0.047	0.047	mg/l
cis-1,3-Dichloropropene		< 1.000	< 1.000	< 1.000	< 1.000							1.000	1.000	1.000	ug/l
pH			6.950	6.410	7.160							6.410	7.160	6.840	S.U.
trans-1,2-Dichloroethene				< 1.000	< 1.000							1.000	1.000	1.000	ug/l
trans-1,3-Dichloropropene		< 1.000	< 1.000	< 1.000	< 1.000							1.000	1.000	1.000	ug/l

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4333

* Average for this Quarter

WELL NO.:1145

03/11/93

PARAMETER ...	A90	B90	C90	D90	A91	B91	C91	D91	A92	B92	C92	MIN	MAX	AVG	UNITS
Benzene				0.830								0.830	0.830	0.830	ug/l
Ethyl benzene			<	0.500								0.500	0.500	0.500	ug/l
Lead				0.042								0.042	0.042	0.042	mg/l
Toluene			<	0.500								0.500	0.500	0.500	ug/l
Total Petroleum Hydrocarbon			<	1.000								1.000	1.000	1.000	mg/l
Xylenes, Total			<	1.000								1.000	1.000	1.000	ug/l

292

4333

* Average for this Quarter

WELL NO.:1299

03/11/93

PARAMETER ...	A90	B90	C90	D90	A91	B91	C91	D91	A92	B92	C92	MIN	MAX	AVG	UNITS
Benzene			<	0.500								0.500	0.500	0.500	ug/l
Ethyl benzene			<	0.500								0.500	0.500	0.500	ug/l
Lead				0.006								0.006	0.006	0.006	mg/l
Toluene			<	0.500								0.500	0.500	0.500	ug/l
Total Petroleum Hydrocarbon			<	1.000								1.000	1.000	1.000	mg/l
Xylenes, Total			<	1.000								1.000	1.000	1.000	ug/l

293

4333

* Average for this Quarter

WELL NO.:1304

03/11/93

PARAMETER	...	A90	B90	C90	D90	A91	B91	C91	D91	A92	B92	C92	MIN	MAX	AVG	UNITS
Benzene				<	0.500								0.500	0.500	0.500	ug/l
Ethyl benzene				<	0.500								0.500	0.500	0.500	ug/l
Lead					0.010								0.010	0.010	0.010	mg/l
Toluene				<	0.500								0.500	0.500	0.500	ug/l
Total Petroleum Hydrocarbon				<	1.000								1.000	1.000	1.000	mg/l
Xylenes, Total				<	1.000								1.000	1.000	1.000	ug/l

294

4333

* Average for this Quarter

WELL NO.:1317

03/11/93

PARAMETER ...	A90	B90	C90	D90	A91	B91	C91	D91	A92	B92	C92	MIN	MAX	AVG	UNITS
Benzene			<	0.500								0.500	0.500	0.500	ug/l
Ethyl benzene			<	0.500								0.500	0.500	0.500	ug/l
Lead				0.093								0.093	0.093	0.093	mg/l
Toluene			<	0.500								0.500	0.500	0.500	ug/l
Total Petroleum Hydrocarbon			<	1.000								1.000	1.000	1.000	mg/l
Xylenes, Total			<	1.000								1.000	1.000	1.000	ug/l

295

4333

* Average for this Quarter

WELL NO.:1332
03/11/93

PARAMETER ...	A90	B90	C90	D90	A91	B91	C91	D91	A92	B92	C92	MIN	MAX	AVG	UNITS
1,1,1-Trichloroethane									< 1.000	< 1.000		1.000	1.000	1.000	ug/l
1,1,2,2-Tetrachloroethane									< 1.000	< 1.000		1.000	1.000	1.000	ug/l
1,1,2-Trichloroethane									< 1.000	< 1.000		1.000	1.000	1.000	ug/l
1,1-Dichloroethane									< 1.000	< 1.000		1.000	1.000	1.000	ug/l
1,1-Dichloroethene									< 1.000	< 1.000		1.000	1.000	1.000	ug/l
1,2-Dichloroethane									< 1.000	< 1.000		1.000	1.000	1.000	ug/l
1,2-Dichloroethene (Total)									< 1.000	< 1.000		1.000	1.000	1.000	ug/l
1,2-Dichloropropane									< 1.000	< 1.000		1.000	1.000	1.000	ug/l
2-Chloroethyl vinyl ether									< 10.000	< 10.000		10.000	10.000	10.000	ug/l
2-Hexanone									< 2.000	< 2.000		2.000	2.000	2.000	ug/l
4-Methyl-2-pentanone									< 2.000	< 2.000		2.000	2.000	2.000	ug/l
Acetone									< 2.000	< 2.000		2.000	2.000	2.000	ug/l
Alkalinity at CaCO3									408.000	422.000		408.000	422.000	415.000	mg/l
Aluminum									7.160	2.840		2.840	7.160	5.000	mg/l
Aluminum, (Dissd.)									< 0.200	< 0.200		0.200	0.200	0.200	mg/l
Ammonia, as nitrogen									0.370	0.280		0.280	0.370	0.325	mg/l
Antimony									< 0.020	< 0.020		0.020	0.020	0.020	mg/l
Antimony, (Dissd.)									< 0.020	< 0.020		0.020	0.020	0.020	mg/l
Arsenic									0.006	< 0.005		0.005	0.006	0.005	mg/l
Arsenic, (Dissd.)									< 0.005	< 0.005		0.005	0.005	0.005	mg/l
Barium									0.390	0.330		0.330	0.390	0.360	mg/l
Barium, (Dissd.)									0.320	0.380		0.320	0.380	0.350	mg/l
Benzene									< 1.000	< 1.000		1.000	1.000	1.000	ug/l
Beryllium									< 0.005	< 0.005		0.005	0.005	0.005	mg/l
Beryllium, (Dissd.)									< 0.005	< 0.005		0.005	0.005	0.005	mg/l
Bromodichloromethane									< 1.000	< 1.000		1.000	1.000	1.000	ug/l
Bromoform									< 1.000	< 1.000		1.000	1.000	1.000	ug/l
Bromomethane									< 1.000	< 1.000		1.000	1.000	1.000	ug/l
Cadmium									< 0.001	< 0.001		0.001	0.001	0.001	mg/l
Cadmium, (Dissd.)									< 0.001	< 0.001		0.001	0.001	0.001	mg/l
Calcium									275.000	294.000		275.000	294.000	284.500	mg/l
Calcium, (Dissd.)									278.000	284.000		278.000	284.000	281.000	mg/l
Carbon disulfide									< 1.000	< 1.000		1.000	1.000	1.000	ug/l
Carbon tetrachloride									< 1.000	< 1.000		1.000	1.000	1.000	ug/l
Chloride									1,080.000	963.000		963.000	1,080.000	1,021.500	mg/l
Chlorobenzene									< 1.000	< 1.000		1.000	1.000	1.000	ug/l
Chloroethane									< 1.000	< 1.000		1.000	1.000	1.000	ug/l

* Average for this Quarter

296

4333

WELL NO.:1332

PARAMETER	...	A90	B90	C90	D90	A91	B91	C91	D91		A92		B92	C92	MIN	MAX	AVG	UNITS
Chloroform										<	1.000	<	1.000		1.000	1.000	1.000	ug/l
Chloromethane										<	1.000	<	1.000		1.000	1.000	1.000	ug/l
Chromium, Total											0.039		0.024		0.024	0.039	0.032	mg/l
Chromium, Total (Dissd.)											0.004	<	0.002		0.002	0.004	0.003	mg/l
Cobalt											0.011		0.009		0.009	0.011	0.010	mg/l
Cobalt, (Dissd.)										<	0.005	<	0.005		0.005	0.005	0.005	mg/l
Copper											0.027	<	0.020		0.020	0.027	0.024	mg/l
Copper, (Dissd.)										<	0.020	<	0.020		0.020	0.020	0.020	mg/l
Cyanide										<	0.005	<	0.005		0.005	0.005	0.005	mg/l
Dibromochloromethane										<	1.000	<	1.000		1.000	1.000	1.000	ug/l
Ethyl benzene										<	1.000	<	1.000		1.000	1.000	1.000	ug/l
Fluoride											0.400		0.430		0.400	0.430	0.415	mg/l
Iron											13.900		5.070		5.070	13.900	9.485	mg/l
Iron, (Dissd.)											0.100		0.680		0.100	0.680	0.390	mg/l
Lead											0.004	<	0.003		0.003	0.004	0.004	mg/l
Lead, (Dissd.)										<	0.003	<	0.003		0.003	0.003	0.003	mg/l
Magnesium											91.000		71.500		71.500	91.000	81.250	mg/l
Magnesium, (Dissd.)											49.000		67.200		49.000	67.200	58.100	mg/l
Manganese											6.760		4.890		4.890	6.760	5.825	mg/l
Manganese, (Dissd.)											6.240		5.020		5.020	6.240	5.630	mg/l
Mercury										<*,***.***			*,***.***		*,***.***	*,***.***	0.000	mg/l
Mercury, (Dissd.)										<*,***.***		<*	*,***.***		*,***.***	*,***.***	0.000	mg/l
Methyl ethyl ketone										<	2.000	<	2.000		2.000	2.000	2.000	ug/l
Methylene chloride										<	1.000	<	1.000		1.000	1.000	1.000	ug/l
Molybdenum										<	0.010	<	0.010		0.010	0.010	0.010	mg/l
Molybdenum, (Dissd.)										<	0.010	<	0.010		0.010	0.010	0.010	mg/l
Nickel											0.017	<	0.010		0.010	0.017	0.014	mg/l
Nickel, (Dissd.)										<	0.010	<	0.010		0.010	0.010	0.010	mg/l
Nitrogen, Nitrate										<	0.020		0.030		0.020	0.030	0.025	mg/l
Phenols										<	0.005	<	0.005		0.005	0.005	0.005	mg/l
Phosphorus, Total											9.400		0.290		0.290	9.400	4.845	mg/l
Potassium											9.400		3.700		3.700	9.400	6.550	mg/l
Potassium, (Dissd.)											3.200		2.800		2.800	3.200	3.000	mg/l
Selenium										<	0.005	<	0.005		0.005	0.005	0.005	mg/l
Selenium, (Dissd.)										<	0.005	<	0.005		0.005	0.005	0.005	mg/l
Silver										<	0.001		0.005		0.001	0.005	0.003	mg/l
Silver, (Dissd.)										<	0.001	<	0.001		0.001	0.001	0.001	mg/l

PARAMETER ...	A90	B90	C90	D90	A91	B91	C91	D91	A92	B92	C92	MIN	MAX	AVG	UNITS
Sodium									373.000	389.000		373.000	389.000	381.000	mg/l
Sodium, (Dissd.)									352.000	364.000		352.000	364.000	358.000	mg/l
Specific conductance									3,860.000	3,870.000		3,860.000	3,870.000	3,865.000	umhos/c
Styrene									< 1.000	< 1.000		1.000	1.000	1.000	ug/l
Sulfate									42.000	54.000		42.000	54.000	48.000	mg/l
TOC									19.000	17.000		17.000	19.000	18.000	mg/l
TOX									15.000	53.000		15.000	53.000	34.000	ug/l Cl
Tetrachloroethene									< 1.000	< 1.000		1.000	1.000	1.000	ug/l
Thallium									< 0.010	< 0.010		0.010	0.010	0.010	mg/l
Thallium, (Dissd.)									< 0.010	< 0.010		0.010	0.010	0.010	mg/l
Toluene									< 1.000	< 1.000		1.000	1.000	1.000	ug/l
Total dissolved solids									2,580.000	2,490.000		2,490.000	2,580.000	2,535.000	mg/l
Trichloroethene									< 1.000	< 1.000		1.000	1.000	1.000	ug/l
U-TOTAL									3.200	2.900		2.900	3.200	3.050	ug/l
Vanadium									< 0.050	< 0.050		0.050	0.050	0.050	mg/l
Vanadium, (Dissd.)									< 0.050	< 0.050		0.050	0.050	0.050	mg/l
Vinyl acetate									< 2.000	< 2.000		2.000	2.000	2.000	ug/l
Vinyl chloride									< 1.000	< 1.000		1.000	1.000	1.000	ug/l
Xylenes, Total									< 1.000	< 1.000		1.000	1.000	1.000	ug/l
Zinc									0.046	0.031		0.031	0.046	0.039	mg/l
Zinc, (Dissd.)									< 0.020	< 0.020		0.020	0.020	0.020	mg/l
cis-1,3-Dichloropropene									< 1.000	< 1.000		1.000	1.000	1.000	ug/l
pH									6.840	6.750		6.750	6.840	6.795	S.U.
trans-1,2-Dichloroethene									< 1.000	< 1.000		1.000	1.000	1.000	ug/l
trans-1,3-Dichloropropene									< 1.000	< 1.000		1.000	1.000	1.000	ug/l

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* Average for this Quarter

WELL NO.:1353

03/11/93

PARAMETER	...	A90	B90	C90	D90	A91	B91	C91	D91	A92	B92	C92	MIN	MAX	AVG	UNITS
Benzene				<	0.500								0.500	0.500	0.500	ug/l
Ethyl benzene				<	0.500								0.500	0.500	0.500	ug/l
Lead					0.088								0.088	0.088	0.088	mg/l
Toluene				<	0.500								0.500	0.500	0.500	ug/l
Total Petroleum Hydrocarbon				<	1.000								1.000	1.000	1.000	mg/l
Xylenes, Total				<	1.000								1.000	1.000	1.000	ug/l

* Average for this Quarter

WELL NO.:1523

03/11/93

PARAMETER ...	A90	B90	C90	D90	A91	B91	C91	D91	A92	B92	C92	MIN	MAX	AVG	UNITS
1,1,1-Trichloroethane									< 1.000	1.000		1.000	1.000	1.000	ug/l
1,1,2,2-Tetrachloroethane									< 1.000	1.000		1.000	1.000	1.000	ug/l
1,1,2-Trichloroethane									< 1.000	1.000		1.000	1.000	1.000	ug/l
1,1-Dichloroethane									< 1.000	1.000		1.000	1.000	1.000	ug/l
1,1-Dichloroethene									< 1.000	1.000		1.000	1.000	1.000	ug/l
1,2-Dichloroethane									< 1.000	1.000		1.000	1.000	1.000	ug/l
1,2-Dichloroethene (Total)									< 1.000	1.000		1.000	1.000	1.000	ug/l
1,2-Dichloropropane									< 1.000	1.000		1.000	1.000	1.000	ug/l
2-Chloroethyl vinyl ether									< 10.000	10.000		10.000	10.000	10.000	ug/l
2-Hexanone									< 2.000	2.000		2.000	2.000	2.000	ug/l
4-Methyl-2-pentanone									< 2.000	2.000		2.000	2.000	2.000	ug/l
Acetone									< 2.000	2.000		2.000	2.000	2.000	ug/l
Alkalinity at CaCO3									334.000	306.000		306.000	334.000	320.000	mg/l
Aluminum									148.000	20.800		20.800	148.000	84.400	mg/l
Aluminum, (Dissd.)									< 0.200	< 0.200		0.200	0.200	0.200	mg/l
Ammonia, as nitrogen									< 0.020	0.070		0.020	0.070	0.045	mg/l
Antimony									< 0.040	< 0.020		0.020	0.040	0.030	mg/l
Antimony, (Dissd.)									< 0.020	< 0.020		0.020	0.020	0.020	mg/l
Arsenic									0.070	0.022		0.022	0.070	0.046	mg/l
Arsenic, (Dissd.)									< 0.005	< 0.005		0.005	0.005	0.005	mg/l
Barium									1.320	0.510		0.510	1.320	0.915	mg/l
Barium, (Dissd.)									< 0.200	< 0.200		0.200	0.200	0.200	mg/l
Benzene									< 1.000	1.000		1.000	1.000	1.000	ug/l
Beryllium									0.008	< 0.005		0.005	0.008	0.006	mg/l
Beryllium, (Dissd.)									< 0.005	< 0.005		0.005	0.005	0.005	mg/l
Bromodichloromethane									< 1.000	1.000		1.000	1.000	1.000	ug/l
Bromoform									< 1.000	1.000		1.000	1.000	1.000	ug/l
Bromomethane									< 1.000	1.000		1.000	1.000	1.000	ug/l
Cadmium									0.002	< 0.001		0.001	0.002	0.001	mg/l
Cadmium, (Dissd.)									< 0.001	< 0.001		0.001	0.001	0.001	mg/l
Calcium									840.000	477.000		477.000	840.000	658.500	mg/l
Calcium, (Dissd.)									105.000	111.000		105.000	111.000	108.000	mg/l
Carbon disulfide									< 1.000	1.000		1.000	1.000	1.000	ug/l
Carbon tetrachloride									< 1.000	1.000		1.000	1.000	1.000	ug/l
Chloride									5.000	8.000		5.000	8.000	6.500	mg/l
Chlorobenzene									< 1.000	1.000		1.000	1.000	1.000	ug/l
Chloroethane									< 1.000	1.000		1.000	1.000	1.000	ug/l

* Average for this Quarter

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WELL NO.:1523

PARAMETER	...	A90	B90	C90	D90	A91	B91	C91	D91	A92	B92	C92	MIN	MAX	AVG	UNITS
Chloroform										< 1.000	1.000		1.000	1.000	1.000	ug/l
Chloromethane										< 1.000	1.000		1.000	1.000	1.000	ug/l
Chromium, Total										0.489	0.108		0.108	0.489	0.299	mg/l
Chromium, Total (Dissd.)										< 0.002	< 0.002		0.002	0.002	0.002	mg/l
Cobalt										0.110	0.020		0.020	0.110	0.065	mg/l
Cobalt, (Dissd.)										< 0.005	< 0.005		0.005	0.005	0.005	mg/l
Copper										0.241	0.051		0.051	0.241	0.146	mg/l
Copper, (Dissd.)										< 0.020	< 0.020		0.020	0.020	0.020	mg/l
Cyanide										< 0.005	< 0.005		0.005	0.005	0.005	mg/l
Dibromochloromethane										< 1.000	1.000		1.000	1.000	1.000	ug/l
Ethyl benzene										< 1.000	1.000		1.000	1.000	1.000	ug/l
Fluoride										0.280	0.220		0.220	0.280	0.250	mg/l
Iron										231.000	74.000		74.000	231.000	152.500	mg/l
Iron, (Dissd.)										0.160	< 0.100		0.100	0.160	0.130	mg/l
Lead										0.129	0.023		0.023	0.129	0.076	mg/l
Lead, (Dissd.)										< 0.003	< 0.003		0.003	0.003	0.003	mg/l
Magnesium										325.000	165.000		165.000	325.000	245.000	mg/l
Magnesium, (Dissd.)										32.000	32.800		32.000	32.800	32.400	mg/l
Manganese										3.700	1.430		1.430	3.700	2.565	mg/l
Manganese, (Dissd.)										0.155	0.052		0.052	0.155	0.104	mg/l
Mercury										<*,***.***	<*,***.***		*,***.***	*,***.***	0.000	mg/l
Mercury, (Dissd.)										<*,***.***	<*,***.***		*,***.***	*,***.***	0.000	mg/l
Methyl ethyl ketone										< 2.000	2.000		2.000	2.000	2.000	ug/l
Methylene chloride										< 1.000	1.000		1.000	1.000	1.000	ug/l
Molybdenum										0.045	0.016		0.016	0.045	0.031	mg/l
Molybdenum, (Dissd.)										< 0.010	< 0.010		0.010	0.010	0.010	mg/l
Nickel										0.230	0.103		0.103	0.230	0.167	mg/l
Nickel, (Dissd.)										< 0.010	< 0.010		0.010	0.010	0.010	mg/l
Nitrogen, Nitrate										1.370	1.440		1.370	1.440	1.405	mg/l
Phenols										< 0.005	0.008		0.005	0.008	0.007	mg/l
Phosphorus, Total										3.440	< 0.100		0.100	3.440	1.770	mg/l
Potassium										54.600	10.500		10.500	54.600	32.550	mg/l
Potassium, (Dissd.)										1.000	< 1.000		1.000	1.000	1.000	mg/l
Selenium										< 0.005	< 0.005		0.005	0.005	0.005	mg/l
Selenium, (Dissd.)										< 0.005	< 0.005		0.005	0.005	0.005	mg/l
Silver										< 0.001	< 0.001		0.001	0.001	0.001	mg/l
Silver, (Dissd.)										< 0.001	< 0.001		0.001	0.001	0.001	mg/l

* Average for this Quarter

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PARAMETER ...	A90	B90	C90	D90	A91	B91	C91	D91	A92	B92	C92	MIN	MAX	AVG	UNITS
Sodium									6.100	4.600		4.600	6.100	5.350	mg/l
Sodium, (Dissd.)									8.400	3.500		3.500	8.400	5.950	mg/l
Specific conductance									798.000	743.000		743.000	798.000	770.500	umhos/c
Styrene									< 1.000	1.000		1.000	1.000	1.000	ug/l
Sulfate									65.000	73.000		65.000	73.000	69.000	mg/l
TOC									52.000	34.000		34.000	52.000	43.000	mg/l
TOX									< 10.000	< 10.000		10.000	10.000	10.000	ug/l Cl
Tetrachloroethene									< 1.000	1.000		1.000	1.000	1.000	ug/l
Thallium									< 0.010	< 0.010		0.010	0.010	0.010	mg/l
Thallium, (Dissd.)									< 0.010	< 0.010		0.010	0.010	0.010	mg/l
Toluene									< 1.000	1.000		1.000	1.000	1.000	ug/l
Total dissolved solids									430.000	453.000		430.000	453.000	441.500	mg/l
Trichloroethene									< 1.000	1.000		1.000	1.000	1.000	ug/l
U-TOTAL									6.100	22.000		6.100	22.000	14.050	ug/l
Vanadium									0.728	< 0.050		0.050	0.728	0.389	mg/l
Vanadium, (Dissd.)									< 0.050	< 0.050		0.050	0.050	0.050	mg/l
Vinyl acetate									< 2.000	2.000		2.000	2.000	2.000	ug/l
Vinyl chloride									< 1.000	1.000		1.000	1.000	1.000	ug/l
Xylenes, Total									< 1.000	1.000		1.000	1.000	1.000	ug/l
Zinc									0.751	0.273		0.273	0.751	0.512	mg/l
Zinc, (Dissd.)									< 0.020	< 0.020		0.020	0.020	0.020	mg/l
cis-1,3-Dichloropropene									< 1.000	1.000		1.000	1.000	1.000	ug/l
pH									7.170	7.020		7.020	7.170	7.095	S.U.
trans-1,2-Dichloroethene									< 1.000	1.000		1.000	1.000	1.000	ug/l
trans-1,3-Dichloropropene									< 1.000	1.000		1.000	1.000	1.000	ug/l

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* Average for this Quarter

ATTACHMENT E

FORMS

Forms

CONTENTS

SECTION

E1 Field Permeability Tests - Rising/Falling Head . . . . . .

E2 Pumping Test and Yield Test Water Level Measurement Form . . . . . .

E3 Packer Test Observation Well Water Level Measurement Form . . . . . .

E4 Packer Test Data Sheet - Constant Head . . . . . .

E5 Packer Test Data Sheet - Pressure Pulse . . . . . .

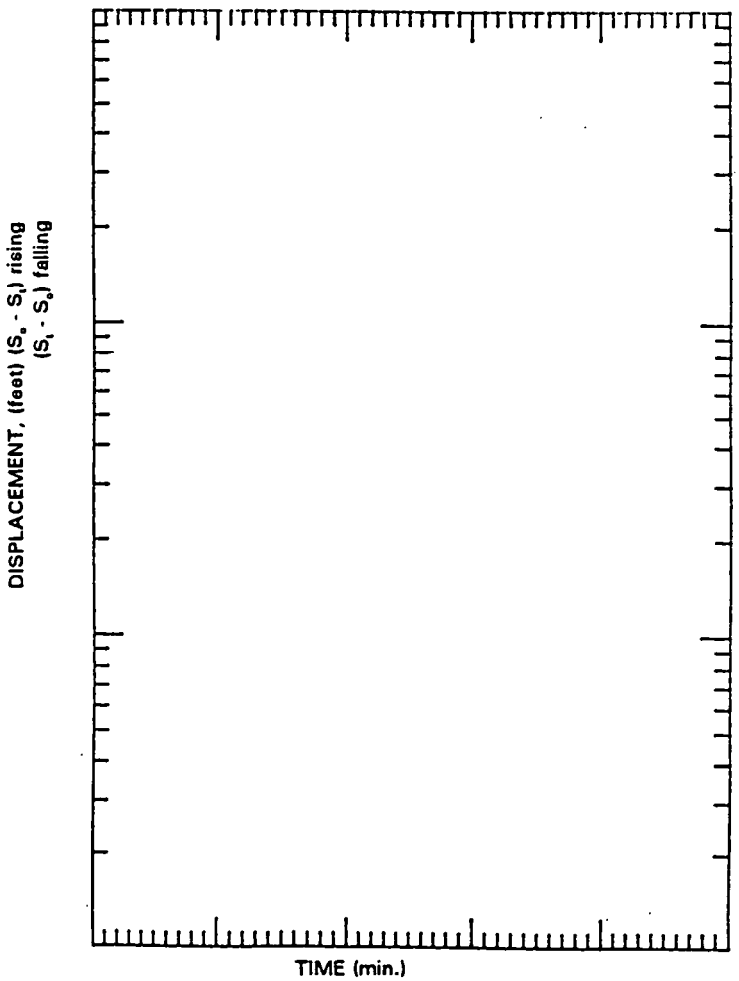
FIELD PERMEABILITY TESTS
RISING/FALLING HEAD*

PROJECT _____ TESTED BY _____ DATE _____
PROJECT NO. _____ CALCULATED BY _____ DATE _____
BORING NO. _____ CHECKED BY _____ DATE _____

RADIUS OF WELL CASING, r_c _____ (feet)
WELL SCREEN LENGTH, L (from log) _____ (feet)
SAND PACK LENGTH, $L_{(s)}$ (from log) _____ (feet)
DEPTH OF WELL _____ (feet)
STATIC WATER LEVEL _____ (feet)
STATIC HEIGHT OF WATER IN WELL, H _____ (feet)

INITIAL DRAWDOWN DUE TO INSTANTANEOUS REMOVAL/ADDITION OF SLUG, S_o _____

ELAPSED TIME t MIN	DEPTH TO WATER IN CASING S_t FEET



*Reference: Bouwer and Rice, 1976

Pumping Test and Yield Test
Water Level Measurement Form

Elevation (MSL): _____ top of casing

Observation well/piezometer no.: _____
Pumped well no.: _____
Project: _____

Pump/yield test performed by(Name): _____
Reference point measurements by: _____
Method of measurement: _____
Depth Correction: _____

b = _____

Average Q at end of test _____ gpm r = ____ ft. r^2 = _____

Date	Hour:Min	t (min)	t' (min)	t/t'	s (ft.)	s' (ft.)	(s_p - s')	Meter Reading (gals.)	Ave. Q	Remarks

b = saturated thickness (ft)
r = distance from pumped well to observation well or piezometer (ft.)
Q = flow rate (gpm)

s = measured drawdown (ft.)
s' = residual drawdown (ft.) at t'
s_p = drawdown at end of pumping period (final s)
t = elapsed time since pumping began (min)
t' = elapsed time since pumping stopped (min)

Reference: Bureau of Reclamation (1981) and Stallman (1971)

Packer Test
Observation Well Water Level Measurement Form

Elevation (MSL): _____ top of casing

Observation well/piezometer no.: _____

Pump-in boring no.: _____

Pump-in test performed by(Name): _____

Project: _____

Reference point measurements by: _____

Method of measurement: _____

Depth Correction: _____

b = _____

Average Q at end of test _____ gpm r = ____ ft.

r^2 = _____

Date	Hour:Min	t (min)	t' (min)	t/t'	s (ft.)	s' (ft.)	(s_p - s')	Meter Reading (gals.)	Ave. Q	Remarks

b = test interval thickness (ft)
r = distance from pump-in test boring to observation well or piezometer (ft.)
Q = flow rate (gpm)

s = measured head change (ft.)
s' = residual head change (ft.) at t'
s_p = head change at end of pumping period (final s)
t = elapsed time since pumping began (min)
t' = elapsed time since pumping stopped (min)

Reference: Bureau of Reclamation (1981) and Stallman (1971)

PACKER TEST
DATA SHEET FOR IN SITU MEASUREMENT OF TRANSMISSIVITY USING THE CONSTANT HEAD INJECTION TEST

Project _____
Test Location _____
Formation Type _____
Date _____
Testing by _____

Test No. _____
Borehole No. _____
Borehole Dip and Dip Direction _____
Measured Depth of Test to Top Packer, ft _____
Borehole Diameter, ft _____
Formation Temperature, o C _____

Equipment Description	Serial No.	Date of Last Calibration

Length of Packed-Off Interval, ft _____
Length of Tubing above Top Packer, ft _____
Water Temperature, o C _____

Packer Pressure, psi _____
Tubing ID, inches _____
Shut-In Borehole Pressure, psi _____
Constant Water Injection Pressure, psi _____

Adapted from ASTM Method D 4630-86

PACKER TEST
DATA SHEET FOR IN SITU MEASUREMENT OF TRANSMISSIVITY AND STORATIVITY USING THE PRESSURE PULSE TECHNIQUE

Project _____
Test Location _____
Formation Type _____
Date _____
Testing by _____

Test No. _____
Borehole No. _____
Borehole Dip and Dip Direction _____
Measured Depth of Test to Top Packer, ft _____
Borehole Diameter, inches _____
Formation Temperature, o C _____

Equipment Description	Serial No.	Date of Last Calibration

Length of Packed-Off Interval, ft _____
Length of Tubing above Top Packer, ft _____
Water Temperature, o C _____

Packer Pressure, psi _____
Tubing ID, inches _____
Maximum Pulse Pressure, psi _____
Pulse Decay Time, sec. _____

Reference: ASTM Method D 4631-86

ATTACHMENT F

DATA QUALITY OBJECTIVES

Data Quality Objectives

CONTENTS

SECTION

F1 Data Quality Objectives 1: pH, Temperature, Specific Conductance, Dissolved Oxygen, and Water Level Measurement . . . . . .

F2 Data Quality Objectives 2: Cations, Anions, VOCs, Uranium, Gross Alpha, and Gross Beta Analysis . . . . . .

F3 Data Quality Objectives 3: Geotechnical Analysis . . . . . .

ATTACHMENT F1

DATA QUALITY OBJECTIVES 1
pH, TEMPERATURE, SPECIFIC CONDUCTANCE, DISSOLVED OXYGEN, WATER LEVEL

DATA QUALITY OBJECTIVE
LOGIC FLOW PROCESS WORKSHEET

Purpose: This Worksheet has been designed and created to assist personnel with the completion of the seven-step Data Quality Objective Logic Flow. Please note that this Worksheet is not to be submitted as a DQO Logic Flow, rather it is to be utilized as tool for the Logic Flow completion.

Please note a series of suggestions and questions accompanying each step of the Logic Flow. These suggestions and questions should be addressed and considered when completing each of the seven steps. Also note that not all of the suggestions and questions will apply to every sampling project. If a suggestion and/or question does not apply to your sampling project, please note why it does not and proceed to the next question.

For further information concerning the seven-step Logic flow, please consult Appendix C of the Sitewide CERCLA Quality Assurance Project Plan (SCQ) (*note: formerly known as the QAPjP).

In summary, the seven steps of a DQO Logic Flow are as follows:

1. State the Problem(s) of the Situation to be Resolved
2. Identify the Decision(s) to be made that Affect the Situation
3. Identify Inputs that Affect the Decision(s)
4. Define the Boundaries of the Situation
5. Develop a Logic Statement that Applies to the Decision
6. Establish Constraints on the Uncertainty of the Decision
7. Optimize a Design for Obtaining Quality Data

- PLEASE PROCEED WITH THE WORKSHEET -

DQO LOGIC FLOW WORKSHEET

Step 1: State the Problem(s) of the Situation to be Resolved

GOAL: A description of the problem; and any resource, time, or other practical limits on the data collection.

1) Identify the personnel that will comprise the sample planning team. These team members should possess knowledge and expertise that affect the sampling plan i.e. analytical, engineering, statistical, data review, etc.

PARSONS: John Osweiler and Jerry Boeckman

FERMCO: Ken Broberg, Dan Stropes, and Harriet Richardson

2) Estimate the sampling project budget based on personnel, material, analysis and extraneous costs (OPTIONAL).

N/A

3) Are there any specific resource or time limitations for the sampling project? Example: Limitations on data collection due to time of the year (fiscal or seasonal).

The sampling project must begin in March and be completed within 3 weeks so that the data can be analyzed and summarized for the CRU-5 RI/FS report.

4) Prepare a statement of the problem. The following elements should be considered:

a. An overall description of the problem as it is known.

The hydraulic transport and conductivity of the Glacial Till/Vadose Zone (GT/VZ) under the FEMP is being studied to enable groundwater modeling to be performed to assist in the preparation of the OU-5 RI/FS. It is necessary to collect water level, pH, specific conductance, dissolved oxygen, and temperature data from monitoring wells at the site for modeling input.

b. Any important social or political considerations (i.e. local, state or regional).

No social or political impacts are anticipated.

DQO LOGIC FLOW WORKSHEET

c. Organization and review of existing relevant information for each well.

Groundwater quality data is available for each well in dBase format from the FERMCO Groundwater Programs Implementation Group.

5) Will the new analytical data to be obtained be a CRITICAL factor for resolving the defined problem? Why?

No. The data is being acquired to comply with the SCQ, not for any specific requirement of the actual sampling method.

DQO LOGIC FLOW WORKSHEET

Step 2: Identify the Decision(s) to be made that Affect the Situation

The data collected during the field activities will be used as input for groundwater modeling.

GOAL: A statement of the decision that will be made using the environmental data and the actions that will result.

1) What are the initial ideas for approaches that will resolve the problem?

N/A

2) What are the range of actions that might be taken based on the outcome of the analytical study? Note: Consider DOE Orders that may influence these actions.

N/A

3) Specify the criteria for taking these actions. Use an "if..., then...," logic statement to formulate the criteria (i.e., if the analytical results exceed the RCRA regulatory limits, then long term storage is an option for action). If the criteria are not known at the time, then specify how they will be established.

N/A

4) State the decision as a choice among alternative courses of action that will resolve one or more components of the problems.

N/A

DQO LOGIC FLOW WORKSHEET

Step 3: Identify Inputs that Affect the Decision(s)

GOAL: A list of environmental variables or characteristics to be measured; the criteria for taking action; and other information needed in order to make the decision.

1) What analytes or characteristics of the analytes are to be measured?

pH
Temperature
Specific conductance
Dissolved oxygen
Water level

2) What is the criteria that would prompt action to be taken? Examples: Regulatory action limits, clean versus non-clean.

N/A

3) Confirm that each analyte or characteristic identified in question #1 can be quantitatively measured. If it cannot, then determine if is reasonable to make assumptions about the variable in order to draw a conclusion without the assistance of analytical data.

All characteristics can be quantitatively measured.

DQO LOGIC FLOW WORKSHEET

Step 4: Define the Boundaries of the Situation

GOAL: A detailed description of the population for which the decision will be made, including area (spatial) and time (temporal) limits involved.

1) What is the population for which the decision will be made? Example of a population could be: people, objects, or a portion of media.

Groundwater in the glacial till/vadose zone.

2) What are the spatial boundaries to be affected by the decision, i.e., Plant One Pad, OU-5, Fire Training Center, etc.?

All groundwater underlying the FEMP and also in the South Plume area.

3) What are the temporal boundaries of the decision? Example: Airborne contamination from x date to y date.

N/A

4) Are there any other additional characteristics that are required to determine what belongs in the population?

No

5) What is the smallest population, if applicable, that can be involved in the decision making process? Example: Studying a section within a department for more precise data.

N/A

6) Verify that the practical considerations identified in Step 1: State the Problem, are consistent with these boundaries.

Practical considerations are consistent with boundaries of the situation.

DQO LOGIC FLOW WORKSHEET

Step 5: Develop a Logic Statement that Applies to the Decision

GOAL: A statement that defines how environmental data will be summarized and used to make the decision.

Note: The purpose of this step is to integrate the outputs from the previous steps into a single statement specifying how environmental data will be summarized and used to make the decision, including quantitative criteria for determining what action to take.

It is important that someone with statistical expertise be involved in this step to be certain that the decision rule is stated in a manner that leads to an efficient sample design.

1) How will the study results be summarized? How will the results be calculated (i.e., mean, range, maximum, etc)?

Field characteristics (pH, specific conductance, etc.) will be tabulated. No statistical evaluation will be made.

2) Develop a Decision Rule as an "If..., then..., statement that incorporates the study results (sample concentrations), the criteria for taking action (action levels), and the actions(s) that will be taken under various possible scenarios (removal, remediation, etc). Example: If the mean concentration of a contaminant exceeds the action level for a group of samples, then a corrective action must be initiated.

N/A

3) Will all the data to be obtained be required for the decision? If not, then define a more narrowly-focused set of analytes and/or characteristics.

No

4) Will any other FEMP activities be able to utilize the analytical results to be collected?

Unknown at this time.

DQO LOGIC FLOW WORKSHEET

Step 6: Establish Constraints on the Uncertainty of the Decision

GOAL: To control decision errors, stated as limits on the acceptable probability of making an incorrect decision based on the study findings. These limits on uncertainty may be expressed as acceptable false positive and false negative error rates.

Note: Consult a statistician for definitions and further explanatory information.

1) For the decision to be made, what would define a "false positive" error and what would the consequence(s) be?

N/A

2) For the decision to be made, what would define a false negative error and what would the consequence(s) be?

N/A

3) Consider the consequences of false positive(s) and/or negative(s) on the following issues and rank in order of importance:

* cost *(N/A)*
* health risks *(N/A)*
* social impacts *(N/A)*
* ecological risks *(N/A)*
* political/credibility *(N/A)*

4) Are the false positive or the false negative errors greater concerns on the above issues?

N/A

5) Determine if the level of concern for either type of decision error depends on the magnitude of the error. Example: Determine a threshold level where anything above would have an economic effect and anything below would have a health effect.

N/A

6) What is the estimated magnitude of the expected consequences?

N/A

DQO LOGIC FLOW WORKSHEET

7) Decide what magnitude of false positive and false negative errors would be "almost always," "often," "sometimes," and "almost never" acceptable.

N/A

8) What is the statistically acceptable probabilities for the occurrence of each of these errors?

N/A

9) Define a region of statistical indifference which is the area in which the probability of an incorrect outcome is not controlled because, under the stated conditions, either decision is acceptable.

N/A

10) Combine the probability statements into a formal statement of the levels of uncertainty that can be tolerated in the data results.

DQO LOGIC FLOW WORKSHEET

Step 7: Optimize a Design for Obtaining Quality Data

GOAL: The cost design for the study (selected from a group of alternative designs) that is expected to achieve the DQO's.

1) What are the estimated distribution of site-related contaminants of potential concern?

N/A

2) Based on all of the above information and the relative costs of proposed sampling and analysis options, what is the lowest cost sampling and analysis plan that will achieve the desired data and constraints on uncertainty? Consider the following:

a. What is the sample design?

Field Parameters.

b. How many samples will be collected?

One set from each well.

c. What level of Quality Assurance is required?

Field measurements (Level A).

d. What are the requirements for precision, accuracy, sensitivity, and completeness?

As stated in SCQ.

e. What analytical methods are required?

N/A

DQO LOGIC FLOW WORKSHEET

SUMMARY:
(In conjunction with the DQO Summary form)

1) State the analytical support levels (ASL's) required, and briefly explain the rationale behind the choice.

Field Measurements: ASL A as specified in SCQ (pH, S.C. Temperature, DO, and Water Level).

2) Identify the analyte(s) of interest.

Same as above.

3) What type and how many field Quality Assurance samples are required?

N/A

4) What type and how many laboratory Quality Control samples are required?

N/A

DQO SUMMARY FORM

Revision:
Effective Date:

1.A. Task/Description: OU #: 5

Field analyses of pH, specific conductance, temperature, dissolved oxygen, and water level of monitoring wells at the FEMP.

1.B. Project Phase: (Circle the appropriate selection.)
RI FS RD RA R A OTHER (specify)

1.C DQO No.: _____ DQO Reference No.:

---

2. Media Characterization: (Circle the appropriate selection.)

Soil Groundwater Surface Water Sediment Waste
Wastewater Air Biological Other Building Debris (Solids)

---

3. Data Use with Data Quality Level (A-E): (Circle the appropriate Data Use and Data Quality Level selection[s].)

Site Characterization A B C D E Risk Assessment A B C D E
Evaluation of Alternatives A B C D E Engineering Design A B C D E
Monitoring during remediation activities A B C D E
Other A B C D E (Explain) Removal Action

4.A. Regulatory Driver: DOE Order 5400.5 and NRC 1.86

4.B. Objective:

To fulfill requirements of SCQ Appendix J.

---

5. Site Information (Description):

Glacial till characterization recommends sampling monitoring wells at selected locations across the site. Information from this task will be used in the CRU-5 RI/FS.

DQO SUMMARY FORM

DQO Number:

6.A. Data Types with appropriate Data Quality Level Equipment Selection and SCQ Reference: (Place an "X" to the right of the appropriate box or boxes selecting the type of analysis or analyses required. Then select the type of equipment to perform the analysis if appropriate. Please include a reference to the SCQ Section.)

1. pH X
   Temperature X
   Specific Conductance X
   Dissolved Oxygen X

2. Uranium ___
   Full Radiologic ___
   Metals ___
   Cyanide ___
   Silica ___

3. BTX ___
   TPH ___
   Oil/Grease___

4. Cations ___
   Anions ___
   TOX ___
   TOC ___
   TCLP ___
   CEC ___
   COD ___

5. VOA ___
   ABN ___
   Pesticides ___
   PCB ___

6. Other (specify) X
   Water Level
   _____
   _____

6.B. Equipment Selection and SCQ Reference:

Equipment Selection	Refer to SCQ Section
Level A _____	SCQ Section: 9
_____	
Level B _____	SCQ Section: _____
Level C _____	SCQ Section: _____
Level D _____	SCQ Section: _____
Level E _____	SCQ Section: _____

pH - Precision of ±0.05 pH
Temperature - Precision of ±0.5 degrees C
Specific Conductance - Precision of ±1 percent of full scale
Dissolved Oxygen - Precision of ±0.1 mg/l
Water Level - Precision of ±0.01 foot

DQO SUMMARY FORM

DQO Number:

7.A. Sampling Methods and Procedures: (Circle the appropriate selection.)

Environmental Biased Grab Non-intrusive Phased
Source Grid Composite Intrusive

Other (specify): _____

7.B. Sample Work Plan Reference: (List the samples required. Reference the work plan or sampling plan guiding the sampling activity, as appropriate.)

Background samples: N/A
Critical samples: _____

7.C. Sample Collection Procedure Reference: (Please provide a specific reference to the SCQ Section and subsection guiding sampling collection procedures.)

Sample Collection Procedures Reference: Section K

---

8. Quality Assurance/Control Samples: (Place an "X" to the right of the appropriate selection[s].)

8.A. Field Quality Assurance Samples:

Trip Blanks ___
Field Blanks ___
Equipment Rinseate Samples ____
Preservative Blanks ___
Container Blanks ___
Duplicate Samples ___
Split Samples ___
Spiked Blanks ___
Other (specify) _____

8.B. Laboratory Quality Control Samples:

Method Blank ___
Matrix Duplicate/Replicate (Matrix Spike Duplicates) ___

Matrix Spike ___
Surrogate Spikes ___

Other (specify) ____

DQO SUMMARY FORM

---

9. Other: Please provide any other germane information that may impact the data quality or gathering of this particular objective, task, or data use.

All equipment must be accurately calibrated and in proper working order.

ATTACHMENT F2

DATA QUALITY OBJECTIVES 2
CATIONS, ANIONS, VOCs, URANIUM, GROSS ALPHA, GROSS BETA

DATA QUALITY OBJECTIVE
LOGIC FLOW PROCESS WORKSHEET

Purpose: This Worksheet has been designed and created to assist personnel with the completion of the seven-step Data Quality Objective Logic Flow. Please note that this Worksheet is not to be submitted as a DQO Logic Flow, rather it is to be utilized as tool for the Logic Flow completion.

Please note a series of suggestions and questions accompanying each step of the Logic Flow. These suggestions and questions should be addressed and considered when completing each of the seven steps. Also note that not all of the suggestions and questions will apply to every sampling project. If a suggestion and/or question does not apply to your sampling project, please note why it does not and proceed to the next question.

For further information concerning the seven-step Logic flow, please consult Appendix C of the Sitewide CERCLA Quality Assurance Project Plan (SCQ) (*note: formerly known as the QAPjP).

In summary, the seven steps of a DQO Logic Flow are as follows:

1. State the Problem(s) of the Situation to be Resolved
2. Identify the Decision(s) to be made that Affect the Situation
3. Identify Inputs that Affect the Decision(s)
4. Define the Boundaries of the Situation
5. Develop a Logic Statement that Applies to the Decision
6. Establish Constraints on the Uncertainty of the Decision
7. Optimize a Design for Obtaining Quality Data

- PLEASE PROCEED WITH THE WORKSHEET -

DQO LOGIC FLOW WORKSHEET

Step 1: State the Problem(s) of the Situation to be Resolved

GOAL: A description of the problem; and any resource, time, or other practical limits on the data collection.

1) Identify the personnel that will comprise the sample planning team. These team members should possess knowledge and expertise that affect the sampling plan i.e. analytical, engineering, statistical, data review, etc.

PARSONS: John Osweiler and Jerry Boeckman

FERMCO: Ken Broberg, Dan Stropes, and Harriet Richardson

2) Estimate the sampling project budget based on personnel, material, analysis and extraneous costs (OPTIONAL).

N/A

3) Are there any specific resource or time limitations for the sampling project? Example: Limitations on data collection due to time of the year (fiscal or seasonal).

The sampling project must begin in March and be completed within 3 weeks so that the data can be analyzed and summarized for the CRU-5 RI/FS report.

4) Prepare a statement of the problem. The following elements should be considered:

a. An overall description of the problem as it is known.

The hydraulic transport and conductivity of the Glacial Till/Vadose Zone (GT/VZ) under the FEMP is being studied to enable groundwater modeling to be performed to assist in the preparation of the OU-5 RI/FS. Groundwater analysis for volatile organic compounds, general chemistry (anions and cations), and total uranium is needed for modeling input.

b. Any important social or political considerations (i.e. local, state or regional).

No social or political impacts are anticipated.

DQO LOGIC FLOW WORKSHEET

c. Organization and review of existing relevant information.

Historical groundwater quality data is available in dBase format from the FERMCO Groundwater Programs Implementation Group and has been included in Attachment D of the Glacial Till/Vadose Zone Hydraulic Investigations Work Plan. All methods for Level A field sampling are described in the Sitewide CERCLA Quality Assurance Project Plan (SCQ) (DOE 1992).

5) Will the new analytical data to be obtained be a CRITICAL factor for resolving the defined problem? Why?

Yes. Without the data, the hydraulic conductivity of the GT/VZ cannot be studied.

DQO LOGIC FLOW WORKSHEET

Step 2: Identify the Decision(s) to be made that Affect the Situation

The data collected from the laboratory analysis will be used as input for groundwater modeling.

GOAL: A statement of the decision that will be made using the environmental data and the actions that will result.

1) What are the initial ideas for approaches that will resolve the problem?

N/A

2) What are the range of actions that might be taken based on the outcome of the analytical study? Note: Consider DOE Orders that may influence these actions.

N/A

3) Specify the criteria for taking these actions. Use an "if..., then...," logic statement to formulate the criteria (i.e., if the analytical results exceed the RCRA regulatory limits, then long term storage is an option for action). If the criteria are not known at the time, then specify how they will be established.

N/A

4) State the decision as a choice among alternative courses of action that will resolve one or more components of the problems.

N/A

DQO LOGIC FLOW WORKSHEET

Step 3: Identify Inputs that Affect the Decision(s)

GOAL: A list of environmental variables or characteristics to be measured; the criteria for taking action; and other information needed in order to make the decision.

1) What analytes or characteristics of the analytes are to be measured?

General Chemistry (Anions and Cations)

Gross Alpha

Gross Beta

Total Uranium

Volatile Organic Compounds

(See attached list of TALs)

2) What is the criteria that would prompt action to be taken? Examples: Regulatory action limits, clean versus non-clean.

N/A

3) Confirm that each analyte or characteristic identified in question #1 can be quantitatively measured. If it cannot, then determine if is reasonable to make assumptions about the variable in order to draw a conclusion without the assistance of analytical data.

All characteristics can be quantitatively measured.

DQO LOGIC FLOW WORKSHEET

Step 4: Define the Boundaries of the Situation

GOAL: A detailed description of the population for which the decision will be made, including area (spatial) and time (temporal) limits involved.

1) What is the population for which the decision will be made? Example of a population could be: people, objects, or a portion of media.

Groundwater in the glacial till/vadose zone.

2) What are the spatial boundaries to be affected by the decision, i.e., Plant One Pad, OU-5, Fire Training Center, etc.?

All groundwater underlying the FEMP and also in the South Plume area.

3) What are the temporal boundaries of the decision? Example: Airborne contamination from x date to y date.

N/A

4) Are there any other additional characteristics that are required to determine what belongs in the population?

No

5) What is the smallest population, if applicable, that can be involved in the decision making process? Example: Studying a section within a department for more precise data.

N/A

6) Verify that the practical considerations identified in Step 1: State the Problem, are consistent with these boundaries.

Practical considerations are consistent with boundaries of the situation.

DQO LOGIC FLOW WORKSHEET

Step 5: Develop a Logic Statement that Applies to the Decision

GOAL: A statement that defines how environmental data will be summarized and used to make the decision.

Note: The purpose of this step is to integrate the outputs from the previous steps into a single statement specifying how environmental data will be summarized and used to make the decision, including quantitative criteria for determining what action to take.

It is important that someone with statistical expertise be involved in this step to be certain that the decision rule is stated in a manner that leads to an efficient sample design.

1) How will the study results be summarized? How will the results be calculated (i.e., mean, range, maximum, etc)?

Upon receipt of laboratory results, the data will be evaluated for range.

2) Develop a Decision Rule as an "If..., then..., statement that incorporates the study results (sample concentrations), the criteria for taking action (action levels), and the actions(s) that will be taken under various possible scenarios (removal, remediation, etc). Example: If the mean concentration of a contaminant exceeds the action level for a group of samples, then a corrective action must be initiated.

If a data point does not appear to fall within the range of typical values for historic groundwater samples, then a duplicate sample may be collected. If a sample cannot be collected or the data point is determined not to be critical, then the data point may be deemed erroneous and not used in the modeling activities.

3) Will all the data to be obtained be required for the decision? If not, then define a more narrowly-focused set of analytes and/or characteristics.

No

4) Will any other FEMP activities be able to utilize the analytical results to be collected?

Groundwater Modeling and Health and Safety.

DQO LOGIC FLOW WORKSHEET

Step 6: Establish Constraints on the Uncertainty of the Decision

GOAL: To control decision errors, stated as limits on the acceptable probability of making an incorrect decision based on the study findings. These limits on uncertainty may be expressed as acceptable false positive and false negative error rates.

Note: Consult a statistician for definitions and further explanatory information.

1) For the decision to be made, what would define a "false positive" error and what would the consequence(s) be?

N/A

2) For the decision to be made, what would define a false negative error and what would the consequence(s) be?

N/A

3) Consider the consequences of false positive(s) and/or negative(s) on the following issues and rank in order of importance:

* cost *(N/A)*
* health risks *(N/A)*
* social impacts *(N/A)*
* ecological risks *(N/A)*
* political/credibility *(N/A)*

4) Are the false positive or the false negative errors greater concerns on the above issues?

N/A

5) Determine if the level of concern for either type of decision error depends on the magnitude of the error. Example: Determine a threshold level where anything above would have an economic effect and anything below would have a health effect.

N/A

6) What is the estimated magnitude of the expected consequences?

N/A

DQO LOGIC FLOW WORKSHEET

7) Decide what magnitude of false positive and false negative errors would be "almost always," "often," "sometimes," and "almost never" acceptable.

N/A

8) What is the statistically acceptable probabilities for the occurrence of each of these errors?

N/A

9) Define a region of statistical indifference which is the area in which the probability of an incorrect outcome is not controlled because, under the stated conditions, either decision is acceptable.

N/A

10) Combine the probability statements into a formal statement of the levels of uncertainty that can be tolerated in the data results.

N/A

DQO LOGIC FLOW WORKSHEET

Step 7: Optimize a Design for Obtaining Quality Data

GOAL: The cost design for the study (selected from a group of alternative designs) that is expected to achieve the DQO's.

1) What are the estimated distribution of site-related contaminants of potential concern?

N/A

2) Based on all of the above information and the relative costs of proposed sampling and analysis options, what is the lowest cost sampling and analysis plan that will achieve the desired data and constraints on uncertainty? Consider the following:

a. What is the sample design?

Three test wells and six lysimeters will be installed as stated in the Work Plan. Groundwater samples will be collected from saturated zones in the test wells and pore moisture samples from the lysimeters.

b. How many samples will be collected?

Two sets of samples will be collected from each test well. One set of samples will be collected before the pumping test and one set during the pumping test. One sample will be collected from each lysimeter.

c. What level of Quality Assurance is required?

Lab Analysis (Level B).

d. What are the requirements for precision, accuracy, sensitivity, and completeness?

As stated in SCQ.

e. What analytical methods are required?

Anions
Cations
Gross Alpha
Gross Beta
Total Uranium
Volatile Organic Analysis

All analyses will be performed in accordance with the SCQ.

DQO LOGIC FLOW WORKSHEET

SUMMARY:
(In conjunction with the DQO Summary form)

1) State the analytical support levels (ASLs) required, and briefly explain the rationale behind the choice.

ASLB, Rapid turnaround required for data use in CRU-5 RI risk assessment. CLP protocols not required.

2) Identify the analyte(s) of interest.

Anions
Cations
Gross Alpha
Gross Beta
Total Uranium
Volatile Organic Compounds

3) What type and how many field Quality Assurance samples are required?

As specified in Table 2-2 of Appendix A of SCQ.

4) What type and how many laboratory Quality Control samples are required?

As specified in Table 2-2 of Appendix A of SCQ.

DQO SUMMARY FORM

Revision:
Effective Date:

1.A. Task/Description: OU #: 5

Analytical tests for isotopic age dating, general chemistry, and total uranium.

1.B. Project Phase: (Circle the appropriate selection.)
RI FS RD RA R A OTHER (specify)

1.C DQO No.: _____ DQO Reference No.:

---

2. Media Characterization: (Circle the appropriate selection.)

Soil Groundwater Surface Water Sediment Waste
Wastewater Air Biological Other Building Debris (Solids)

---

3. Data Use with Data Quality Level (A-E): (Circle the appropriate Data Use and Data Quality Level selection[s].)

Site Characterization A B C D E Risk Assessment A B C D E
Evaluation of Alternatives A B C D E Engineering Design A B C D E
Monitoring during remediation activities A B C D E
Other A B C D E (Explain) Removal Action

4.A. Regulatory Driver: DOE Order 5400.5 and NRC 1.86

4.B. Objective:

To determine if radiological contamination is present and compile radiological data to determine the disposition requirements of the debris. Also, differences in contaminant concentrations will be needed to see what kind of groundwater mixing is occurring between the different sand bodies beneath the plant areas and waste pits. The wells are being drilled in new areas that have not been fully characterized.

---

5. Site Information (Description):

Glacial till characterization recommends sampling monitoring wells at selected locations across the site. Information from this task will be used in the CRU-5 RI/FS.

DQO SUMMARY FORM

Revision:
Effective Date:

DQO Number:

6.A. Data Types with appropriate Data Quality Level Equipment Selection and SCQ Reference: (Place an "X" to the right of the appropriate box or boxes selecting the type of analysis or analyses required. Then select the type of equipment to perform the analysis if appropriate. Please include a reference to the SCQ Section.)

1. pH ___
   Temperature ___
   Specific Conductance ___
   Dissolved Oxygen ___

2. Uranium X
   Full Radiologic ___
   Metals ___
   Cyanide ___
   Silica ___

3. BTX ___
   TPH ___
   Oil/Grease ___

4. Cations X
   Anions X
   TOX ___
   TOC ___
   TCLP ___
   CEC ___
   COD ___

5. VOA X
   ABN ___
   Pesticides ___
   PCB ___

6. Other (specify) X
   Gross Alpha
   Gross Beta

6.B. Equipment Selection and SCQ Reference:

Equipment Selection	Refer to SCQ Section
Level A	SCQ Section:
Level B In accordance with the procedures in the SCQ	SCQ Section:
Level C	SCQ Section:
Level D	SCQ Section:
Level E	SCQ Section:

DQO SUMMARY FORM

DQO Number:

7.A. Sampling Methods and Procedures: (Circle the appropriate selection.)

Environmental Biased Grab Non-intrusive Phased
Source Grid Composite Intrusive

Other (specify): _____

7.B. Sample Work Plan Reference: (List the samples required. Reference the work plan or sampling plan guiding the sampling activity, as appropriate.)

Background samples: N/A
Critical samples: _____

7.C. Sample Collection Procedure Reference: (Please provide a specific reference to the SCQ Section and subsection guiding sampling collection procedures.)

Sample Collection Procedures Reference: Section K

---

8. Quality Assurance/Control Samples: (Place an "X" to the right of the appropriate selection[s].)

8.A. Field Quality Assurance Samples:

Trip Blanks	X	Container Blanks	___
Field Blanks	___	Duplicate Samples	___
Equipment Rinseate Samples	____	Split Samples	___
Preservative Blanks	___	Spiked Blanks	___

Other (specify) As specified in Table 2-2 of Appendix A of the SCQ.

8.B. Laboratory Quality Control Samples:

Method Blank ___ Matrix Duplicate/Replicate (Matrix Spike Duplicates) ___

Matrix Spike ___ Surrogate Spikes ___

DQO SUMMARY FORM

Other (specify) ____

9. Other: Please provide any other germane information that may impact the data quality or gathering of this particular objective, task, or data use.

All equipment must be accurately calibrated and in proper working order.

Volatile Organics

1. 1,1 - Dichloroethane
2. 1,1 - Dichloroethane
3. 1,1,1 - Trichloroethane
4. 1,1,2 - Trichloroethane
5. 1,1,2,2 - Tetrachloroethane
6. 1,2 - Dichloroethane
7. 1,2 - Dichloroethene (total)
8. 1,2 - Dichlorothylene
9. 1,2 - Dichloropropane
10. 2 - Butanone
11. 2 - Hexanone
12. 4 - Methyl-2-pentanone
13. Acetone
14. Benzene
15. Bromodichloromethane
16. Bromoform
17. Bromomethane
18. Carbon disulfide
19. Carbon tetrachloride
20. Chlorobenzene
21. Chloroethane
22. Chloroform
23. Chloromethane
24. cis - 1,3 - Dichloropropene

General Chemistry

1. Sodium
2. Magnesium
3. Calcium
4. Chloride
5. Sulfate
6. Bicarbonate
7. Silicon
8. Potassium
9. Carbonate
10. Silicate
11. Fluoride
12. Iron
13. Nitrate
14. Boron
15. Strontiuem
16. Total Dissolved Solids
17. Alkalinity
18. pH
19. TSS

Radiological

1. Total uranium
2. Gross alpha
3. Gross beta

Volatile Organics

25. Dibromochloromethane
26. Ethylbenzene
27. Methylene chloride
28. Styrene
29. Tetrachloroethene
30. Toluene
31. Total xylenes
32. trans-1,3-Dichloropropene
33. Trichloroethene
34. Vinyl acetate
35. Vinyl chloride

SUMMARY OF CHEMICAL AND PHYSICAL ANALYSES:
(Chemical Analysis)

Analysis	Number of Samples* SP	QA/QC	Sample Containers	Preservative	Holding Time	
Total Uranium	13	5	1000 ml plastic or glass	HNO to pH < 2	180 days	
Gross	12	5	1000 ml plastic or glass	HNO to pH < 2	180 days	Alpha
Gross Beta	12	5	"	"	"	
VOC's EPA 8240	13	5	2, 40 ml vials with teflon septum caps	4 drops concentrated HCl, cool to 2-6 C	14 days	
General Chemistry						
Metals: sodium magnesium calcium potassium iron silicon boron strontium	12	5	1000 ml plastic container for all metals	HNO to pH < 2	180 days	
Nitrate	12	5	1, 500 ml plastic container	H SO to pH < 2 cool to 4 C	28 days	

(General Chemistry, cont.)

Nitrogen (ammonia)	12	5	1, 500 ml plastic container	H SO to pH < 2 cool to 4 C	28 days
Pumping Tests					
Anions: chloride sulfate bicarbonate carbonate fluoride	12	5	1000 ml plastic container for all anions	NA	28 days
alkalinity					14 days
Silicate	12	5	500 ml plastic container	NA	28 days
pH	12	5	125 ml plastic container	NA	24 hours
Total Dissolved Solids	12	5	1000 ml plastic container	cool to 4 C	7 days
Total Suspended Solids	12	5	500 ml plastic container	cool to 4 C	7 days

SP: Individual sampling point or well
QA/QC: Quality Assurance/Quality Control Samples consisting of the following:
1 field rinseate or equipment wash blank
2 field blanks
1 duplicate
1 matrix spike

All samples to be shipped in sealed coolers under chain of custody via an overnight delivery service.

No special shipping arrangements are required unless the samples are regarded as hazardous. If hazardous samples are to be shipped, then the appropriate DOT regulations are to be followed as per the SCQ.

ATTACHMENT F3

DATA QUALITY OBJECTIVES 3
GEOTECHNICAL ANALYSES

DATA QUALITY OBJECTIVE
LOGIC FLOW PROCESS WORKSHEET

Purpose: This Worksheet has been designed and created to assist personnel with the completion of the seven-step Data Quality Objective Logic Flow. Please note that this Worksheet is not to be submitted as a DQO Logic Flow, rather it is to be utilized as tool for the Logic Flow completion.

Please note a series of suggestions and questions accompanying each step of the Logic Flow. These suggestions and questions should be addressed and considered when completing each of the seven steps. Also note that not all of the suggestions and questions will apply to every sampling project. If a suggestion and/or question does not apply to your sampling project, please note why it does not and proceed to the next question.

For further information concerning the seven-step Logic flow, please consult Appendix C of the Sitewide CERCLA Quality Assurance Project Plan (SCQ) (*note: formerly known as the QAPjP).

In summary, the seven steps of a DQO Logic Flow are as follows:

1. State the Problem(s) of the Situation to be Resolved
2. Identify the Decision(s) to be made that Affect the Situation
3. Identify Inputs that Affect the Decision(s)
4. Define the Boundaries of the Situation
5. Develop a Logic Statement that Applies to the Decision
6. Establish Constraints on the Uncertainty of the Decision
7. Optimize a Design for Obtaining Quality Data

- PLEASE PROCEED WITH THE WORKSHEET -

DQO LOGIC FLOW WORKSHEET

Step 1: State the Problem(s) of the Situation to be Resolved

GOAL: A description of the problem; and any resource, time, or other practical limits on the data collection.

1) Identify the personnel that will comprise the sample planning team. These team members should possess knowledge and expertise that affect the sampling plan i.e. analytical, engineering, statistical, data review, etc.

PARSONS: John Osweiler and Jerry Boeckman

FERMCO: Ken Broberg, Dan Stropes, and Harriet Richardson

2) Estimate the sampling project budget based on personnel, material, analysis and extraneous costs (OPTIONAL).

N/A

3) Are there any specific resource or time limitations for the sampling project? Example: Limitations on data collection due to time of the year (fiscal or seasonal).

The sampling project must begin in March and be completed within 3 weeks so that the data can be analyzed and summarized for the CRU-5 RI/FS report.

4) Prepare a statement of the problem. The following elements should be considered:

a. An overall description of the problem as it is known.

The hydraulic transport and conductivity of the Glacial Till/Vadose Zone (GT/VZ) is being studied to enable groundwater modeling to be performed to assist in the preparation of the OU-5 RI/FS. Monitoring wells need to be installed in specific locations on site, and geotechnical laboratory testing will be performed to determine subsurface properties.

b. Any important social or political considerations (i.e. local, state or regional).

No social or political impacts are anticipated.

DQO LOGIC FLOW WORKSHEET

c. Organization and review of existing relevant information.

All methods for monitoring well installation and geotechnical laboratory analyses are described in the Sitewide CERCLA Quality Assurance Project Plan (SCQ) (DOE 1992).

5) Will the new analytical data to be obtained be a CRITICAL factor for resolving the defined problem? Why?

Yes. Without the data, the hydraulic conductivity of the GT/VZ cannot be accurately studied.

DQO LOGIC FLOW WORKSHEET

Step 2: Identify the Decision(s) to be made that Affect the Situation

The geotechnical data will be used as input to the groundwater model.

GOAL: A statement of the decision that will be made using the environmental data and the actions that will result.

1) What are the initial ideas for approaches that will resolve the problem?

N/A

2) What are the range of actions that might be taken based on the outcome of the analytical study? Note: Consider DOE Orders that may influence these actions.

N/A

3) Specify the criteria for taking these actions. Use an "if..., then...," logic statement to formulate the criteria (i.e., if the analytical results exceed the RCRA regulatory limits, then long term storage is an option for action). If the criteria are not known at the time, then specify how they will be established.

N/A

4) State the decision as a choice among alternative courses of action that will resolve one or more components of the problems.

N/A

DQO LOGIC FLOW WORKSHEET

Step 3: Identify Inputs that Affect the Decision(s)

GOAL: A list of environmental variables or characteristics to be measured; the criteria for taking action; and other information needed in order to make the decision.

1) What analytes or characteristics of the analytes are to be measured?

Primarily:
Grain-size analysis
Soil index properties
Moisture content
Soil density
Atterberg limits
Constant head permeability tests
Specific gravity
Void ratio
Porosity

Secondarily:

2) What is the criteria that would prompt action to be taken? Examples: Regulatory action limits, clean versus non-clean.

N/A

3) Confirm that each analyte or characteristic identified in question #1 can be quantitatively measured. If it cannot, then determine if is reasonable to make assumptions about the variable in order to draw a conclusion without the assistance of analytical data.

All characteristics can be quantitatively measured.

DQO LOGIC FLOW WORKSHEET

Step 4: Define the Boundaries of the Situation

GOAL: A detailed description of the population for which the decision will be made, including area (spatial) and time (temporal) limits involved.

1) What is the population for which the decision will be made? Example of a population could be: people, objects, or a portion of media.

Subsurface soils of the FEMP.

2) What are the spatial boundaries to be affected by the decision, i.e., Plant One Pad, OU-5, Fire Training Center, etc.?

N/A

3) What are the temporal boundaries of the decision? Example: Airborne contamination from x date to y date.

N/A

4) Are there any other additional characteristics that are required to determine what belongs in the population?

No

5) What is the smallest population, if applicable, that can be involved in the decision making process? Example: Studying a section within a department for more precise data.

N/A

6) Verify that the practical considerations identified in Step 1: State the Problem, are consistent with these boundaries.

Practical considerations are consistent with boundaries of the situation.

DQO LOGIC FLOW WORKSHEET

Step 5: Develop a Logic Statement that Applies to the Decision

GOAL: A statement that defines how environmental data will be summarized and used to make the decision.

Note: The purpose of this step is to integrate the outputs from the previous steps into a single statement specifying how environmental data will be summarized and used to make the decision, including quantitative criteria for determining what action to take.

It is important that someone with statistical expertise be involved in this step to be certain that the decision rule is stated in a manner that leads to an efficient sample design.

1) How will the study results be summarized? How will the results be calculated (i.e., mean, range, maximum, etc)?

Upon receipt of laboratory results, the data will be evaluated for range. Engineering judgement will be used to provide confidence in the test results.

2) Develop a Decision Rule as an "If..., then..., statement that incorporates the study results (sample concentrations), the criteria for taking action (action levels), and the actions(s) that will be taken under various possible scenarios (removal, remediation, etc). Example: If the mean concentration of a contaminant exceeds the action level for a group of samples, then a corrective action must be initiated.

If a data point does not appear to fall within the range of typical values for soils with similar index properties, then a duplicate test may be performed. If extra sample material is not available or the data point is determined not to be critical, then the data point may be deemed erroneous and not used in modeling activities.

3) Will all the data to be obtained be required for the decision? If not, then define a more narrowly-focused set of analytes and/or characteristics.

All data will be required.

4) Will any other FEMP activities be able to utilize the analytical results to be collected?

Unknown at this time.

DQO LOGIC FLOW WORKSHEET

Step 6: Establish Constraints on the Uncertainty of the Decision

GOAL: To control decision errors, stated as limits on the acceptable probability of making an incorrect decision based on the study findings. These limits on uncertainty may be expressed as acceptable false positive and false negative error rates.

Note: Consult a statistician for definitions and further explanatory information.

1) For the decision to be made, what would define a "false positive" error and what would the consequence(s) be?

Engineering judgement.

2) For the decision to be made, what would define a false negative error and what would the consequence(s) be?

Engineering judgement.

3) Consider the consequences of false positive(s) and/or negative(s) on the following issues and rank in order of importance:

* cost *(N/A)*
* health risks *(N/A)*
* social impacts *(N/A)*
* ecological risks *(N/A)*
* political/credibility *(N/A)*

4) Are the false positive or the false negative errors greater concerns on the above issues?

No difference.

5) Determine if the level of concern for either type of decision error depends on the magnitude of the error. Example: Determine a threshold level where anything above would have an economic effect and anything below would have a health effect.

N/A

6) What is the estimated magnitude of the expected consequences?

N/A

DQO LOGIC FLOW WORKSHEET

7) Decide what magnitude of false positive and false negative errors would be "almost always," "often," "sometimes," and "almost never" acceptable.

N/A

8) What is the statistically acceptable probabilities for the occurrence of each of these errors?

N/A

9) Define a region of statistical indifference which is the area in which the probability of an incorrect outcome is not controlled because, under the stated conditions, either decision is acceptable.

N/A

10) Combine the probability statements into a formal statement of the levels of uncertainty that can be tolerated in the data results.

DQO LOGIC FLOW WORKSHEET

Step 7: Optimize a Design for Obtaining Quality Data

GOAL: The cost design for the study (selected from a group of alternative designs) that is expected to achieve the DQO's.

1) What are the estimated distribution of site-related contaminants of potential concern?

N/A

2) Based on all of the above information and the relative costs of proposed sampling and analysis options, what is the lowest cost sampling and analysis plan that will achieve the desired data and constraints on uncertainty? Consider the following:

a. What is the sample design?

Soil borings as stated in the Work Plan.

b. How many samples will be collected?

As stated in the Work Plan.

c. What level of Quality Assurance is required?

Field and Sampling Activities (Level B)
Lab Analysis (Level B)

d. What are the requirements for precision, accuracy, sensitivity, and completeness?

As stated in SCQ.

DQO LOGIC FLOW WORKSHEET

e. What analytical methods are required?

Grain-Size Analysis: ASTM D422
Moisture Content: ASTM D2216
Atterberg Limits: ASTM D4318
Cohesive Soil Density: ASTM D2937

Cohesionless Soil Density: ASTM D4564
Constant Head Permeability Test for Fine Grain Soils: EPA-9100
Specific Gravity: ASTM D854
Soil Index Properties: Calculated from grain-size analysis, moisture content, and Atterberg limits
Void Ratio: Calculated from soil density
Porosity: Calculated from void ratio
Degree of Saturation: Calculated from moisture content, specific gravity, and void ratio

DQO LOGIC FLOW WORKSHEET

SUMMARY:
(In conjunction with the DQO Summary form)

1) State the analytical support levels (ASLs) required, and briefly explain the rationale behind the choice.

Field and Sampling Activities (Level B)
Lab Analysis (Level B)

2) Identify the analyte(s) of interest.

Grain-size analysis
Soil index properties
Moisture content
Soil density
Atterberg limits
Constant head permeability tests
Specific gravity
Void ratio
Porosity

3) What type and how many field Quality Assurance samples are required?

N/A

4) What type and how many laboratory Quality Control samples are required?

N/A

DQO SUMMARY FORM

1.A. Task/Description: OU #: 5

1.B. Project Phase: (Circle the appropriate selection.)
RI FS RD RA R A OTHER (specify)

1.C DQO No.: _____ DQO Reference No.:

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2. Media Characterization: (Circle the appropriate selection.)

Soil Groundwater Surface Water Sediment Waste
Wastewater Air Biological Other Building Debris (Solids)

---

3. Data Use with Data Quality Level (A-E): (Circle the appropriate Data Use and Data Quality Level selection[s].)

Site Characterization A B C D E Risk Assessment A B C D E
Evaluation of Alternatives A B C D E Engineering Design A B C D E
Monitoring during remediation activities A B C D E
Other A B C D E (Explain) Removal Action

4.A. Regulatory Driver: DOE Order 5400.5 and NRC 1.86

4.B. Objective:

To determine hydraulic conductivity at different points on the site.

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5. Site Information (Description):

Glacial till characterization recommends sampling monitoring wells at selected locations across the site. Information from this task will be used in the CRU-5 RI/FS.

DQO SUMMARY FORM

DQO Number:

6.A. Data Types with appropriate Data Quality Level Equipment Selection and SCQ Reference: (Place an "X" to the right of the appropriate box or boxes selecting the type of analysis or analyses required. Then select the type of equipment to perform the analysis if appropriate. Please include a reference to the SCQ Section.)

1. pH ___
   Temperature ___
   Specific Conductance ___
   Dissolved Oxygen ___

2. Uranium ___
   Full Radiologic ___
   Metals ___
   Cyanide ___
   Silica ___

3. BTX ___
   TPH ___
   Oil/Grease___

4. Cations ___
   Anions ___

5. VOA ___
   ABN ___

6. Other (specify) X
   Grain-size analysis, soil index properties, moisture content, soil density, Atterberg limits, constant head permeability tests, specific gravity, void ratio, and porosity

TOX ___
TOC ___
TCLP ___
CEC ___
COD ___

Pesticides ___
PCB ___

6.B. Equipment Selection and SCQ Reference:

Equipment Selection	Refer to SCQ Section
Level A _____	SCQ Section: _____
_____	
Level B Grain Size Analysis: ASTM D422	SCQ Section: _____
Moisture Content: ASTM D2216	
Atterberg Limits: ASTM D4318	
Cohesive Soil Density: ASTM D2937	

DQO SUMMARY FORM

Cohesionless Soil Density: ASTM D4564

Constant Head Permeability Test: ASTM D2434

Specific Gravity: ASTM D854

Soil Index Properties: Calculated from grain-size analysis, moisture content, and Atterberg limits

Void Ratio: Calculated from soil density

Porosity: Calculated from void ratios

Level C _____ SCQ Section: _____

Level D _____ SCQ Section: _____

Level E _____ SCQ Section: _____

7.A. Sampling Methods and Procedures: (Circle the appropriate selection.)

Environmental Biased Grab Non-intrusive Phased
Source Grid Composite Intrusive

Other (specify): _____

7.B. Sample Work Plan Reference: (List the samples required. Reference the work plan or sampling plan guiding the sampling activity, as appropriate.)

Background samples: N/A

Critical samples: _____

7.C. Sample Collection Procedure Reference: (Please provide a specific reference to the SCQ Section and subsection guiding sampling collection procedures.)

Sample Collection Procedures Reference: Section K

DQO SUMMARY FORM

DQO Number:

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8. Quality Assurance/Control Samples: (Place an "X" to the right of the appropriate selection[s].)

8.A. Field Quality Assurance Samples:

Trip Blanks	___	Container Blanks	___
Field Blanks	___	Duplicate Samples	___
Equipment Rinseate Samples	____	Split Samples	___
Preservative Blanks	___	Spiked Blanks	___

Other (specify) N/A

8.B. Laboratory Quality Control Samples:

Method Blank ___ Matrix Duplicate/Replicate (Matrix Spike Duplicates) ___

Matrix Spike ___ Surrogate Spikes ___

Other (specify) N/A

9. Other: Please provide any other germane information that may impact the data quality or gathering of this particular objective, task, or data use.

N/A

(Geotechnical Lab Analysis)

Analysis	Number of Samples	Sample Container	Holding Times
Shelby/Dennison Tube: Tube: Grain size (hydrometer) Atterberg Limits Lab Density Moisture Content Porosity Void Ratio Specific Gravity Constant Head Permeability (triaxial cell with back pressure)	30 (min.)	Wax sealed, air and moisture proof, Shelby or Dennison tube	6 months
Split Spoon: Grain size (hydrometer)	150 (min.)	Wax sealed, air and moisture proof, 150 ml glass jar	