STANDARD OPERATING PROCEDURES

VOLUME II OF VI
GROUNDWATER

ROCKY FLATS PLANT
ENVIRONMENTAL MONITORING AND ASSESSMENT DIVISION
P.O. Box 464
Golden, CO 80402

February 1991

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STANDARD OPERATING PROCEDURES

VOLUME II OF VI
GROUNDWATER

VOLUME I: FIELD OPERATIONS

ROCKY FLATS PLANT

ENVIRONMENTAL ASSESSMENT AND MONITORING DIVISION

STANDARD OPERATING PROCEDURES

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ROCKY FLATS PLANT

ENVIRONMENTAL ASSESSMENT AND MONITORING DIVISION

STANDARD OPERATING PROCEDURES

VOLUME VI: AIR

TITLE:

WATER LEVEL MEASUREMENTS
IN WELLS AND PIEZOMETERS

Approved By:

J. W. Langman

1.0 TABLE OF CONTENTS

2.0 PURPOSE AND SCOPE

This standard operating procedure (SOP) describes procedures that will be used at Rocky Flats to measure water levels in wells and piezometers at the Rocky Flats Plant (RFP). Water level data can be obtained from wells, piezometers, or from surface water manifestations of the groundwater systems, such as springs, lakes, and streams.

Groundwater level measurements will be recorded to the nearest 0.01 foot, and the accuracy of repeated measurements will be within 0.05 foot. Each well will have a permanent, easily identified measuring point (MP) from which the water level measurement is taken.

This procedure describes various acceptable methods for measuring water levels in wells and piezometers which will meet regulatory guidelines of accuracy. This procedure is intended to be sufficiently detailed so that conformance will result in reliable data which are collected in a consistent manner.

3.0 RESPONSIBILITIES AND QUALIFICATIONS

All personnel are required to have a complete understanding of the procedures described within this SOP and receive specific training regarding these procedures, as required. For example, personnel who do not have prior experience in the use and calibration of electric sounders will be given oral instructions and field demonstrations on the use of this equipment.

Only qualified personnel will be allowed to perform these procedures. Required qualifications vary depending on the activity to be performed. The subcontractor's project manager will document personnel qualifications related to this procedure in the subcontractor's project QA files.

This procedure describes various acceptable methods for measuring water levels in wells and piezometers which will meet regulatory guidelines of accuracy. This procedure is intended to be sufficiently detailed so that conformance will result in reliable data which are collected in a consistent manner.

4.0 REFERENCES

4.1 SOURCE REFERENCES

The following is a list of references reviewed prior to the writing of this procedure.

A Compendium of Superfund Field Operations Methods. EPA/540/P-87/001. December 1987.

Freeze, R. Allen and John A. Cherry. Groundwater. Prentice-Hall, Inc. Englewood Cliffs, N.J. 1979.

Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA. Interim Final. October, 1988.

National Handbook of Recommended Methods for Water Data Acquisition. Department of the Interior. 1977.

RCRA Facility Investigation Guidance. Interim Final. May 1989.

RCRA Groundwater Monitoring Technical Enforcement Guidance Document. OSWER-9950.1, September, 1986.

The Environmental Survey Manual. DOE/EH-0053. Volumes 1-4. August 1987.

4.2 INTERNAL REFERENCES

Related SOPs cross-referenced by this SOP are:

- SOP 1.3, General Equipment Decontamination
- SOP 2.6, Groundwater Sampling

5.0 METHODS

Field measurements typically include depth to standing water and the total depth of the well. Water level measurements will be recorded to the nearest 0.01 foot as specified by the RCRA Guidance Document. The method will also be adequate to attain an accuracy of 0.05 foot. In addition, the following conditions must be considered in order to obtain acceptably accurate groundwater level measurements:

- A survey mark will be placed on the inner well casing for use as a permanent MP. This will be done by notching the inner well casing with a file.

- Water levels in piezometers will be allowed to stabilize for a minimum of 24 hours after well construction and development, prior to measurement. Water levels require varying time periods to reach static conditions in new wells. Therefore, the date and time of construction will be noted along with the initial water level measurement, and the date and time of the initial water level measurement.

- At the RFP, multiple sampling events of the same well may occasionally occur over only a few days. If some of these wells are slow recharge wells, water levels may not be representative of static conditions. In order to prevent a misinterpretation of static water levels due to this scenario, the date of the last sampling or well purging event will be documented in the water level measurement database.

- Static water levels will be measured with electric sounders. If non-aqueous phase liquids are potentially present, an interface probe will be used.

5.1 SURVEYING THE MEASURING POINT

Each well must have a permanent, easily identified notched MP on the north side of the inner casing from which the depth to water is consistently measured. The MP should be established by a licensed surveyor and typically is located and marked at the top of the inner well casing. The MP should be established in relation to an established benchmark such as those provided by the U.S. Geological Survey and/or a National Geodetic Vertical Datum (NGVD). The survey will also note the well location coordinates and the coordinates of any temporary benchmark.

For comparability, water level measurements must be referenced to the same datum (elevation). The MP is measured in reference to land surface datum (LSD) and is the most convenient place to measure the water level in a well. A MP correction of a water level measurement converts the measurement to a distance above or below land surface at the well.

The MP must be as permanent as possible, clearly defined, marked, and easily located. If at all possible, position the point so that a leveling rod can be set on it directly over the well and the measuring tape can hang freely when it is in contact with the MP.

The reference point (RP) for water level measurements is an arbitrary datum established by a permanent benchmark set on or near the well. It is used to check the measuring point, and its greatest value is in reestablishing a MP if one is destroyed or changed.

5.2 DETERMINATION OF IMMISCIBLE LAYERS

Currently, no known historical evidence exists to indicate that immiscible layers (i.e., dense or light non-aqueous phase liquids) are present in the RFP groundwater. Observations of the tops and bottoms of the water columns in wells have not shown the presence of non-aqueous immiscible phases. However, because the potential may exist for the presence of immiscible organic compounds at some locations, procedures have been established to detect the presence of these compounds and to sample them, if present. The first step in this process is the determination of a positive response using the organic vapor analyzer in the well head, and then the determination of the presence and thickness of any light/dense non-aqueous liquids.

In the areas where a potential may exist for non-aqueous phase organic liquids, this procedure will be implemented along with the measurement of static water elevations in each well prior to each sampling event.

5.2.1 Use of Interface Probe to Detect Immiscible Layers and Measure Static Water Levels

Follow the manufacturer's instructions for utilization of the interface probe. As with other water level measurements, the probe will be sufficiently precise to measure water levels to the nearest 0.01 foot and the accuracy of repeated measurements must agree within 0.05 foot. When lowering the probe, care will be taken to minimize rubbing of the tape against the well casing.

Typically, the interface probe will have differing sound tones or patterns to distinguish between aqueous and non-aqueous organic layers. When measuring the depth to aqueous or non-aqueous phases, results will be recorded to the nearest 0.01 foot. Results will be measured from the appropriate MP on the inner well casing.

Due to the difficulty in decontamination of the interface probe after passing through a non-aqueous organic phase, the interface probe will not be used to measure total depth to the bottom of the well when light non-aqueous phase liquids (LNAPLs) are present. Instead, a steel tape will be utilized. The procedure for use of the steel tape is given in Subsection 5.3.2.

Wells containing LNAPLs will be checked for the presence of dense non-aqueous phase liquids (DNAPLs) by lowering the purge pump to the bottom of the well and collecting the first purge water from the bottom of the well in a 1-liter glass container. The container will be initially checked with an organic vapor analyzer (OVA) for the presence of organic vapors. The liquid in the glass container will be allowed to stand for 15 minutes and visually observed for the presence of separate phases. If no DNAPLs have separated out of the solution after 15 minutes, the well will be presumed free of DNAPLs.

The interface probe will be moved up and down to locate the point where the appropriate indicator tone or sound is reproducible obtained. Measurements from three consecutive readings must not differ more than ± 0.05 foot. The three readings will be taken by two different individuals, with one person typically taking the first and third readings and another individual taking the second reading. An average of the reproducible readings will be utilized for the determination of the water level. Once the water level has been determined and recorded, the probe will be carefully retrieved, to ensure minimal rubbing of the tape against the inside well casing. The probe and cable will be decontaminated between use at each well following procedures given in Section 6.0 and SOP 1.3, General Equipment Decontamination.

If either LNAPLs or dense non-aqueous phase liquids are found to be present, the well will be sampled for these contaminants as described in SOP 2.6, Groundwater Sampling.

5.3 INSTRUMENTS AND ASSOCIATED WATER LEVEL MEASUREMENT TECHNIQUES

Water level measurement instruments are used to determine the water level in boreholes, wells, and other open underground structures. Generally, outside power sources are not required to operate these devices. However, many require that batteries be replaced or recharged periodically. Measurements may be made with a number of different devices and procedures.

Subsection 5.3.1 describes the use of electronic devices in water level measurement. Subsection 5.3.2 describes the use of the steel tape in measuring water levels. Electronic well sounding devices are preferred for use at the RFP. Typically, steel tapes will only be utilized for measuring the depth to the bottom of well when LNAPLs are present. The use of the steel tape in wells containing LNAPLs will help ensure that the interface probe and other electronic water level measuring devices do not become grossly contaminated and will thus aid in the prevention of cross-contamination.

5.3.1 Electric Water Level Sounders

Typically, a solinist water level sounder will be utilized for measuring groundwater levels at the RFP. Before lowering the electric sounding probe into the well, the circuitry can be checked by dipping the probe in water and observing the indicator. Contact with the water surface will be indicated by an audible tone. The probe will be lowered slowly into the well until contact with the water surface is indicated. The electric tape is marked at the MP and partly withdrawn; the distance from the mark to the nearest tape band is measured and added to (or subtracted from) the band reading to obtain the depth to water. Three readings will be taken by two different individuals with one person typically taking the first and third readings and another individual taking the second reading. If the three measurements do not agree within 0.05 foot, continue to measure until the reason for the lack of agreement is determined or until three consecutive readings are shown to agree within 0.05 foot. An average of the reproducible readings will be utilized for the determination of the water level.

Electric sounders are recommended for measuring the depth to water in wells that are being pumped because they generally do not require removal from the well for each reading. However, if oil is present in the well, if water is cascading into the well, or if the water surface exhibits turbulent behavior, measuring water level with the electric sounder may be difficult. Oil not only insulates the contacts of the probe, but the probe will also give an erroneous reading if there is a considerable thickness of oil. As discussed previously, if an LNAPL is present, a steel tape will be utilized for measuring the total depth to the bottom of the well.

When oil is present, it may be necessary to determine the thickness and density of the oil layer before calculating the true water level. Methods for determining the thickness of a floating immiscible layer, including oil, are discussed in Subsection 5.2.1.

5.3.2 Graduated Steel Tape

Graduated steel tapes will normally only be used for determination of the total well depth for wells containing LNAPLs. The graduated steel tape method is considered an accurate method for measuring the water level in nonflowing wells (National Handbook of Recommended Methods for Water Data Acquisition, 1977, pp. 2-8). A slender weight will be attached to the end of the tape to create tautness and to permit some feel for obstructions. The tape will be lowered to the bottom of the well, and the tape read from the MP on the inner well casing.

The tape is read at the point being held at the MP. As an accuracy check, three measurements will be made. If the three measurements do not agree within 0.05 foot, continue to measure until the reason for the lack of agreement is determined or until the results are shown to be within 0.05 foot.

Before and after each well measurement, that part of the tape measure that becomes wetted will be decontaminated. Decontamination procedures are discussed in Section 6.0 of this SOP, Decontamination, and in SOP 1.3, General Equipment Decontamination.

6.0 DECONTAMINATION

Extraneous contaminant materials can be introduced into the water or soil at a site during water level measurements. Trace quantities of contaminant materials thus transported may later be captured in a sample and lead to false positive analytical results and, ultimately, to an incorrect assessment of the contaminant conditions associated with the site. Decontamination procedures for water level measurement equipment and for the personnel who use the equipment are performed for the dual purposes of minimizing cross-contamination and of providing a safe and healthy working environment.

Equipment should be constructed of stainless steel, Teflon®, or other inert materials that have been approved by EG&G. Equipment will be decontaminated after use at a well and prior to use at another well. Procedures for decontamination are set forth in the site-specific health and safety plan and SOP 1.3, General Equipment Decontamination.

7.0 QUALITY ASSURANCE/QUALITY CONTROL

The frequency of measurements depends on the objectives established in the Work Plan or the FSP for a given project and the accuracy desired in measuring changes in water level. The Work Plan or FSP outlines objectives for which water level data will be used, and the frequency of measurements will be guided by the accuracy of changes in water level needed to meet these objectives.

All data will be recorded on a Groundwater Level Measurements/Calculations Form (Form 2.1A) before leaving the well site.

The electronic sounders will be calibrated quarterly by following the manufacturer's instructions or by suspending the sounder and measuring it against a steel tape if no other calibration instructions are supplied. Results will be recorded on the water level measurement form and marked as a calibration measurement.

8.0 DOCUMENTATION

A permanent record of the implementation of this SOP will be kept by documenting field observations and data. Observations and data will be recorded with black waterproof ink onto a Groundwater Level Measurements/Calculations Form.

The following information should be recorded for each observation-well site:

- The RFP Project Number
- The date and time of the water level measurements
- The names of personnel performing the measurements
- The equipment manufacturer, model, and serial number
- The last calibration date and the date due for the next calibration
- The last date the well was sampled or purged
- The name of the QC reviewer and the date of the QC review

Individual measurements are entered onto the Groundwater Level Measurements/Calculations Form as the measurements are performed. The information is recorded as follows:

1. Record well number in the first column.

2. Record the top of the well casing elevation in the second column (TOWC Elevation).

3. Measure and record the depth to water from the measuring point in the third column (DW). The measurement will be taken a total of three times by two different individuals, with one person typically taking the first and third readings and another individual taking the second reading. Measurements from the three readings must agree within 0.05 foot. If the three measurements do not agree within 0.05 foot, continue to measure until the reason for the lack of agreement is determined or until three consecutive readings are shown to agree within 0.05 foot. An average of the reproducible readings will be utilized for the determination of the water level.

4. Calculate and record the groundwater elevation by subtracting the depth to water from the MP from the top of well casing elevation in the fourth column (GW Elevation).

5. In the fifth column record the initials of the individual who checks the calculation done in Step 4.

6. Measure the total depth of the well from the MP and record this value in Column 6 (MTD). The measurement will be taken a total of three times by two different individuals, with one person typically taking the first and third readings and another individual taking the second reading. Measurements from the three readings must agree within 0.05 foot. If the three measurements do not agree within 0.05 foot, continue to measure until the

reason for the lack of agreement is determined or until three consecutive readings are shown to agree within 0.05 foot. An average of the reproducible readings will be utilized for the determination of the water level.

7. In some devices, the length of the probe end may not have been taken into consideration when marking the measuring tape. In this case, the length of the probe end will need to be added to the measured total depth in order to determine the total depth of the well from the MP. Record the length of the probe end in column seven (Probe end).

8. Determine the total depth of the well from the measuring point by adding the length of the probe end to the measured total depth from the MP and record this value in column 8 (TD).

9. In the ninth column, record the initials of the individual who checks the calculation done in Step 8.

10. In the tenth and final column, record weather conditions and comment, on significant features or activities near the well that could affect the water level.

ROCKY FLATS PLANTS

Form 2.1A

ENVIRONMENTAL RESTORATION PROGRAM

GROUND WATER LEVELS

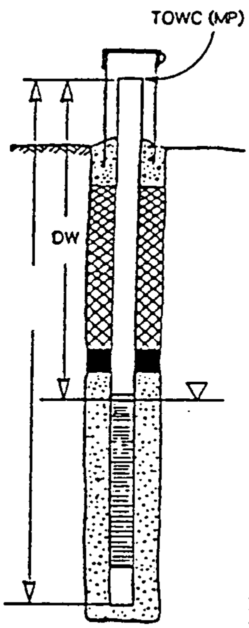
Measurements/Calculations

Rocky Flats Project
Project No. ____________________
Date ____________________
Personnel ____________________
____

EQUIPMENT: Manufacturer __________ Model __________ Serial No.

Calibration: Date Passed ________________ Date Due ________________

QC REVIEW: Name ________________________ Date ________________



Looking West

	(constant) – (meas) = calc				(meas) + (const) = calc				
Well No.	TOWC[a] Elevation	DW[b]	GW Elevation	Chk'd By	MTD[c]	Probe[d] End	TD[e]	Chk'd By	Comments

Footnotes:

a = TOWC = top of well casing
b = DW = depth to water from MP
c = MTD = measured total depth from MP
d = Probe End = length beyond measuring point on probe
e = TD = total depth of well from MP

Notes:

- All measurements are relative to Mark Point (MP) = north side of TOWC.
- QC review by supervisor is a check of reasonableness.
- Elevations are datum mean sea level.

rfp_02

TITLE:
WELL DEVELOPMENT

Approved By: J. A. Langmuir

1.0 TABLE OF CONTENTS

2.0 PURPOSE AND SCOPE

This standard operating procedure (SOP) describes procedures that will be used at the Rocky Flats Plant (RFP) to develop new and redevelop pre-existing monitoring wells.

3.0 RESPONSIBILITIES AND QUALIFICATIONS

All personnel performing this procedure are required to have 40-hour OSHA classroom training which meets Department of Labor regulation 29 CFR 1910.120(e)(3)(i). In addition, all personnel are required to have a complete understanding of the procedures described within this SOP and have received specific training regarding these procedures.

4.0 REFERENCES

4.1 SOURCE REFERENCES

The following is a list of references reviewed prior to the writing of this procedure:

A Compendium of Superfund Field Operations Methods. EPA/540/P-87/001. December 1987.

Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA. Interim Final. October 1988.

RCRA Facility Investigation Guidance. Interim Final. May 1989.

RCRA Groundwater Monitoring Technical Enforcement Guidance Document. EPA. OSWER-9950.1. September 1986.

4.2 INTERNAL REFERENCES

Related SOPs cross-referenced in this SOP are as follows:

- SOP 3.6, Monitoring Well and Piezometer Installation
- SOP 1.3, General Equipment Decontamination
- SOP 1.5, Handling of Purge and Development Water
- SOP 1.15, Use of PIDs and FIDs
- SOP 1.16, Field Radiological Measurements

5.0 PROCEDURES FOR MONITORING WELL DEVELOPMENT AND REDEVELOPMENT

Monitoring well development is the process by which the well drilling fluids and mobile particulates are removed from within and adjacent to the newly installed wells. This process can also be used to remove sediment or other built-up material from an older well. The objective of a completed well development activity is to provide groundwater inflow that is as physically and chemically representative as possible of the aquifer that is open to the piezometer or well.

5.1 MATERIALS AND EQUIPMENT

The following is a list of well development and associated equipment:

- Stainless steel or Teflon® bailer
- Mechanical reel equipped with a stainless steel cable
- Inertial pump
- Water quality test kit (pH, SC, T, and turbidity)
- Wash/Rinse tubs

- Clear plastic sheeting
- Disposable latex or vinyl gloves
- Nonphosphate, lab detergent (e.g., Liquinox)
- Containers for development water (see SOP No. 1.5, Handling of Purge and Development Water)
- Water level probe - sufficiently accurate to measure water levels to the nearest 0.01 foot
- Weighted tape measure - sufficiently accurate to measure depths to the nearest 0.10 foot
- Distilled water
- Field book and field forms
- Health and safety equipment
- Organic vapor detector (OVD)
- Calculator

5.2 PROCEDURES

5.2.1 Well Development Procedures for New Wells

Well development for new wells will be conducted no sooner than 48 hours and no longer than 2 weeks after installation. These new wells will be developed utilizing low-energy methods. The equipment of choice for well development is an inertial pump or bottom discharge/filling bailer. High-energy methods such as submersible pumps, surge blocks, overpumping, backwashing and well jetting will not be used due to the possibility of formation fines clogging the well screen.

All newly installed wells will be checked for the presence of immiscible layers prior to well development. The method for detecting these layers in monitoring wells is discussed in

SOP 2.1, Water Level Measurements in Wells and Piezometers. If an immiscible layer of 5 mm or greater has been detected in a newly installed well, well development procedures will not continue until the EG&G project manager has been notified. In the case where an immiscible layer is not identified, a water level measurement will be taken according to SOP 2.1, Water Level Measurements, and well development activities will continue. The water level measurement along with the total depth measurement will be used to determine the volume of water in the well casing. Well casing calculations are presented in Subsection 5.2.1.1 of this SOP.

Formation water and fines will be evacuated by slowly lowering and raising the inertial pump or bailer intake throughout the water column. The inertial pump may be placed inside a decontaminated 1-inch diameter PVC pipe if the pump intake cannot be lowered to the bottom of the well. The PVC pipe will prevent the inertial pump intake from bending prior to reaching the desired depth. EG&G will determine whether an inertial pump will be dedicated to a specific well based on verified organic vapor detector (OVD) readings obtained during the drilling of the well. OVD readings are described in SOP 1.5, Photoionization Detectors (PIDs) and Flame Ionizing Detectors (FIDs). If a bailer is used for well development, it will be used with a mechanical reel equipped with a stainless steel cable. Development equipment will be protected from the ground surface with clear plastic sheeting. Development equipment, including bailers and pumps, will be decontaminated before well development begins and between well sites according to SOP 1.3, General Equipment Decontamination.

Estimated recharge rates will be measured following the procedures outlined in SOP 2.1, Water Level Measurements in Well and Piezometers. Decontamination and development water will be handled according to SOP 1.7., Handling of Decontamination Water and Wash Water, and SOP 1.5, Handling of Purge and Development Water, respectively.

5.2.1.1 Development Criteria for New Wells

Development shall proceed in the manner described herein and continue until the following are met:

- Removal of a minimum of five well casing volumes. Typical well casing volume calculations include:

  a. 2-inch diameter well:
  0.16 gal/ft x ___(linear ft of water) = gallons of water

  b. 4-inch diameter well:
  0.65 gal/ft x ___ (linear ft of water) = gallons of water

  c. 6-inch diameter well:
  1.5 gal/ft x ___ (linear ft of water) = gallons of water

  Graduated containers will be used to measure the amount of water removed.

- Three consecutive well casing volume readings of pH, temperature, and specific conductance are recorded (i.e., consecutive temperatures that are within 1°C, and pH readings that are within 0.2 units) and consecutive conductivity readings fall within 10 percent of each other. The calibration and use of these field instruments is described in SOP 2.5, Measurement of Groundwater Field Parameters.

- The goal of monitoring turbidity is to obtain water with formation turbidity units (FTU) within 10 percent of each other for three consecutive readings. These readings should also be without a downward trend.

- If water is used during monitoring well drilling, the total fluid added will be calculated, and five times the fluid lost in the borehole during drilling will be recovered in addition to the five well casing volumes.

- The sediment in the well has been completely removed. One week after initial development, the well will be checked for the accumulation of additional sediment. Any additional sediment will be removed at the time of measurement.

- In low-yielding water-bearing formations, distilled water may be introduced into the well to facilitate development. The amount of distilled water must be recovered from the well within 8 hours or 3 times the amount prior to ceasing development activities.

5.2.2 Redevelopment of Pre-existing Wells

The pre-existing monitoring wells will be redeveloped in a manner similar to the well development for new wells. The equipment and procedures used for redevelopment will also be consistent with the equipment and procedures used for the development of new wells.

5.2.2.1 Redevelopment Criteria for Pre-existing Wells

The criteria to be followed for redevelopment of pre-existing wells will be:

- The removal of sediment inside the well.

- If the accumulated sediments cannot be removed, the goal of redevelopment will be to obtain stable field parameters (i.e., consecutive temperatures that are within 1°C, pH readings within 0.2 units and conductivity) after removing three well casing volumes.

- If the above mentioned results cannot be obtained, five well casing volumes will be removed.

6.0 DOCUMENTATION

The following well development information will be recorded on the Well Development and Sampling Form (Form 2.2A) for newly installed wells.

- Well I.D. and location survey coordinates

- Well designation

- Date(s) of well installation

- Date(s) and time of well development

- Static water level from measuring point

- Total depth from measuring point
- Quantity of water used during drilling
- Volume of well casing volume
- Field measurements of pH, specific conductance (SC), turbidity, DO, and temperature, taken in at least half-casing volumes
- Screened interval
- Depth from top of well casing to top of sediment inside well, before and after development
- Physical description of removed water throughout development (color and turbidity)
- Type of pump and/or bailer
- Well stick-up
- Quantity of water removed and time for removal (incremental and total values)

The redevelopment of pre-existing wells will be documented on the Ground Water Re-Development Log Form (Form 2.2B).

WELL DEVELOPMENT AND SAMPLING FORM

Recorder's Name and Title ______

Well ID ______

Survey location coordinates: North ______ East ______

Date this report ______ Date well installation ______ Date well development ______

Well designation: ______

Ground elevation: Est: ______ Survey: ______

Screened interval: ______ Formation: ______

Measuring point (MP): Top of well casing/other: ______ Well stick up: ______

Water level (below MP): Start: ______ End: ______

Well depth (below MP): ______ Water elevation (BGS) ______

Method used to measure water level: ______ Estimated recharge rate: ______

Volume of saturated annulus (assume 30 percent porosity): ______

Volume Calculation: ______

Quantity of water used during drilling: ______

Depth of sediment (below MP): Before: ______ After: ______

Development equipment: ______

Sampling equipment: ______

pH meter No. ______ Calibration: ______

Specific conductance meter No.: ______ Calibration: ______

F.T.U. meter No.: ______ Calibration: ______

Time	Pumping Rate gpm	FTU	pH	Temp. °C	S.C. umhos/cm at °C	Cum. Vol. of H_2O Removed		Physical Description of Water
						Gallons	Casing Vols.	

Comments: ______

______

______

______

______

ROCKY FLATS PLANT
ENVIRONMENTAL RESTORATION
PROGRAM

ROCKY FLATS PLANT
GROUND WATER RE-DEVELOPMENT LOG

Project Name: Ground Water Re-Development
Well I.D. ______
Project No.: 304902 . 1 2 • 0 3 • 0 1
Team Members: ______
QC Review By/Date: ______
Solinst: ______ Serial Number ______ Calibration Date
Date: ______

PURGE METHOD - TYPE USED:
☐ PUMP ☐ PNEUMATIC ☐ PERISTALTIC ☐ INERTIA ☐ OTHER ______
☐ BAILER ☐ TEFLON ☐ STAINLESS ☐ OTHER ______

PURGING REQUIREMENTS & CALCULATIONS - Datum: Top of Well Casing (TOWC)

ID = Well Casing Inside Diameter (inches) = ______
UV = Unit Casing Volume (gal/linear foot) = ______
WD = Depth to Water (feet) = ______
TD = Total Depth (feet) = Measured Total Depth (MTD)+Probe End ______
IC = Initial Water Column (feet) = TD - WD = ______ - ______ = ______
IV = Initial Water Volume (gallons) = UV x IC = ______ x ______ = ______

Checked by: ______

PURGED VOLUMES and RECHARGE

Volume Purged (GAL)	Temp (°C)	Conductance (mS/cm)	pH (SU)	DO (mg/L)	Nitrate (ppm)	Time (24-hour)	Turbidity (FTU)	Water Description (Color, Turbidity, Odor, Oil, etc.)

EQUIPMENT CALIBRATION

Equipment Type	Equipment ID #	Standard Used	Equipment Reading	Temp	Date	Time

FINAL WATER LEVEL MEASUREMENTS FROM MARK ON NORTH SIDE OF INNER CASING

Team Member	Reading	Total Depth	Probe End	Measured Total Depth	Avg. Meas. Total Depth
1	1				
2	2				
1	3				

Signature ______

Signature ______

rlp_1l

COMMENTS

VOLUME 1

VOLUME 2

VOLUME 3

EVALUATION

TITLE:
PUMP-IN BOREHOLE PACKER TESTING

Approved By: J. W. Langman, Jr.

1.0 TABLE OF CONTENTS

LIST OF APPENDIXES

2.0 PURPOSE AND SCOPE

This standard operating procedure (SOP) describes procedures that will be used at the Rocky Flats Plant (RFP) to conduct in situ pump-in borehole hydraulic conductivity tests in uncased portions of boreholes in bedrock, using packers. Various packer testing arrangements can be used for in situ hydraulic conductivity tests in uncased portions of boreholes.

Relatively large-scale, multiple-well, pump-out tests are generally preferred over single-well tests such as slug tests and packer tests for evaluating aquifer characteristics. However, the information obtained using less-costly, single-hole packer tests is frequently useful and cost-effective, particularly in relatively low-permeability formations. A standard operating procedure addendum (SOPA) will describe project-specific testing requirements.

This SOP describes packer testing equipment and procedures and Quality Assurance/Quality Control (QA/QC) that will be used for field data collection and documentation in order to attain acceptable standards of accuracy, precision, comparability, representativeness, and completeness.

3.0 PERSONNEL QUALIFICATIONS

Personnel conducting pump-in borehole packer tests will be geologists, geotechnical engineers, or field technicians with an appropriate amount of applicable field experience or on-the-job training under the supervision of another qualified person.

4.0 REFERENCES

4.1 SOURCE REFERENCES

A Compendium of Superfund Field Operations Methods. EPA/540/P-87/001. December 1987.

ASTM D 4630-86. Standard Test Method for Determining Transmissivity and Storativity of Low-Permeability Rocks by In-Situ Measurements Using the Constant Head Injection Test. December 1986.

ASTM D 4631-86. Standard Test Method for Determining Transmissivity and Storativity of Low-Permeability Rocks by In-Situ Measurements Using the Pressure Pulse Technique. December 1986.

Groundwater Monitoring. U.S. DOE, Water and Power Resources Service, 1981.

Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA. Interim Final. October 1988.

RCRA Groundwater Monitoring Technical Enforcement Guidance Document. EPA. OSWER-9950.1. Washington D.C. September 1986.

RCRA Facility Investigation Guidance. Interim Final. May 1989.

4.2 INTERNAL REFERENCES

Related SOPs cross-referenced by this SOP are as follows:

- SOP 3.2, Drilling and Sampling Using Hollow-Stem Auger Techniques

- SOP 3.4, Rotary Drilling and Rock Coring

5.0 EQUIPMENT AND PROCEDURES

A packer test is an in situ test used to measure the apparent hydraulic conductivity of the soil or rock surrounding a borehole by measuring the flow rate of water pumped into or out of a discrete depth interval of the borehole that is isolated by rubberized inflatable packers under known pressures. This SOP addresses "pump-in" tests, in which water is injected into the test interval at constant applied pressure (constant head), or a constant rate of flow, or as a pressure pulse. Packer tests will be conducted in portions of boreholes drilled in bedrock indicated by the Field Sampling Plan (FSP). Water injected into boreholes during packer testing will be RFP potable water or commercially available distilled water. RFP tap water will be used unless the FSP or a SOPA states otherwise. The Quality Assurance Addendum (QAA) will address tap water testing requirements. Single packers, double packers, or straddle packers will be used to isolate a desired length of borehole for testing. Downhole packer test equipment will be decontaminated between boreholes according to SOP 1.3, General Equipment Decontamination.

5.1 EQUIPMENT

Packer tests will be conducted using an arrangement that will satisfy the requirements of the FSP. A straddle packer arrangement can be used to test a segment of a borehole isolated between two packers, or a single packer can be used to test a segment of borehole between the hole bottom and the packer. In some cases, for instance when testing very low-permeability formations, a single packer test tool may be modified into a double packer test tool arrangement that has a pressure sensor between the two packers to help detect slow leaks around the packers. This type of double packer test tool arrangement may be further expanded and modified into a straddle packer test tool that has two packers positioned above and two packers below the test interval.

The packers will be of a diameter compatible with the borehole diameter so the test zone can be properly isolated (i.e., sealed off from other depth intervals in the boring). Electronic pressure transducers with an accuracy of ± 0.1 pounds per square inch (psi) or better will be placed above, below, and within the test zone to monitor test pressures and to check for proper sealing of the packers. The transducers will be attached to electronic data logging equipment capable of monitoring and recording pressure versus time. Example schematic diagrams of packer tests set-ups are included in Appendixes A and B.

Because of fluctuations in pressure that can occur using conventional pumping equipment, the surface equipment used for water injection will consist of a water supply reservoir pressurized with compressed gas (nitrogen or air). The supply reservoir will be attached to the test section with rigid water-tight steel tubing. For relatively high injection rates (greater than approximately 0.5 gallon per minute [gpm]), the change in water level in the reservoir will be used to calculate flow quantity by means of a graduated transparent tube in parallel with the reservoir tank. For low injection rates, a variable-area flow meter system capable of measuring flow rates as low as 0.001 gpm will be used. To cover the range in flow rates between 0.5 and 0.001 gpm, the flow meter system will consist of at least three individual flow meters in a common manifold system with appropriate by-pass and shut-off valves, so flow may be switched from one meter to another during a test, if necessary. The diameters of the pressure tank and flow meters will provide for overlap in the measurement ranges of the equipment. The reservoir and flow tanks will be connected by water-tight steel tubing through the upper packer(s) to allow injection of water into the test interval. A fast-acting, remotely controlled shut-in valve will be placed approximately 2 feet above the upper packer.

If flow rates are high (i.e., if the reservoir empties in less than the 20-minute minimum test duration), an alternative injection system will be required. In this situation, a conventional packer test setup using clean water pumping equipment and a manifold system with an impeller-type flow meter and appropriate flow restriction and by-pass valves will be used. However, there is a potential for large volumes of water injected to alter groundwater chemistry in nearby wells or to influence contaminant plumes. In any case, no more than 50 gallons of water will be injected during a packer test without the approval of the EG&G project hydrogeologist.

5.2 PROCEDURES

Packer tests will be conducted in general accordance with Subsections 6.3 and 6.4 of ASTM D 4630, "Standard Test Method for Determining Transmissivity and Storativity of Low-Permeability Rocks by In-Situ Measurements Using the Constant Head Injection Test," and Subsections 6.3 and 6.4 of ASTM D 4631, "Standard Test Method for Determining Transmissivity and Storativity of Low-Permeability Rocks by In-Situ Measurements Using the Pressure Pulse Technique." These references are presented in Appendixes A and B, respectively. With the exception of the injection pressures, the procedures will be consistent with the referenced sections. Other portions of the referenced methods should be read because they are also applicable and contain useful information, but are not necessarily a requirement of this SOP.

A borehole will be drilled and, if required, prepared so it is suitable for testing. The project data quality objectives and subsurface conditions will dictate appropriate preparation. The objectives of borehole preparation are to provide a borehole that can be sealed with packers, to provide a borehole sidewall with hydraulic properties similar to those of the formation, and to leave water in the borehole similar in physical characteristics to the formation water. Depending on the formation characteristics and drilling methods, borehole preparation activities may consist of flushing and/or purging. Geophysical and caliper borehole logs may be used to select borehole zones for testing and to evaluate whether difficulties seating packers are likely to be encountered. If the borehole is flushed and/or purged, sufficient time will be allowed before testing to allow induced pressures (pressure transients) in the formation to dissipate.

After a suitable borehole has been provided, testing will commence at the intervals predetermined or determined based on information from the geophysical and/or caliper logs. The packers will be inserted at the desired level in the borehole and inflated to seal off the test section. If the borehole is not already filled with water to a level above the upper packer, it will be before the packers are inflated. A packer inflation pressure approximately 200 psi above the maximum anticipated test pressure should be used. However, if there are problems with rupturing packers due to yielding of the rock at this pressure, lower inflation pressures may be used. The probability of leakage will be increased at lower packer inflation pressures.

Once the test is set up as described above, various procedures may be used, depending on project requirements. The three basic types of tests are:

1. Constant head
2. Constant rate of flow
3. Pressure pulse

In general, the constant head and pressure pulse tests are preferred for relatively low-permeability formations while the constant rate of flow test is frequently used for higher flow rates.

5.2.1 Constant Head Test

After the packers have been set and the test section and supply tube filled with water in a manner such that there is no entrapped air, the downhole valve will be shut and the shut-in test section pressures allowed to dissipate (as determined from the pressure transducer in the test section).

After the shut-in pressure has dissipated and the stabilized pressure recorded, the reservoir pressure will be increased to the desired test pressure and the downhole valve opened. Readings of flow rate versus time will be obtained while the pressure (head) is maintained at approximately a constant value. A record of pressure versus time for each of the three pressure transducers will also be kept. Injection of water into the test section will continue at a constant head until the flow rate stabilizes, or a minimum of 20 minutes. Conditions will be considered stabilized when at least 3 consecutive five-minute flow readings do not vary by more than 10 percent. Test durations will frequently be 30 to 60 minutes. However, durations of as long as 4 to 6 hours may sometimes be required for conditions to stabilize. If test durations longer than 60 minutes occur regularly on a project, the EG&G project hydrogeologist should evaluate the cost-effectiveness of the testing program and modify it if warranted. If either of the pressure transducers above and below the test section show a rapid pressure response to a pressure increase in the test section, the packers will be reseated to eliminate leakage around them. The test interval depth will have to be modified if the packers cannot be properly seated at the original target depth. The EG&G project manager will be involved in determining any offset test intervals unless the offset is small.

The project-specific test program may require several increasing pressure increments for "stepped" tests. After each increment, the downhole valve will be shut in and the test section shut-in pressure allowed to dissipate. The maximum injection pressure at the test section must not exceed the effective overburden pressure at the test section to avoid hydraulic fracturing. Hydraulic fracturing will normally be avoided if the total hydraulic pressure in the test section does not exceed 0.5 psi per foot depth to the center of the test section. Since the head of the column of water in the tubing is approximately 0.43 psi per foot ($[62.4\ lb/ft^2/ft\ depth]/[144\ in^2/ft^2] = 0.43 lb/in^2/ft$ depth), this means the sum of the reservoir head above the ground surface and the pneumatic pressure applied to the reservoir should not exceed 0.07 psi per foot of depth to the test section. In other words, 0.5 psi/ft depth (total allowable) minus 0.43 psi/ft depth (head in tubing) = 0.07 psi/ft (maximum applied pressure above ground surface).

5.2.2 Constant Rate of Flow Test

The procedures for a constant rate of flow test are essentially the same as for a constant head test except that the injection rate is held constant and readings of pressure versus time are obtained. Injection of water into the test section will continue at a constant rate until the pressure stabilizes, or for a minimum of 20 minutes. Conditions will be considered stabilized when at least 3 consecutive five-minute pressure readings do not vary by more than 10 percent. Test durations will frequently be 30 to 60 minutes. However, durations of as long as 4 to 6 hours may sometimes be required for conditions to stabilize. If test durations longer than 60 minutes occur regularly on a project, the EG&G project hydrogeologist should evaluate the cost-effectiveness of the testing program and modify it if warranted. The automatic data acquisition equipment will record pressure versus time. As for the constant head test, the project-specific test program may require stepped tests provided that the maximum test pressure does not exceed the maximum described in Subsection 5.2.1 to avoid hydraulic fracturing.

If relatively high flow rates (that is, if the reservoir empties in less than the 20-minute minimum test duration) are encountered, it may not be practical to use the pressurized reservoir and downhole pressure transducer test setup described herein. In this case, testing will use a more conventional packer test setup consisting of pumping equipment and a manifold system with an impeller-type flow meter and appropriate flow restriction and bypass valves. If the transducer in the test section is ineffective due to turbulence, a pressure gauge on the manifold system may be used. Testing with this equipment may also follow the constant head test procedure; however, in either case, it may be difficult to accurately control flow rates and pressures.

5.2.3 Pressure Pulse Test

Borehole preparation and packer placement will be the same as described in Subsection 5.2.1. The pressure pulse test can use the same test setup as described for the constant head test, provided the downhole shut-in valve can be opened and closed rapidly. Alternatively, the downhole shut-in valve may be replaced with a fast-acting valve between the pressure source and water supply tube. Similarly, the pressure transducer in the test section may be relocated to the water-supply line at the top of the borehole between the fast-acting valve and the test section (see Figure 2 in ASTM D 4631).

Once the packers are in place, the water supply tubing will be rapidly pressurized and then shut in by opening and closing the fast-acting valve. The resulting pressure pulse and decay transient will be recorded by the electronic data logging equipment starting at the time the valve is closed. The transducers above and below the test section will also be read to check for leaks around the packers. If leakage occurs, the packers will be reseated to eliminate leakage around them. The test depth interval will have to be modified if the packers cannot be properly seated at the original target depth. The EG&G project manager will be involved in determining any offset test intervals unless the offset is small.

5.3 METHODS OF ANALYSIS

For each injection test, data analysis will be conducted using a selected analytical procedure appropriate for the hydraulic conditions and estimated flow patterns. The project hydrogeologist responsible for interpreting the test results will select the analytical methods used. The appendixes discuss some available analytical techniques. The methods used may include those presented in the following published literature:

Doe, T. and J. Remer. 1980. "Analysis of constant-head well tests in nonporous fractured rock" Proceedings, 3rd Invitational Well-testing Symposium. University of California. Berkeley. LBL-12076 pp.87-89.

Hsieh, P.A., S.P., Neuman and E.S. Simpson, 1983. "Pressure testing of fractured rocks - a methodology employing three-dimensional cross-hole tests." Department of Hydrology and Water Resources. University of Arizona. NUREG Publication CR-3213.

Hsieh, P.A., S.P. Neuman, G.K. Stiles, and E.S. Simpson. 1985. "Field determination of the three-dimensional hydraulic conductivity tensor of anisotropic media: 2. methodology and application to fractured rocks." Water Resources Research. Volume 21. No. 11. pp. 1667-1676.

Hvorslev, M.J. 1951. Time lag and soil permeability in groundwater observations. Bulletin No. 36. U.S. Army Engineer Waterways Experiment Station. Vicksburg, Mississippi.

Jacob, C.E., and S.W. Lohman. 1952. "Nonsteady flow to a well of constant drawdown in an extensive aquifer." American Geophysical Union Transactions. V. 33. pp. 559-569.

O'Rourke, J.E., Essex, R.J. and Ranson, B.K. 1977. "Field Permeability Test Methods with Applications to Solution Mining." prepared by Woodward-Clyde Consultants for the Bureau of Mines, U.S. Department of Interior. published by the National Technical Information Service. PB-272452. 180 pp.

Zeigler, T.W. 1976. Determination of rock mass permeability. Technical Report S-76-2. U.S. Army Engineer Waterways Experiment Station. Vicksburg, Mississippi.

6.0 DOCUMENTATION

Documentation for this SOP will include a schematic diagram of the test setup. This diagram will show the relative positions of all gauges, valves, transducers, and packer elements within the test tool string. The diagram will accompany the data records for each test. For each type of test, a data form will be developed to record flow/time/pressure data. Form 2.3A is a pump-in borehole packer test summary sheet that will be used to document borehole information and test type. It includes a checklist for required data.

The following information will be documented:

- Project identification
- Date
- Borehole identification/Elevation
- Drilling subcontractor
- Responsible geologist's/engineer's name
- Type of test
- Formation/rock type tested
- Elevations of top and bottom of test section (or depths from reference point of known elevation)
- Description/Elevation of Depth Reference
- Water level in borehole before testing
- Packer inflation pressure

- Shut-in pressure/Stabilized pressure
- Data logger file name for pressure versus time data

The documentation checklist addresses the following:

- Diagram of test tool setup
- Calibration documentation
- Records of pressure and flow rates with time for constant-head and constant rate-of-flow tests (attach to test summary form)
- Pulse pressure and pulse decay time records for pressure pulse tests (attach to test summary)

PUMP-IN BOREHOLE PACKER TEST SUMMARY SHEET

Project No. ________Date ____

Borehole Identification ____

Drilling and/or Packer Testing Subcontractor ____________________________

Geologist/Engineer ____

Type of Test ____

Formation/Rock Type Tested ____

Top and Bottom Depths of Test Interval (below ground level) ____________________

Description/Elevation of Depth Reference ______________________________

Water Level in Borehole Before Testing ______________________________

Packer Inflation Pressure ____

Shut-in Pressure/Stabilized Pressure ____________________________________

Data Logger File Name ____

DOCUMENTATION CHECKLIST

Diagram of test tool setup prepared? (Y/N) by (Contractor's Representative) ______________

Documentation of calibrations received? (Y/N) by (Contractor's Representative) ____________

Documentation of flow meter calibration checks received? (Y/N) by (Contractor's Representative) _____

Documentation of gauge/transducer calibration checks received? (Y/N) by (Contractor's Representative)

____

Pressure versus time data for each gauge/transducer obtained/recorded? (Y/N) by (Contractor's Representative) ____

Flow rate versus time data obtained/recorded? (Y/N) by (Contractor's Representative) __________

COMMENTS:____

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____

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APPENDIX A

STANDARD TEST METHOD FOR DETERMINING TRANSMISSIVITY AND STORATIVITY OF LOW PERMEABILITY ROCKS BY IN-SITU MEASUREMENTS USING THE CONSTANT HEAD INJECTION TEST

Standard Test Method for Determining Transmissivity and Storativity of Low-Permeability Rocks by In-Situ Measurements Using the Constant Head Injection Test[1]

This standard is issued under the fixed designation D 4630; 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 constant head injection.

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 permeability, 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 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 G—dimensionless function.
2.2.4 K—hydraulic conductivity (LT^{-1}).
2.2.5 P—excess test hole pressure ($ML^{-1}T^{-2}$).
2.2.6 Q—excess water flow rate (L^3T^{-1}).
2.2.7 Q_o—maximum excess water flow rate (L^3T^{-1}).
2.2.8 S—storativity (or storage coefficient) (dimensionless).
2.2.9 S_s—specific storage (L^{-1}).
2.2.10 T—transmissivity (L^2T^{-1}).
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 start of test (T).
2.2.18 α—dimensionless parameter.
2.2.19 μ—viscosity of water ($ML^{-1}T^{-1}$).
2.2.20 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.

3.2 The test itself involves rapidly applying a constant pressure to the water in the packed-off interval and tubing string, and recording the resulting changes in water flow rate. The water flow rate is measured by one of a series of flow meters of different sensitivities located at the surface. The initial transient water flow rate is dependent on the transmis-

[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.

Current edition approved Oct. 31, 1986. Published December 1986.

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

sivity and storativity of the rock surrounding the test interval and on the volume of water contained in the packed-off interval and tubing string.

4. Significance and Use

4.1 *Test Method*—The constant pressure injection test method is used to determine the transmissivity and storativity of low-permeability formations surrounding packed-off intervals. Advantages of the method are: (*a*) it avoids the effect of well-bore storage, (*b*) it may be employed over a wide range of rock mass permeabilities, and (*c*) it is considerably shorter in duration than the conventional pump and slug tests used in more permeable rocks.

4.2 *Analysis*—The transient water flow rate data obtained using the suggested test method are evaluated by the curve-matching technique described by Jacob and Lohman (**1**)[2] and extended to analysis of single fractures by Doe *et al.* (**2**). If the water flow rate attains steady state, it may be used to calculate the transmissivity of the test interval (**3**).

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 $\mu m/s$ 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.

[2] The boldface numbers in parentheses refer to the list of references at the end of this standard.

5. Apparatus

NOTE—A schematic of the test equipment is shown in Fig. 1.

5.1 *Source of Constant Pressure*—A pump or pressure intensifier shall be capable of providing an additional amount of water to the water-filled tubing string and packed-off test interval to produce a constant pressure of up to 1 MPA (145 psi) in magnitude, preferably with a rise time of less than 1 % of one half of the flow rate decay ($Q/Q_o = 0.5$).

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 constant pressure to be applied to the packed-off interval and less than the formation fracture pressure at that depth.

5.3 *Pressure Transducers*—The pressure shall be measured as a function of time, with the transducer located in the packed-off test interval. The pressure transducer shall have an accuracy of at least ±3 kPa (±0.4 psi), including errors introduced by the recording system, and a resolution of at least 1 kPa (0.15 psi).

5.4 *Flow Meters*—Suitable flow meters shall be provided for measuring water flow rates in the range from 10^3 cm^3/s to 10^{-3} cm^3/s. Commercially available flow meters are capable of measuring flow rates as low as 10^{-2} cm^3/s with an accuracy of ±1 % and with a resolution of 10^{-5} cm^3/s; these can test permeabilities to 10^{-3} md based on a 10-m packer spacing. Positive displacement flow meters of either the tank type (Haimson and Doe (**4**) or bubble-type (Wilson *et al.* (**3**) are capable of measuring flow rates as low as 10^{-3} cm^3/s; these can test permeabilities to 10^{-4} md based on a 10-m packer spacing.

5.5 *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 constant pressure shall be attached to the steel tubing at the surface. A remotely controlled downhole valve, located in the steel tubing immediately above the upper packer, shall be used for shutting in the test interval and for instantaneous starting of tests.

6. Procedures

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, preferably 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

TABLE 2 Values of G(α) for Values of α Between 10^{-4} and 10^{12} [A]

	10^{-4}	10^{-3}	10^{-2}	10^{-1}	1	10	10^{2}	10^{3}
1	56.9	18.34	6.13	2.249	0.985	0.534	0.346	0.251
2	40.4	13.11	4.47	1.716	0.803	0.461	0.311	0.232
3	33.1	10.79	3.74	1.477	0.719	0.427	0.294	0.222
4	28.7	9.41	3.30	1.333	0.667	0.405	0.283	0.215
5	25.7	8.47	3.00	1.234	0.630	0.389	0.274	0.210
6	23.5	7.77	2.78	1.160	0.602	0.377	0.268	0.206
7	21.8	7.23	2.60	1.103	0.580	0.367	0.263	0.203
8	20.4	6.79	2.46	1.057	0.562	0.359	0.258	0.200
9	19.3	6.43	2.35	1.018	0.547	0.352	0.254	0.198
10	18.3	6.13	2.25	0.985	0.534	0.346	0.251	0.196
	10^{4}	10^{5}	10^{6}	10^{7}	10^{8}	10^{9}	10^{10}	10^{11}
1	0.1964	0.1608	0.1360	0.1177	0.1037	0.0927	0.0838	0.0764
2	0.1841	0.1524	0.1299	0.1131	0.1002	0.0899	0.0814	0.0744
3	0.1777	0.1479	0.1266	0.1106	0.0982	0.0883	0.0801	0.0733
4	0.1733	0.1449	0.1244	0.1089	0.0968	0.0872	0.0792	0.0726
5	0.1701	0.1426	0.1227	0.1076	0.0958	0.0864	0.0785	0.0720
6	0.1675	0.1408	0.1213	0.1066	0.0950	0.0857	0.0779	0.0716
7	0.1654	0.1393	0.1202	0.1057	0.0943	0.0851	0.0774	0.0712
8	0.1636	0.1380	0.1192	0.1049	0.0937	0.0846	0.0770	0.0709
9	0.1621	0.1369	0.1184	0.1043	0.0932	0.0842	0.0767	0.0706
10	0.1608	0.1360	0.1177	0.1037	0.0927	0.0838	0.0764	0.0704

[A] From Jacob and Lohman (1).

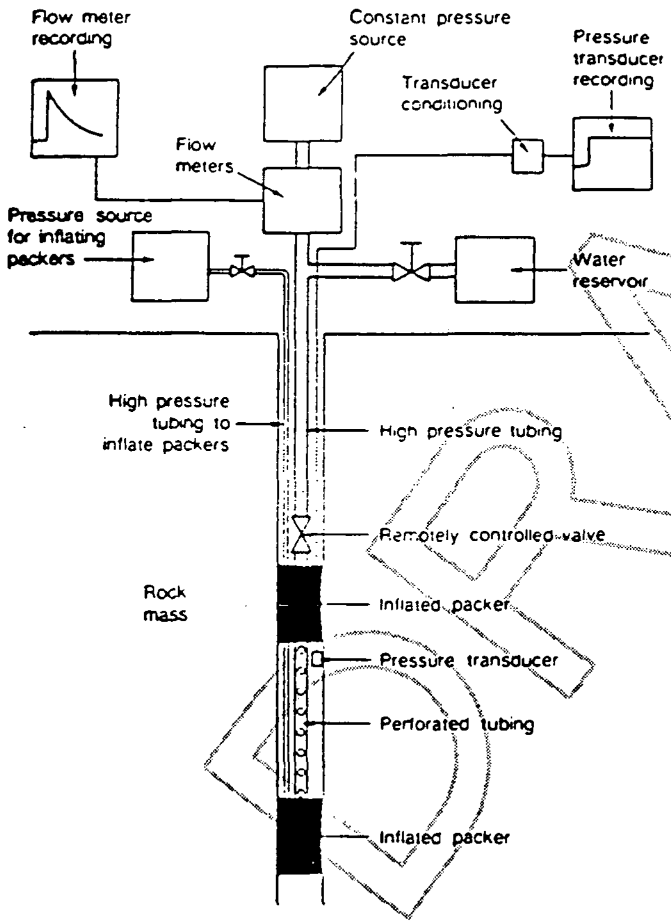

FIG. 1 Equipment Schematic

the zones of potential interest. In particular, run electrical-induction and gamma-gamma density logs. Whenever possible, also use sonic logs and the acoustic televiewer. 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*—Determine test intervals 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 three or more tests in each rock type, if homogeneous. If the rock is not homogeneous, the sets 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*—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. Close the downhole valve to shut in the test interval, and allow the test section pressures (as

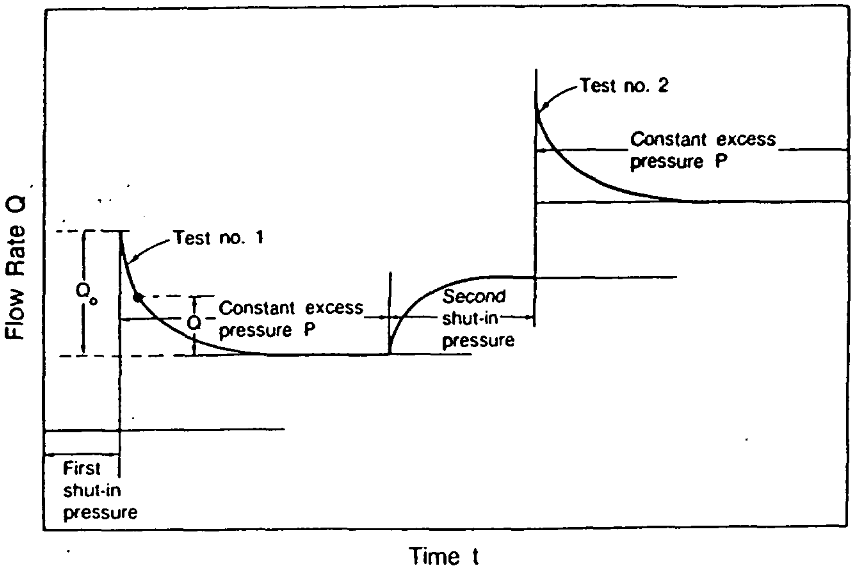

FIG. 2 Typical Flow Rate Record

Data Sheet

Project ____________________
Test Location ____________________
Rock Type ____________________
Date ____________________
Testing by ____________________

Test No. ____________________
Borehole No. ____________________
Borehole Dip and Dip Direction ____________________
Measured Depth of Test to Top Packer, m ____________________
Borehole Diameter, mm ____________________
Rock Temperature, °C ____________________

Equipment Description	Serial No.	Date of last Calibration

Length of Packed-off Interval, m ____________________
Length of Tubing Above Top Packer, m ____________________
Water Temperature, °C ____________________

Packer Pressure, kPa ____________________
Tubing ID, mm ____________________
Shut-in Borehole Pressure, kPa ____________________
Constant Water Pressure, kPa ____________________

FIG. 3 Data Sheet for In Situ Measurement of Transmissivity and Storativity Using the Constant Head Injection Test

determined from downhole pressure transducer reading) to dissipate.

6.4.2 *Constant Pressure Test*—Pressurize the tubing, typically to between 300 and 600 kPa (50 to 100 psi) above the shut-in pressure. This range of pressures is in most cases sufficiently low to minimize distortion of fractures adjacent at the test hole, but in no case should the pressure exceed the minimum principal ground stress. It is necessary to provide sufficient volume of pressurized water to maintain constant pressure during testing. Open the down-hole valve, maintain the constant pressure, and record the water flow rate as a function of time. Then close the down-hole valve and repeat the test for a higher value of constant test pressure. A typical record is shown in Fig. 2.

7. Calculations and Interpretation of Test Data

7.1 The solution of the differential equation for unsteady state flow from a borehole under constant pressure located in an extensive aquifer is given by Jacob and Lohman (**1**) as:[3]

$$Q = 2\pi TP\, G(\alpha)/\rho g, \tag{1}$$

where:

Q = water flow rate,
T = transmissivity of the test interval,
P = excess test hole pressure,
ρ = water density,
g = acceleration due to gravity, and
$G(\alpha)$ = function of the dimensionless parameter α:

$$\alpha = Tt/Sr_w^2 \tag{2}$$

where:

t = time elapsed from start of test,

[3] For bounded aquifers the reader is referred to Hantush (5).

S = storativity, and
r_w = radius of the borehole over the test interval.

7.1.1 In Fig. 2, the flow rate in the shut-in, packed-off interval is considered constant. In those cases where the response of the shut-in interval is time dependent, interpretation of the constant pressure test is unaffected, provided the time dependency is linear.

7.2 To determine the transmissivity, T, and storativity, S, data on the water flow rate at constant pressure as a function of time are plotted in the following manner (**1**).

7.2.1 First, plot a type curve on logarithmic paper of the function $G(\alpha)$ versus α where values of $G(\alpha)$ are given in Table 2.

7.2.2 Second, on transparent logarithmic paper to the same scale, plot values of the flow rate, Q, versus values of time, t.

7.2.3 Then, by placing the experimental data over the theoretical curve, the best fit of the data to the curve can be made.

7.2.4 Determine the values of transmissivity, T, and storativity, S, using Eqs. 1 and 2 from the coordinates of any point in both coordinate systems.

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 constant pressure test program, and the characteristics of 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 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 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 any 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, value of constant pressure transmissivity and storativity, and flow rate as a function of time.

8.1.4.3 *Graphic Data*—Present water flow rate versus time curves for each test, together with the appropriate type curves used for their interpretation.

8.1.4.4 *Other*—Other analyses or presentations may be included as appropriate, for example: (*a*) discussion of the characteristic of the permeable zones, (*b*) histograms of results, and (*c*) comparison of results to other studies or previous work.

8.1.5 *Appended Data*—Include in an appendix a completed data form (Fig. 3) for each test.

9. Precision and Bias

9.1 *Error Estimate:*

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 flow rate determination, measurement of time, and type curve matching.

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 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**) Jacob, C. E., and Lohman, S. W., "Non-Steady Flow to a Well of Constant Drawdown in an Extensive Aquifer," Trans. American Geophys. Union, Vol 33, 1952, pp. 559–569.

(**2**) Doe, T. W., Long, J. C. S., Endo, H. K., and Wilson, C. R., "Approaches to Evaluating the Permeability and Porosity of Fractured Rock Masses," *Proceedings of the 23rd U.S. Symposium on Rock Mechanics*, Berkeley, 1982, pp. 30–38.

(**3**) Wilson, C. R., Doe, T. W., Long, J. C. S., and Witherspoon, P. A., "Permeability Characterization of Nearly Impermeable Rock Masses for Nuclear Waste Repository Siting," *Proceedings*, Workshop on Low Flow, Low Permeability Measurements in Largely Impermeable Rocks, OECD, Paris, 1979, pp. 13–30.

(**4**) Haimson, B. C., and Doe, T. W., "State of Stress, Permeability, and Fractures in the Precambrian Granite of Northern Illinois," *Journal of Geophysics Research*, Vol 88, 1983, pp. 7355–7371.

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Aquifers," *Journal of Geophysics Research*, Vol 64, 1959, pp. 1043–1052.

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(8) Freeze, R. A., and Cherry, J. A., *Groundwater*, Prentice-Hall, Englewood Cliffs, NJ, 1979.

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APPENDIX B

STANDARD TEST METHOD FOR DETERMINING TRANSMISSIVITY AND STORATIVITY OF LOW PERMEABILITY ROCKS BY IN-SITU MEASUREMENTS USING THE PRESSURE PULSE TECHNIQUE

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

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[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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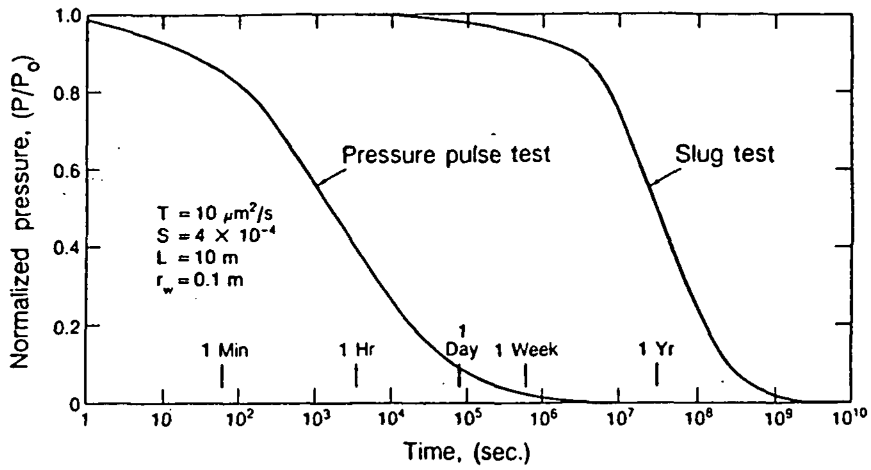

FIG. 1 Comparative Times for Pressure Pulse and Slug Tests

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.

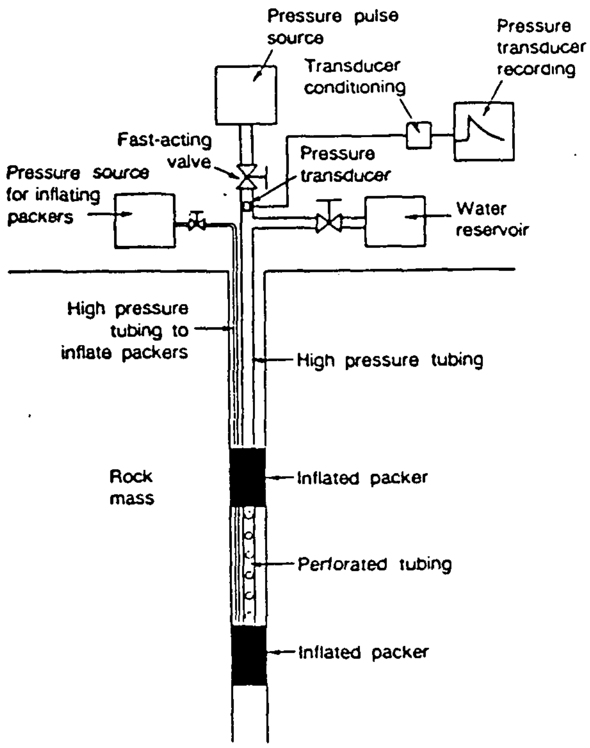

FIG. 2 Schematic of Test Equipment

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:

$$\frac{P}{P_o} = F(\alpha,\beta) \qquad (1)$$

where:

α and β = dimensionless parameters given by:

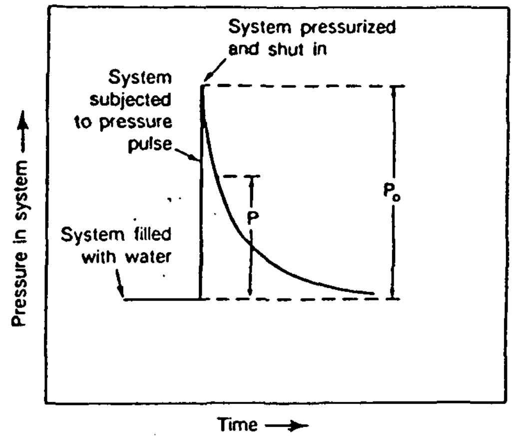

FIG. 3 Typical Pressure Record

$$\alpha = \pi r_w^2 S / V_w C_w \rho g \tag{2}$$

and

$$\beta = \beta T t / V_w C_w \rho g \tag{3}$$

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 $\alpha\beta = \left(\frac{\pi^2 r_w^{\ 2} T S t}{(V_w C_w \rho g)^2}\right)$ 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

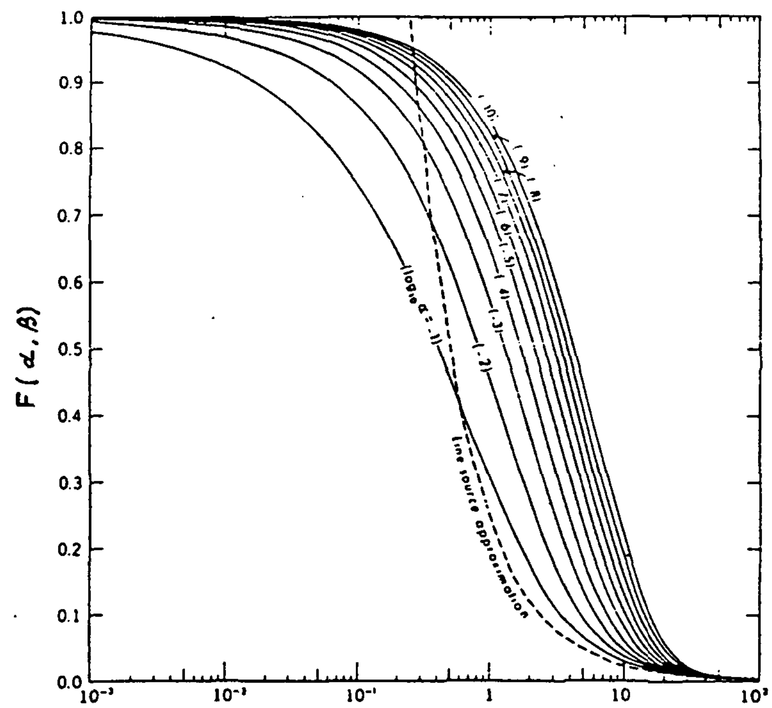

FIG. 4 Type Curves of the Function $F(\alpha, \beta)$ Against the Parameter β for Different Values of α

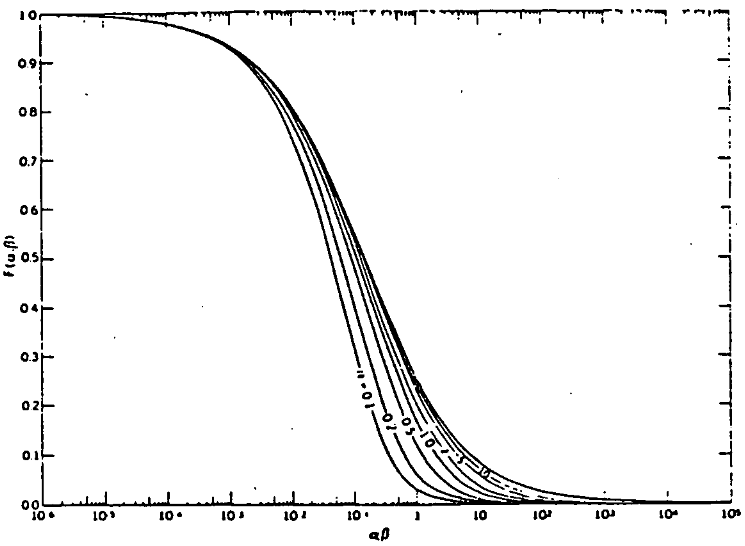

FIG. 5 Type Curves of the Function F(α, β) Against the Product Parameter $\alpha\beta$

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.

REFERENCES

(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.

(2) Wang, J. S. Y., Narasimhan, T. N., Tsang, C. F., and Witherspoon, P. A., "Transient Flow in Tight Fractures," *Proceedings of the 1st Invitational Well Testing Symposium*, Berkeley, 1977, pp. 103–116.

(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.

(5) Papadopulos, S. S., Bredehoeft, J. D., and Cooper, H. H., "On the Analysis of 'Slug Test' Data," *Water Resources Research*, Vol 9, 1973, pp. 1087–1089.

(6) Doe, T. W., Long, J. C. S., Endo, H. K., and Wilson, C. R., "Approaches to Evaluating the Permeability and Porosity of Fractured Rock Masses," *Proceedings of the 23rd U.S. Symposium on Rock Mechanics*, Berkeley, 1982, pp. 30–38.

(7) Earlougher, R. C., "Advances in Well Test Analysis," *Society of Petroleum Engineers of AIME*, New York, NY, 1977.

(8) Freeze, R. A., and Cherry, J. A., *Groundwater*, Prentice-Hall, Englewood Cliffs, NJ, 1979.

(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.

TITLE:
SLUG TESTS

Approved By: J. W. Langman Jr.

1.0 TABLE OF CONTENTS

2.0 PURPOSE AND SCOPE

The purpose of this standard operating procedure (SOP) is to provide the technical guidance and methods for performing slug tests on piezometers at the Rocky Flats Plant (RFP).

The procedures in the following section will be implemented for conducting the slug tests.

3.0 QUALIFICATIONS

Personnel performing slug test procedures will be geologist, hydrologists, hydrogeologists, engineers, or field technicians with an appropriate amount of applicable field experience or on-the-job training under supervision of a qualified person.

4.0 REFERENCES

4.1 SOURCE REFERENCES

The following is a list of references reviewed prior to the writing of this procedure:

Cooper, H.H., Jr., J.D. Bredehoeft, and I.S. Papadopulos, 1967, Response of a Finite Diameter Well to an Instantaneous Change of Water. Water Resources Research, 3(1).

Hazardous Waste Management Practice Site Investigation Baseline Procedures, Woodward-Clyde Consultants, August 1982.

Hvorslev, M.J., 1951, Time Log and Soil Permeability in Groundwater Observations, Bulletin No. 36, Waterways Experiment Station, Corps of Engineers, Vicksburg, Miss.

4.2 INTERNAL REFERENCES

Related SOPs cross-referenced in this SOP are:

- SOP 1.3, General Equipment Decontamination
- SOP 2.1, Water Level Measurements in Wells and Piezometers

5.0 PROCEDURES FOR SLUG INJECTION/WITHDRAWAL TEST

A falling head slug test shall be performed by "instantaneously" introducing a solid slug below the water level into piezometers, or monitoring wells. Slug tests will not be performed simultaneously in adjacent piezometers (i.e., within 50 feet vertically or horizontally).

5.1 PRETEST DATA RECORDING

A Slug Test Data Form (Form 2.4A, see Section 6.0 - Documentation) will be completed prior to conducting each test. The following information will be obtained from existing well logs prior to performance of the slug test and will be recorded on the Slug Test Data Form.

- Casing diameter
- Borehole diameter
- Location of surveyed measuring point
- Total casing depth
- Static water level, Ho (prior to introducing slug)
- Screen depth and interval
- Location of gravel pack
- Lithology of screened interval

For 4-inch diameter wells, a 5-foot-long, 3-inch diameter, stainless steel slug will be used to provide the "instantaneous" head change. For 2-inch diameter wells, a 5-foot-long, 1.5-inch diameter, stainless steel slug will be used.

5.2 FIELD PROCEDURES FOR SLUG INJECTION TEST

An excess head, large enough to provide meaningful data for slug test analysis, will be created in each piezometer or well tested during the slug injection test. Before use at each piezometer, all equipment and cables will be decontaminated according to SOP 1.3, General Equipment Decontamination.

The static water level will be measured in accordance with SOP 2.1, Water Level Measurements in Wells and Piezometers. The measuring point shall be the survey point where the surface elevation was measured, otherwise the point of reference will be the rim of the top of casing. Water levels will be recorded to the nearest 0.01 foot.

The total casing depth will be determined with a weighted measuring tape.

Water levels during the slug test will be measured with the Hermit Environmental Data Logger, Model SE1000B, or a similar measuring device. The operations manual for the measuring device will be available in the field for reference. Using the manufacturer's operation manual, the appropriate transducer probe will be selected for the piezometer or well to be tested.

The transducer probe will be set in the piezometer at the appropriate depth as determined by the sensitivity of the transducer, height of the water column in the well, and length of the slug to be introduced into the piezometer. The probe cable will be secured to the outside of the piezometer casing. Initially, the transducer probe pressure readout (reference level) will be set to zero while the probe is in the water. The depth to water on the data logger from static water level to transducer probe will be checked with the known depth of submergence to verify that the probe is working properly. The probe will then be referenced to appropriate datum. A pre-run checkout test will be performed by setting the data logger to the appropriate parameters (as outlined in the owner's manual), initiating recording of measurements on the data logger, and raising and lowering the transducer probe in the well to simulate water level changes. The measurements of the changing water levels will continue for 10 minutes. The data will then be reviewed to verify that equipment is operating properly.

After completion of the initial pre-run checkout, the solid slug will be lowered into the piezometer so that the bottom of the slug is approximately 2 to 3 feet above the initial static water level.

Immediately prior to introduction of the slug below the water level in the piezometer, water levels will be recorded with the data logger. The slug will then be quickly lowered so that it is positioned 1 to 2 feet below the static water level in the piezometer or well and above the transducer probe. If there is insufficient water in the piezometer or well to allow complete submergence of the slug, the slug will be immersed as fully as possible without disturbing the transducer probe. The transducer probe shall remain stationary during and after the process of lowering the solid slug. The test will continue until water levels return to 10 percent of their static water level or until 48 hours have elapsed.

The water level recording interval will be set to the logarithmic mode. The frequency of measurement will be approximately as follows:

Elapsed Time (after lowering slug)	Log Sample Interval
0-2 sec.	0.2 sec.
2-20 sec.	1.0 sec.
20-120 sec.	5.0 sec.
2-10 min.	3.0 sec.
10-100 min.	2 min.
100-1000 min.	10 min.
1E3-1E4 min.	100 min.

The water level in the piezometer or well will be checked periodically with the water level indicator to verify that the data logger is functioning properly. The test completion time required will depend upon the hydraulic conductivity of the surrounding formation.

If a printer is available, all data generated by the pressure transducer and recorded by the data logger shall be printed out in the field. The printout of the slug test data shall be stapled to the corresponding Slug Test Data Form (Form 2.4A).

Slug tests performed in piezometers or wells that are expected to exhibit slow pressure falloff (as indicated by piezometer development records) will be measured with a water level indicator. Changes in water levels are expected to be slow enough that a sufficient number of water level measurements can be recorded manually using the water level indicator.

5.3 SLUG TEST METHOD OF ANALYSIS

The slug test data will be analyzed using the appropriate analytical method. Methods will include Hvorslev (1951), or Cooper, Bredehoeft, and Papadopulos (1967).

6.0 DOCUMENTATION

Information required by this SOP will be documented on the Slug Test Data Form (Form 2.4A). Borehole dimensions and other information required on this form can be found on applicable borehole log sheets.

Use of field logbooks to supplement the data form documentation is optional. Logbooks may be used to describe field conditions, instrument readings, and other event specific information.

SLUG TEST DATA FORM

Location ______________________
Borehole No. ______________________
Test Date ______________________
Measuring Point ______________________
Type of Test ______________________
Transductor Probe Serial No. __________
Datalogger Test Run No. __________
(include time and date for identification purposes)

Name ______________________
Groundwater Elevation Before Test ______________________
Total Casing Depth ______________________
Borehole Diameter ______________________
Casing Diameter ______________________
Screened Interval ______________________
Sand Pack Interval ______________________

Lithology Tested ______________________

Actual Time	Elapsed Time	Depth to Water from Top of Casing (ft)	H Excess Head (ft)	H/HO

Actual Time	Elapsed Time	Depth to Water from Top of Casing (ft)	H Excess Head (ft)	H/HO

TITLE:
FIELD MEASUREMENT OF
GROUNDWATER FIELD PARAMETERS

Approved By: J. W. Langman

1.0 TABLE OF CONTENTS

LIST OF TABLES

2.0 PURPOSE AND SCOPE

Chemical and physical data collection on location during the sampling of groundwater will supplement analytical data. Data collected in the field will be referred to as field parameters. This standard operating procedure (SOP) describes measurement procedures that will be used for the collection of the following field parameters: pH, specific conductance, dissolved oxygen, temperature, nitrate and N, and turbidity.

The collection frequency of these field parameters specific to individual projects will be detailed in individual field sampling plans. However, some criteria for the collection of field parameters will be consistent for all programs. Those criteria will be described in this SOP.

3.0 RESPONSIBILITIES AND QUALIFICATIONS

All personnel performing these procedures are required to have 40-hour OSHA classroom training which meets Department of Labor Regulation 29 CFR 1910.120(e)(3)(i). In addition, all personnel are required to have a complete understanding of the procedures described within this SOP and receive specific training regarding these procedures if necessary.

4.0 REFERENCES

4.1 SOURCE REFERENCES

The following is a list of references reviewed prior to the writing of this procedure.

A Compendium of Superfund Field Operations Methods. EPA/540/P-87/001.

Data Quality Objective for Remedial Activities Development Process. EPA/540/G-87/003. 1987.

HACH DR/2000 Spectrophotometer Handbook. HACH Company. Loveland, CO 1988.

HACH Water Analysis Handbook. HACH Company. Loveland, CO 1989.

RCRA Groundwater Monitoring Technical Enforcement Guidance Document. EPA,OSWER-9950.1. September 1986.

Standard Methods for the Examination of Water and Wastewater. 16th Edition. Method 212. 1985.

The Environmental Survey Manual. DOE/EH-0053. Appendix E, "Field Protocols and Guidance." 1987.

4.2 INTERNAL REFERENCES

Related SOPs cross-referenced by this SOP are:

- SOP 1.3, General Equipment Decontamination
- SOP 1.7, Handling of Decontamination Wash Water
- SOP 2.6, Groundwater Sampling
- SOP 1.13, Containerizing, Preserving, Handling, and Shipping of Soil and Water Samples

5.0 FIELD MEASUREMENT PROCEDURES

Several of the parameters required to be measured are physically or chemically unstable and must be tested either in the borehole using a probe (in situ) or immediately after collection using a field test kit or instrument (EPA 1986). Examples of unstable parameters include pH, redox potential, dissolved oxygen, and temperature. Although specific conductivity of a substance is relatively stable, it is recommended that this characteristic be measured in the field. Most instruments measuring conductivity require temperature compensation; therefore, the temperature of the samples should be measured at the time conductivity is measured.

The spectrophotometric methodology utilized in this SOP is applicable to a wide range of chemical analyses. Turbidity, nitrate/nitrite, and many other parameters may be measured using this methodology. If analyses not addressed in this SOP are needed, and may be performed using this methodology, they will be added as addenda to this SOP. All field analyses will meet the data quality objectives specified in the subcontractor's Quality Assurance Project Plan (QAPjP).

The standardization/calibration of in situ monitoring equipment or field-test probes and kits will be completed according to the manufacturer's specifications, at the frequency specified in the appropriate work plans or at the minimum frequency specified in Table 2.5-1 of this SOP. Instruments which meet the acceptance criteria specified in Table 2.5-1 or more stringent criteria specified in the work plans are acceptable for use in the field. Instruments not meeting the specified criteria must be calibrated prior to each use, so that the acceptance criteria are met. Samples will be collected for field parameter measurements according to SOP 2.6, Groundwater Sampling.

Solutions used for standardizing, calibrating, or titrating will br checked prior to use in the field to determine if the expiration dates have been exceeded. Any expired solutions will be discarded and replaced with new solutions.

Forms applicable to this SOP are contained in SOP 2.6, Groundwater Sampling.

TABLE 2.5-1
Calibration/Standardization Frequencies and
Minimum Acceptance Criteria for Field Measurements

Parameter	Frequency of stand./calib.	Procedure	Acceptance Criteria
pH	Each well	Calibrate	Standard Value ± 0.2 pH units
Specific Conductance	Each well	Calibrate	Standard Value ± 10%
Temperature	Weekly	Calibrate[a]	± 1.0•C (difference between measured value and NIST calibrated thermometer or thermometer calibrated against an NIST traceable thermometer)
Dissolved Oxygen - Electrode Sensor	Each well	Calibrate	Standard Value ± 10%
Dissolved Oxygen - Photometric Baseline[b]	Each sample	Zero instrument	0.0 mg/l
Total Alkalinity	For each new lot of titrant	Standardize	Standard Value ± 10%
Nitrate/ Nitrite as N Baseline[b]	Each sample	Zero instrument	0.0 mg/L
	Each lot	Determine Reagent	<1.0 mg/l
Blank Value on each new lot of nitraver 5 ampuls	Each lot	Standardize each new lot of nitraver 5 ampuls[c]	Standard Value ± 10%
Turbidity Baseline[b]	Each sample each new lot of calibration reagent	Zero Instrument Check Standard Solution	0 FTUs ± 2 FTUs

[a] Instruments that will be utilized to measure temperature sensitive parameters (pH, specific conductance, and D.O.) will also require weekly calibration or standardization if they are utilized to measure temperature to adjust the associated temperature sensitive parameter value.

Some of these instruments may allow for actual field calibration while others will not be capable of temperature adjustment and may therefore only be standardized. Instruments which allow for actual field calibration will be calibrated weekly. Instruments that do not allow for calibration will be standardized. If the standardization is outside the acceptance limits, the instrument should be returned to the manufacturer for maintenance and repair.

[b] A chemically untreated portion of the sample will be used as a blank to establish a zero level for the parameter prior to measurement of the chemically treated sample.

[c] Follow manufacturer's recommendations for standardizing the reagent lots, to be utilized for field measurements.

5.1 TEMPERATURE

Temperature measurements will be made with a high quality mercury-filled thermometer or thermistor having an analog or digital readout device that has been standardized by comparison with a thermometer calibrated against a National Institute of Standards and Technology (NIST) calibrated thermometer. All temperature measuring devices will be scaled to indicate degrees Celsius in increments of 1°C or less as appropriate to meet data quality objectives. Thermometers will be the Teflon®-coated safety type of thermometer. Glass thermometers will be transported in a protective case to prevent breakage. Field thermometers will also be enclosed in an armored casing to prevent breakage.

Temperature measurements made for the purpose of providing adjustment factors for other field parameters will be conducted simultaneously with those related measurements. Volumes and methods of collection will be determined by the procedural requirements of the primary field measurement taken. Thermometers or thermistors used in the field will be standardized at least weekly against an NIST traceable thermometer. This standardization will be verified daily. Verification will consist of comparing the temperature measured with the field instrument against an NIST traceable thermometer. If the result of calibration verification shows a variance of more than .5 degrees, the variance will be recorded, and the instrument will be calibrated before the next temperature measurement. Thermometers and thermistors that cannot be calibrated within the variance criteria will be replaced. Since the temperature on the HACH pH meter is capable of being calibrated by field personnel, instead of only standardized, the pH meter will be utilized to determine water temperatures in the field unless a standardized mercury thermometer is used.

5.1.1 Temperature Measurement by Thermometer

The following procedure will be used when collecting temperature measurements using a thermometer:

- Sampling personnel will wear chemical-resistant gloves, which will be disposed between sites, when performi field temperature measurements. The Site Health and Safety Plan will be followed at all times.

  - A mercury-filled standardized thermometer will be used.

  - Standardize the thermometer at least weekly to the criteria specified in Table 2.5-1. If the acceptance criteria specified in Table 2.5-1 are not met, replace the thermometer so that the acceptance criteria presented in Table 2.5-1 are met.

  - The thermometer will be inspected before each field trip to ensure that there are neither cracks in the glass nor air spaces or bubbles in the mercury.

  - A portion of well water will be transferred to a beaker previously rinsed with distilled water. The thermometer will be inserted into the sample collection container, and the sample in the container will be swirled. The temperature reading will be taken when the mercury column stabilizes.

  - The temperature measurement will be recorded to the nearest 0.5•C.

  - The thermometer will be decontaminated in accordance with SOP 1.3, General Equipment Decontamination.

  - Liquids and materials from decontamination operations will be handled in accordance with SOP 1.7, Handling of Decontamination Water and Wash Water.

5.1.2 Temperature Measurement by HACH ONE pH Meter

- Sampling personnel will wear chemical-resistant gloves, which will be disposed between sites, when performing field temperature measurements. The Site Health and Safety Plan will be followed at all times.

- Standardize the probe at least weekly to the criteria specified in Table 2.5-1. If the acceptance criteria specified in Table 2.5-1 are not met, calibrate the instrument following the manufacturer's instructions so that the acceptance criteria presented in Table 2.5-1 are met.

- A portion of well water will be transferred to a beaker previously rinsed with distilled water. The probe will be inserted into the sample collection container, and the sample in the container will be swirled. The temperature reading will be taken when the digital readout stabilizes.

- The temperature will be recorded on the field logsheet to the nearest ± 0.1•C.

- The probe will be decontaminated in accordance with SOP 1.3, General Equipment Decontamination.

- Liquids and materials from decontamination operations will be handled in accordance with SOP 1.7, Handling of Decontamination Water and Wash Water.

5.2 DISSOLVED OXYGEN (D.O.) - SPECTROPHOTOMETER

This procedure describes the measurement of D.O. using the High Range D.O. AccuVac Ampul and measuring the color change in a spectrophotometer at 535 nm. The high range D.O. AccuVac Ampul contains a reagent vacuum sealed in a 12-ml ampul. When the ampul is broken open in a sample containing D.O., it forms a yellow color which then turns purple. The method is applicable to D.O. measurements up to 13.0 mg/l O_2. The following method will be used to measure D.O. concentrations in groundwater when using the HACH DR2000 Spectrophotometer:

- Press "445" and then "READ/ENTER" to enter the stored program number for D.O.

- When the display shows "DIAL nm to 535," rotate the wave length dial until the display shows "535 nm."

- Press the "READ/ENTER" key. The display will show "mg/l O_2 HRDO."

- Fill a blank zeroing vial with at least 10 ml of sample, and fill a blue ampul cap with sample.

- Prior to collection of the sample water for D.O. measurement, the sample beaker shall be rinsed with distilled water. Fill a high-range D.O. AccuVac Ampul with sample by holding the ampul with the pointed tip down in a beaker containing 50 to 100 ml of sample and breaking the tip of the ampul with your gloved finger. Be sure to keep the tip of the ampul immersed in the water at all times while the ampul fills completely.

- Immediately after filling and without inverting the ampul, securely place the blue ampul cap that has been filled with the sample over the tip of the AccuVac ampul, and shake the ampul for approximately 30 seconds. Securing the cap is important in order to prevent contamination with atmospheric oxygen. If the seal between the ampul and cap is breached, discard the ampul and start again.

- Press the "SHIFT" and then the "TIMER" keys. A two-minute reaction period will begin in which oxygen, which was degassed during aspiration, is allowed to redissolve and react. Wipe the outside of the ampul with a paper towel to clean off finger prints and any liquid present, and then place the sample ampul into the AccuVac vial adapter. Place the vial adapter containing the sample into the cell holder. The grip tab on the vial adapter is placed to the rear of the cell holder.

- When the timer beeps and the display shows "mg/l O_2 HRDO," remove the adapter from the cell holder and shake the ampul for 30 seconds by continuing to invert the ampul.

- Place the blank in the cell holder and close the lid.

- Press "zero" and the display will show "wait" then "0.0mg/L O_2 HRDO."

- Remove the blank and place the AccuVac vial adapter containing the sample into the cell holder with the grip tab on the vial adapter to the rear of the cell holder.

- Close the lid, and after waiting approximately 30 seconds for the air bubbles to disperse from the light path, press the "READ/ENTER" key.

- Record the displayed result as mg/l of D.O.

5.3 pH

This procedure describes the method to be utilized to measure pH in the field using a HACH ONE (model 43800-00) pH meter. If an instrument other than the HACH ONE pH meter is used, the manufacturer's instructions will be followed for calibration and use. All pH meters used for field measurements will be temperature compensating.

Measurements in the field will be performed in the following manner:

- Meters will be calibrated daily prior to the start of field activities following the manufacturer's instructions. The automatic calibration mode will be used with buffers of pH 7 and pH 4.

- Sampling personnel will wear chemical-resistant gloves, which will be disposed between sites, when performing field pH measurements.

- Before each field activity, the meter will be checked for cracked or fouled electrodes and battery condition in accordance with the manufacturer's recommendations.

- Calibration will be verified immediately before the pH measurement is taken. Verification will consist of recording the instrument reading of a pH 7 standard solution.

- The probe and sample beaker will be thoroughly rinsed with distilled water and the excess water removed.

- The probe will be placed into the beaker containing 100 ml of sample, the dispenser button pressed, and the electrode swirled at a constant rate until the meter reading stabilizes. The stirring rate should be maintained so as to minimize the surface disturbance of the sample.

- The pH will be read and recorded to the nearest ± 0.01 pH unit.

- The probe will be rinsed thoroughly with distilled water and stored in accordance with the manufacturer's recommendations.

- Sampling tools, instruments, and equipment will be protected from sources of contamination before use and will be decontaminated after use as specified in SOP 1.3, General Equipment Decontamination.

- Calibration will be verified at the end of each work day. Verification will consist of recording the instrument reading of a pH 7 standard solution. If the instrument reading varies from the standard by more than ± .2 pH units, the instrument will be checked for a malfunction. If the variance continues for two consecutive days, the frequency of calibration of that instrument will be increased. Calibration will then be performed prior to use at each site.

5.4 SPECIFIC CONDUCTANCE

Conductance is the reciprocal of resistance, and, therefore, is often reported in units of reciprocal ohms or mhos. The international system of units, the siemen (S), will be used to report conductivity for this program. Most waters have a specific conductance much less than 1 siemen; therefore, data will be reported in microsiemens (μS)/cm. Measurements should be made prior to conducting the pH measurement sequence.

This procedure describes the method to be utilized to measure specific conductance in the field using a HACH Conductivity/TDS Meter (model 44600). If an instrument other than the HACH meter is used, the manufacturer's instructions will be followed for calibration and use. All conductivity meters used for field measurements will be temperature compensating. This will allow for the recording of specific conductance measurements directly from the meter. All conductivities will also have adjustable readings which will allow for accurate calibration to a known standard.

The following method will be used to measure specific conductance in the field using the HACH conductivity meter:

- The meter will be calibrated at the start of each day prior to any field activities. Calibration will be performed according to manufacturer's instructions and the guidance given in Table 2.5-1. All three instrument ranges will be calibrated with one standard solution. A solution of 1.99 mS/cm NaCl is preferred.

- Before each field activity, the meter will be checked for damage to the probe and for weak batteries in accordance with manufacturer's recommendations.

- Sampling personnel will wear chemical-resistant gloves, which will be disposed between sites, when performing field conductivity measurements.

- The probe and sample beaker will be thoroughly rinsed with distilled water, and excess water will be removed.

- The probe will be immersed in the sample to a depth of at least 1 inch below the surface of the sample. The probe will be agitated vertically to dislodge any trapped air bubbles and to allow the meter reading to stabilize.

- The temperature and the temperature-compensated conductance reading will be recorded on the field form.

- The probe will be thoroughly rinsed with distilled water after use.

- Sampling tools, instruments, and equipment will be protected from sources of contamination before use and will be decontaminated after use as specified in SOP 1.3, General Equipment Decontamination.

- Calibration will be verified at the end of each day. Verification will consist of recording the instrument reading of a standard solution. If the instrument reading varies by more than 10 percent of the standard, the instrument will be checked for malfunction. If the variance continues for two consecutive days, the calibration frequency for that instrument will be increased. Calibration will then be performed prior to each sampling event.

5.5 TOTAL ALKALINITY- ORION TOTAL ALKALINITY TEST KIT

This section describes the procedure that will be utilized to measure total alkalinity in the field using an ORION Total Alkalinity Test Kit and HACH ONE. The ORION test kit includes a reagent composed of several acids and a conversion wheel. After the pH of a solution is recorded, the reagent is added to the solution, and the pH is recorded again. Using the conversion wheel, the pH difference is converted to total alkalinity as ppm $CaCO_3$. The procedure for determining total alkalinity is as follows:

- Sampling personnel will wear chemical-resistant gloves, which will be disposed between sites, when performing total alkalinity measurements.

- The pH meter will be calibrated as described in Subsection 5.3. During the daily calibration of the pH meter, verification of proper alkalinity measurement will be performed following manufacturer's instructions. If the verification measurement varies by more than 10 percent, the reagent and standard will be replaced.

- At the appropriate point during a sampling event, transfer 100 ml of sample into a clean beaker.

- Measure and record the pH of the sample using the HACH ONE pH meter as described in Subsection 5.3.

- Dispense 10 ml of Total Alkalinity Reagent into the sample and stir well using the pH probe.

- Measure and record the resulting pH of the sample as described in Subsection 5.3.

- Using the gray side of the Total Alkalinity Conversion Wheel, find the resulting pH value and record the total alkalinity of the sample.

- If the alkalinity is off scale, the measurement will be repeated using a fresh sample. The sample and reagent volume will be adjusted according to the manufacturer's instructions.

- Upon completion of all alkalinity measurements, the probe will be thoroughly rinsed with distilled water after use.

- Sampling tools, instruments, and equipment will be protected from sources of contamination before use and will be decontaminated after use as specified in SOP 1.3, General Equipment Decontamination.

5.6 NITRATE/NITRITE AS N - CADMIUM REDUCTION SPECTROPHOTOMETRIC METHOD

This procedure describes the measurement of nitrate/nitrite nitrogen using the HACH DR2000 Spectrophotometer and HACH AccuVac Ampuls. The method is a cadmium reduction method in which cadmium metal reduces nitrates present in the sample to nitrite. The nitrite ion reacts in an acidic medium with sulfanilic acid to form an intermediate diazonium salt which couples to gentisic acid to form an amber-colored product which is measured with the spectrophotometer at 500 nanometers. Nitrate/nitrite nitrogen from 0 to 30 mg/l may be measured with this method. Tests with standard solutions and a single operator have yielded a standard deviation of ± 1.0 mg/l nitrate/nitrite nitrogen. The procedure for measuring nitrate/nitrite as N using HACH AccuVac Ampuls is as follows:

- Sampling personnel will wear chemical-resistant gloves, which will be disposed between sites, when performing nitrate/nitrite measurements.

- Press "360" and the "READ/ENTER" key to enter the stored program number for high range nitrate nitrogen AccuVac Ampuls.

- When the display shows "Dial nm to 500," rotate the wave length dial until the display reads "500 mn."

- Press "READ/ENTER."

- After the display reads "mg/l N NO_3 H AV," collect at least 40 ml of sample in a beaker and fill a NitraVer 5 Nitrate AccuVac Ampul with the sample. Fill the ampul by holding the ampul with the pointed tip down into the water sample in the beaker and breaking the tip of the ampul with a gloved finger. Keep the tip immersed until the ampul fills completely.

- Immediately press the "SHIFT" and then the "TIMER" keys. This begins a one-minute mixing period. After pressing the "SHIFT" and "TIMER" keys, invert the ampul repeatedly to mix the sample, until the timer beeps.

- When the timer beeps, press the "SHIFT" and then the "TIMER" keys. This begins a five-minute reaction period. During this reaction period, wipe off liquid or fingerprints on the ampul, place the ampul into the AccuVac Vial Adapter, and place the adapter containing the sample ampul into the cell holder.

- Fill a blank zeroing vial, previously rinsed with distilled water, with at least 10 ml of sample.

- When the timer beeps and the display shows "mg/l N NO_3H AV," remove the sample and place the blank vial into the cell holder.

- Close the lid and press the "CLEAR/ZERO" key. The display will show "Wait" and then "0.0 mg/l N $N0_3$ H AV."

- Remove the blank vial; place the AccuVac vial adapter containing the sample into the cell holder with the grip tab positioned at the rear of the cell holder and close the lid.

- Press the "READ/ENTER" key and record the result displayed as mg/l of nitrate/nitrite as nitrogen.

- A reagent blank value must be determined on each new lot of Nitraver 5 Ampuls. To determine the reagent blank value, repeat the measurement procedure by substituting distilled water as the sample. Repeat the measurement for 3 ampuls from the lot and take the average of the three values as the reagent blank value. Use this value as the reagent blank value for all nitrate/nitrite measurements performed with this lot of Nitraver 5 Ampuls.

- Subtract the value of the reagent blank from the recorded value to obtain the actual (corrected) nitrate/nitrite-nitrogen concentration in mg/l, and record.

5.7 TURBIDITY

This procedure describes the measurement of turbidity using the HACH DR2000 Spectrophotometer absorptometric method. The turbidity test measures an optical property of the water sample which results from the scattering and absorbing of light by the particulate matter present. The amount of turbidity registered is dependent on such variables as the size, shape, and refractive properties of the particles. This procedure is calibrated using formazin turbidity standards, and the readings are in terms of formazin turbidity units (FTU).

- Sampling personnel will wear chemical-resistant gloves, which will be disposed between sites, when performing turbidity measurements.

- Enter the stored program number for turbidity; press "750 Read/Enter." The display will show "Dial nm to 450."

- Rotate the wave length dial until the small display shows "450 nm."

- Press "Read/Enter." The display will show "FTU Turbidity."

- Pour 25 ml of deionized water (blank) into a sample cell.

- Place the blank into the cell holder and close the light shield.
- Press "zero" and the display will show "wait" and then "0 . FTU Turbidity."
- Agitate the sample designated for turbidity measurement so that all sediments are suspended. Pour 25 ml of the sample into another clean sample cell; place into the cell holder and close the light shield.
- Press "Read/Enter" and the display will show "wait" and then the result in FTUs will be displayed.

5.7.1 Accuracy Check: Standard Solution Method

The stored program has been calibrated using a milky white suspension of a polymer called formazin. The turbidity of this stock solution is 400 FTU and it should be prepared monthly. Standard formazin solutions for checking the spectrophotometer accuracy can be prepared as follows:

- Dissolve 1.000 gram of hydrazine sulfate in deionized water and dilute to 100-ml volumetric flask.
- Dissolve 10.00 grams of hexamethylenetetramine in deionized water and dilute to 100-ml volumetric flask.
- Mix 5.0 ml of each solution in a 100-ml volumetric flask and allow to stand undisturbed for 24 hours at 25• ± 3•C.
- Dilute to the 100-ml mark and mix.

6.0 DOCUMENTATION

All records of field measurements will be recorded on the appropriate forms contained in SOP 2.6, Groundwater Sampling.

All instrument calibration/standardization activities will be recorded on a calibration/standardization logsheet or in a bound field notebook specific to each instrument. Records will be maintained in a locked filing cabinet and will be reviewed periodically by the project QA/QC officer.

TITLE:
GROUNDWATER SAMPLING

Approved By: J. W. Langman Jr.

1.0 TABLE OF CONTENTS

LIST OF TABLES

2.0 PURPOSE AND SCOPE

This standard operating procedure (SOP) describes procedures that will be used at the Rocky Flats Plant (RFP) to sample groundwater from monitoring wells. All monitoring wells currently sampled on a quarterly basis and all new wells which will be installed in 1991 will be sampled following these procedures.

This SOP describes equipment decontamination and transport, site preparation, detection and sampling of immiscible layers, water level measurements, well purging, sample collection, field and analytical parameters, quality assurance/quality control (QA/QC) requirements, and documentation that will be used for field data collection.

3.0 RESPONSIBILITIES AND QUALIFICATIONS

All personnel performing these procedures are required to have 40-hour OSHA classroom training which meets Department of Labor regulation 29 CFR 1910.120(e)(3)(i). In addition, all personnel are required to have a complete understanding of the procedures described within this SOP and receive specific training regarding these procedures if necessary.

4.0 REFERENCES

4.1 SOURCE REFERENCES

The following is a list of references reviewed prior to the writing of this procedure.

A Compendium of Superfund Field Operations Methods. EPA/540/P-87/001. 1987.

Data Quality Objectives for Remedial Activities, Development Process. EPA/540/G-87/003. 1987.

Engineering Support Branch Standard Operating Procedures and Quality Assurance Manual. EPA Region IV Environmental Service Division. 1986.

RCRA Ground Water Monitoring Technical Enforcement Guidance Document. OSWER-9950.1. September 1986.

Test Methods for Evaluating Solid Waste, SW-846. Volume II. Field Methods. Second Edition. EPA. 1982.

User's Guide to the Contract Laboratory Program. EPA. December 1988.

4.2 INTERNAL REFERENCES

Related SOPs cross-referenced by this SOP are:

- SOP 1.3, General Equipment Decontamination
- SOP 1.5, Handling of Purge and Development Water
- SOP 1.7, Handling of Decontamination Water and Wash Water
- SOP 1.11, Field Communications
- SOP 1.12, Rocky Flats Plant Access and Control
- SOP 1.13, Containerizing, Preserving, Handling, and Shipping of Soil and Water Samples

- SOP 1.14, Data Base Management
- SOP 2.1, Water Level Measurements in Wells and Piezometers
- SOP 2.2, Well Development
- SOP 2.5, Measurement for Groundwater Field Parameters

5.0 GROUNDWATER SAMPLING PROCEDURES

5.1 INTRODUCTION

All of the alluvial monitoring wells installed on RFP property in 1986 and 1987 were constructed of either 2-inch stainless steel or 4-inch flush threaded PVC. Monitoring wells installed prior to 1986 were constructed mainly of 6-inch PVC. Limited well construction details are available for the pre-1986 wells at RFP. Bedrock wells (post-1985) completed in the weathered zone were built with 4-inch flush threaded PVC. Bedrock wells (post-1985) completed in the unweathered zone were constructed of 2-inch stainless steel or 2-inch flush threaded PVC. The screened interval of all post-1985 alluvial monitoring wells extends from approximately 0.5 foot below the alluvial/bedrock contact to a depth above the estimated highest seasonal water level. The screened interval of post-1985 bedrock monitoring wells is restricted to isolated sandstone lenses. Monitoring wells installed in 1989 were deep bedrock wells and have a 1-foot sump added to the base of the screen.

Procedures for groundwater sampling are designed to obtain a sample that is truly representative of the formation water beneath the site in question. Since an estimate of the quality of formation water is desired, standing water within the well must be purged before sampling. Also, a measure of the static water elevations is important to determine if horizontal and vertical flow gradients change during site characterization activities.

The groundwater sampling procedures can be initiated after taking the required water level measurements (SOP No. 2.1, Water Level Measurements in Wells and Piezometers) and purging the well in accordance with this SOP. Methods for accomplishing each of these activities are included in this SOP in the following sequence:

- Collection of immiscible layers samples, if present
- Well purging
- Groundwater sampling using a bailer
- Groundwater sampling using a peristaltic pump
- Groundwater sampling with a gas-powered piston pump

5.2 GENERAL EQUIPMENT REQUIREMENTS

Downhole sampling equipment will be constructed of inert material such as polytetrafluoroethylene (Teflon®) or stainless steel. This equipment will be assessed on an individual basis prior to use in the field.

The following is a primary list of well sampling and associated equipment:

- Bailers - Teflon®, stainless steel, or other appropriate inert materials

- Teflon® coated stainless steel leaders

- Peristaltic pumps

- Water level measuring devices - sufficiently accurate to measure water levels to the nearest 0.01 foot

- Plastic sheeting
- Distilled water
- Phosphate-free laboratory grade detergent
- Tap water
- Organic vapor detector (OVD)
- Gloves - latex or vinyl
- Calculator
- Containers precleaned to EPA specifications
- Coolers with sufficient blue ice to cool samples to 4^{0}C
- Preservatives (trace metals grade)
- Disposable in-line 0.45-micrometer filters
- Logbooks and field forms
- HACH portable laboratory equipment for measuring field parameters for pH, temperature, specific conductance, dissolved oxygen, total alkalinity, and nitrate

Additional equipment needed to meet the subcontractor's health and safety standards, personnel and equipment decontamination, and any specialized sampling equipment will also be required.

5.3 EQUIPMENT DECONTAMINATION AND TRANSPORTATION

Guidelines presented in SOP 1.3, General Equipment Decontamination, will be followed for decontaminating equipment involved in groundwater sampling operations. Equipment associated with the tasks involved in groundwater sampling will be decontaminated upon arrival at RFP prior to use in the field. At a minimum, all sampling equipment will also be decontaminated between sample locations. If field conditions require more frequent decontamination, the frequency will be increased appropriately.

Transportation of all equipment will be performed in a manner that eliminates any possibility of source or cross-contamination. Calibration fluids, fuel, decontamination, and all other sources of contamination will be segregated from sampling equipment during transport. Purge water being transported to holding areas will be kept in closed containers.

If the decontamination of downhole equipment is not performed at the well, used downhole equipment will be wrapped in plastic sheeting and/or segregated from clean equipment to eliminate the possibility of cross contamination.

5.3.1 Routine Field Decontamination

Decontamination of delicate equipment and the routine decontamination of sampling equipment prior to use at each well will consist of the following steps:

- The equipment will be vigorously hand scrubbed with a solution of a phosphate-free laboratory grade detergent and tap water. Distilled water may be used instead of tap water.

- Rinse with copious amounts of tap water or distilled water by submerging or spraying.

- The equipment will then be triple rinsed thoroughly with approved distilled water.

- If the decontaminated equipment will not immediately be packaged to eliminate any adhesion of airborne impurities, an additional final rinse should be performed immediately prior to actual sampling operations.

5.3.2 Decontamination of Sampling Pumps

The external surfaces of all non-dedicated pumping equipment will be decontaminated as described in Subsection 5.3.1. Internal surfaces will be decontaminated as follows:

- Pump a solution of a phosphate-free laboratory grade detergent and water through the equipment.

- Displace the soap solution immediately by pumping approved distilled water; equivalent to 10 volumes of the pump storage capacity through the equipment.

- If any detergent solution remains in the pump, continue pumping distilled water through the system until the detergent is no longer visibly present. Sudsing will be the common indicator used to determine incomplete rinsing.

5.3.3 Unusual Decontamination Requirements

When equipment becomes grossly contaminated, routine decontamination of sampling equipment is not considered sufficient and thus is not allowed. This situation and other unusual equipment decontamination problems shall be reported to the field site supervisor. The field site supervisor will then consult with EG&G representatives for proper decontamination procedures.

5.3.4 Disposition of Decontamination Water

All water generated during the decontamination of equipment used in contaminated wells will be containerized for transport and discharged at the decontamination pad wastewater holding area. Refer to SOP No. 1.7, Handling of Decontamination Water and Wash Water for the criteria to identify clean and dirty wastewater. Clean water will be discharged on the ground. This discharge will be a minimum of 50 feet from any well and 200 feet from any stream channel. Water will not be allowed to discharge directly into any stream or erosional gully.

5.4 SITE PREPARATION

Sheet plastic will be used to protect clean equipment from contacting contaminated surfaces. Plastic wrapped around the well protective casing and staked on the ground where rope or sampling tools are placed eliminates a substantial amount of possible source contamination. Pickup tailgates, if used as a work area, should also be wrapped in plastic, and this plastic will be changed at each well. Plastic bags and sheeting along with the segregation of clean and dirty equipment will be used to reduce the chances of cross contamination significantly. If a mechanical bailer retrieval system is used the amount of plastic appropriate for protection of sampling equipment may be lessened. The site supervisor will have the responsibility for determining the amount of plastic sheeting required.

Disposable latex or vinyl gloves will be used at all times when handling sampling equipment. Gloves will be changed between each site and as often as necessary to ensure the integrity of clean sampling equipment.

5.5 COLLECTION OF IMMISCIBLE LAYER SAMPLES

When specified in the Field Sampling Plan (FSP) and/or the well to be sampled contains immiscible layers, the immiscible phases must be collected before purging activities begin. The appropriate method for detecting these layers is discussed in SOP No. 2.1, Water Level Measurements in Wells and Piezometers. The method of choice for collecting light phase immiscibles is a bottom valve bailer or peristaltic pump. Dense non-aqueous phase liquids (DNAPL) or "sinkers" will be collected with a bottom double check valve bailer or peristaltic pump.

In all cases, care must be taken to carefully lower the bailer into the well so that agitation of the immiscible layer is minimal. Any bailer used to collect immiscible layers will be dedicated to the well which is sampled. Peristaltic pumps will be equipped entirely with siliceous tubing when sampling immiscible layers. Dedicated equipment used for collecting immiscible layers will be decontaminated prior and after use as described in Subsection 5.3 of this SOP. Immiscible layer sampling will be performed as follows:

- Dedicated bailers will be removed from the well and decontaminated as specified in Subsection 5.3 of this SOP. Dedicated pump tubing if used will also be decontaminated prior to use.

- For light non-aqueous phase liquids (LNAPLs), the bailer will be carefully lowered to the midpoint of the immiscible layer and allowed to fill while it is being held at this level. The bailer must be lowered into the immiscible layer slowly so that minimal agitation of the immiscible layer occurs. Peristaltic pump intakes will also be lowered to the midpoint of the immiscible layer.

If a DNAPL layer is being sampled, either the double check valve bailer or peristaltic pump may be used. The bailer will be lowered into the well until bottom is encountered. Peristaltic pump intakes will also be lowered to the well bottom. Care must be taken not to submerge the pump intake into accumulated sediments.

- At no time should the bailer or line be allowed to touch the ground or come in contact with other physical objects that might introduce contaminants into the well.

- Immediately after sampling is completed, all equipment will be decontaminated. Dedicated bailers will be suspended in the well from the well cap. The bailer will be suspended above the high water level. Siliceous tubing used with peristaltic pumps will be discarded.

5.6 WELL PURGING

Purging stagnant water from a well is required so that the collected sample is representative of the formation groundwater. The device used (bailer or pump) depends upon aquifer properties, individual well construction, and data quality objectives. Wells which contain immiscible layers will not be purged. Any well scheduled for purging and sampling that subsequently has immiscible layers identified must be reported to EG&G. The EG&G project manager will be notified immediately prior to continued activities.

Before obtaining water level elevations or initiation of purge activity, obtain the following information in reference to the well to be sampled:

- Well location
- Diameter(s) of well
- Depth of well
- Screen interval(s)
- Information on waste disposal methods (i.e., acceptable disposal methods, sites, and receptors)

Record the well number site, date, sampling team members, visitors, well condition, and any other pertinent information on the field logsheet, or in the field logbook.

The data collected during instrument calibration will be recorded on the sample collection form or appropriate calibration log in order to document that the calibration was performed in a satisfactory manner. Instruments will be calibrated as described in SOP 2.5, Measurement of Groundwater Field Parameters.

Water level measurements will be collected as specified in SOP No. 2.1, Water Level Measurements in Wells and Piezometers. Measure the depth to the top of the water column in order to determine the height of the water column in the well. Use the total depth obtained during the quarterly water level measurement program. Calculate the well casing volume using the well casing inner diameter and the height of the water column in the well. The formula for calculating the volume in gallons of water in the well casing is as follows:

$(Q\ r^2h)\ 7.481$ = gallons; where Q = 3.142
r = inside radius of the well pipe in feet
h = linear feet of water in well
7.481 = gallons per cubic foot of water

- Calculations of the volume of water in typical well casings may be done as follows:

a. 2" diameter well:

0.16 gal./ft x ____ (linear ft of water) = gallons of water

b. 4" diameter well:

0.65 gal./ft x ____ (linear ft of water) = gallons of water

c. 6" diameter well:

1.5 gal./ft x ____ (linear ft of water) = gallons of water

Wells that are screened across the entire saturated thickness will have casing volumes calculated by multiplying the entire saturated thickness with the appropriate storage capacity factor.

Wells that are screened in a specific interval below the static water level will have two casing volume calculations. The first volume removed will be calculated using entire water column height. All subsequent volumes will be calculated using the screen interval plus 2 feet. Purging duration will be based on recharge rates for the screened interval plus 2 feet.

5.6.1 Purging Duration

Purging will be considered complete if any of the following conditions are met:

(1) At least three casing volumes of water are removed from the well, and the last three pH, specific conductance, and temperature measurements deviate by less than 10 percent. If readings are not stabilized after three volumes, continue purging until stabilization or until five volumes have been removed. Field parameter measurements shall be collected after every half casing volume is removed from the well. When casing volumes are less that 1 liter, parameter measurements will be collected after each whole casing volume is removed. If readings do not stabilize after five well volumes, obtain additional guidance from the project manager concerning the proper course of action.

(2) A well is dewatered when the static water level requires more than thirty minutes to recover to 90 percent of its original level. For wells which are screened in a specific interval below the static water level, the criteria of 90 percent recovery in less than thirty minutes, will apply only to the screened interval plus 2 feet.

The recharge rate during recovery will be calculated linearly by determining the amount of recharge for a minimum of 10 minutes. This will be accomplished by following the procedures outlined in SOP 2.1, Water Level Measurements in Wells and Piezometers, to determine water levels. The linear feet of water in the well will then be divided either by the original saturated thickness or the screened interval plus two feet, as appropriate. This percent of recovery is then multiplied by 3 to determine the recovery rate for 30 minutes. If the value obtained is less than 90 percent of the well's original saturated thickness, prior to the start of purging, then purging will be considered complete.

Wells that dewater (have a slow recharge rate that is less than that specified in (2) above) will not be restricted by parameter stabilization requirements. Sampling of these wells will follow the protocol established in Subsection 5.8.

If a well does not dewater, and the collection method for Volatile Organic Compound (VOC) sample collection is different from the purging method, parameters will be measured from the first water evacuated by the new method after the collection of the VOC sample. If the parameters measured are not within the tolerances allowed, as specified in Item (1) above, the previously collected VOC samples will be discarded, and purging with the new evacuation method will continue until three sets of readings are collected that indicate stabilization of the parameters within the limits specified in item (1), above. The VOC sample will then be collected again followed by the remaining sample suite.

5.6.2 Purging Methods

Wells will be purged by either bailing or pumping. When purging a well, care will be taken to ensure that the rate of water withdrawal during purging never exceeds the rate of withdrawal at which the well was developed. All purge times (initiation and completion) and the rate of purging will be recorded on the field log sheets.

5.6.2.1 Bailing

Generalized procedures for purging a well with a bailer are as follows:

- When purging a well with a bailer, the site will be prepared as discussed in Subsection 5.4. Properly decontaminated equipment will then be used to determine the static water level of the well. If the total depth of the well is not measured during the quarterly water level program, measure the total depth of the well. This information will be used to determine the volume of water in the well casing.

- A 5 foot leader of Teflon® coated stainless steel cable will be attached to the bailer. New rope of polypropylene or other inert material, will be securely tied to the leader. The rope length should be approximately equal to the total depth of the well. If a mechanical reel equipped with a stainless steel cable is used, attach the bailer directly to the cable. The bailer will be slowly lowered into the well until water is encountered. Agitation of the well water will be minimized. Lowering the bailer to the bottom of the well will be avoided so sediments accumulated in the bottom do not become suspended. For wells that dewater, the bailer should not be allowed to strike the well bottom with force. The bailer will be raised either by hand, ensuring that the rope or cable does not come in contact with any potentially contaminated surfaces. The bailer should be raised and lowered slowly to limit surge energy. Also, the rope should not be allowed to drag along the well casing or against other objects that will cause fraying. The discharge rates and the amount of water purged will be monitored.

Wells with significant levels of contamination may have dedicated bailers installed. These wells will be selected by EG&G. Dedicated bailer systems will consist of a Teflon® bailer with check valve and a 5-foot leader of Teflon® coated stainless steel. Bailer sampling attachments and rope or stainless steel reel cable will not be dedicated to individual wells.

Prior to the initiation of purging all dedicated equipment will be decontaminated as described in Subsection 5.3 of this SOP. Dedicated equipment will be decontaminated at the conclusion of sampling activities and suspended from the well cap above the high water table. If the well interval above the high water table is not adequate to allow for storage in the casing, dedicated equipment will be stored in labeled and sealed plastic bags at the equipment trailer.

5.6.2.2 Pumping

Pump designs that meet the following criteria are allowed for purging:

- The pump is constructed of a material that does not introduce a source of contamination to the well.
- The pump drive system does not introduce a source of contamination into the well.
- All downhole parts to the pump can be easily decontaminated.

- A return check system that does not allow pumped water to return to the well is integral in the pump design.

- The pump is easily used and does not require excessive amounts of time to install, use, remove, and decontaminate.

A variety of pumps are currently in use to purge groundwater. These include peristaltic pumps, submersible piston pumps, and inertial pumps. Procedures for the use of each style of pump is specific to its applications. User manuals, which accompany each pump, will be referenced for operating procedures.

Basic operating procedures common to all pumps are as follows:

- Regardless of the type of pump being utilized, the site will be prepared as described in Subsection 5.4. Properly decontaminated equipment will be used to determine the static water level and total depth of the well. This information will be utilized to determine the volume of water in the well casing.

- Decontaminated pumps should be positioned at the top of the water column. As the water column is drawn down, the pump will be lowered an equivalent distance. This method eliminates the stagnation of water above the pump. For wells that historically dewater or in cases where a permanent dedicated pump has been installed, the pump may be positioned near the bottom. The discharge rates and the amount of water purged will be monitored during purging. Pumps will be decontaminated as soon as practical after use following procedures described in Subsection 5.3 of this SOP.

- Tubing, which is used for purging wells, that enters the well casing should be constructed of an inert material. Disposable silicon tubing will be used in the drive mechanism of peristaltic pumps and discarded after each well is purged. The air supply for all air driven pumps will be free of oil (i.e., no hydrocarbon containing substances will be added to the compressor).

5.7 FIELD PARAMETERS

SOP No. 2.5, Measurement for Groundwater Field Parameters, will be followed. The following field parameters will be measured during groundwater sampling:

Parameter	Relative Precision	Minimum Calibration
pH	.01 pH units	Daily
Conductivity	10 uS/cm	Daily
Temperature	.1 degrees C	Weekly
Dissolved Oxygen (D.O.) photometric	.1 mg/l	Each sample
Total Alkalinity unfiltered	1 mg/l	Each well
Nitrate as N photometric	.1 mg/l	Each sample
Turbidity, photometric (FTU)	2 FTU	Each sample

The measuring equipment will be stored and handled in a manner that will maintain the integrity of the equipment. Specific procedures and requirements for calibration and use of measuring equipment are given in SOP No. 2.5, Measurement for Groundwater Field Parameters. Appropriate field manuals will accompany each instrument in the field. Each instrument will also be given an identification number. All logbook and field form references to individual instruments will refer to this number for ease of identification.

Field parameters will be measured at the following intervals:

- Conductivity, pH, temperature, D.O., and turbidity will be measured prior to well purging. This initial bail of water will be carefully removed from the well. This water will be transferred to a sample beaker by decanting the bailer through a bottom control valve. Wells purged with a pump will similarly have the first water removed, and measured for parameters. D.O. will be measured first to limit the sample's exposure time to the atmosphere. Conductivity, pH, and temperature will then be measured.

- During purging operations, conductivity, pH, and temperature will be measured after every half casing volume* of water is removed from the well. Wells that have half volumes less than the volume of a sample bailer will only be measured after every full casing volume of water is removed from the well. D.O. and turbidity will be measured at least once during well purging at the discretion of the sampling crew.

- During purging, if a well is dewatered prior to the measurement of the final required set of parameters, then conductivity, pH, temperature, and turbidity will be measured immediately before the start of sample collection. These parameters may be delayed until sampling is completed if, at the discretion of the sampling crew, the well recharge has provided insufficient water volume to collect all the samples and also measure parameters.

* A half-volume is defined as the volume of one-half the initial well casing water volume, which will be calculated as specified in Subsection 5.6.

- The final D.O. will be measured immediately following volatile sample collection. Water remaining in the bailer after the filling of VOC vials will be transferred to a beaker using the bottom decanting valve. A determined effort will be made to limit this water from agitation and exposure to the atmosphere. If there is insufficient water in the bailer to perform this test, water decanted from the next bailer of water will be used to measure D.O. prior to any sample collection. This parameter may be delayed until sampling is completed if, at the discretion of the sampling crew, the well recharge has provided insufficient water volume to collect all the samples and also measure parameters.

- Whenever a method used to remove well water is changed, a set of field parameters will be recorded from water removed with the new method.

- Nitrate will be measured from purge water generated at wells in the vicinity of the West Spray Field and at other selected sites as determined by the subcontractor's and EG&G's project manager. The water tested will come from the first purge volume. The proper disposal method for the generated purge water will be determined by nitrate measurements taken after each purge volume. If the nitrate measurement is below 7.5 mg/l, then the water will be discharged directly to the ground. If the nitrate measurement is above 7.5 mg/l, then the water will be containerized. After the purging process is completed, any collected purge water will be checked for nitrate. If the measured value is below 10.0 mg/l, then the water will be discharged directly to the ground. However, if the concentration of nitrate is greater than or equal to 10 mg/l, the water will be containerized for transport to the decontamination pad disposal facility.

- Total alkalinity measurements will be collected only once upon completion of purging. For wells that do not dewater and sample collection proceeds to completion immediately after purging, alkalinity will be measured after the completion of all other final purge field parameters. Wells that dewater and require repeated visits for the collection of samples will have alkalinity measured subsequent to the collection of the sample for inorganic water chemistry. Alkalinity will not be measured if sufficient water is not available.

5.8 GROUNDWATER SAMPLING

Techniques used to withdraw groundwater samples from a well will be based on consideration of the parameters of interest. The order of collection, collection techniques, choice of sample containers, preservatives, and equipment are all critical to ensure that samples are not altered or contaminated. The preferred methods for collection of groundwater samples are either bailing and/or the use of bladder pumps.

5.8.1 Sample Collection

The following discussion involves collection of groundwater samples using bailers, and peristaltic or bladder pumps. Regardless of the collection method, care will be taken not to alter the chemical nature of the sample during the collection activity by agitating the sample or allowing prolonged contact with the atmosphere. In order to assist in minimizing the potential for altering the sample and maximizing the available water, the following sample collection sequence is preferred:

- HSL VOC
- Gross Alpha and Beta (filtered)
- $^{233/234}U$, ^{235}U,^{238}U (filtered)
- $^{233/234}U$, ^{235}U,^{238}U
- TSS
- $^{239/240}$Plutonim

- ^{241}Americium
- Metals - TAL, with Cs, Li, Sr, Sn, Mo, Si (filtered)
- TDS, Cl, F, SO_4, CO_3, HCO_3
- Nitrate/Nitrite, as N
- Orthophosphate (filtered)
- Tritium
- $^{89/90}$Strontium (filtered)
- ^{226,228}Radium (filtered)
- ^{137}Cesium (filtered)
- Cyanide
- Radiation Screening

Upon completion of purging, VOC samples will be collected first. Sampling should be done as soon as possible after the well has been evacuated. If VOCs are to be collected by a method other than that used for purging (i.e., displacement or peristaltic pump), then all other samples will be collected prior to removing the pump from the well.

For wells that dewater, the well will be allowed to recover 50 percent of its original volume before the start of sampling. If a well will not recover 50 percent within 24 hours after dewatering, the VOC sample will be collected when a sufficient volume of water has accumulated for VOC sample collection. The calculation for recovery will be performed as described in Subsection 5.6.1. However, 50 percent recovery will be used instead of 90 percent. If a sufficient volume of water for VOC sample collection has still not accumulated within 24 hours after the completion of purging, VOCs will not be collected for that well.

The containers used for sample collection from poor producing wells may differ from those used for high yield wells in some instances due to constraints on obtaining enough sample to fill sample containers. In some instances smaller containers may be utilized, or chemical parameters normally collected in separate containers may be combined into a single container. Well histories can be used to identify which wells may require the modified sample suite. These wells will be sampled for a maximum of 72 hours after the completion of purging, with the exception of VOC sample collection discussed in the previous paragraph. The completion of purging will be considered 0 hour. At the end of 72 hours, partial samples will be measured. Accumulated sample will be compared to the minimum volume requirements identified in Table 2.6-1. If the minimum volume requirement for the target parameter has not been achieved, the partial sample and bottle will be disposed. This volume may be less than the typical volume collected. All parameters which have only minimum samples volumes collected and all uncollected parameters will be documented.

The order of the parameters in this sample hierarchy may be changed at the discretion of the sampling team. Changes in the hierarchy will be based on the predicted number of parameters that will be collected. The sampling team must document their calculations that will substantiate any change in the sample order prior to deviation from this plan.

Sample containers will be stored away from sunlight and will be cooled to 4°C prior to filling. Immediately after collection, samples requiring cooling will be cooled to 4°C. A chilled cooler will be used as the storage container. Whenever a sample bottle which requires chilling is not being physically handled, it will be placed in the cooler to prevent heating or freezing, exposure to sunlight, and possible breakage.

VOC samples will be collected using a bailer equipped with a bottom-decanting control valve. Vials will be filled by dispensing water through the control valve and along the inside edge of the slightly tilted sample vial. Care will be taken to eliminate aeration of the sample water. The vials will be filled beyond capacity so the resulting meniscus will produce an airtight seal when capped. The capped vial will be checked for trapped air by lightly tapping the vial in an inverted position. If air becomes trapped in the vial, the sample water will be discarded, and the vial will be refilled. If two consecutive attempts to fill a VOC vial result in trapped air bubbles, the vial will be discarded.

TABLE 2.6-1
SAMPLE CONTAINERS AND PRESERVATIVES
FOR GROUNDWATER SAMPLES

PARAMETER	MINIMUM CONTAINER[1]	PRESERVATIVE
Radiation Screen	6 oz poly	None
VOC - CLP	2 - 40ml amber glass	Cool to 4^0C
TSS	125 ml poly	
TDS, Cl, F, SO_4, CO_3, HCO_3	1 L poly	Cool to 4^0C
Metals - CLP, with Cs, Li, Sr, Sn, Mo, Si	1 L poly	Filtered, HNO_3 to pH <2, Cool to 4^0C
Orthophosphate	250 ml poly	Filtered, Cool to 4^0 C
Nitrate / Nitrite as N	250 ml poly	H_2SO_4 to pH <2, Cool to 4^0C
Cyanide	1 L poly	Na OH to pH >12, Cool to 4^0C
Gross Alpha / Beta	550 ml poly	HNO_3 to pH <2
$^{233/234}U$, ^{235}U, ^{238}U	100 ml poly	Filtered, HNO_3 to pH <2
$^{239/240}Pu$	1 L poly	HNO_3 to pH <2
^{241}Am	1 L poly	HNO_3 to pH <2
$^{89/90}Sr$	700 ml poly	Filtered, HNO_3 to pH <2
$^{226/228}Ra$	750 ml poly	Filtered, HNO_3 to pH <2
^{137}Cs	2.5 L poly	Filtered, HNO_3 to pH <2
^3H	100 ml glass	Cool to 4^0C

1 The volume listed is the minimum amount required for analysis. Actual sample volumes may be slightly higher and some parameters may be combined in a single container.

VOC vials will never be filled and stored below capacity because of insufficient quantities of water in the bailer. Except for the VOC vials, adequate air space should be left in the bottle to allow for expansion.

Sites will be prepared prior to sampling as described in Subsection 5.4. All necessary and appropriate information will be recorded on the appropriate field forms or in the logbook.

Samples will be placed in the appropriate containers and packed with ice in coolers as soon as practical. Packaging, labeling, and preparation for shipment will follow procedures as specified in SOP No. 1.13, Containerizing, Preserving, Handling, and Shipping of Soil and Water Samples. When sampling is complete, the well cap will be replaced and locked.

Sampling tools, instruments, and equipment will be protected from sources of contamination before use and decontaminated after use as specified in Subsection 5.3. Liquids and materials from decontamination operations will be handled in accordance with SOP No. 1.5, Handling of Purge and Development Water. Sample containers will also be protected from sources of contamination. Sampling personnel will wear chemical-resistant gloves when handling samples. Gloves will be decontaminated or disposed of between well sites.

5.8.1.1 Groundwater Sampling Using a Bailer

This portion of SOP 2.6 describes the use of a bailer for collecting groundwater samples that may be used to obtain physical, chemical, or radiological samples.

A bailer is carefully lowered into the well by means of a new polypropylene rope or other line made of inert material. After filling within the well, the bailer is withdrawn by retrieving the bailer line, and the bailer contents are drained into the appropriate containers. Certain recommendations and/or constraints should be observed when using bailers for sampling groundwater quality monitoring wells:

- Only bottom-filling Teflon® bailers or bailers made of other inert materials will be used.
- Only unused, decontaminated, or dedicated bailer line will be used. A 5-foot leader of Teflon® coated stainless steel cable will be attached to the bailer.
- A reel upon which the bailer line may be wound is helpful in lowering and raising the bailer. It also reduces the chance of contamination.
- Bailers constructed with adhesive joints will not be used.

Lower the bailer slowly to the interval from which the sample is to be collected. A determined effort will be taken to minimize disturbance of the water column when raising and lowering the bailer in order to prevent aeration of the water column. Sample bottles will be filled by allowing the water to flow out the valve in the bottom of the bailer and into and along the side of the sample bottle. Water needed for samples requiring filtration will be collected in a stainless steel container and the water then filtered and containerized.

5.8.1.2 Groundwater Sampling Using a Peristaltic Pump

Use of peristaltic pumps will be limited to collecting sample aliquots for radionuclides, metals, and other species that are not subject to volatilization and degassing. Peristaltic pumps will never be used to collect volatile organics or other volatile species. All downhole tubing will be composed of

Teflon®. Only the portion of tubing which is inserted into the mechanical drive will be made of silica. This drive portion of the tubing will be discarded after each use.

5.8.1.3 Groundwater Sampling Using a ®Bennett Gas-Powered Piston Submersible Pump

The gas-powered piston submersible pump is a portable system for purging wells with water depths up to 250 feet. The system is operated by compressed gas (air or nitrogen) and driven by an air motor. The pump is self-priming, and the gas that drives the pump does not contact the purged water. The pump is constructed from stainless steel and can be decontaminated easily.

The feasibility of using this pump for well purging and sampling will be the responsibility of the site supervisor. The following criteria will be considered when using this pump:

- The compressor used to power the pump will be located a minimum of 15 feet away from the well to eliminate the contamination of equipment with exhaust.
- If the seal located between the motor and the pump is bridged, air will exit through the discharge line. If this problem occurs, pump operations will be stopped and the seals replaced. If the shaft is worn and a proper seal cannot be maintained, the shaft will be replaced.
- Upon completion of purging, the pump will be allowed to continue pumping at a rate no less than .5 liters per minute. Allowing the pump to stop will cause the water trapped in the discharge lines to equilibrate to ambient temperatures. This is not acceptable. During sampling, the pump can be slowed to any rate which allows efficient sampling.

- After completion of sample collection, the pump must be removed to allow for VOC sample collection with a bailer. While retrieving the pump, water used to rinse the lines will not be allowed to trickle into the well.

5.8.2 Sample Filtering and Preservation

Samples for metals, Gross Alpha/Beta, $^{233/234}$Uranium, ^{235}Uranium, ^{238}Uranium, $^{89/90}$Strontium, ^{137}Cesium, ^{226}Radium, and ^{228}Radium will be filtered in the field at the well location during the sampling event through a disposable 0.45-micrometer membrane filter. If a peristaltic or bladder pump is being utilized, a disposable filter may be attached directly to the sample delivery line so that the sample is filtered directly into the sample container as it exits the delivery line. Discharge pressure will be gauged so it does not exceed 50 psi. Alternatively, sample water may be collected in a stainless steel container and filtered with a peristaltic or vacuum pump. Samples to be analyzed for volatile organic species will not be filtered. Before sample collection, 100 to 200 milliliters of sample water will be passed through the filter in order to rinse the filter and filtration apparatus of possible contaminating substances.

Samples requiring filtration will be filtered prior to addition of preservative chemicals. Preservatives will be added to sample bottles prior to the introduction of sample water. The preservative will be added in multiple 5 ml aliquots appropriate to the size of the bottle. One-liter bottles will have 5 ml of sample added prior to sample collection, while 4-liter bottles may have up to 20 ml of acid added. After sample collection has been completed the pH of preserved samples will be checked as follows:

- A small amount of sample will be poured from the sample bottle directly onto approved pH paper. Care will be used so that the threaded neck of the bottle does not contact the pH paper.

- The pH paper will be checked against the supplied color chart. If the appropriate pH has not been achieved, additional preservative will be added to the sample in 5ml aliquots, and the pH test will be repeated.

5.8.3 Sample Screening

A sample for radiation screening will be collected for each well sampled, as specified in Subsection 5.8.1. This sample may be obtained from static well water up to 3 days before the sampling event. If the radiation screen is being collected during the sampling event, it may be obtained from the purge water prior to completion of purging. This sample will be delivered to the EG&G or subcontracted radiation screening laboratory on the day of collection. The sample will be screened for gross alpha, and samples from the corresponding well will be handled according to the levels of radioactivity detected in the sample, as specified in SOP No. 1.13, Containerizing, Preserving, Handling, and Shipping of Soil and Water Samples.

5.8.4 QA/QC SAMPLES

The frequency and types of field QA/QC samples collected during groundwater sampling are described in the Environmental Restoration Quality Assurance Program Plan. This SOP details the applicable criteria for collecting QA/QC samples.

5.8.4.1 Duplicates

Duplicate samples will be collected only from wells that produce enough water to collect two full suites of analytes without dewatering. The wells which produce sufficient water will be incorporated into the sampling program such that the required duplicate frequency can be maintained.

Wells scheduled for duplicate sample collection will be sampled as described in Subsection 5.8 of this SOP. After collection of a complete suite of samples, all downhole equipment will not be decontaminated. Duplicate collection will be performed using the same equipment used for the original sample collection. The duplicate sample suite will be collected in the same order as the original sample suite beginning with VOCs. Additional field parameters will not be measured during duplicate sample collection.

When a pump is being used for sample collection, all samples collected through the pump will be collected first. VOCs, collected using a bailer, will follow. After collection of the original VOC sample, the bailer will be emptied. The bailer will then be lowered into the well and allowed to fill a second time. Water from the second filling will be used for the duplicate VOC sample.

If a well is being used for matrix spike (MS) and matrix spike duplicate (MSD) samples the duplicate will be collected after collection of the MS and MSD.

All duplicate samples will be given a sample number different from the original sample.

5.8.4.2 MATRIX SPIKE AND MATRIX SPIKE DUPLICATE

MS and MSD samples will be collected only from wells that produce enough water to collect the required suites of analytes without dewatering. The site supervisor will assign MS and MSD samples to reflect the different groundwater matrices established by EG&G.

MS and MSD samples will be collected as follows:

- The well will be purged as described in Subsection 5.6 of this SOP.

- After completion of purging, VOC samples will be collected. The original sample will be collected followed by the MS and MSD. These samples will be collected in immediate succession. All D.O. parameter measurements will be taken after filling the last VOC vial.

- The remaining parameters not requiring filtering will be collected. For each sample parameter, the original sample, MS, and MSD will be collected concurrently. The original sample bottle will be filled one-third full followed by the MS and MSD sample bottles which will also be filled one-third full. Each bottle will be rotated in the sequence, filling in one-third full until all three bottles are full. For analytes not requiring a MSD, only the original sample and the MS will be collected.

- After the original sample, MS, and MSD (where appropriate) are collected for one parameter, the process will be repeated for the next parameter.

- Parameters requiring filtering will be collected similarly. When a bailer is used, a stainless steel bucket will be filled with sample water. As samples are collected and the reservoir of water in the bucket is depleted, additional water may be added at the discretion of the sample crew. When a pump is used, the filter will be attached directly to the discharge line. Sample bottles will be filled as described above, partially filling the original sample, MS, and MSD in rotating sequence until each parameter bottle is full.

- Radiochemistry samples may have more than one bottle for each parameter group. In this case, all required bottles will be included in the rotating sequence.

- Field Parameter measurements will not be required for MS and MSD samples.

MS and MSD samples will retain the original sample number. However, a suffix of MS or MSD will be added to the sample number to correspond with each QA/QC sample.

5.8.4.3 Replicates and Splits

Replicate and split samples will be collected in the same manner as described for the MS and MSD. Replicates and splits exceeding three samples will be referred to EG&G for further instructions.

5.8.4.4 Field Equipment Rinses

Field equipment rinses will be collected in a manner designed to reflect sampling techniques. All equipment used during sampling will be rinsed with distilled water. The resulting rinsate will be collected in bottles identical to those used for the original sample.

5.8.4.4.1 Bailed Wells. After completion of sampling, all equipment will be decontaminated. Prior to leaving the well location, the equipment rinse will then be collected as follows:

- The bailer will be filled with distilled water by pouring the water into the top opening. When polypropylene rope is used, the water should be allowed to rinse a short section of clean rope while filling the bailer.

- The rinse water should then be decanted to the VOC vials through the bottom valve. This will be done in the same manner used during sample collection.

- For the remaining unfiltered parameters, the bailer will be filled with distilled water each time additional rinsate is needed. The rinsate will then be transferred to sample bottles in the same manner used during collection.

- Filtered parameters will also be collected in an identical manner to the original samples. The bailer will be filled with distilled water. The rinse water will then be transferred to a stainless steel bucket. The rinse water in the bucket will then be filtered through a new disposable filter.

- Rinse samples will be preserved to the same pH levels as original samples.

5.8.4.4.2 Pumped Wells. Only sampling equipment used during the pumping of wells will be included in the field equipment rinse. VOC rinse samples will be collected using a bailer as described in Subsection 5.8.4.4.1. Distilled water will be pumped from a stainless steel bucket when simulating sampling conditions for all other parameters. These samples will be collected as follows:

- While filling the bucket, distilled water will be poured over the lower section of pump power and discharge lines.

- The volume of stored water in the pump lines will be purged at least once with the rinse water before sample collection.

- Sample bottles will be filled directly from the pump discharge line, simulating actual sampling techniques. Filtered rinsate will be passed through a disposable filter attached directly to the discharge line.

5.8.4.5 Distilled Water Blanks

Distilled water used for the final decontamination of equipment will be transferred directly to sample bottles to determine any baseline contamination they may have introduced into the samples. Five gallon bottles of water will be opened in a controlled area such as the bottle storage room. Distilled water will then be poured directly from the 5-gallon bottle into the appropriate sample bottle. A Teflon®, glass, or stainless steel funnel may be used to help control flows into small mouth bottles. Blank samples will be preserved to the appropriate pH required for each analyte.

5.9 SAMPLE HANDLING AND CONTROL

Pre-cleaned sample containers will be obtained from the contract analytical laboratory. Preserving solution will be added to the bottles by either the laboratory, the sample manager at the sample trailer, or preferably, the sample technician in the field. If preserving solution is added by the sample manager, the sample manager will also label the bottles to indicate the type of sample to be taken.

The sampling containers, preservation requirements, and holding times for the various types of analyses are shown in Table 2.6-1. Additional information on containerizing, preserving, and handling of the water samples is given in SOP 1.13, Containerizing, Preserving, Handling, and Shipping of Soil and Water Samples. Groundwater samples will be properly labelled so that they can be easily identified. The sample numbering system has been assigned by EG&G. Sample identification (ID) numbers will be assigned to each physical sample. The sample ID number will contain the following information as part of a nine to twelve character, alpha-numeric code:

Character(s)	Description	Code
1 and 2	Project ID	GW
3 through 7	Sample Number	00001 to 99999
8 and 9	Subcontractor ID	Alpha (e.g. IT = International Technology Corp.) .
10, 11, and 12	QA/QC	MS for matrix spike, MSD for matrix spike duplicate

Sample numbers will be assigned on a daily basis by the subcontractor's sample manager. Numbers will be assigned consecutively, beginning with 00001. Assignment of sample numbers will be tracked and maintained on the subcontractor's computer at the subcontractor's base laboratory.

6.0 DOCUMENTATION

All field activities will be recorded on Form 2.6A, Field Activity Daily Log, Form 2.6B, Groundwater Sample Collection Log, and Form 2.6C, Well Status Form. Summary information of the days activities or needed information not recorded on the field forms should be recorded in a bound field logbook. Logbooks and field forms will be assigned to field personnel and will remain in their custody during all sampling activities. The cover of each logbook will contain the following information at a minimum:

- Name of the organization to which the book is assigned
- Book number
- Project name
- Start and end dates

Logbook pages will be sequentially numbered before any data recording. All data and information pertinent to field sampling will be recorded in the logbook or on the field forms that identify all required data entries. Enough detail must be included in the documentation to reconstruct the sampling event. Field form entries will include the following minimum information:

- Date and time
- Names of field personnel
- Names of all visitors
- Location of field activities
- Description of sampling sites including weather conditions

- All field observations and comments
- Field parameters
- Sample identification information
- References to all prepared field activity forms and chain-of-custody records

Field logbooks will normally be kept only by the field sampling team leaders and the site supervisor and will be used only to summarize field activities and to document project information not required by the SOP field forms.

Permanent ink will be used for all entries in the logbooks and on the field forms. Mistakes will be crossed out with a single line, initialed, and dated. Unused pages or partial pages will be voided by drawing a line through the blank sections and initialling. Any deviation from this SOP will require documentation in the site supervisor's logbook.

The field activity daily log narrative should create a chronological record of the media team's activities, including the time and location of each activity. Any descriptions of problems encountered, personnel contacted, deviations from the SOP, and visitors on site should also be included. The weather conditions, date, signature of the person responsible for entries, and the number of field activity daily log sheets used to record media team activities for a given day will also be included.

The Groundwater Levels Measurement/Calculations Form (see SOP 2.1, Water Level Measurements in Wells and Piezometers) and the Chain of Custody Record (see SOP 1.13, Containerizing, Preserving, Handling, and Shipping of Soil and Water Supplies) will also be completed for each site. All blank fields on the forms must be completed or voided.

Form 2.6A

U.S. DEPARTMENT OF ENERGY

FIELD ACTIVITY DAILY LOG

DAILY LOG			
DATE			1991
NO.			
SHEET	OF		

ROCKY FLATS PROJECT: Ground Water Sampling Program	PROJECT NO. 304902 .
FIELD ACTIVITY SUBJECT:	
DESCRIPTION OF DAILY ACTIVITIES AND EVENTS:	
VISITORS ON SITE:	CHANGES FROM PLANS AND SPECIFICATIONS, AND OTHER SPECIAL ORDERS AND IMPORTANT DECISIONS.
WEATHER CONDITIONS: (precip.,temp.,clouds)	IMPORTANT TELEPHONE CALLS:
IT TEAM PERSONNEL:	
SIGNATURE OF PREPARER	DATE:

U.S. DEPARTMENT OF ENERGY

ROCKY FLATS PLANT
GROUND WATER SAMPLE COLLECTION LOG

Project Name: Quarterly Ground Water Sampling
Sample No.: GW ___ ___ ___ ___ ___ IT
Project No.: 304902 . ___ . ___ . ___
Well I.D. ___
COC/RFA/ No.: ___
Samples Collected By: ___
COC/RFA No.: ___
Zone: ___ ___
QC Review By/Date: ___
Dates Collected: ___

PURGE METHOD - TYPE USED:

☐ PUMP ☐ PERISTALTIC ☐ OTHER ___

☐ BAILER ☐ TEFLON ☐ OTHER ___

PURGING REQUIREMENTS & CALCULATIONS - Datum: Top of Well Casing (TOWC) **PURGE DATE:** ___

ID = Well Casing Inside Diameter (inches) = ___
UV = Unit Casing Volume (gal/linear foot) = ___
WD = Depth to Water (feet) = ___
TD = Total Depth (feet) = Measured Total Depth (MTD)+Probe End ___
IC = Initial Water Column (feet) = TD - WD = ___ - ___ = ___
IV = Initial Water Volume (gallons) = UV x IC = ___ x ___ = ___
SD = Depth to Top of Screen = ___ - 2ft = ___
Is WD less than SD - 2ft? (Y/N) ___ If Y, then:
AC = Adjusted Water Column(ft) = TD-SD = ___ - ___ = ___
AV = Adjusted Casing Volume(gal) = UVxAC = ___ x ___ = ___
If No, then 3 x IV = 3 x ___ = ___

Checked by: ___

PURGED VOLUMES and RECHARGE

Volume Purged (GAL)	Temp (°C)	Conductance (mS/cm)	pH (SU)	DO (mg/L)	Nitrate (ppm)	Time (24-hour)	Turbidity (FTU)	Water Description (Color, Turbidity, Odor, Oil, etc.)

PURGE VOLUMES & RECHARGE

Actual purged volume (gallons) = ___ Purged dry? (Y/N) = ___
90% of IC = 0.9 x IC(or AC) = 0.9x ___ = ___
10 minute Water Level Recovery: Time Start ___ Time Stop ___
ER = Estimated 30 minute recharge = (TD-10 minute WD)x3=(___ - ___)x3= ___
Depth to water prior to sampling ___ Time ___ Date ___
Depth to water prior to sampling ___ Time ___ Date ___
Depth to water prior to sampling ___ Time ___ Date ___

Checked by: ___