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December 11, 2007

Mr. Aaron Yue
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Subject: Work Plan for East Ravine Groundwater Investigation
PG&E Topock Compressor Station, Needles, California

Dear Mr. Yue

This letter transmits the *Work Plan for East Ravine Groundwater Investigation*. The work plan is submitted in conformance with DTSC's October 29, 2007 letter, and the work plan submittal schedule authorized by your electronic communication with Terri Herson on November 14, 2007.

If you have any questions, please do not hesitate to contact me. I can be reached at (805) 234-2257.

Sincerely,

Yvonne Meeks

Yvonne Meeks
Topock Remediation Project Manager

cc. Chris Guerre/DTSC
Kris Doebbler/DOI

Enclosure

Work Plan for East Ravine Groundwater Investigation

PG&E Topock Compressor Station
Needles, California

Prepared for

California Department of Toxic Substances Control

On Behalf of

Pacific Gas and Electric Company

December 11, 2007

CH2MHILL
155 Grand Avenue, Suite 1000
Oakland, CA 94612

Work Plan for East Ravine Groundwater Investigation

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This work plan was prepared under supervision of a California Certified Engineering Geologist:

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Acronyms and Abbreviations

µg/L	micrograms per liter
AOC	Area of Concern
APE	Area of Potential Effect
ASTM	American Society for Testing and Materials
bgs	below ground surface
BLM	U.S. Bureau of Land Management
BOR	Bureau of Reclamation
Caltrans	California Department of Transportation
CDFG	California Department of Fish and Game
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
CEQA	California Environmental Quality Act
CMT	Continuous Multichannel Tubing
COPC	constituent of potential concern
Cr(T)	total chromium
Cr(VI)	hexavalent chromium
DI	deionized
DTSC	California Department of Toxic Substances Control
EM	electromagnetic (flow logging)
ESA	Endangered Species Act
FCR	field contact representative
HNWR	Havasu National Wildlife Refuge
GMP	Groundwater and Surface Water Monitoring Program
gpm	gallons per minute
IDW	investigation-derived waste
IM	Interim Measure
MW	monitoring well
NHPA	National Historic Preservation Act

NRHP	National Register of Historic Places
OSHA	Occupational Safety and Health Administration
PBA	programmatic biological assessment
PG&E	Pacific Gas and Electric Company
PVC	polyvinyl chloride
RCRA	Resource Conservation and Recovery Act
RFI	RCRA Facility Investigation
RI	Remedial Investigation
ROW	right-of-way
RQD	rock quality designation
SHPO	State Historic Preservation Office
SOP	standard operating procedure
SWFL	southwestern willow flycatcher
USDOI	U.S. Department of the Interior
USFWS	United States Fish and Wildlife Service
VOC	volatile organic compound

1.0 Introduction

Pacific Gas and Electric Company (PG&E) is addressing chromium in groundwater at the Topock Compressor Station near Needles, California, under the oversight of the California Department of Toxic Substances Control (DTSC) and the U.S. Department of the Interior (USDOI). On October 29, 2007, DTSC issued a letter entitled "Workplan for Groundwater Investigation in Area of Concern 10 – East Ravine at Pacific Gas and Electric Company, Topock Compressor Station" to PG&E (DTSC, 2007a). The DTSC letter required that PG&E submit a work plan for conducting a groundwater investigation in the vicinity of Area of Concern (AOC) 10 - East Ravine, and nearby bedrock monitoring well MW-23.

This work plan has been prepared in response to DTSC's October 29 letter and describes the objectives, technical approach and rationale, field investigative methods, administrative approvals, proposed schedule, and reporting plans for this groundwater investigation.

1.1 Project Background

The Topock Compressor Station is located in San Bernardino County, approximately 15 miles to the southeast of Needles, California (Figure 1; all figures are located at the end of this document). Investigative and remedial activities are being performed under the Resource Conservation and Recovery Act (RCRA) Corrective Action process as well as the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) pursuant to agreements with DTSC and USDOI, respectively. Under the terms of these agreements, PG&E is conducting the RCRA facility investigation/remedial investigation (RFI/RI) at the Topock Compressor Station. The purpose of the RFI/RI is to identify and evaluate the nature and extent of hazardous waste and constituent releases at the compressor station. Since 1996, there have been six phases of investigation at the Topock site to collect data to complete the RFI/RI. PG&E is currently planning additional data collection to complete the RFI/RI, including the activities proposed in this work plan. Information obtained through the implementation of this work plan is intended to be combined with the existing dataset and included in the Final RFI/RI report for the site.

As directed by DTSC, the Final RFI/RI for the site is being separated into three volumes, to efficiently manage the large amount of information associated with the RFI/RI, and to accelerate the remediation by allowing earlier remedial planning for those portions of the RFI/RI completed earlier. The *Revised Final RFI/RI Report, Volume 1 – Site Background and History* (CH2M HILL, 2007a) was completed in August 2007 and includes the site background and history of the Topock Compressor Station, including description and background information for the East Ravine and AOC 10. Volumes 2 and 3 of the Final RFI/RI are pending completion.

Separately from the investigation activities documented in this work plan, PG&E is planning a soil sampling investigation to supplement the existing soil dataset for AOC 10. Planned soil sampling activities for AOC 10 are documented in the *Draft RCRA Facility*

Investigation/Remedial Investigation Soil Investigation Work Plan, Part A (CH2M HILL, 2006), as modified by DTSC (2007b).

1.2 Investigation Background

The site conceptual model developed for the RFI/RI reflects a collective understanding that the groundwater chromium plume is confined to the Alluvial Aquifer and is bounded, south and southeast of the compressor station, by the Miocene Conglomerate and older crystalline bedrock that underlie the site. However, elevated concentrations of hexavalent chromium (Cr[VI]) have recently been observed sporadically in well MW-23 (Miocene Conglomerate bedrock monitoring well), which is located immediately north of the East Ravine. Additionally, historic soil sampling data indicate some of the highest chromium concentrations in soils at the site have been detected in the drainage depressions in the East Ravine (areas designated AOC-10). Historical aerial photographs of this portion of the site show the presence of an impoundment within the East Ravine that contained liquids of unknown composition during several years in the 1960s (CH2M HILL, 2007a). Given these findings, DTSC has directed that additional drilling and groundwater investigation are needed to characterize the groundwater flow pathway and groundwater conditions of bedrock formations in the East Ravine and MW-23 area.

1.2.1 Investigation Area Overview

The area of remedial investigation lies within a larger geographic area that is considered sacred by the Fort Mojave Indian Tribe and other Tribes. Figure 2 shows the location of the East Ravine and AOC 10, and site features and facilities in the investigation area. The East Ravine is a small ravine located on the southeast side of the compressor station, which drains eastward towards the Colorado River. Portions of the East Ravine are on PG&E property outside the compressor station fenceline and other portions of the ravine are located on property owned by the Havasu National Wildlife Refuge (HNWR). Existing groundwater monitoring wells in the investigation area include two wells completed in the Alluvial Aquifer (MW-12 and MW-21) and two wells completed in the Miocene Conglomerate formation (MW-23 and MW-48).

Three subareas, designated AOC 10b, 10c, and 10d (Figure 2), have been identified within the East Ravine where water and sediment have collected within low areas or behind small earthen embankments. Based on information available to PG&E, the embankments were not designed as engineered dam structures (Russell, 2007). A description of East Ravine features, prior RFI soil sampling results, and the soil constituents of potential concern (COPCs) identified at AOC 10 are described in the Revised Final RFI/RI Report, Volume 1 (CH2M HILL, 2007a).

1.2.2 Chromium Sampling Results at Well MW-23

Anomalously high Cr(VI) results have been observed on two occasions in recent groundwater sampling at bedrock well MW-23. In December 2006, a Cr(VI) concentration of 1,920 micrograms per liter (µg/L) was reported in one of two duplicate samples (samples collected on the same day) from this well. The anomalously high sample was re-analyzed at the lab, and the elevated Cr(VI) concentration was confirmed. The other duplicate sample that day showed non-detectable levels of Cr(VI). The second anomalously elevated Cr(VI) result (1,020 µg/L) was observed in a March 2007 sample from MW-23. A subsequent sample collected in May 2007 from MW-23 contained Cr(VI) at a concentration of 14.4 µg/L, typical of prior historical sampling at this low recharge bedrock monitoring well.

At DTSC's direction, a special sampling effort was conducted in June 2007 at well MW-23 to confirm and further investigate the anomalously high Cr(VI) results, and to better understand the effects of purging, recovery, and sampling methods on groundwater analytical results. The anomalous concentrations and pumping conditions observed in December 2006 and March 2007 were not reproducible in the sampling test. The MW-23 sampling study and results are summarized in PG&E's Second Quarter 2007 groundwater monitoring report (CH2M HILL, 2007b).

1.3 Investigation Objectives

In accordance with DTSC's October 29 directive, additional site investigation is needed to investigate the groundwater pathway at AOC 10 and the adjoining East Ravine area to supplement the final RFI/RI. The primary objectives of the groundwater investigation in the East Ravine area are to:

- Determine whether elevated concentrations of Cr(VI) and other inorganic constituents are present in groundwater in the bedrock formation(s) beneath the East Ravine area. If elevated concentrations of Cr(VI) are confirmed in bedrock, evaluate the presence and potential extent of the groundwater impact.
- Assess the potential for perched groundwater to occur at the base alluvium/bedrock contact underlying the East Ravine area.
- Install permanent monitoring wells at the bedrock formation(s) and at the base alluvium contact to provide ongoing groundwater quality monitoring in the East Ravine area.

During implementation of the work plan, PG&E will continue coordination with stakeholders regarding field procedures by which potentially-affected environmental, cultural, and spiritual resources are best preserved. PG&E also intends to conduct this work in a manner consistent with the conservation/mitigation measures discussed within the Programmatic Biological Assessment (PBA) (CH2M HILL, 2007c).

2.0 Field Investigation and Drilling Activities

This section describes the drilling, well installation, and groundwater characterization activities proposed for the East Ravine. The primary topics addressed include investigation overview; selection and rationale for the drilling sites; site preparation and access; and description of the drilling, characterization, well installation, and sampling activities and methods proposed or considered applicable for this groundwater investigation.

2.1 Investigation Overview

A phased groundwater characterization and well installation program has been developed to address DTSC's October 29 directive for the East Ravine groundwater investigation. Figure 2 shows the potential locations where wells would be installed. Wells will initially be installed at the two "primary" drilling sites, designated Sites A and B. If the results of the groundwater characterization at Sites A or B indicate that further investigation and well installations are needed, three additional contingency locations designated Sites C, D, and E (step-out contingency investigation) have been identified, as shown on Figure 2. Alternate drilling sites are included for two of the contingency drilling sites (Figure 2).

Two separate borings/wells are proposed to address the investigation objectives for Sites A and B. The first boring at each of the primary drilling sites will be a deeper exploration borehole drilled into bedrock to confirm the depth to bedrock and characterize groundwater conditions in bedrock to the target depths for these locations. A second shallow boring will be advanced adjacent to the bedrock borehole to install an alluvium monitoring well to assess potential "perched water" conditions at the base alluvium/bedrock contact. The estimated drilling depths and general characterization activities for drill Sites A and B are summarized in Table 1. (All tables are located at the end of this document.) The investigation and sampling methods and procedures are described in Sections 2.3 through 2.7.

Table 1 also presents the general investigation plan that will be implemented in the event that additional groundwater characterization will be needed at the three contingency drilling Sites C, D, and E. Site selection and implementation criteria for the three contingency drilling sites are discussed in Section 2.1.3 below.

Two site cross-sections were prepared to illustrate the hydrogeologic conditions and groundwater investigation plan for the primary drilling Sites A and B, and are shown on Figure 3. Cross-sections A and B extend northward from the bedrock surface outcrops that are exposed immediately south of East Ravine to the alluvial deposits near Interstate I-40. The cross-sections show the depth and elevation of the existing monitoring wells MW-12, MW-23, and MW-48, as well as the groundwater table and the approximate southern limit of the Alluvial Aquifer in the investigation area. Also depicted on the cross-sections is the inferred depth and location of the Chemehuevi detachment fault, which is a regional geologic feature that is exposed along the base of the bedrock slope immediately south and southeast of the Topock Compressor Station.

It should be noted that only limited shallow soil sampling (maximum 2 feet depths below ground surface [bgs]) has been conducted previously in the AOC 10 areas of East Ravine. No borings have been drilled to confirm the depth or type of bedrock underlying the East Ravine area. The estimated/inferred depths to bedrock listed in Table 1 and shown on drilling site cross-sections (Figure 3) are based on the geologic mapping of the surface bedrock outcrops south and east of the investigation area. The depth to the detachment fault was estimated by projecting the slope of the bedrock outcrop to the south of the East Ravine northward to the drilling locations. This bedrock outcrop is thought to be the footwall of the detachment fault.

2.1.1 Primary Drilling Site A

As shown on Figure 2, drilling Site A is located on a level staging area on PG&E property immediately north of East Ravine. The depth to bedrock at Site A is estimated at approximately 30 feet bgs, and a target drilling depth of 180 feet is proposed for this location, consistent with the expected depth of the detachment fault (Figure 3). If the fault is not encountered at or above the target depth, the borehole at Site A will be advanced to a maximum depth of 200 feet in an attempt to reach the fault.

2.1.2 Primary Drilling Site B

Drilling Site B is located on the level portion of the gravel pipeline access road crossing East Ravine on the HNWR (Figure 2). The depth to bedrock at Site B is estimated at approximately 20 feet bgs and a target drilling depth of 150 feet is proposed for this location. The depth to the fault at Site B is inferred to be about 140 feet. If the fault is not encountered at or above the target depth, the borehole at Site B will be advanced to a maximum depth of 200 feet in an attempt to reach the fault.

2.1.3 Contingency Drilling Sites

As shown on Figure 2, contingency drilling Sites C, D, and E were identified as potential step-out locations if further investigation of East Ravine groundwater conditions is required. Table 1 summarizes the investigation objectives and potential drilling plan for these three sites. Drilling site selection and criteria for implementing contingency investigation are outlined below.

Contingency Drilling Site C. If the groundwater characterization and sampling at Sites A and B confirm that Cr(VI) is present in bedrock at greater than 100 μg/L, additional drilling at Site C could be initiated, at the direction of DTSC, to better delineate the presence and extent of potential Cr(VI) in bedrock immediately east of the primary drilling sites. The drilling and characterization activities would be similar to those for primary Site B. An alternate Site C bedrock drilling location has also been identified if contingency Site C is not feasible or approved.

Contingency Drilling Site D. If the groundwater characterization and sampling at Sites A and B confirm that Cr(VI) is present in bedrock at greater than 100 μg/L, additional drilling at Site D could be initiated, at the direction of DTSC, to better delineate the presence and extent of potential Cr(VI) in bedrock adjacent to the upper and central drainage depressions in the East Ravine (AOC 10c and 10b). The drilling and characterization activities would be similar to those for primary Site A.

Contingency Drilling Site E. If the groundwater characterization and sampling at Site B confirms that Cr(VI) is present in bedrock at greater than 50 μg/L, additional step-out drilling at Site E could be initiated, at the direction of DTSC, to better delineate the presence and extent of potential Cr(VI) in bedrock immediately northeast of East Ravine, and nearest the river. The drilling and characterization activities would be similar to those for primary Site B. Site E is located adjacent to a large gas pipeline, and has narrow access. Two alternate Site E bedrock drilling locations have been identified if contingency Site E is not feasible or approved.

The decision to proceed with contingency groundwater investigation would be made after the groundwater investigation and two rounds of sampling have been completed at the primary Sites A and B. Refer to Section 5 for further discussion of the project implementation schedule and the proposed interim reporting plan regarding the contingency groundwater investigations.

2.2 Site Preparation, Access, and Equipment Staging

The proposed access routes and drilling sites will be field-checked and clearly delineated prior to mobilization. If modifications to the access routes are needed, additional surveys will be conducted to ensure that cultural resources and sensitive habitat will not be impacted; that native vegetation is protected; and that integrity of pipelines and other structures is maintained. Field activities associated with the equipment access and well drilling on federal lands will be coordinated with USFWS to ensure the protection of cultural and biological resources. Extensive grading for equipment access is not anticipated for any of the drilling sites shown on Figure 2 except Site E. Minor grading and use of a winch may be required for rig access if the chosen location is in the small ravine at drilling Site E.

Site preparation shall occur prior to equipment mobilization. Site preparation shall include identifying biologically and/or culturally sensitive areas, identifying subsurface utilities and other structural constraints, identifying site hazards, and establishing access routes and work areas that will minimize impacts to these features to the extent possible. Drill rigs shall be cleaned before mobilization to the site and following completion of drilling at the site if visible grease, oil, or other contamination is evident on the equipment. After the drill rigs have been mobilized into place, the staging areas will be established in the drilling work area. Plastic sheeting will be laid on the ground surface in the staging areas to keep the drilling materials and equipment clean and to minimize impacts to the ground surface from the drilling materials and equipment. Materials to be stored at the well site include drilling equipment and well construction materials (e.g., casing and grout). In accordance with OSHA requirements, the exclusion zones for the drilling sites will be demarcated.

The proposed primary staging area for drilling equipment and investigation-derived waste (IDW) management will be on PG&E property as shown on Figure 2. Additional equipment and material staging will be on compressor station property, as needed.

Drilling and well installations shall conform to state and local regulations. CH2M HILL will obtain authorizations and applications required for drilling and well installation. Utility clearances will also be obtained prior to commencement of drilling. Approvals and authorizations are discussed in Section 4.

2.3 Borehole Drilling and Requirements

The drilling, core/borehole logging, and well construction will be performed under the supervision of a California Professional Geologist. The drilling and well installation activities will be conducted in accordance with this work plan and modified methods and standard operating procedures (SOPs) from the *Topock Program Sampling, Analysis, and Field Procedures Manual* (CH2M HILL, 2005). The SOPs relevant for the investigation activities for this project are included in Appendix A.

Table 1 summarizes proposed target drilling parameters for groundwater investigation borings and wells. Figure 2 presents the proposed locations of the borings and monitoring wells. The methods, equipment, and procedures for drilling, core logging, and depth-specific groundwater sampling are described below.

Two boreholes will be drilled at each primary location (Sites A and B). The shallow borehole will extend to the top of bedrock to provide monitoring of the alluvial aquifer or possible perched groundwater. The deeper borehole will extend into the bedrock through a conductor casing installed through the alluvial interval to isolate the bedrock from overlying alluvium.

2.3.1 Drilling Methods

The drilling methods used may vary depending on the conditions encountered. The preferred drilling methods are described below. Additional methods that may be used if conditions encountered are different than expected include hollow-stem auger, mud rotary, downhole hammer, and dual-tube air methods such as Stratex® or Odex®.

Rotosonic methods are preferred for drilling through unconsolidated materials above bedrock. This method involves advancing a rotating and vibrating drill casing or core barrel through the subsurface. Rotosonic drilling can produce a continuous core from the land surface to the target drilling depths; generates minimal drilling wastes; and typically can drill through gravel, cobble, and softer bedrock formations. Rotosonic methods would not be suitable for penetrating the harder Miocene Conglomerate or metadiorite bedrock beneath the alluvium.

Wireline diamond-bit core drilling methods are preferred for drilling through consolidated bedrock. This method utilizes a rotating dual-barreled drill casing with a diamond bit to efficiently collect relatively undisturbed core. Drilling fluid, typically water with no additives, is used to move drill cuttings out of the borehole. Wireline diamond-bit coring minimizes drilling time because the outer barrel and bit remain in the borehole while the inner barrel is lowered and raised in and out of the outer barrel on a wireline to retrieve core, therefore precluding the need to assemble and disassemble drilling rods to retrieve core.

Rotosonic borings drilled to the alluvium/bedrock interface to facilitate perched groundwater monitoring well installation will be a minimum of six inches in diameter.

Rotosonic borings drilled to facilitate conductor casing installation for subsequent bedrock coring will be a minimum of seven inches in diameter. The conductor casing installed will be composed of steel or Schedule 80 polyvinyl chloride (PVC) and have an inner diameter adequate for the advancement of HQ-size (approximately 3.7 inches) coring tools.

Rotosonic drilling and wireline bedrock coring activities will be conducted using either standard truck-mounted or a track-mounted rotosonic drilling rig. A tracked or balloon-tired forklift will be used to support the drilling rig by transporting cuttings, tools, and excess core generated from the drilling sites to the staging area. Given the close proximity of each drilling location to National Trails Highway, one or more standard highway vehicles or small all-terrain vehicles will be used to transport crew, equipment, and materials from the staging area to the drill site. Disposal procedures for IDW are discussed in Section 3.

2.3.2 Core Logging

Lithologic descriptions will be logged of each borehole based on visual inspection of the retrieved core under the supervision of a California Professional Geologist. At a minimum, the field log will document the following information:

General

- Unique boring or well identification
- Purpose of the boring (e.g., monitoring well)
- Location in relation to an easily identifiable landmark
- Names of the drilling subcontractor and logger
- Start and finish dates and times
- Drilling method
- Drilling rate and rig reactions, such as chatter, rod drops, and bouncing
- If applicable, types of drilling fluids and depths at which they were used
- Diameters of conductor casing, casing type, and methods of installation

Soil Core Logging

- Depth at which saturated conditions were first encountered
- Lithologic descriptions (based on the Unified Soil Classification System)
- Sampling-interval depths
- Zones of caving or heaving

Rock Core Logging

- Depth at which drilling fluid was lost and the volume lost
- Changes in drilling fluid properties
- Drilling rate
- Fractures per foot
- Core discontinuity description
- Rock quality designation (RQD)

The results of the continuous core logging of the boreholes will be summarized in an interpretive log for hydrogeologic characterization to assist in selecting well screen intervals.

2.4 Bedrock Characterization

The uncased bedrock boreholes, which will be segregated from the alluvium by a grouted conductor casing, provide ideal conditions for characterization of the bedrock. Potential bedrock characterization methods including geophysical logging, interval specific permeability and groundwater quality testing, and hydraulic testing are described in the following subsections; however, the methods chosen for field implementation will be based on field conditions observed during drilling and subsequent bedrock characterization tests. To ensure the final bedrock characterization testing methods are appropriate to meet the objectives of this work plan, methods will be chosen in consultation with DTSC prior to implementation.

2.4.1 Borehole Development and Geophysical Logging

Immediately following drilling activities, each borehole drilled into bedrock will be developed to remove drilling fluids from the borehole and obtain an estimate of borehole capacity. Borehole development will be accomplished by pumping. During development pumping, temperature, pH, specific conductance, and turbidity will be measured using field instruments. Because the bedrock portion of the borehole will be uncased, at least initially, to facilitate geophysical logging as described below, mechanical surging of the borehole will not be conducted. Should the borehole not produce sufficient groundwater recharge, potable water may be added to the borehole to facilitate pumping for removal of fines.

Following borehole development, a down-hole geophysical survey will be conducted in each borehole drilled into the bedrock to assist in hydrogeologic characterization. The following geophysical logs will be performed:

- Caliper log
- Natural gamma ray log
- Electric logs (spontaneous potential, short and long normal)
- Acoustic televiewer log
- Video log

These types of geophysical logs provide information about formation mineralogy, fracturing (quantity, aperture, and orientation), and competence and can be used for hydrogeologic interpretation and water quality characterization. Geophysical logs will not be run in boreholes terminated in the alluvium.

2.4.2 Permeability Testing

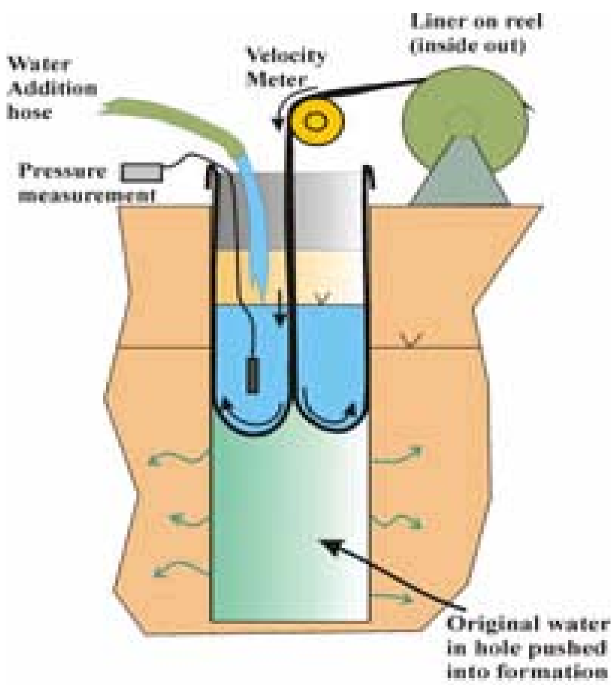
Based on data collected during borehole development and geophysical logging, relative permeability testing may be conducted to obtain a flow profile in each borehole drilled into the bedrock. The purpose of this testing will be to qualitatively assess the relative permeability of individual fractures or zones of fractures within the borehole. Results of the relative permeability testing will aid in the determination of whether additional hydraulic testing, as described in Section 2.4.3, is applicable.

The effectiveness of permeability testing methods is dependent on the yield of the interval tested. Four different permeability testing methods are proposed in the following subsections, in no particular order. Each of these has advantages and disadvantages and different limitations.

2.4.2.1 FLUTe™ Hydraulic Conductivity Profiler

This method involves the installation of a flexible membrane liner manufactured by Flexible Liner Underground Technologies, LLC (FLUTe™). A recently developed technique, the FLUTe™ Hydraulic Conductivity Profiler, allows identification of permeable zones within the borehole during installation of the liner. The basis of the technique is that, as the sealing liner descends, it displaces the borehole water into the formation. The description and schematic of this system is presented below from the company's web site (http://flut.com/meth_14.htm):

> As the everting blank liner is installed, the water in the borehole is forced from the hole into the formation by whatever flow paths are available (e.g., fractures). The liner descent rate is controlled by the rate at which water can flow from the hole via those paths. The everting liner is somewhat like the perfectly fitting piston sliding down the hole, except the liner doesn't slide in the hole, it grows in length at the bottom end of the dilated liner at the "eversion point" as we call it. As the liner everts, it covers the flow paths sequentially. Each time that the liner covers a flow path, the transmissivity of the hole beneath the liner is decreased and the total flow rate out of the hole is reduced. This reduction in flow rate causes a reduction in the descent rate of the liner. The roller at the wellhead measures the liner velocity and the pressure gauge measures the excess head in the liner which is driving the liner down the hole.



> When the liner begins its descent in the hole, all of the flow paths are open and the descent rate is highest. As the liner sequentially covers those flow paths, the liner descent rate decreases to produce a monotonically decreasing velocity with depth in the hole.

> As changes in velocity are logged, one can determine the location of the flow path in the hole, and the magnitude of the velocity change is the measure of the flow that was occurring in that flow path before it was covered by the everting liner. From the velocity profile, one can calculate a conductivity profile for the hole.

This technique is especially well-suited to situations where flow from the hole is often dominated by a few, relatively free-flowing fractures. However, if the permeability of the bedrock is uniformly low, this technique may not be sensitive enough to identify very small changes in flow at each small fracture zone, and the time required for the test can be excessive. Typical bedrock wells at Topock require days to weeks for water levels to return to normal after sampling. If the new bedrock wells have low permeability similar to the existing wells, the everting liner permeability measurements could require several days to complete because the liner must displace all the water in the borehole. Supplemental information about this method is provided in Appendix B.

2.4.2.2 Borehole Dilution Hydrophysical Testing

Borehole dilution hydrophysical testing can be used to identify intervals of groundwater inflow and outflow as well as vertical flow components within a well or borehole with a high level of precision. Hydrophysical testing can be applied under ambient or pumping conditions and in a wide range of groundwater flow conditions, including very low-flow conditions that may be below the practical application range of other methods.

Each test is typically performed by replacing the groundwater fluid column in the monitoring well with deionized (DI) water. When testing ambient flow conditions, care is taken to maintain the static water level in the monitoring well during DI water emplacement, which prevents 'artificial' inflow or outflow in the borehole; conversely, when testing induced flow conditions, the water level is maintained at a level below the static level during DI water emplacement. Once the DI emplacement is complete, the movement of formation groundwater back into the well is monitored over time by measuring changes in electrical conductance in the borehole fluid column. The DI water has very low electrical conductivity. As formation water moves into the borehole from permeable fractures, the electrical conductivity near those fractures increases. The locations in the borehole and the rates at which the DI water is diluted by formation groundwater is used to determine several physical groundwater parameters such as groundwater flow velocity and hydraulic conductivity. These parameters reflect aquifer hydraulic conditions in the immediate vicinity of the borehole. Supplemental information about this method is provided in Appendix B.

2.4.2.3 Electromagnetic Flow Logging

The borehole electromagnetic (EM) flow meter is a down-hole instrument used to measure the vertical distribution of groundwater flow to a well or borehole. As water flows through a magnetic field created within the instrument, a voltage is induced and measured. This measured voltage is proportional to the average velocity of the water within the well. In the absence of ambient vertical flow in a well or borehole, as is likely the case in the bedrock at the site, an upward vertical gradient must be induced by pumping from the top of the fluid column. Flow measurements are then collected at a designated interval from the bottom to the top of the fluid column and analyzed to provide an additive vertical profile of flow. The EM flow meter is most precise when measuring flow rates greater than 0.1 foot per minute.

2.4.2.4 Packer Testing

Packer testing can be performed on individual fractures or groups of fractures identified during bedrock core analysis and geophysical logging. A fracture or fracture group of interest is isolated by positioning an inflatable packer above and below, and pumping from the isolated zone to directly measure yield. During pumping, pressure conditions above, below, and between the packers (i.e., the pumping interval) are monitored to evaluate the degree of segregation and hydraulic response in the pumping interval. Packer testing is most appropriately applied in boreholes with smooth, competent walls (i.e., those that have been cased or cored), so that a competent hydraulic seal can be established with the packer; however, the method is not effective in very low-flow (less than approximately 0.5 gallon per minute [gpm]) hydraulic conditions.

2.4.3 Hydraulic Testing

Hydraulic testing may be required to characterize the hydraulics of the entire bedrock borehole and evaluate the degree of hydraulic communication with other wells. The type of tests that may be conducted will depend on bedrock yield.

2.4.3.1 Constant Rate Extraction Testing

If the boreholes can sustain constant pumping rates of 1 gpm or more, constant rate extraction testing may be appropriate to evaluate the hydraulic properties of the bedrock and the degree of hydraulic communication with other bedrock wells and Alluvial Aquifer wells. Results of borehole development and permeability testing will aid in planning the pumping location, rate and duration of the test such that primary bedrock fractures are drained and influence in other bedrock and alluvial observation wells may be observed. DTSC will be consulted following the collection of permeability testing data to determine if constant rate extraction testing is required to meet the objectives of this work plan.

2.4.3.2 Slug Testing

If the boreholes do not produce groundwater recharge adequate for constant rate extraction testing, slug testing may be performed on an individual borehole. Slug testing requires a nearly instantaneous decrease or increase in pressure head within a well or borehole and the subsequent monitoring of pressure head recovery to ambient conditions. The analysis of pressure head recovery data provides an estimation of hydraulic conductivity and transmissivity for the tested well only.

2.4.4 Initial Bedrock Groundwater Characterization

Initial groundwater samples may be collected from the uncased bedrock boreholes to determine if multiple zones of different water quality are present. Data collected during geophysical logging and permeability/hydraulic testing will be used to identify discrete target sampling depths. Samples collected will be analyzed for the parameters listed in Table 2.

The tool used for initial groundwater sample collection will depend on the number of target zones identified, and if performed, the method of permeability testing. By choosing the sample collection method based on the equipment used for permeability testing, samples can be collected during the same mobilization. If borehole capacity is determined to be exceptionally low, therefore precluding the need for permeability testing, or if primary zones of inflow are not identified during permeability testing, then depth-discrete groundwater samples may not be collected. In this case, a single initial groundwater sample will be collected from the borehole using the methods approved for the Topock site-wide Groundwater and Surface Water Monitoring Program (GMP).

Proposed depth-discrete groundwater sample collection methods are presented in the following subsections.

2.4.4.1 Hydra-Sleeve™

The Hydra-Sleeve™ tool is proposed for initial groundwater sample collection if the FLUTe™ Hydraulic Conductivity Profiler or EM flow meters are used for permeability testing. The Hydra-Sleeve™ tool has been used successfully at the Topock site for previous sample collection tasks. Supplemental information about this sampling technique is provided in Appendix B.

The Hydra-Sleeve™ sampling tool is used to collect depth-discrete groundwater samples by "coring" a target portion of the well fluid column. The tool is especially applicable in low yield environments, is designed to minimize the blending of fluid from different vertical zones, and does not draw water in from outside the well screen. To collect the sample, a weighted disposable polyethylene sleeve is lowered to the target depth and then raised to collect the "core" of the fluid column.

2.4.4.2 Wireline Grab Sampler

The wireline grab sampler is proposed for initial groundwater sample collection if borehole dilution hydrophysical testing is performed to characterize borehole permeability. The wireline used for the geophysical logging and hydrophysical testing is the same used to control the wireline grab sampler. This tool has been used successfully to collect depth-discrete groundwater samples for metals analysis at a different PG&E site.

The wireline grab sampler is similar in concept to the Hydra-Sleeve™ sampling tool but is different in that it can be opened and closed using controls at the well head. This tool is sealed at surface pressure and lowered to the target depth on a wireline. Once at depth, the sample chamber is opened and groundwater is drawn into the sample chamber via differential pressure. Once full, the sampler is again sealed and raised to the surface.

2.4.4.3 Wireline Straddle Packer

Wireline straddle packer testing may be performed to characterize the permeability of specific intervals of the bedrock borehole. Given that this method of hydraulic testing requires groundwater extraction from a hydraulically segregated portion of the borehole, a groundwater sample from the tested interval can easily be collected once hydraulic tests are complete. Groundwater is extracted from the target interval using an electric submersible pump, which is the same tool used to collect groundwater samples as part of the Topock GMP. As mentioned in Section 2.4.2.4, this tool is most applicable in higher flow environments.

2.5 Monitoring Well Installation

The following subsections describe the potential well designs and construction materials for alluvial and bedrock monitoring wells. Figures 4A and 4B present the generalized specifications and schematics for proposed well construction. Consistent with existing wells at the site, the new alluvium monitoring wells will be identified by the well number (e.g., MW-99) followed by S for shallow well completion. The bedrock monitoring wells will be identified by the well number, followed by BR, BR1, BR2, BR3, etc., as applicable for single-completion or multiple-completion well construction (e.g., MW-99BR, MW-99BR1, MW-99BR2, etc.).

2.5.1 Alluvial Monitoring Well Design and Specifications

Single-screen monitoring wells will be constructed in boreholes terminated at the interface of bedrock and the alluvium at drilling Sites A and B. As illustrated in the cross-sections (Figure 3), the bedrock-alluvium interface is anticipated to be of a higher elevation than the groundwater table; therefore, the purpose of the alluvial monitoring wells at these locations is to monitor groundwater that may become temporarily perched at the alluvium/bedrock interface during groundwater recharge events. Alluvium monitoring wells will be installed using materials and procedures described in the following subsections and illustrated in Figures 4A and 4B.

2.5.1.1 Well Casing and Screen

The alluvium monitoring wells will be constructed with 2-inch-diameter Schedule 40 PVC casing and a 5-foot length of factory-slotted well screen. Casing requirements are as follows:

- Casing will be new, unused, and decontaminated.
- Glue will not be used to join casing, and casings will be joined only with compatible threads that will not interfere with the planned use of the well.
- The PVC casing will conform to ASTM Standard F 480-88A or the National Sanitation Foundation Standard 14 (Plastic Pipe System).
- The casings will be straight and plumb.

Well screen requirements are as follows:

- Requirements that apply to casing also apply to well screen, except for strength requirements.
- Well screens will be factory-slotted, with a size of 0.020 inch.

2.5.1.2 Borehole Completion Materials

The annular space will be filled with a filter pack, a bentonite seal, or casing grout between the well casing and the borehole wall.

Filter Pack. The filter pack will consist of No. 3 silica sand (or equivalent) (consistent with other monitoring wells completed in the Alluvial Aquifer) and will extend from the bottom of the hole to approximately 2 feet above the top of the well screen. The top of the sand pack will be sounded to verify its depth during placement. Additional filter pack will be placed as required to return the level of the pack to 2 feet above the screen. A minimum 1-foot-thick layer of fine sand will be placed above the No. 3 sand filter pack to minimize the potential for the bentonite slurry (seal) material to invade the filter pack adjacent to the top of the well screen during well construction.

The contractor will record the volume of filter pack emplaced in the well. Potable water may be used, with the approval of the field geologist, to emplace the filter pack, as long as no contaminants are introduced to the subsurface.

Annular Seals. The bentonite seal requirements are as follows:

- The bentonite seal will consist of at least 2 feet of bentonite between the filter pack and the casing grout.
- Only 100 percent sodium bentonite will be used.
- Bentonite chips or pellets will be hydrated with potable water if the transition seal is not below the water table; otherwise a bentonite slurry (1 gallon water for 2 pounds bentonite) will be used.

A surface seal will be installed in the uppermost 20 feet of the constructed wells. The proposed method of grouting the wells is designed to ensure that the wells can be abandoned in place and will not need to be drilled out for abandonment. The grout requirements for the surface seal are as follows:

- The casing grout will extend a minimum of 20 feet bgs.
- The grout will be a cement mixture in the following proportions: a) 94 pounds of neat Type I or Type II Portland or American Petroleum Institute Class A cement; b) not more than 4 pounds of 100 percent sodium bentonite powder; and c) not more than 8 gallons of water.
- The grout for the surface seal will be pumped into place using tremie pipe in one continuous operation.

The expected volume of each ingredient in the grout mixture will be pre-calculated and documented.

2.5.2 Bedrock Monitoring Well Design and Specifications

Data collected during drilling and subsequent bedrock characterization testing will be used to evaluate if a well screen or screens are required in the bedrock boreholes. Screen installation for an open bedrock borehole, should it be determined necessary, will be conducted during a mobilization subsequent to borehole drilling. To ensure that future water quality data collected at these locations are appropriate to meet the objectives of this work plan, final well design will be chosen in consultation with DTSC prior to implementation.

Due to the relatively small diameter of an HQ-core borehole (approximately 3.7 inches), a conventional monitoring well, as defined above for the alluvial monitoring wells, cannot be properly constructed. Drilling methods that would be required to enlarge the bedrock borehole diameter (air rotary or mud rotary) are not preferred. Health and safety risks associated with hexavalent chromium in the aerosol form preclude the use of air rotary drilling methods at the site. Utilizing mud rotary drilling methods would require the use of bentonite-based drilling mud. The relatively "low impact" development methods required to maintain the integrity of the uncased borehole may not effectively remove bentonite mud from the formation and skew the hydraulic characterization of the bedrock interval. It is therefore proposed that alternative methods be used if monitoring wells are constructed within the open rock boreholes.

Materials and procedures that could be used for the installation of single- and multiple-screen monitoring wells within the bedrock boreholes are presented in the following subsections.

2.5.2.1 Single-Completion Bedrock Monitoring Well

In the event a single zone is chosen for groundwater monitoring and requires segregation from the remainder of the borehole, a Schedule 40 PVC screen of appropriate length will be installed. A filter pack will not be installed around the screen. The screened interval will be hydraulically separated from the remainder of the borehole with pre-packed bentonite packers. The packers consist of mesh socks filled with dry bentonite that are installed on sections of blank PVC casing above and below the screen prior to installation in the borehole. As the bentonite hydrates it swells and extrudes through the mesh, sealing off the monitoring interval in the borehole.

2.5.2.2 Multiple-Completion Bedrock Monitoring Well

The decision to monitor multiple zones within the bedrock will be based on lithologic, hydraulic, and chemical characterization data collected during a previous mobilization. The Solinst® CMT Multilevel System is proposed to establish up to seven discrete monitoring intervals.

The CMT (Continuous Multilevel Tubing) system utilizes a continuous length of multi-channel polyethylene tubing that can be installed to facilitate groundwater sample collection from target depths identified during bedrock characterization. Individual monitoring zones are hydraulically separated by bentonite or inflatable packers. Groundwater samples are collected using small inertial pumps within each channel of the CMT assembly. The CMT system is ideal for the depth-specific characterization of metals and other non-volatile analytes; however, some volatile organic compounds (VOCs) can permeate the polyethylene material and compromise the sample results. Because of the limited use of VOCs at the compressor station, and because VOCs would not be expected to remain in surface runoff as it flows down the ravine, VOCs are not identified as a COPC in East Ravine groundwater (CH2M HILL, 2007a); therefore CMT is considered an option for use at this site.

2.5.3 Surface Completion

Surface completions for constructed wells will consist of a subsurface well vault, unless access and siting conditions allow an above-ground, steel, locking wellhead monument. Figure 4 provides a schematic diagram of well construction, including surface completion. The subsurface well vault will be set in concrete and equipped with an appropriate cover or lid. Wells inside the vault will be equipped with water-tight well seals to prevent surface water from entering the wells if the vaults fill with water. The wells will be secured as soon as possible after drilling by using corrosion-resistant locks. For above-ground completions, the wellhead monument completion will be placed over the casing and cap and seated in a minimum 4-foot by 4-foot by 4-inch-thick concrete pad. The ground surface will be free of vegetation and scoured to a depth of 4 inches before setting the concrete pad. The concrete pad will be sloped away from the well sleeve. The identity of the well will be permanently marked on the casing cap and the protective sleeve. In addition, metal tags will be attached to each of the well casings to identify the specific wells within each well monument.

2.5.4 Well Development

Unless perched water is encountered, monitoring wells installed in the alluvium to monitor for perched groundwater will not undergo development. If perched water is encountered, development of alluvial wells will be accomplished through a combination of surging, bailing, and possibly pumping depending on the yield of the wells. Boreholes installed into bedrock will be developed to remove drilling fluids immediately once drilling is complete, as discussed in Section 2.4.1. Single- or multiple-screen monitoring wells that may be installed in the bedrock will not be installed using fluids and will not be constructed with a filter pack; therefore, screens constructed within the bedrock will not require development. Purging associated with the groundwater sampling procedure will ensure that groundwater samples are representative of the target interval.

2.5.5 Well Survey and Completion Diagram

Following surface completion, the new monitoring wells will be surveyed for well datum elevation and location. In addition to the lithologic core logs to be prepared for the borings, a well completion diagram will be prepared for each monitoring well installed. The diagrams include: well identification; drilling method and boring depth; installation date; elevation of ground surface and well measuring point; and the length and description of the well screen, casing, filter pack, bentonite seal, casing grout, and any back-filled material.

2.6 Groundwater Sample Collection

Groundwater sample collection from wells screened in the alluvium will be dependent on the occurrence of perched groundwater at the bedrock-alluvium interface. One groundwater sample from each alluvial well containing groundwater within 30 days of installation will be collected. Groundwater samples will be collected in accordance with methods and SOPs used for the Topock GMP (CH2M HILL, 2005 and Appendix A). Samples collected from the perched groundwater will be analyzed as defined on Table 2, assuming sufficient volume of water is available for all parameters.

Initial groundwater samples will be collected from the bedrock monitoring intervals within approximately 7 days after well screen installation. The wells will be purged and sampled using the casing volume method (CH2M HILL, 2005 and Appendix A). Purge rates will be selected to obtain representative groundwater samples from the aquifer zone. A second, confirmation sampling will be conducted approximately 8 weeks after the initial well sampling.

Consistent with the Topock Field Procedures Manual (CH2M HILL, 2005 and Appendix A), the samples for total chromium (Cr[T]), metals, and cations will be filtered in the field. The Cr(VI) samples will be filtered in the laboratory before analysis. One field duplicate sample is required every 10 samples, at a minimum of one per event. For the initial groundwater sampling, field duplicates will be collected at one well for all analytes. One equipment blank should be collected per day, per crew, per piece of non-dedicated equipment.

2.7 Site Restoration Activity

Proposed drilling Sites B, C, and E (including alternate locations) are located on HNWR property managed by the U.S. Fish and Wildlife Service (USFWS) and drilling Sites A and D are located on PG&E property (Figure 2). With the exception of Site E, all areas have been previously disturbed and contain limited to no vegetation. Site E spans an area that is partially disturbed and partially in a ravine/wash, which contains sparse vegetation. Given the sparse vegetation in the proposed work areas, no formal site restoration and revegetation plan is anticipated. Temporary signage or other effects that may be erected during well construction will be removed upon completion of drilling and well installation activities. After well installation at the sites located on HNWR/USFWS property, PG&E will work with the agencies to implement potential restoration at the drilling sites (if grading is required) and to minimize future disturbance from post-installation groundwater monitoring activities.

3.0 Waste Management and Decontamination

3.1 Investigation-derived Waste Management

Several types of waste materials will be generated during the drilling, development, and sampling of the exploration borings and monitoring wells. IDW materials that will be generated include groundwater, drill cuttings, and incidental trash.

Water generated during drilling, development, and sampling activities will be collected in bins or portable storage tanks temporarily located in staging areas near the drilling sites, or at the PG&E Topock Compressor Station as needed (Figure 2). Secondary containment will be set up at the drilling area for the portable storage tanks or bins. Water generated from the monitoring well installations will be processed at the IM No. 3 treatment plant or transported to a PG&E-contracted offsite disposal facility.

Drill cuttings include the fragments of rock and soil that are removed to create the borehole. The cuttings will be contained in lined roll-off bins at the staging areas during the drilling and sampling activities. After sampling and characterization, the cuttings bins will be removed from the staging areas. It is estimated that the soil IDW bins temporarily stored in the staging areas will not remain longer than 45 days. Cuttings will be transported to a permitted offsite disposal facility; alternatively, if cuttings are shown to free from contaminants, cuttings may be disposed of onsite if acceptable to the property owner and in compliance with applicable laws and regulations.

Incidental trash will be collected at the end of each drilling shift and hauled from the drill site to an appropriate offsite disposal facility.

3.2 Equipment Decontamination

The backs of the drilling rigs and down-hole drilling tools will be decontaminated prior to arrival at the site and subsequent to finishing the well installations at each site. Decontamination will be accomplished by steam-cleaning the core barrel, drill stem, drive casing, and back of the drilling rig. The pre- and post-mobilization steam-cleaning will be conducted on a temporary decontamination pad (lined with plastic sheeting) located on PG&E compressor station property (Figure 2). Rinsate from the decontamination operation will be collected on the containment pad and transferred to the cuttings bin or purge water tanks. The decontamination rinsate will be managed along with the cuttings or purge water.

4.0 Approvals and Authorizations

4.1 Anticipated Approvals

Implementation of work plan activities will require prior approval from DTSC and the USDOI pursuant to their authority under RCRA and CERCLA, respectively. Anticipated approvals and authorizations for implementation of the groundwater investigation outlined in this work plan are listed on Table 3.

Portions of the proposed activities are located on the HNWR, which is managed by the USFWS. The USDOI is the parent agency of the USFWS; the anticipated USDOI approval mechanism is an approval letter from the HNWR. It is expected that the HNWR approval letter will address USDOI's CERCLA approval, and will also address conditions imposed to comply with Section 7 of the Endangered Species Act (ESA) and Section 106 of the National Historic Preservation Act (NHPA).

As discussed further in Section 4.2 (Biological Evaluation) below, the proposed work plan activities are considered consistent with the previously completed Programmatic Biological Assessment and associated Section 7 consultation, and therefore in compliance with ESA requirements. Compliance with Section 106 of the NHPA is expected to involve a 30-day consultation with local Native American tribes followed by a 30-day consultation with the State Historic Preservation Office (SHPO).

Approval from the DTSC is subject to compliance with the California Environmental Quality Act (CEQA). It is anticipated that the subject activities qualify for an exemption from CEQA, pursuant to Section 15061 of the CEQA Guidelines.

Portions of the work plan activities are within the jurisdiction of the California Department of Fish and Game (CDFG), pursuant to Section 1600 et seq. of the Fish and Game Code. Compliance with Section 1600 requirements is provided via the existing CDFG Streambed Alteration Agreement No. 1600-2005—0140-R6, as amended in January 2007.

The proposed work plan activities are in proximity to Interstate 40, but outside of the right-of-way (ROW) maintained by the California Department of Transportation (Caltrans). No Caltrans approval is required; however, adjustment to the planned location of project facilities should be reevaluated for proximity to the Caltrans ROW.

Pipeline infrastructure owned and/or maintained by private entities is located at and near the project site, approximate locations of which are shown on Figure 2. Prior to field work, the precise ROW of any nearby pipelines will be determined and coordination will occur as needed with the affected pipeline company to obtain prior approval and comply with applicable requirements. In addition, prior to implementation of the subject activities, Underground Service Alert notifications will be made so that utility companies can locate and mark the locations of their underground facilities.

Prior to drilling activity, compliance with the well permit requirements of the County of San Bernardino will be provided.

4.2 Biological Evaluation

The previously completed PBA (CH2M HILL, 2007c) and associated ESA Section 7 consultation addressed a variety of PG&E Topock remedial and investigative actions at the project site, including those identified in this work plan. The PBA provides programmatic coverage of remedial and investigative actions up to the final remedy (expected by 2012) and avoids the need for project-specific consultations under the federal ESA. Groundwater characterization activities, such as those proposed at the East Ravine, are addressed in the PBA as a Category 1 activity (i.e., well installation, maintenance, and operation). Applicable, measures are identified in the PBA to offset potential impacts resulting from this category of activity.

The purpose of this biological evaluation is to outline the proposed groundwater characterization activities at the East Ravine as they relate to federally-listed species and to determine if the actions are within the context and boundaries of the PBA, as requested by the USDOI Bureau of Land Management (BLM). To achieve this purpose, this section discusses project timing, project location and habitat sensitivity, habitat loss, conservation measures, listed species determinations, and conclusions.

The federally-listed species being considered and evaluated include the southwestern willow flycatcher (SWFL—*Empidonax traillii extimus*), Yuma clapper rail (*Rallus longirostris yumanensis*), Mojave desert tortoise (*Gopherus agassizii*), bonytail chub (*Gila elegans*), and razorback sucker (*Xyrauchen texanus*).

4.2.1 Project Timing

The proposed work plan activities are anticipated to commence in early May 2008. The precise start date is contingent upon receipt of necessary approvals and authorizations as discussed in Section 4.1. Due to the proximity of proposed well Site E (including alternate locations) to potentially sensitive avian habitat, drilling activity in this area may need to occur outside of the bird nesting season, defined as March 15 to September 30 in the PBA. Alternatively, construction activity at well Site E may be allowed to occur during this time period, subject to appropriate conservation measures described below in Section 4.2.4 of this work plan (e.g., nesting bird surveys and establishment of sufficient buffers).

Well Sites A and D (Figure 2) are located within PG&E's compressor station property, and are sufficiently upland from the sensitive riparian habitat along the Colorado River such that no direct or indirect effects to avian species would result. Similarly, well Sites B and C are located over 200 feet from sensitive riparian habitat identified in the PBA and therefore are not expected to be subject to the nesting bird restrictions established in the PBA.

4.2.2 Project Location and Habitat Sensitivity

Proposed well Sites A and D are located within the property boundary of the PG&E compressor station. This industrialized area is located upland from the Colorado River floodplain and does not include sensitive biological habitat. Well Sites B and C are located on the HNWR several hundred feet upland of the Colorado River floodplain. Project activity at these sites is expected to be limited to the existing roadways and immediately adjacent areas. Well Site E (including alternative sites) is proximate to the Colorado River floodplain, including potentially sensitive avian habitat and designated critical habitat for the bonytail chub.

4.2.3 Habitat Loss

No habitat loss will occur during well installation activities at well Sites A and D; these sites are located on previously disturbed areas within the Topock Compressor Station. Well installation activities at Sites B and C may require limited vegetation removal, but are expected to be sited primarily within or adjacent to existing access roads. Installation activity at well Site E (including alternative sites) could result in floodplain habitat loss, defined as "the removal of trees and perennial shrubs" in the PBA. However, the maximum total habitat loss resulting from the work plan activities is estimated to be less than 0.5 acre. Therefore, the proposed work plan activities described herein would conform to the cumulative limits of 2.5 acres of floodplain habitat loss and 3.0 acres of upland habitat loss prescribed in the PBA. Additional conservation measures applicable to the work plan activities are described below.

4.2.4 Conservation Measures

The work plan activities related to proposed well Site E locations would conform to the applicable conservation measures specified for the SWFL, including minimizing habitat loss. Construction activity at well Site E may be conducted outside of the bird nesting season to minimize impacts to potentially sensitive riparian habitat. If construction activity at well Site E occurs during the bird nesting season, a pre-construction survey for nesting birds will be conducted and construction activity within 200 feet of active nesting areas would be prohibited in accordance with the measures established in the PBA. Well Sites A through D are located sufficiently upland from the Colorado River floodplain (i.e., over 200 feet) to avoid potential impacts to riparian areas.

Groundwater sampling at the wells and other well operation and maintenance activities subsequent to construction may be subject to the modified floodplain sampling procedures referenced in the PBA. These procedures are in effect during the SWFL nesting season (defined as May 1 through September 30 in the PBA) and may be applicable to access and sampling at future well Site E. Due to the distance from sensitive riparian habitat on the Colorado River floodplain, well Sites A through D would not be subject to these modified procedures.

Implementation of the work plan activities will also be subject to the applicable general management measures provided for in the PBA. This is expected to include designation of a field contact representative (FCR) responsible for overseeing compliance with applicable mitigation measures, construction awareness training, and preparation of a construction completion report that includes a quantification of impacted habitat.

4.2.5 Listed Species Determinations

Southwestern willow flycatcher. Through application of the conservation and management measures referenced above and described in detail in the PBA, the potential direct or indirect effects of the proposed work plan activities to the SWFL are expected to be either insignificant or discountable. A determination of "may affect, but not likely to adversely affect" is concluded for this species. This determination is within the context of the PBA.

Yuma clapper rail. Prior surveys conducted at the project site and documented by the PBA have not indicated the presence of Yuma clapper rail in the vicinity of the proposed work plan activities. The application of conservation and management measures referenced above would serve to further limit the potential direct or indirect effects to the Yuma clapper rail, which are expected to be either insignificant or discountable. A determination of "may affect, but not likely to adversely affect" is concluded for this species. This determination is within the context of the PBA.

Mojave desert tortoise. This action will have no direct effect upon this species. The USFWS protocol surveys that were performed in 2004, 2005, 2006, and 2007 resulted in no recent evidence of species presence within the Area of Potential Effect (APE). Therefore, any potential direct effects will be avoided. Also, there is no expected habitat loss as a result of the work plan investigation activities. This determination is within the context of the PBA.

Razorback sucker. This action will have no effect upon this species. The project will not occur within the Colorado River or 100-year floodplain as delineated in the PBA. Therefore, potential direct and indirect effects to this species will be avoided. This determination is within the context of the PBA.

Bonytail chub. This action will have no effect upon this species. The work plan activities will be proximate to, but will not occur within the designated critical habitat for this species, which is coincident with the Colorado River 100-year floodplain. No direct or indirect impacts to critical habitat or the bonytail chub would result from implementation of the work plan activities. This determination is within the context of the PBA.

4.2.6 Conclusion

The activities proposed in this work plan are within the context and boundaries outlined in the PBA. Therefore, this action will be compliant with the federal ESA provided that applicable mitigation measures identified in the PBA are implemented. Additional consultation with the USFWS is not required.

4.3 Archaeological Surveys, Reviews, and Consultations

The area subject to activities described in this work plan was included in an archaeological survey of the APE (Applied Earthworks, 2007). Only one significant archaeological resource was found in this area; a small portion of historic Route 66 (CA-SBR-2910H) is located along an existing gas pipeline (Line 300B) and road alignments in this area. Contingency Site E and its two alternate sites (Alt-1 and Alt-2) are in proximity to this section of Route 66. This portion of Route 66 has been greatly disturbed by the construction of Line 300B. A recent examination of this area indicated that only a very small portion of the original Route 66 pavement is intact. Although deteriorated, the original Route 66 guardrail is still in place at a majority of this location. The narrow roadbed and guardrail at this portion of Route 66 provides this National Register of Historic Places (NRHP) property with integrity of location and feel. Because of the past disturbance to this portion of the Route 66 roadbed, restrictions on temporary vehicle use are not deemed necessary. The general configuration and historic guardrail at the section of Route 66 will be protected so as to not impact the integrity of location and feel of this NRHP historic property.

An additional resource, an unrecorded tin can scatter of approximately 30 to 40 cans and other materials, was recently noted in a small ravine southeast of Site E Alt-1 and within the northern portion of Site E. The oldest artifacts of this scatter appear to be from the 1940s and 1950s.

Sites A, B, C, C Alt-1, D, and E Alt-1 and Alt-2 present no potential to impact either of the two historic resources noted above. Both of the historic sites will be protected from work activities and will be monitored during the course of work. The PG&E FCR will be responsible for providing archaeological sensitivity training to the workers implementing this work plan and for ensuring compliance with all applicable archaeological measures during drilling activities.

Contingency drilling at Site E will occur only if warranted by the results of groundwater characterization at the proposed primary Sites A and B. In the event that drilling at Site E becomes necessary, the unrecorded tin-can scatter will be recorded and evaluated in accordance with NRHP criteria. As noted in Table 1, Site E Alt-1 or Alt-2 may be implemented if Site E is not approved.

The Topock site and adjacent lands are contained within a larger geographic area that is considered sacred by the Fort Mojave Indian Tribe and by other Native American tribes. In recognition of this, work activities will be conducted in a manner which recognizes and respects these resources and the spiritual values of the surrounding lands. PG&E understands that the environmental, cultural, and spiritual resources may not be physically perceptible. To this end, site orientation will stress that all site activities must be conducted in a respectful manner that is conscious of this context. In addition, PG&E will contact the Tribes which have in the past expressed a desire for tribal monitors. In the event there is a desire to monitor this work, PG&E will make arrangements for monitoring of field activities, if acceptable to the landowner and if consistent with security and health and safety considerations.

5.0 Schedule and Reporting

5.1 Project Schedule

Table 4 lists the proposed implementation schedule for the field and reporting activities for the East Ravine groundwater investigation. The proposed field activities are anticipated to commence in early May 2008. The date and schedule for conducting the drilling, investigation, and reporting activities are subject to obtaining approvals and authorizations from DTSC, USDOI, HNWR, and other agencies, as described in Section 4.

5.2 Reporting

Following completion of the primary investigation at Sites A and B, an interim results technical memorandum will be prepared to present the results and document the drilling, well installation, and initial groundwater sampling. The interim results technical memorandum will include the core logs for the borings, initial groundwater characterization data, well construction logs, and the groundwater sampling data and validated analytical results. The technical memorandum will be submitted approximately 4 weeks after the completion of data validation of the second round of initial groundwater well sampling.

Following DTSC and USDOI review of the interim results technical memorandum, the need for contingency well drilling will be assessed. If contingency drilling is not required, PG&E will finalize the technical memorandum 4 weeks after the receipt of comments on the interim document. If contingency drilling is conducted, the final reporting schedule will be determined based on discussion with DTSC and USDOI.

Following the initial sampling, the new wells will be incorporated, as appropriate, in the Topock GMP. Monitoring reports under this program are prepared under separate, routine reporting schedules.

6.0 References

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Tables

TABLE 1
Drilling, Characterization, and Well Installation Plan
Work Plan for East Ravine Groundwater Investigation
PG&E Topock Compressor Station, Needles, California

Site ID	Investigation Objective	Drilling Plan				Characterization & Well Installation
		Ground Surface Elevation feet MSL	Estimated Bedrock Depth feet bgs	Target Boring Depth feet bgs	Drilling Method	Proposed Activities
Site A	Characterize bedrock groundwater conditions to depth of fault	538	30	35	Rotosonic	Log alluvium & set surface conductor casing below bedrock contact
				180	Rotary 4" rock core	Core log, televiewer & geophysical logging suite
						Hydraulic permeability profile (FLUTe or other method)
						Open-hole groundwater sampling for initial water quality evaluation
						Construct bedrock well based on logging & initial characterization
	Assess perched water at bedrock contact	538	30	33	Rotosonic	Install perched-zone monitoring well at base alluvium/bedrock contact
Site B	Characterize bedrock groundwater conditions to depth of fault	510	20	25	Rotosonic	Log alluvium & set surface conductor casing below bedrock contact
				150	Rotary 4" rock core	Core log, televiewer & geophysical logging suite
						Hydraulic permeability profile (FLUTe or other method)
						Open-hole groundwater sampling for initial water quality evaluation
						Construct bedrock well based on logging & initial characterization
	Assess perched water at bedrock contact	510	20	23	Rotosonic	Install perched-zone monitoring well at base alluvium/bedrock contact
CONTINGENCY DRILLING SITES						
Implement if Site A and/or B confirms Cr(VI) in bedrock >100 µg/L						
Site C	Characterize bedrock gw conditions to base of MW-23 screen	525	15	100	Rotary 4" rock core	*same as Site B bedrock characterization & well*
	Assess perched water at bedrock contact	525	15	18	Rotosonic	*same as Site B perched zone well*
Alt-1	*pursue if Site C not feasible or approved*	550	0	125	Rotary 4" rock core	*same as Site C bedrock characterization (alluvium not present)*
Implement if Site A and/or B confirms Cr(VI) in bedrock >100 µg/L						
Site D	Characterize bedrock gw conditions to base of MW-23 screen	573	50	150	Rotary 4" rock core	*same as Site A bedrock characterization & well*
	Assess perched water at bedrock contact	573	50	53	Rotosonic	*same as Site A perched zone well*
Implement if Site B confirms Cr(VI) in bedrock >50 µg/L						
Site E	Characterize bedrock gw conditions to base of MW-23 screen	502	0	80	Rotary 4" rock core	*same as Site B bedrock characterization & well*
Alt-1	*pursue if Site E not feasible or approved*	505	0	85	Rotary 4" rock core	*same as Site B bedrock characterization & well*
Alt-2	*pursue if Site E not feasible or approved*	502	0	80	Rotary 4" rock core	*same as Site B bedrock characterization & well*

Notes:
1. See Figure 2 for proposed drilling site locations and alternate (**Alt**) sites. All drilling sites subject to property owner access agreements.
2. Bedrock well MW-23 screened from 60-80 feet below ground surface (bgs); equals elevation interval 445-425 feet above mean sea level (MSL).
3. See text for potential initial (open-hole) groundwater sampling methods, and bedrock well installation methods.

TABLE 2

Groundwater Sampling and Analysis Plan, Primary Well Locations

Work Plan for East Ravine Groundwater Investigation

PG&E Topock Compressor Station, Needles, California

Analyte	Analytical Method	Standard Reporting Limit	Potential Number of Samples from Prmary Well Locations
Initial Bedrock Groundwater Characterization - Open-hole (post-drilling) Grab Samples			
Hexavalent chromium	Method SW7199	0.2 µg/L	6
Dissolved total chromium (field filtered)	Method SW6010B	1 µg/L	6
Specific conductance	field instrument	NA	6
Oxidation reduction potential	field instrument	NA	6
Dissolved oxygen	field instrument	NA	6
pH	field instrument	NA	6
Temperature	field instrument	NA	6
Groundwater Samples from Installed Bedrock Monitoring Wells - Two Sampling Events			
Hexavalent chromium	Method SW7199	0.2 µg/L	12
Dissolved total chromium (field filtered)	Method SW6010B	1 µg/L	12
Title 22 Metals	Methods SW6010B,SW6020A, SW7470A	various	12
Specific conductance	field instrument	NA	12
Oxidation reduction potential	field instrument	NA	12
Dissolved oxygen	field instrument	NA	12
pH	field instrument	NA	12
Temperature	field instrument	NA	12
Total dissolved solids	EPA 160.1	10 mg/L	12
Chloride, Sulfate, Nitrate	EPA 300.0	0.5 mg/L	12
Alkalinity	EPA 310.1	5 mg/L	12
Ammonia	EPA 350.2	0.5 mg/L	12
General minerals (Ca, Mg, K, Na) (dissolved)	Method SW6010B	1 mg/L	12
Iron (dissolved)	Method SW6010B	0.5 mg/L	12
Manganese (dissolved)	Method SW6010B	0.5 mg/L	12
Total Organic Carbon (TOC)	EPA 415.1/2	0.5 mg/L	12
Oxygen 18	CF-IRMS	NA	12
Deuterium	CF-IRMS	NA	12
Groundwater Samples from Alluvium "perched water" Monitoring Wells			
Hexavalent chromium	Method SW7199	0.2 µg/L	to be sampled when perched water present
Dissolved total chromium (field filtered)	Method SW6010B	1 µg/L	
Oxidation reduction potential	field instrument	NA	
Dissolved oxygen	field instrument	NA	
pH	field instrument	NA	
Temperature	field instrument	NA	
Total dissolved solids	EPA 160.1	10 mg/L	
Chloride, Sulfate, Nitrate	EPA 300.0	0.5 mg/L	
Oxygen 18	CF-IRMS	NA	
Deuterium	CF-IRMS	NA	

NOTES:

Micrograms per liter (µg/L), milligrams per liter (mg/L)

One equipment blank to be collected per day, per crew, per non-dedicated equipment.

Samples analyzed with Method SW6010B may also be analyzed with Methods SW6020A, EPA 200.7 and EPA 200.8.

Installed bedrock wells may be single completion or multi-level wells (assume 3 sample zones per well)

Continuous flow isotope ratio mass spectrometry (CF-IRMS). Not applicable (NA)

TABLE 3
Approvals and Authorizations for Drilling and Well Installation
Work Plan for East Ravine Groundwater Investigation
PG&E Topock Compressor Station, Needles, California

Agency/Organization	Approvals and Authorizations
U. S. DOI/HNWR	Approval letter from DOI/HNWR anticipated. Approval subject to NHPA Section 106 and ESA Section 7 consultations (see below).
California DTSC	As state lead agency, approval letter from DTSC is required. CEQA compliance anticipated to occur via a Categorical Exemption.
California Department of Fish and Game	Project activities have been previously authorized by Streambed Alteration Agreement No. 1600-2005-0140-R6.
U. S. Fish and Wildlife Service	USFWS HNWR compliance with Section 7 ESA requirements provided via a Programmatic Biological Assessment and associated Section 7 consultation.
State Historic Preservation Office	USFWS HNWR approval subject to NHPA Section 106 process involving a 30-day Tribal consultation followed by a 30-day SHPO consultation.
San Bernardino County	Compliance with well drilling permit requirements.
Private Pipeline Companies	As needed, activities located in the ROW of any pipelines will be subject to prior coordination with the owner/manager of the associated facilities.

TABLE 4
Planning and Implementation Schedule
Work Plan for East Ravine Groundwater Investigation
PG&E Topock Compressor Station, Needles, California

Task / Activity	Estimated Duration	Remarks
1.0 Primary Drilling Sites Field Investigation		
Site Kick Off Meeting	1 day	5 days after obtaining final approval from DTSC, DOI, and agencies
Site Preparation & Staging	4 days	primary Sites A and B only
Drilling Equipment Mobilization	3 days	2 drilling rigs: rotosonic for alluvium interval & well; rotary core for bedrock interval & well
Drilling, Characterization, Well Installation - Sites A & B	20 days	Sequence rotosonic drilling, bedrock coring, logging & well installation between Sites A & B
Development & 1st Well Sampling Event	3 days	bedrock wells at Site A and B. Develop & sample alluvium wells if perched water is present
Estimated Total Primary Drilling Investigation Period	*5 weeks*	
2.0 Primary Sites Sampling & Reporting		
Sample Analysis/Data Validation for 1st Event	5 weeks	
Gap Period between Sampling Events	3 weeks	
2nd Well Sampling Event	2 days	2nd sampling scheduled eight weeks after 1st sampling event
Sample Analysis/Data Validation for 2nd Event	5 weeks	
Interim Results Technical Memorandum	4 weeks	draft report scheduled 4 weeks after receipt of validated results of 2nd sampling event
DTSC/DOI & Stakeholder Review/Comments	4 weeks	DTSC assesses need for Contingency Well Drilling
Incorporate Comments & Finalize TM	6 weeks	If contingency well drilling is not required
Estimated Total Primary Sampling and Reporting Period	*27 weeks*	
3.0 Contingency Sites Drilling Investigation (Separate Mobilization)		
Select, Prepare & Stage Contingent Site C (if needed)	4 days	drill & install 1 stepout bedrock well if Sites A and/or B confirm Cr(VI) in bedrock >100 ug/L
Select, Prepare & Stage Contingent Site E (if needed)	4 days	drill & install 1 stepout bedrock well if Site B confirms Cr(VI) in bedrock >50 ug/L
Prepare & Stage for Contingent Site D (if needed)	2 days	drill & install 1 stepout bedrock well if Sites A and/or B confirm Cr(VI) in bedrock >100 ug/L
Contingency Drilling Equipment Mobilization	2 days	assume rotary core for bedrock interval characterization & well installation
Drilling, Characterization & Well Installation	tbd	subject to number of contingency sites and wells
Development & Initial Well Sampling	5 days	
2nd Well Sampling	tbd	2nd sampling scheduled eight weeks after 1st sampling event
4.0 Reporting for Contingency Investigations (if implemented)		
Contingency Investigation Results Technical Memorandui	tbd	

Notes:
Activity durations estimated for primary drilling, sampling and interim reporting. Schedule and activity durations for contingent drilling to be determined (tbd).

Figures

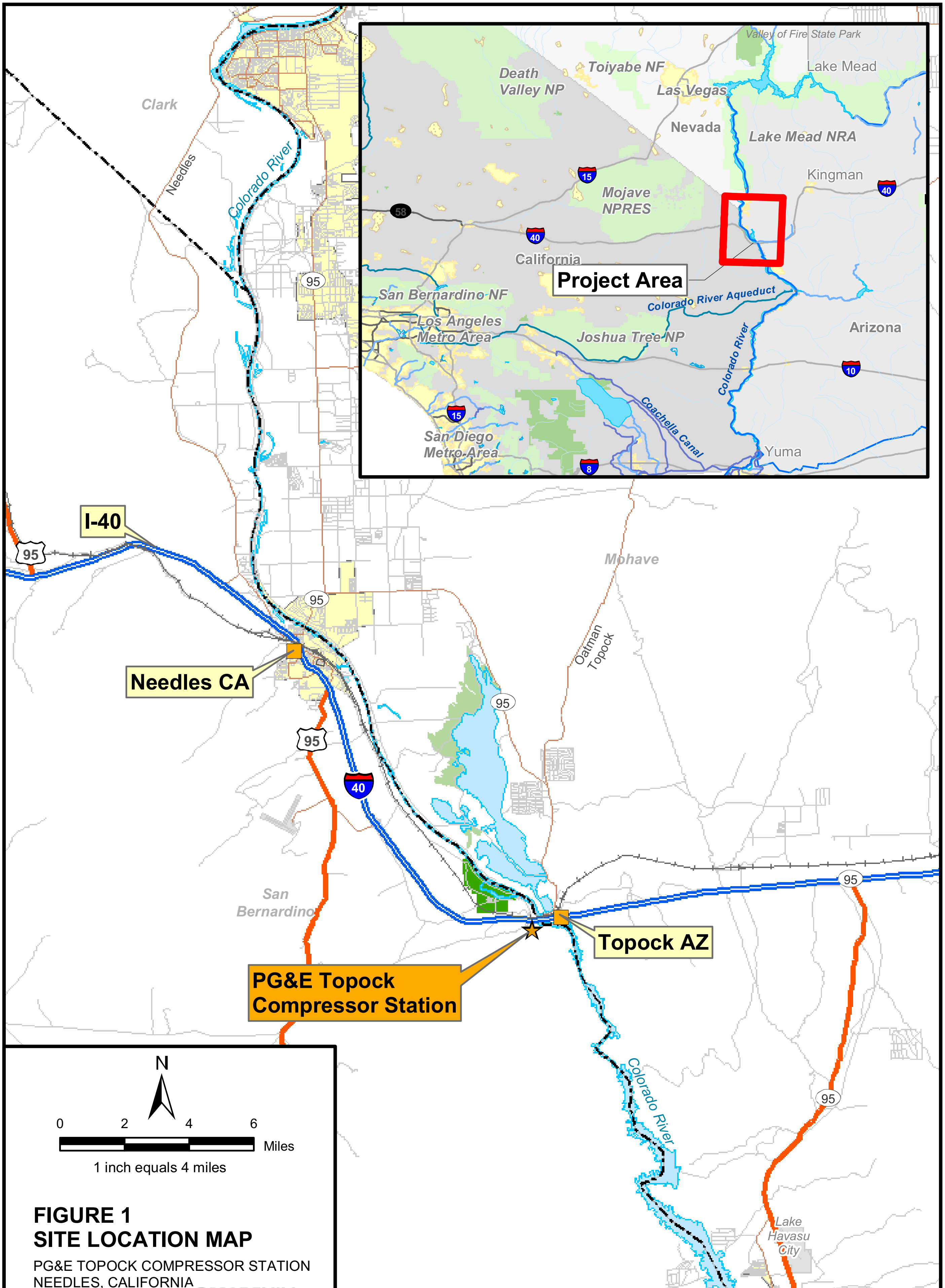

FIGURE 1
SITE LOCATION MAP

PG&E TOPOCK COMPRESSOR STATION
NEEDLES, CALIFORNIA

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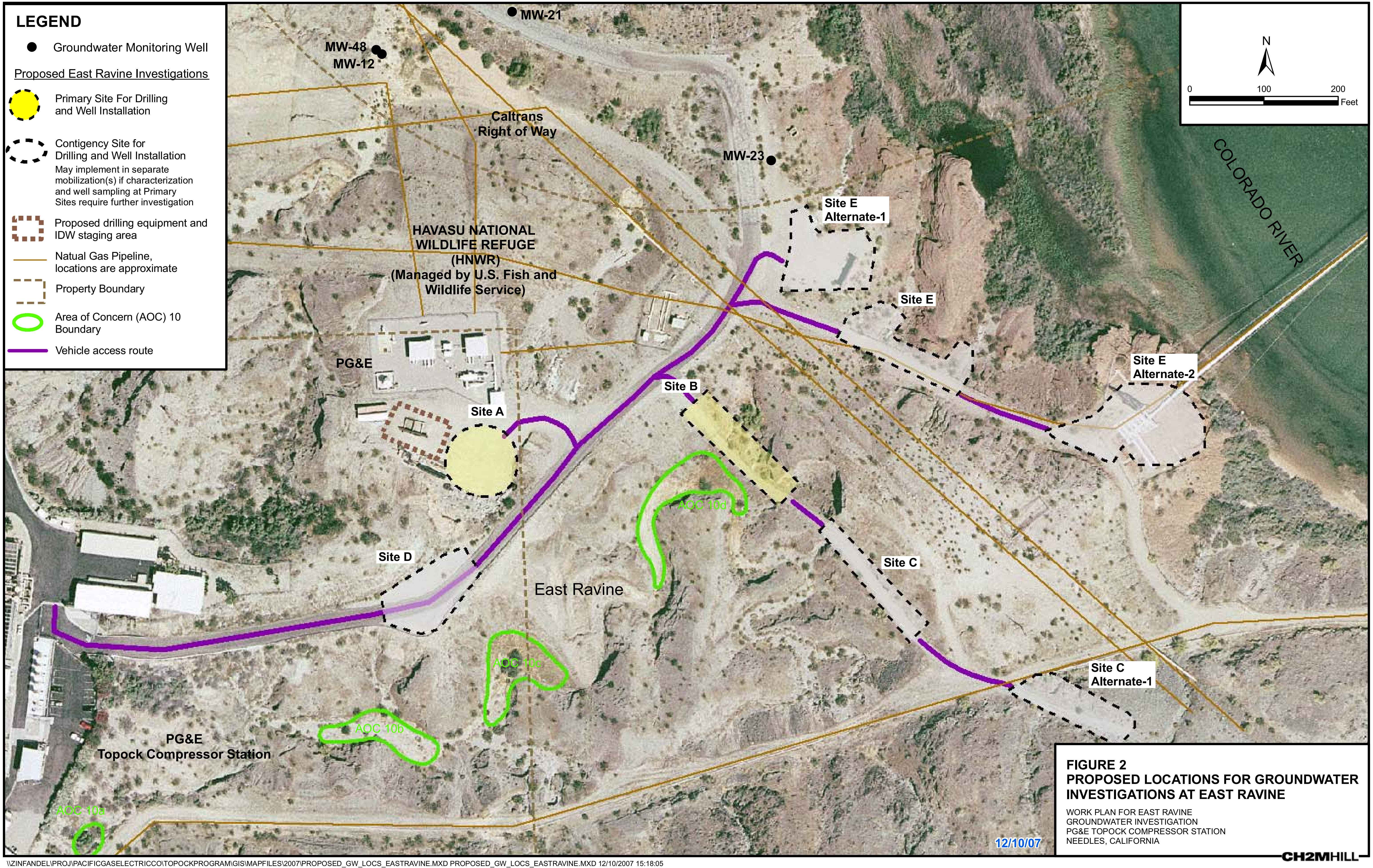

FIGURE 2
PROPOSED LOCATIONS FOR GROUNDWATER INVESTIGATIONS AT EAST RAVINE

WORK PLAN FOR EAST RAVINE GROUNDWATER INVESTIGATION
PG&E TOPOCK COMPRESSOR STATION
NEEDLES, CALIFORNIA

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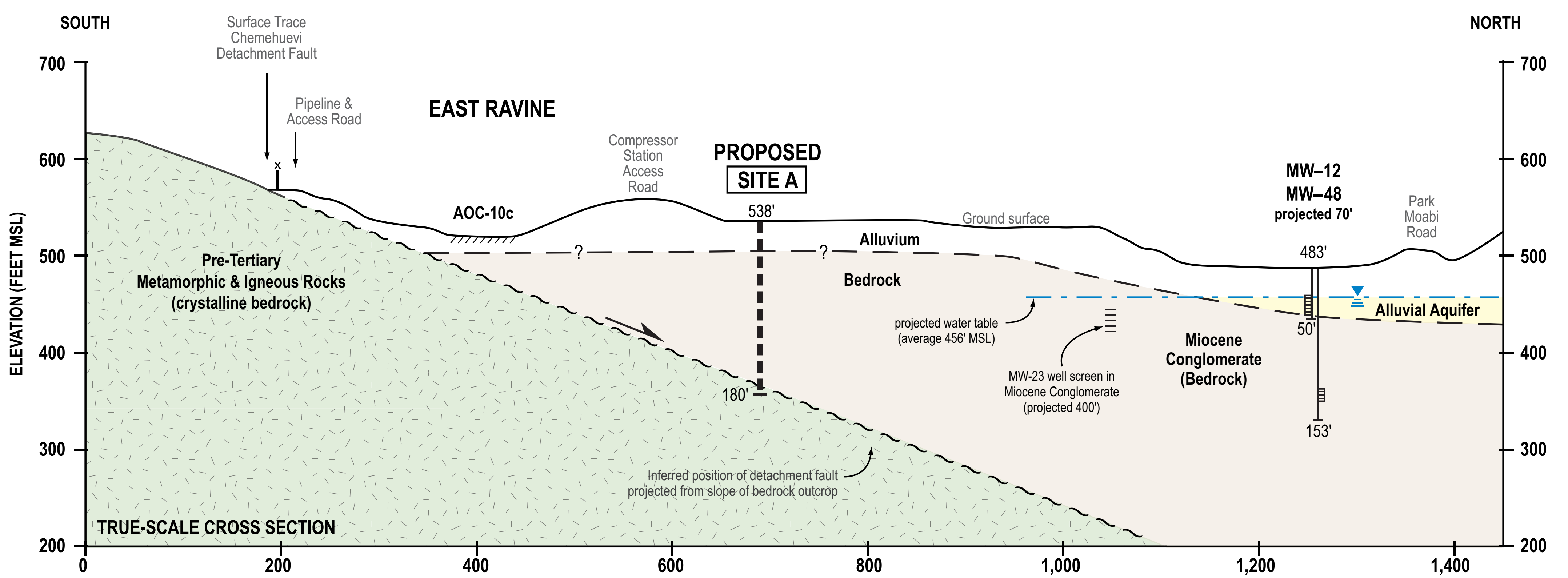
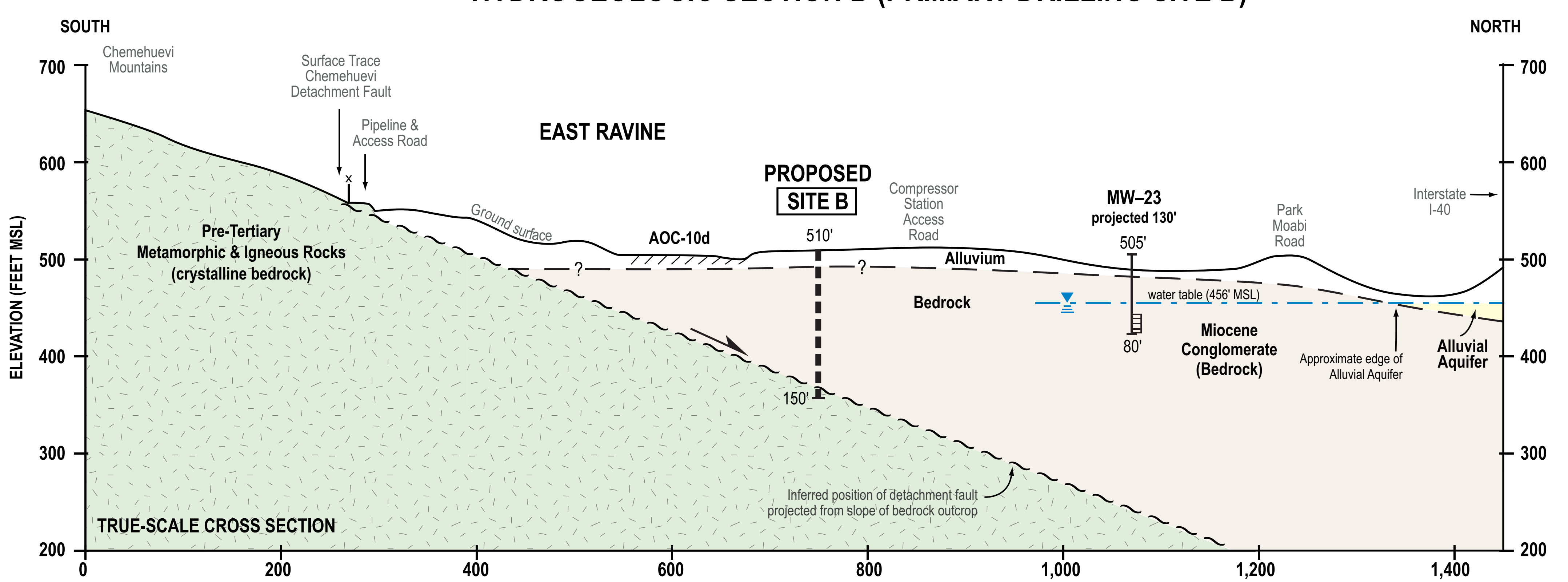
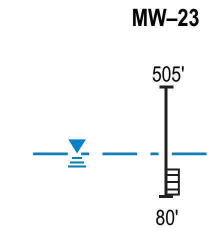
HYDROGEOLOGIC SECTION A (PRIMARY DRILLING SITE A)



HYDROGEOLOGIC SECTION B (PRIMARY DRILLING SITE B)



LEGEND



- Well ID
- Ground surface elevation (feet msl)
- Water level
- Well screen
- Total depth of boring (feet bgs)

Elevations in feet above mean sea level (MSL)

LOCATIONS OF HYDROGEOLOGIC CROSS SECTIONS

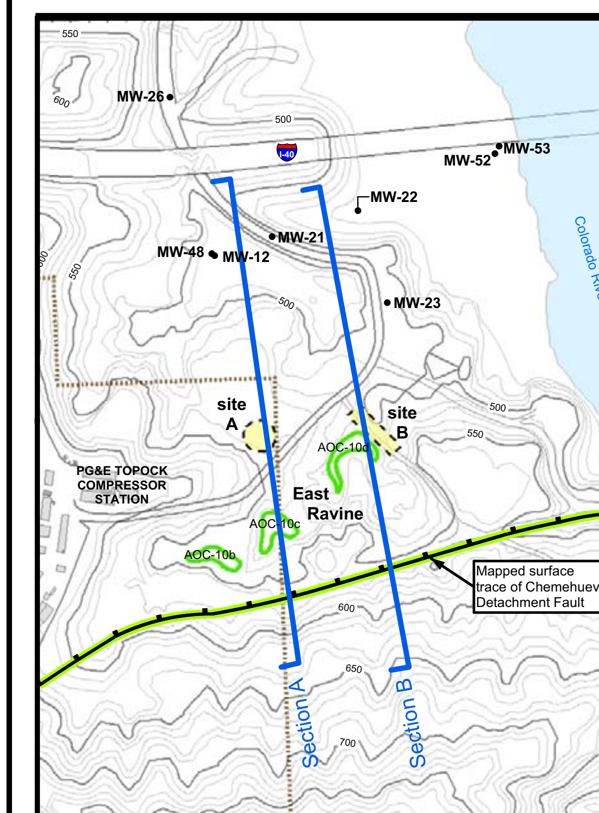


FIGURE 3
EAST RAVINE GROUNDWATER INVESTIGATION CROSS SECTIONS
WORK PLAN FOR EAST RAVINE
GROUNDWATER INVESTIGATION
PG&E TOPOCK COMPRESSOR STATION
NEEDLES, CALIFORNIA

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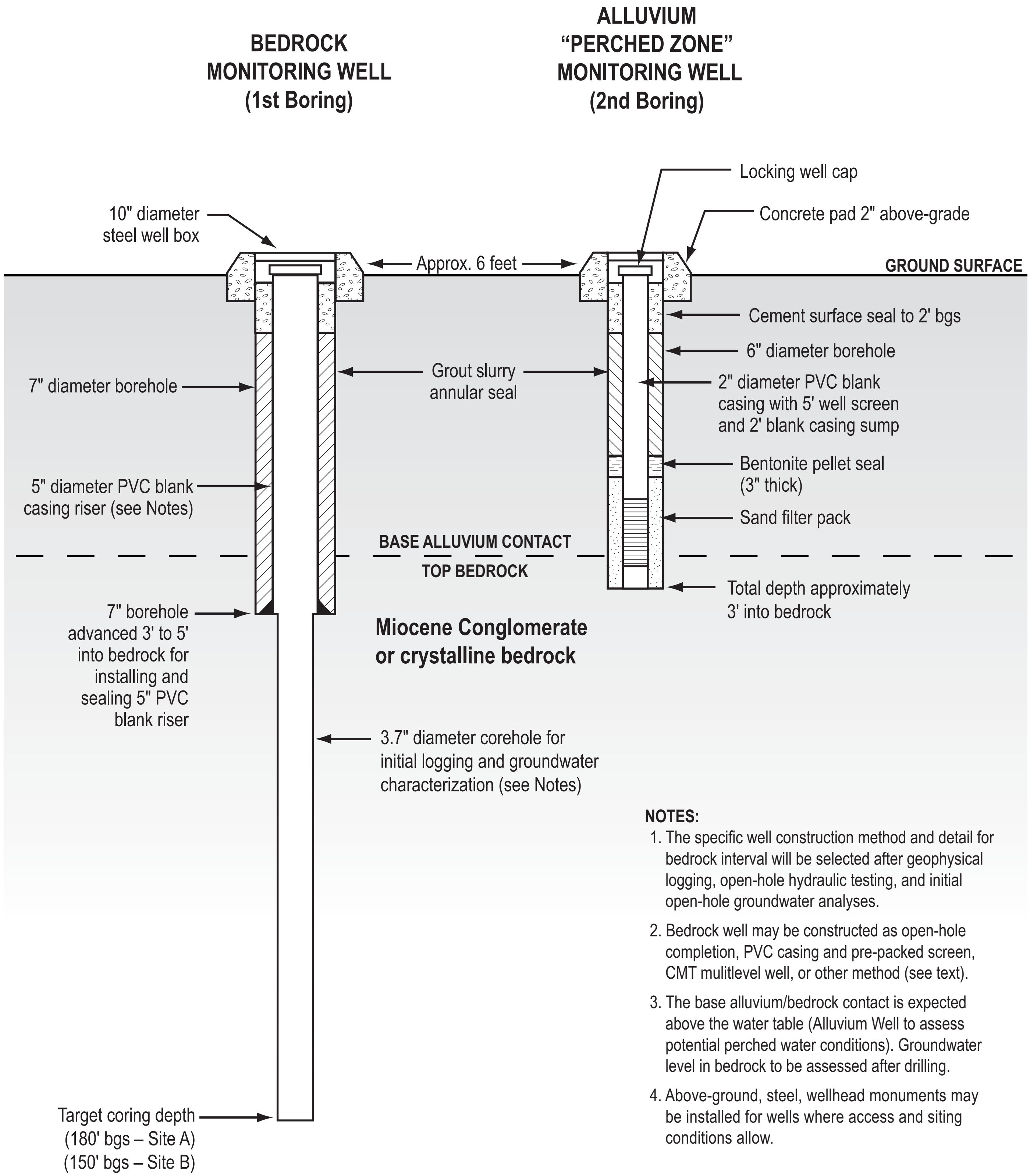


NOTES:

1. The specific well construction method and detail for bedrock interval will be selected after geophysical logging, open-hole hydraulic testing, and initial open-hole groundwater analyses.
2. Bedrock well may be constructed as open-hole completion, PVC casing and pre-packed screen, CMT mulitlevel well, or other method (see text).
3. The base alluvium/bedrock contact is expected above the water table (Alluvium Well to assess potential perched water conditions). Groundwater level in bedrock to be assessed after drilling.
4. Above-ground, steel, wellhead monuments may be installed for wells where access and siting conditions allow.

DIAGRAM NOT TO SCALE
All depths in feet below ground surface (bgs) are approximate and drilling and well installation depths will be determined based on drilling log and characterization results.

FIGURE 4
PROPOSED WELL CONSTRUCTION SCHEMATIC
WORK PLAN FOR EAST RAVINE GROUNDWATER INVESTIGATION
PG&E TOPOCK COMPRESSOR STATION
NEEDLES, CALIFORNIA

CH2MHILL

ES112007007BAO_Proposed_wellschematic.ai_121107_lho

Appendix A
Standard Operating Procedures for Drilling, Logging, Well Installation, and Groundwater Sampling

(Provided on CD-ROM)

Appendix B
Supplemental Information for Bedrock Characterization and Groundwater Sampling Methods

How to locate, and flow test, every major fracture in a borehole in one hour

Carl Keller, Flexible Liner Underground Technologies (FLUTe)

Abstract

A new method has been developed for measuring the flow paths intersected by a borehole. The method uses a flexible, everting liner to drive the water from the borehole. The velocity of the propagation of the liner down the hole decreases as the everting liner seals the flow paths sequentially from the top to the bottom of the hole. Using the velocity of propagation, the excess head driving the liner, and the other measurements of significant parameters, the flow rate into each flow path is calculated. That flow rate is used to define a transmissivity profile for the borehole. Results of measurements with the method are shown for numerous sites. This method is compared to traditional straddle packer techniques to illustrate the similarities and differences. The liner method compares very well to measurements made with packers. The main differences from straddle packer testing are: there are no concerns about bypass leakage, the technique uses 5-10% of the time typically required for packer testing, the spatial resolution of flow paths is far better than possible with packer testing, the liner is usually left in place to seal the entire hole against cross contamination, there is less risk of hole slough entrapping the liner. On the other hand, the liner method, by itself, does not produce water samples for testing. The time to perform a measurement depends more on the flow rate out of the hole than upon the depth of the hole. Small diameter holes are measured more quickly than large diameter holes. The limitations of the method are reviewed with respect to hole size, depths possible, differential pressure limits, and others. Generally, these are not very limiting to most environmental applications. The technique is being extended to possible use in direct push holes with flexible liners emplaced for other purposes*.

The Problem Addressed

Most ground water problems are aided by a good understanding of the existing flow paths. Measurement of those flow paths is central to the science, and the subject of this paper.

Flow path measurements range from simple slug or pumping tests to many other measurements, some of which are broadly collected under the term geophysical measurements. Examples are gamma, resistivity, sonic, and other logs related to the stratigraphy, but not really flow path measurements. Others like caliper, sonic tele-viewer, thermal, chemical, and optical logs tend to locate fractures and beds, but they also are not flow measurements. Natural velocity logs, pumped velocity logs, and packer tests are flow measurements. These measurements are all performed in boreholes, the common means of access to the subsurface.

The method described hereafter is offered as an alternative to pumped hole velocity logs and to straddle packer tests. The advantages are the lower cost, better spatial resolution and collateral benefits. The collateral benefit is the sealing of the borehole against the vertical migration of contamination.

The method in general

The long name for this method is the flexible liner hydraulic conductivity profiler, FHCP. The process is the forcing of water into every flow path, at a known pressure, and the measurement of the flow rate. That sounds like a straddle packer test. Throughout this paper, there will be a comparison with straddle packer methods to illustrate the similarities and the differences.

The process is to install a flexible, everting liner into the borehole. The liner is driven by an internal pressure. As the liner everts (a term that will be explained) down the hole, it forces the borehole water into the formation. The essence of the method is the measurement of the flow into every "significant" flow path as the liner progressively seals the borehole from the top to the bottom. The advantages are the location and hydraulic conductivity measurement of all significant flow paths in the borehole in one-half hour to several hours, relatively independent of the hole depth.

The method in detail

First, one must understand how an everting flexible liner is installed in a hole. The flexible liner installation procedure is shown in Fig. 1. The liner is fed, inside out, from a shipping reel at the wellhead. The open end of the liner is clamped to the casing and the liner is then pushed down into the well. Water is added to the concentric pocket formed by the liner. The water pressure forces the liner deeper into the hole. When the liner reaches the water table in the hole, the water in the hole is forced out of the hole by the pressure of the descending liner. Since the liner is everting (the opposite of inverting) as it rolls out against the hole wall, the liner does not slide against the hole wall. Rather, it grows in volume at the bottom end, which we call the *eversion point*. As the liner grows in length at the eversion point, it forces the water in the hole out the available flow paths. As the liner descends, it sequentially covers the flow paths. The liner descent rate is controlled by the rate that water can flow from the hole into the formation.

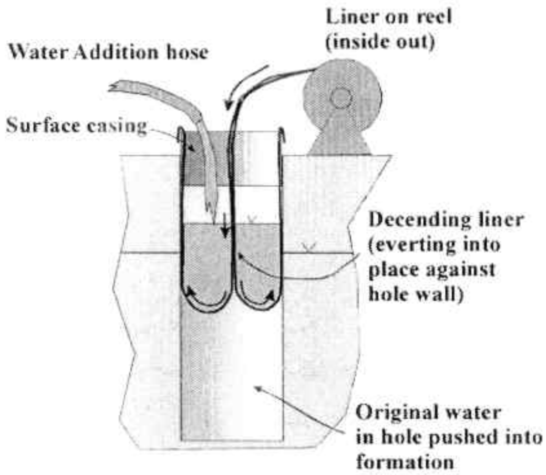


FIGURE 1. Blank liner installation

This blank liner installation is relatively simple and is often done by someone standing at the wellhead with a water hose to supply the water. Often a chair is desirable for that person to be comfortable while the liner descends, pulling itself off of the reel. It takes little effort on the part of the installer. (See Fig. 2 for an installation of a liner in Maine. The operator is switching a pump as needed to keep the liner filled to the top of the casing as the liner descends.) As the liner descends, it slows as the available flow paths are sealed and the remaining transmissivity decreases. The liner descent rate is usually dominated by the hole flow path distribution, the conductivity of those flow paths, and the rate at which water is supplied to the interior of the liner. The liners are removed by the reversal of the procedure.

FIGURE 2. Liner installation

By adding a distance meter to the liner installation, Fig. 3, and a measure of the excess head in the liner above the water table in the formation, we convert the normal blank sealing liner into a flow meter. The flow measured is the flow rate out of the hole. The liner of cross-section A, as shown in Fig. 4, is displacing the water downward with a velocity v_z. The flow rate out of the hole is $Q = v_z \times A$. As the liner propagates, it covers the flow paths sequentially. When the liner travels down the hole, the pressure distribution in the hole below the liner is that shown in Fig. 5A. It is a uniform overpressure throughout the open hole, and there is no overpressure where the liner has sealed the hole. Under the uniform overpressure, flow is occurring out of all unsealed flow paths below the liner. The transmissivity, T(z), below the liner is due to all the unsealed flow paths. As the liner eversion point depth, z,

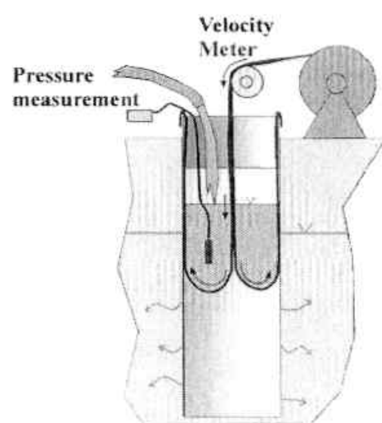


FIGURE 3. Additional measurements to convert a blank liner installation into a profiling device

increases, T decreases.

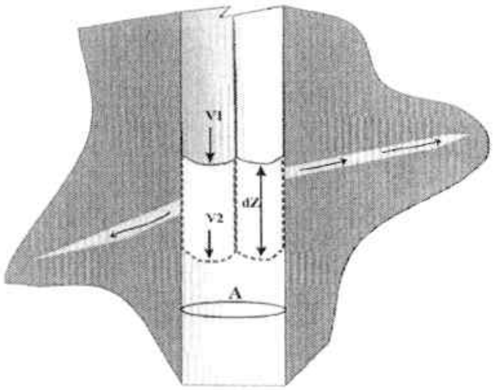
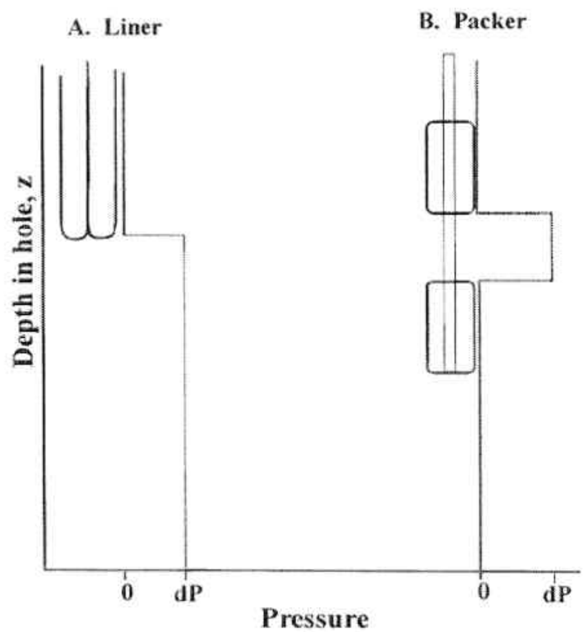


Fig. 4. Liner passing a fracture

We measure the velocity of the liner propagation down the hole to obtain a velocity with depth curve as seen in Fig. 6 (a hole in Paterson, NJ). The velocity is monotonically decreasing as the liner propagates to the bottom of the hole for a constant excess head in the liner. If the liner excess head is varying, the velocity will actually increase as the head increases and decrease as the head decreases. Since this is essentially a linear relationship, we simply divide the velocity by the driving head in the liner to get the velocity per unit driving pressure. That velocity is the one that should be monotonically decreasing. That is what is plotted in Fig. 6.

When the liner seals a flow path, the transmissivity drops by an amount dT. There is a corresponding drop in the flow rate out of the hole $dQ = A \times dv_z$, where dv_z is the drop in the velocity of the liner propagating down the hole. As the liner depth, z, increases, T decreases. Another way of saying that is that the velocity v(z) is monotonically decreasing as the liner moves more and more slowly down the hole.

Fig. 5. Pressure distribution with liner and packer



One can easily see in Fig. 6 where the step changes occur in the velocity. Each step is the location of a flow path. The magnitude of the velocity change is a direct measure of the flow rate into that flow path before it was sealed by the advancing liner.

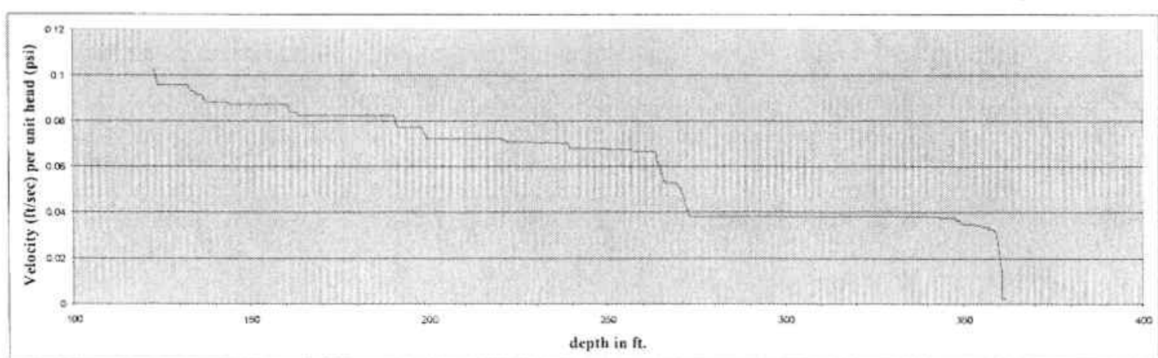


Figure 6. Liner velocity profile in hole

The liner velocity is typically measured every 2 seconds. The excess head, the liner driving force, is recorded at the same time. The pressure in the water below the liner is essentially that in the liner, if the liner is fed freely into the hole. In reality, the liner has some tension on it and the pressure below the liner is calculated as a function of the tension on the liner.

Once the flow rate, the driving pressure for the flow, and the location of the flow path are in hand, we can calculate either a transmissivity distribution (the preferred result) or a conductivity distribution in the hole, and plot it as seen in Fig. 7 (the conductivity). The transmissivity is independent of the liner velocity, but the length of hole assigned to the conductivity calculation depends upon the liner velocity. However, both are correct within the mathematical definition. As the liner passes a permeable bed, the velocity change will occur over a longer interval as a slope in the velocity curve rather than a step change. In the measurement, it is a series of small step changes.

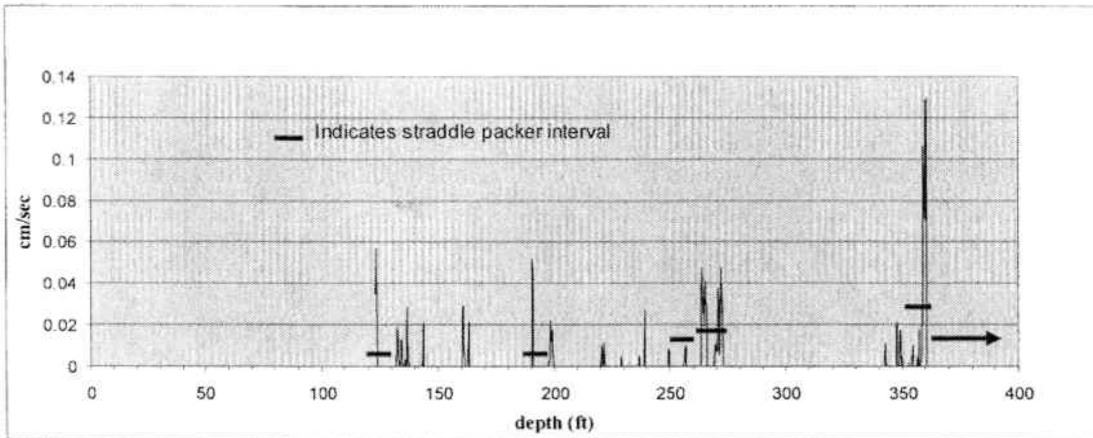


Figure 7. Conductivity profile from velocity profile

It is noteworthy that the conductivity plot of Fig. 7 calculated from a real velocity plot, Fig. 6, shows very fine spatial details of the flow path distribution as well as flow capacity. The very large flow path at 360 ft is obvious in the velocity curve.

Comparison with Straddle Packers

We were provided with straddle packer tests results after we performed the measurement in Fig. 6. The packer tests were done before the liner installation. Fig. 8 shows the integration of the detailed liner measurement over the same interval as the packer test, plotted with the packer test results. The results from this early test of the method were quite satisfying.

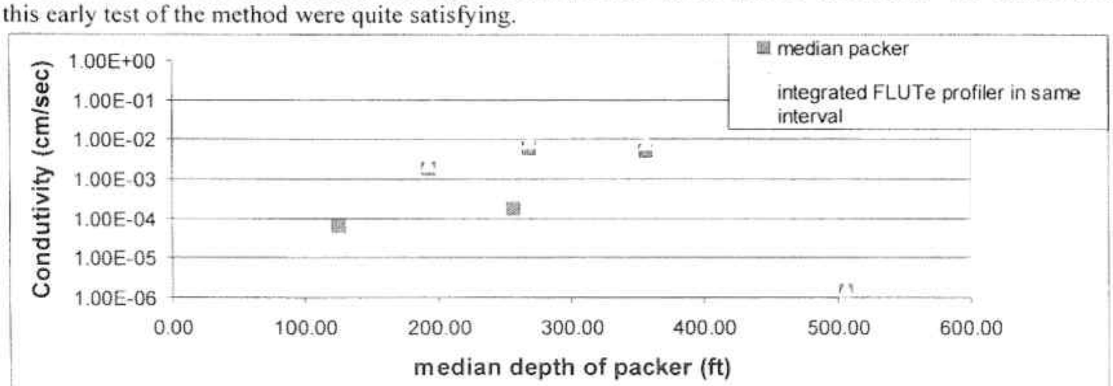


Figure 8. Comparison of straddle packer results to FHC Profiler results

So, what is different from a packer test? First, there is the time to perform the measurement. The measurement of the data in Fig. 6 was done in about 1.5 hr. for 370 ft of hole. A measurement of a hole in Cambridge, Ontario took ~36 min. for 328 ft. That same hole had a complete suite of packer tests over its entire length that took two people, four days. The set up time in each case is about an hour. In other words, it takes only 5-10% of the packer testing time to perform the blank liner installation. The longest liner profiling done to date is 4 hours. That was because of the desire to measure to very low transmissivity levels in a hole with very low flow out of the bottom quarter of a 400 foot hole (those results are shown in the Field Test Results section hereafter).

The time it takes to profile a hole is dependent upon the transmissivity of the hole. That factor is more important than the depth of the hole. Therefore deep holes are often measured in less time than some shallow holes.

Another difference from packer testing is that the liner can be sized to fit any size hole and an undersize hole (e.g., 7") can be measured using a larger liner (8-9") without significant effect. The smallest practical size is probably 2" diameter for the current liner fabrics and measurement equipment. The smallest done to date is less than 3.78 inches.

Another comparison with a straddle packer is shown in Fig. 5B. The pressure profile in a packer is high in the straddled interval and ambient above and below. Therefore, there is a tendency for the injected water to try to bypass the packer by flowing upwards or downwards into the open hole beyond the packers. That flow, called leakage, may be via the formation through fractures or matrix permeability, or between the packer and the hole wall (e.g., a rough hole wall). Such bypass is unlikely for a liner because there is no open hole above the bottom end of the propagating liner. The liner is far more flexible than packers, and therefore conforms quite well with the hole wall. Figure 9 is a snapshot from a video of the interior of a liner showing how very well the liner conforms. It looks like it is painted on the hole wall.

During the liner installation, the liner displaces only one hole-volume of water, no more or less. The integral of the flow measurement is correct. For packers, the total flow measured includes a leakage component that can be large, or small, depending upon hole ruguosity and/or formation permeability where the packer is set. Hence, the packer testing provides only an upper bound on the transmissivity of the straddled interval. If another set of guard packers is used (i.e., 4 packers) with pressure transducers, some of the leakage affects can be detected, but the correction for leakage is not practical

Fig. 9. Interior view of liner conforming to hole

In packer testing, one can inject water or extract water to perform the packer test. The highest extraction rate is usually limited by the size of the pump that can be placed down hole through the access pipe. There are no serious limits on the flow rates (conductivities) that can be measured with the liner system. The limit is how fast water can be poured down the open hole.

The installation of a liner is very gentle with respect to hole stability. The liner roles smoothly out against the hole wall, supporting the hole wall material against sloughing. When the liner is later removed by the reverse process (inversion), the liner is gone when the hole wall is no longer supported. The significance is that the liner is unlikely to be trapped in the hole by sloughing of the hole. In contrast, the scraping of the hole wall with the installation, inflation, deflation, and repositioning of the straddle packer assembly is much more likely to cause the hole wall to slough. Entrapment of a straddle packer assembly is a very real concern of straddle packer testing. The consequence is not only the loss of the packer assembly, but sometimes the loss of the hole.

One disadvantage of the liner method is that one can not obtain a sample from the blank liner measurement. However, there is no contaminated-water disposal cost either. There are flexible liner sampling systems available that do collect samples and measure the head at each sampling interval. That is the subject of other papers at this conference.

The realities of field tests and results

Whereas the concept of the liner measurement is quite simple, the implementation requires some diligence. The machine built to perform the measurements is shown in Fig. 10. This machine measures: the position of the liner, the tension on the liner in time, and controls the tension of the liner to a preset value. That data, plus the head measurement inside the liner, is recorded in a lap-top computer every 2 seconds, or as often as desired. A spreadsheet in the same computer converts the raw data to the plots which are shown in this paper.

Most of our customers purchase a blank liner to seal the hole against vertical flow and associated contaminant migration immediately after the hole is drilled. Measuring the velocity of the installation is a simple addition to the normal installation of a sealing liner.

Other results of actual field measurements are shown in Fig. 11 for a site in Paterson, NJ and in Figs. 12 and 13 at Media, Pennsylvania. The time to collect the data is shown on the graph. The velocity graph alone is a very good identification of the significant flow paths.

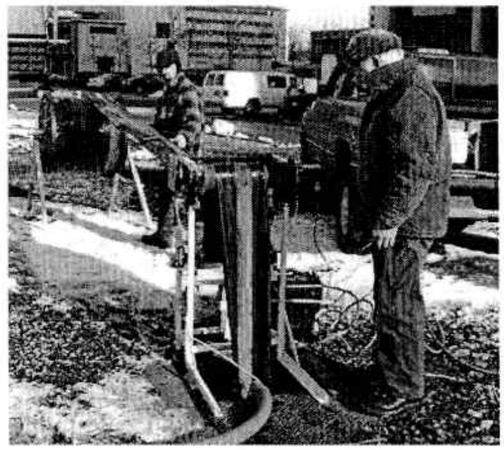


Fig. 10. Profiler machine over 8" hole

Like a pumped-hole velocity profile, the limit of the FHCP resolution is depth dependent. At the top of the hole, where the liner velocity is higher, the resolution is less than at the bottom of the hole. Fortunately, for many geologic sites, the upper most portion of the bedrock is also the most fractured with the largest flow rates and is not limited by the resolution of the method. At the bottom end of the hole, the resolution is extremely high (sub inch) in space and very low flows (< 0.001 gal/sec).

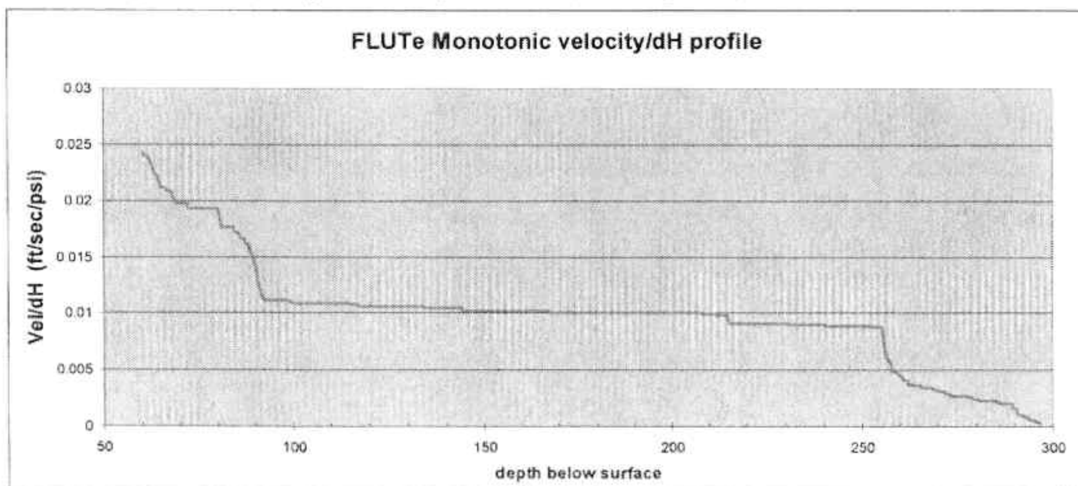


Fig. 11. Profile in 4" hole in Paterson, NJ

Unlike pumped hole velocity profiles, there is no limit on how fast the hole is "pumped" for the liner installation except for how fast water can be poured down the hole. This has an important significance in that the excess head typically is much higher in the liner than the natural head in the hole, and so all flows are outward from the hole with no confusing inflow zones to violate the model. The use of a water flow rate capable of maintaining at least 10 ft of excess head is desirable.

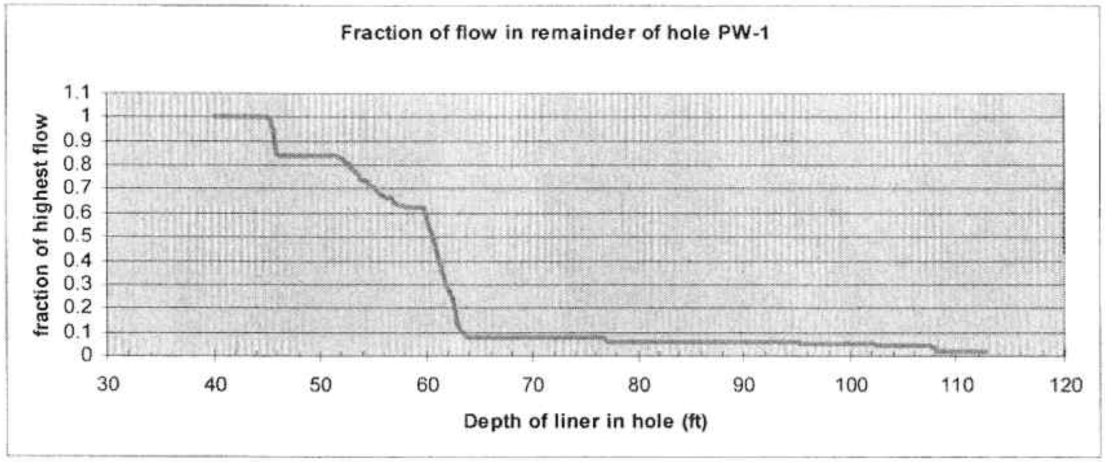


Fig. 12. Profile measured in 200 ft hole in ~3 hrs.

Later, measurements of actual head distribution in the formation (e.g., using a multi level system) can be incorporated into the calculation of a refined transmissivity distribution in the hole. The initial assumption is that the head in the formation is constant.

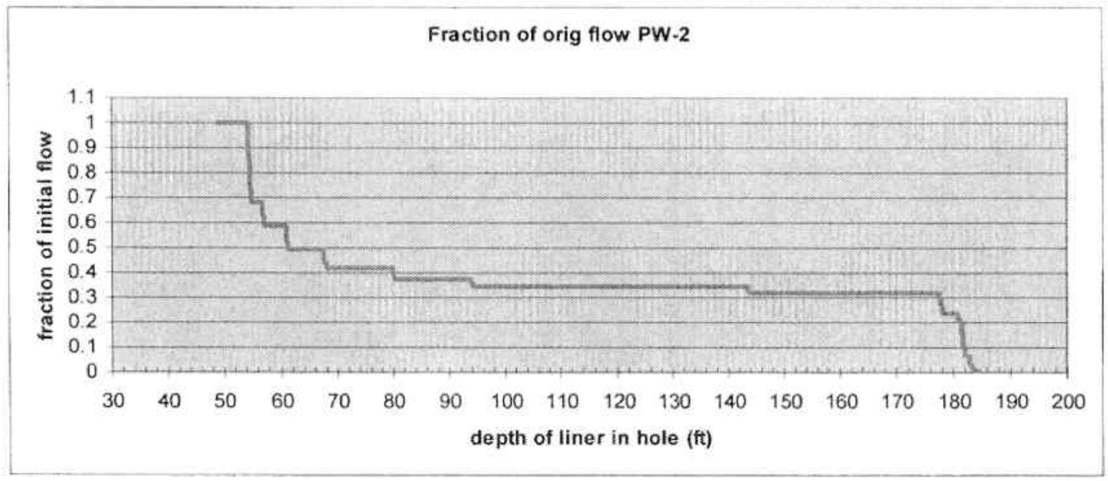


Fig. 13. Profile measured in 185 ft hole in ~30 minutes.

This kind of measurement was first done with our linear capstan system which can pull liners out of holes with 1000 lb of force while measuring the tension and velocity of the liner. Since then, there have been continuing improvements in the procedures and the hardware to obtain better and better sensitivity of the measurement. The data shown was obtained with the state of the art 6-12 months ago. Much has improved since then.

Mathematical models have been developed which can now predict the liner descent velocity based upon estimates of the conductivity profile. This is very useful in assessing the effects of the many variables on the installation such as hole diameter, depth, conductivity, excess head, and friction. Small diameter holes can be profiled more quickly than large diameter holes intersecting the same flow paths because the liner displaces one hole volume, or most thereof.

There is always a question of how this method will work with different conditions. There is no theoretical limit to how deep these liners can go in a hole. The practical limitations are the differential pressures that the liner may experience with great depths. The liner will burst at about 65 psi, if unsupported, in a 6 inch diameter. That is about 150 ft of excess head. Smaller diameter holes can withstand higher differential pressures. The liners propagate through most breakouts quite well. A very large, eccentric breakout with a flat floor can stop the liner, but rarely does. For very deep water tables, there is a certain amount of adhesion of the wet inverted liner against the everted liner. There are several procedures for reducing that effect. Overall there are a wide range of ordinary conditions in which this technique works very well.

Extensions of the method

We are currently working on an FHCP system which will measure the same flows while the liner is being withdrawn. This has an attractive application for our NAPL FLUTe system liners which are installed through direct push rods. Those slender (2.5-3") liners may allow the measurement of the hydraulic conductivity in soft sediments (i.e., no stable hole required) as the liners are being inverted out of the hole. The primary purpose of those liners is to map the DNAPL pure product distribution. The conductivity profiling would be helpful to the remediation design.

Conclusion

The FHCP is a simple concept that has been well tested in the field, and has been shown to be a very convenient and inexpensive means of measuring the significant flow paths intersected by a borehole. The data produced is much more detailed than is obtained with normal straddle packer tests. The limits of resolution are already very good and are getting better with refinements of procedures and hardware.

The largest cost of the method may be the liner. In clean holes, liners are easily reused (just pull/peel/invert it out of the hole). In contaminated holes, the liner is left in place to seal the hole as long as desired. Typically the flow data is used to select the sampling intervals for a multi level sampling system which can measure head and water quality. We often pull the blank and install our flexible liner multi level sampling system in the same day.

The characteristics of the FHCP make it a very attractive alternative to conventional packer testing. One does not need to select where in the hole the test is to be performed, because the whole hole is easily measured. In combination with the ability to provide a long term seal of the hole by leaving the liner in place, the system seems to have very good utility.

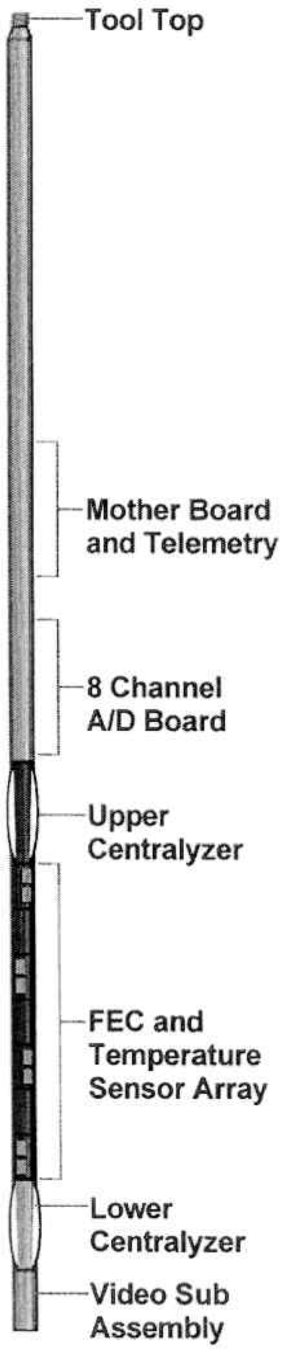
Acknowledgements:

We are very thankful to those who provided the holes for our initial tests and refinements. We are especially thankful to those who also provided other information like packer test results, and video logs of the holes for comparison with the FHCP measurements. These were mainly contaminated sites and not eager for public recognition, but we thank them none-the-less. One research site of the University of Waterloo has been especially useful to our testing of this concept.

* Patents are pending on this method and apparatus in the USA and abroad.

Carl Keller, received a BS in Physics and in Math from Valparaiso University and an MS in Engineering Science from Rensselaer Polytechnic Inst. He spent 3 years developing nuclear reactor calculation models and 25 years designing containment systems for underground nuclear tests. For 10 years he was in charge of all research and containment design for all DOD underground nuclear tests. For 15 years he has developed applications of flexible liners for underground measurements. He received the R&D 100 award in 1994, and holds 12 patents mainly on flexible liner methods. He is owner and principal scientist for Flexible Liner Underground Technologies, FLUTe, 6 Easy St., Santa Fe, NM 87506, carl@flut.com, 505-455-1300, fax 505-455-1400.

Hydrophysical Logging



SPECIFICATIONS	
TOTAL HYDRAULIC HEAD	2000 ft
MINIMUM HOLE DIAMETER	2 in
MAXIMUM HOLE DIAMETER	None
MAXIMUM TEMPERATURE	65°C

RAS provides an advanced method called hydrophysical logging for the hydraulic characterization of aquifers.

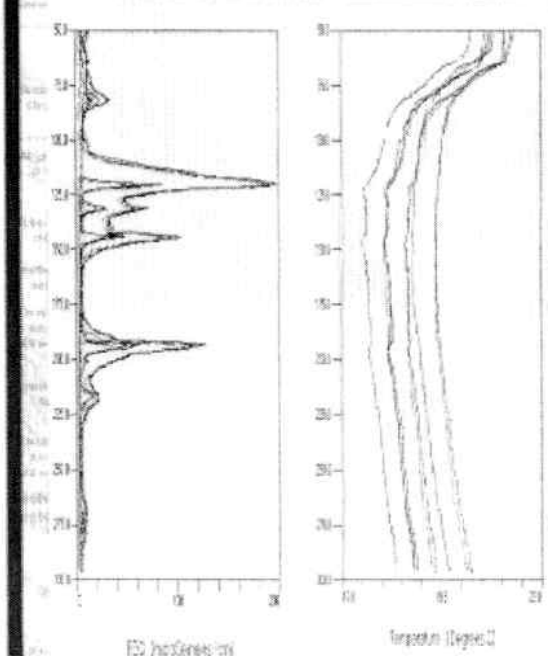
Data acquisition involves logging with RAS's proprietary multi-sensor tool which measures temperature and fluid electrical conductivity. Logging is conducted during procedures replacement of the native wellbore fluids with environmentally safe deionized water. The formation fluids contrast electrically with the deionized water and provide a means of establishing the location of formation fluids and quantifying flow rates in-situ.

The RAS hydrophysical tool is the only multi-FEC/T sensor tool available for the purpose of testing with this technique. Our instrumentation package has been developed as a result of extensive field experience as well as numerous laboratory/numerical simulations conducted in conjunction with several national DOE and USGS laboratories.

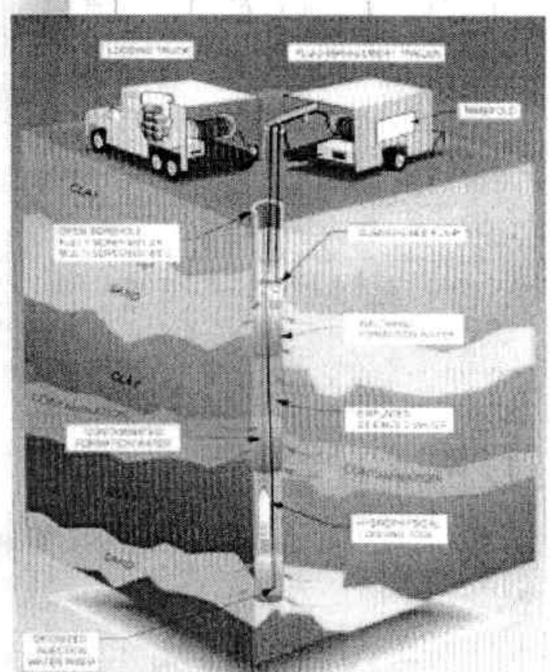
When the hydrophysical method is applied in multiple well investigations, critical data regarding intermediate to large scale permeability and aquifer parameters may be acquired. This information is critical for analyzing the extent of contamination, developing effective remediation plans, understanding groundwater system hydraulics, and calculating aquifer volumetrics/movement.

HYPROPHYSICAL LOGGING SUMMARY

- Technique applicable in a wide variety of hydrogeologic settings: low to high yield bedrock, alluvial/porous settings, karst and volcanic aquifers.
- Both open boreholes and completed wells can be characterized (2 inch minimum diameter).
- Water bearing intervals are identified to one borehole diameter resolution.
- A wide range of interval specific flow rates can be quantified (0.01 to 100+ gpm).
- Flow rates can be assessed independent of borehole diameter.
- Wellbore flow is evaluated under ambient or stressed aquifer conditions.
- A larger volume of aquifer is investigated than by traditional packer testing.
- Interval specific water quality can be evaluated.
- Single and cross-hole aquifer characterization (i.e. larger scale hydraulic connections between two or more wells) can be conducted.
- Data output equivalent to packer testing (Δp and Δq) for transmissivity and hydraulic conductivity can be calculated.



The hydrophysical logging method allows for identification of the water bearing intervals and quantification of the associated flow rates to a high degree of sensitivity.



Formation fluids are replaced with deionized water to allow characterization of in-situ parameters during ambient and pumping conditions.

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RAS
Integrated Subsurface Evaluation

HYPROPHYSICAL LOGGING SUMMARYof KEY POINTS

- **The technique is applicable in a wide variety of hydrogeologic settings: low to high yield bedrock, alluvial/porous settings, karst and volcanic aquifers.**
- **Both open boreholes and completed wells can be characterized (2 inch minimum diameter).**
- **Water bearing intervals are identified to within one borehole diameter resolution.**
- **A wide range of interval specific flow rates can be quantified (0.01 to 100+ gpm).**
- **Flow rates can be assessed independently of borehole diameter.**
- **Wellbore flow can be evaluated under ambient or stressed aquifer conditions.**
- **A larger volume of the aquifer is investigated than by traditional packer testing and is more time and cost effective than packer testing.**
- **Interval specific water quality can be evaluated.**
- **Single and cross-hole aquifer characterization (i.e. evaluate larger scale hydraulic connections between two or more wells) can be accomplished.**
- **Data output equivalent to packer testing** ($\triangle$p and $\triangle$q) **for transmissivity and hydraulic conductivity calculations.**

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Wednesday, December 05, 2007

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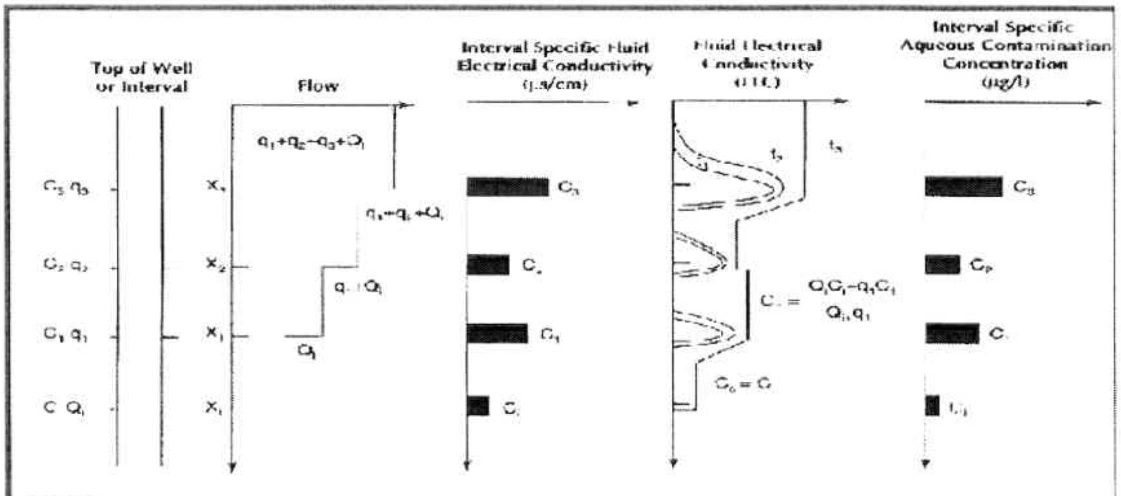
PRINCIPLES OF HPL LOGGING



Legend:
C=Concentration (mass/volume) q=Volumetric Flow Rate (gpm) X=Depth t=Time CiQi-Deionized Water injection

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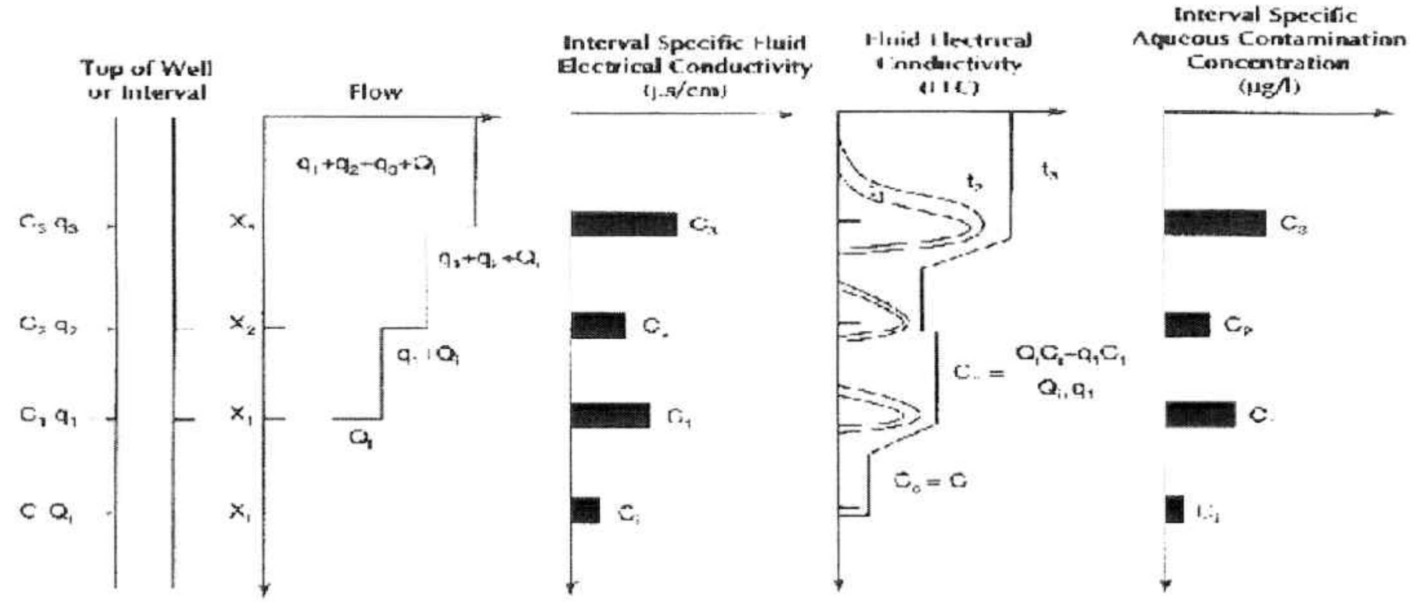
Schematic of well with multiple producing zones. During pumping/non-pumping conditions, each zone is characterized by two parameters: volumetric rate of inflow/outflow, qi, and interval specific concentration, Ci, of the constituent of interest. These constituents range from total dissolved solids (TDS), pH, and hardness (calcium,	Flow schematic with the pump set above the upper most producing intervals (e.g. fractures): a step change increase in flow will occur at each producing interval. As fluid moves from the bottommost interval toward the pump, the flow rate will increase in a step-like	In addition to quantification of flow, HpL evaluates interval specific fluid electrical conductivity (~ TDS).	The integrated relationship between flow and FEC results in a unique time series of electrical conductivity profiles during pumping after the borehole is flushed with deionized water.	As HpL can identity water bearing zones during pumping, a down hole discrete point fluid sampler can be used during flowing conditions to obtain samples above each interval. The observed concentrations generated by this hydrochemical analysis and the interval specific flow rates are used to calculate" actual" (pore water) concentrations

magnesium, iron) to aqueous phase VOCs, pesticides and radionuclides.	function until the point above X3 where total flow is observed.			of any aqueous phase contaminant.



Legend:
C=Concentration (mass/volume) q=Volumetric Flow Rate (gpm) X=Depth t=Time CiQi-Deionized Water injection

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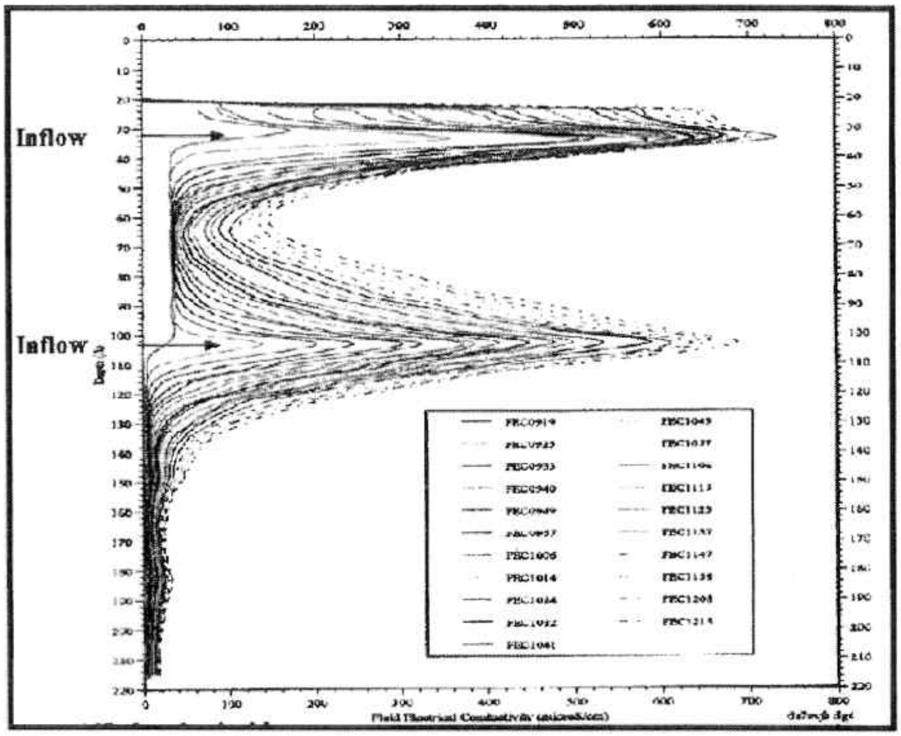
EXAMPLES OF HpL RESULTS

Ambient Horizontal Flow

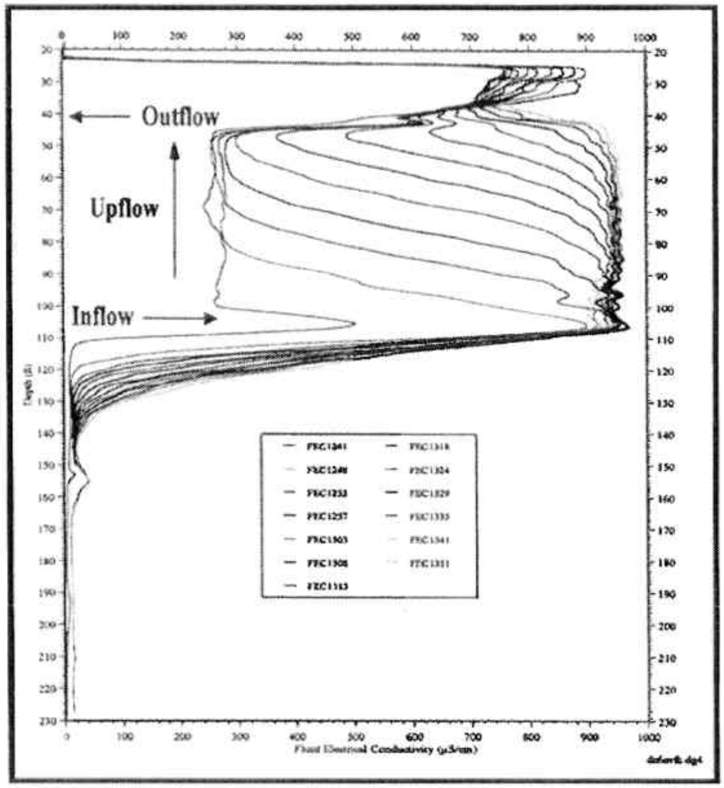


This example shows hydrophysical logs acquired during ambient conditions in the well. Each log represents fluid conditions at a given time following deionized water emplacement. For ambient flow characterization, no pumping is conducted after deionized water emplacement. Based on these hydrophysical logs, it is determined that horizontal inflow is occurring at 32 and 104 feet.

Integrated Subsurface Evaluation

EXAMPLES OF HpL RESULTS

AMBIENT VERTICAL FLOW



Example of hydrophysical logs during ambient vertical (upward) flow conditions. A series of fluid electrical conductivity logs is acquired after flushing the wellbore fluids with deionized water. For ambient flow characterization, the logging is conducted after deionized water is emplaced but before any pumping is initiated.

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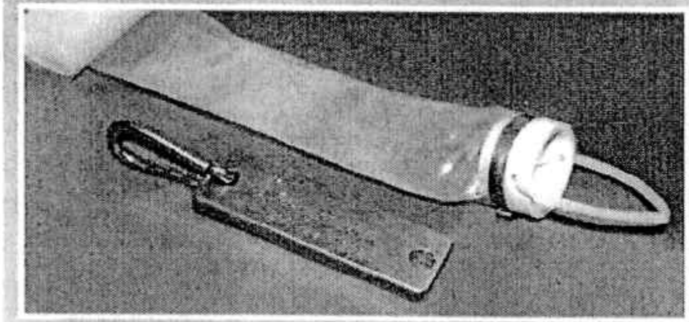
HYDRASleeve

U.S. Patent No. 6,481,300; others pending

Beats bailers for sampling accuracy, turbidity & cost



- Short and long term monitoring
- Low-yield wells
- UST applications
- Discrete interval sampling and vertical profiling

No-Purge Sampling

Cut groundwater sampling costs in half with HydraSleeve

U.S. Patent No. 6,481,300; others pending

No-Purge Groundwater Sampler

Unlike any other groundwater sampler, the HydraSleeve instantaneously "cores" a whole water sample from a defined vertical and horizontal interval (usually within the well screen). HydraSleeve samples do not blend fluid from different vertical zones or pull water in from outside the well screen, but instead sample via ambient and/or diffusive flow of groundwater through the well screen.

The sample is collected without purging and with very little downwell disturbance, providing excellent control of turbidity. This minimizes the time spent on filtration of turbid samples typically collected after purging with a bailer or submersible pump.

Samples can be collected at in-situ pressure with almost no aeration or degassing. This prevents alteration due to loss of volatiles or oxidation of sensitive parameters. Samples can be analyzed for all parameters.

HydraSleeve samplers are inexpensive, disposable, and very quick and easy to use, resulting in significant savings on startup and ongoing costs when compared to other sampling equipment such as bailers or pumps.

Applications

HydraSleeve is the best available technology for sampling low yield wells. It is suitable for both short and long term groundwater monitoring, and is especially useful in narrow, constricted, or damaged wells. It can also be used to sample discrete intervals from surface water bodies and tanks.

Cost savings of HydraSleeve sampling (typically 50 to 75%) make it an extremely effective option for monitoring UST leaks, dry cleaning plants, and other small-scale point-source contaminant sites.

Samples collected with the HydraSleeve correlate well to other sampling methods, and it can even be used for special challenges such as in-well vertical profiling of multilayered contaminant concentrations.

This photograph shows a HydraSleeve after collecting a simulated sample in a clear column of water with red oil floating on the surface. As shown, once the HydraSleeve is full, the closed check valve prevents mixing of any liquid from the upper part of the well into the sample.

HYDRASLEEVE FACTS

- HydraSleeve samplers are inexpensive, disposable, and easy to use.
- A discrete, instantaneous "core" of water is collected from a precisely defined vertical and horizontal interval.
- Samples are collected with little or no aeration, agitation, degassing, or displacement.
- Samples can be collected at in-situ pressure and analyzed for all parameters.
- HydraSleeve samples do not blend fluid from different vertical and/or horizontal zones.

Why No-Purge Sampling Is Better

Historically, the accepted protocol for sampling groundwater monitoring wells required removal of 3 to 5 times the volume of standing water in the well screen, casing, and surrounding filter pack prior to sampling. This "purging" was done to assure that samples came from the screened interval and did not contain stagnant water from the unscreened portion of the well.

Using bailers or pumps, this purging was a time-consuming, costly process; if the well was contaminated, purge water handling, containment, and disposal added expense and hazards to the sampling process.

Over the years, researchers interested in simplifying groundwater sampling have tried to find ways to reduce the burden of purging. Some recent advances in this effort include low-flow pumping and passive diffusion sampling.

The common underlying principle behind these methods and the HydraSleeve is the premise that the screened interval of the well is in dynamic equilibrium with the surrounding formation. Many studies have shown that the flow of groundwater through most well screens is primarily horizontal and laminar, with little or no mixing with the overlying water column.

The HydraSleeve collects a "core" from this water with minimal disturbance, thus delivering a highly representative sample quickly and easily, without generating purge water.

How It Works

The HydraSleeve consists of three basic parts — a reusable weight, a long, flexible sample sleeve (usually a polyethylene tube creased to lay flat), and a check valve. The bottom of the flexible tube is sealed and the weight is attached to it. A top-loading check valve assembly includes an attachment point for the suspension line.

HydraSleeve use is simple and can be performed by one person. The sampler is lowered into the well; after the water column returns to equilibrium, the HydraSleeve is recovered with no mixing from the overlying water in the well.

USING THE HYDRASLEEVE

1 Sampler Placement
The reusable weight is attached and the HydraSleeve is lowered and placed at the desired position in the well screen. In-situ water pressure keeps the sleeve collapsed and check valve closed, preventing water from entering the sampler. Well is allowed to return to equilibrium.

2 Sample Collection
The check valve opens to allow filling when the sampler is moved upward faster than 1 foot per second, either in one continuous upward pull or by cycling the sampler up and down to sample a shorter interval. There is no change in water level, and minimal agitation during collection.

3 Sample Retrieval
When the flexible sleeve is full, the check valve closes and the sampler can be recovered without entry of extraneous overlying fluids. Samples are removed by puncturing the sleeve with the pointed discharge tube and draining the contents into sample containers or field filtration equipment.