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Subject: Pore Water and Seepage Study Overview  
PG&E Topock Compressor Station, Needles, California

Dear Mr. Shopay:

Enclosed is the *Pore Water and Seepage Study Overview*, prepared in compliance with the Department of Toxic Substances Control's (DTSC) letters of June 9 and June 30, 2005 and in consultation with DTSC during subsequent conference calls. This overview describes the conceptual site model and presents technical information on available seepage evaluation and pore water sampling methods.

Please contact me at (805) 546-5243 if you have any questions or if you need additional information.

Sincerely,

*Teri Hesson  
for Yvonne Meeks*

Enclosure  
cc: CWG Members

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# **Pore Water and Seepage Study Overview**

**PG&E Topock Compressor Station  
Needles, California**

July 13, 2005

Prepared for  
**California Department of Toxic Substances  
Control**

On behalf of  
**Pacific Gas and Electric Company**

**CH2MHILL**  
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# Acronyms and Abbreviations

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BLM	United States Bureau of Land Management
BN&SF	Burlington Northern & Santa Fe
BOR	United States Bureau of Reclamation
Cr(III)	trivalent chromium
Cr(VI)	hexavalent chromium
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CWG	Consultative Workgroup
DTSC	California Department of Toxic Substances Control
E&E	Ecology and Environment, Incorporated
IM	Interim Measure
PG&E	Pacific Gas and Electric Company
PWSS	Pore Water and Seepage Study
RFI	Resource Conservation and Recovery Act Facility Investigation
SAP	Sampling and Analysis Plan
TWG	Technical Working Group
USEPA	United States Environmental Protection Agency
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey

# 1.0 Introduction

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Pacific Gas and Electric Company (PG&E) is addressing chromium in groundwater at the Topock Compressor Station in Needles, California, under the oversight of the California Environmental Protection Agency, Department of Toxic Substances Control (DTSC). On June 9, 2005, DTSC issued a letter entitled “Requirement for Submittal of Pore Water and Seepage Workplan, Pacific Gas and Electric Company, Topock Compressor Station, Needles, California (EPA ID No. CAT080011729)” to PG&E. In that letter, DTSC required that PG&E begin planning for a pore water sampling and seepage measurements in the Colorado River.

Figure 1-1 shows the location of the Topock Compressor Station, site features, and the approximate study area for the Pore Water and Seepage Study (PWSS).

## 1.1 Investigation Background

Per DTSC’s June 9 letter, PG&E submitted a technical memorandum entitled *Conceptual Approach for a Pore Water Sampling and Seepage Study* on June 27, 2005. The technical memorandum presented an approach and focused on a set of pore water sampling methods applicable to the site. In a letter dated June 30, 2005, DTSC provided comments and further recommendations for the PWSS.

This submittal, the *Pore Water and Seepage Study Overview*, has been prepared in compliance with DTSC’s June 9, 2005 letter and June 30, 2005 and in consultation with DTSC during subsequent conference calls on June 29 and July 6, 2005. Per the conference calls, PG&E shall first submit this overview on July 13, 2005 to allow for input by the Technical Working Group (TWG) and review by DTSC. Following review of this submittal by DTSC and discussion during the TWG meeting on July 20, 2005, a Draft Work Plan and other accompanying deliverables will be developed in accordance with DTSC’s direction.

### 1.1.1 Overview of Current Site Characterization and Monitoring

In July 2004, PG&E submitted a *Sampling and Analysis Plan, Groundwater and Surface Water Monitoring* (SAP) (CH2M HILL 2004) that describes the scope, schedule, and sampling and analysis procedures for the ongoing Groundwater and Surface Water Monitoring Program. The SAP, approved by DTSC, establishes specific objectives for surface water monitoring at the Topock site, including routine monitoring of near-shore surface water locations both upgradient and downgradient of the Topock site. This program is being further augmented by routine collection of depth-specific surface water samples in the river channel, commencing in July 2005. The additional river channel sampling stations are located approximately one-third of the river width from the corresponding shoreline stations, on the California side (see Figure 1-2). Samples will be collected from 1 foot off the bottom of the river channel, halfway through the water column, and within 1 foot of the water surface (revised SAP) (CH2M HILL 2005a). A pore water sampling and seepage study is being developed in the context of this current surface water sampling program. The upcoming

depth-specific surface water sampling results will provide data that can be compared with pore water sampling results.

### 1.1.2 Previous Pore Water Sampling

Two separate sets of shallow sediment pore water samples have been collected and analyzed for pore water quality using two distinct methods. Both sets were obtained from the edge of the Colorado River in the immediate vicinity of the Topock site and at various upstream reference locations. Samples were collected in 2003 by Ecology and Environment, Inc. (E&E), and the results were reported as part of the Draft and Final Resource Conservation and Recovery Act Facility Investigation reports (RFI) (E&E 2004; CH2M HILL 2005b). In addition, the United States Geological Survey (USGS) collected and analyzed river sediment samples in 2001 (May et al. 2002) for the United States Fish and Wildlife Service (USFWS) and reported the results in a report dated March 2004 (Ingersoll et al. 2004).

For the 2003 RFI pore water characterization (E&E 2004), eight samples from both upstream and within-site locations were collected by wading into the river from shore or a boat, and pushing a drive point piezometer 2 to 3 feet into the river sediments. All samples collected were labeled as "close to shore." A peristaltic pump was then used to sample the water directly from saturated sediments around the drive point. Pore water samples were analyzed using State-certified United States Environmental Protection Agency (USEPA) Method 7196A. Hexavalent chromium [Cr(VI)], at a detection limit of 10 micrograms per liter, was not found in any sample, including those in the river sediments near floodplain wells MW-27, MW-28, and MW-29. Background (upstream) sites included Park Moabi and the river north of Bat Cave Wash. Presumably, those samples collected from several feet deep in river bottom sediments would be representative of shallow groundwater conditions.

In contrast to the interstitial RFI samples, the top 5 centimeters of surface sediments were sampled from the river's edge for the USGS/USFWS study in 2001 (May et al. 2002, Ingersoll et al. 2004). The report does not include identifiable sample locations, making it difficult to assess what area relative to the Topock site is represented by the samples. More importantly, available data suggest that the sampling and analysis methods used in the study have resulted in trivalent chromium [Cr(III)] being falsely reported as Cr(VI). At a minimum, the methodology did not distinguish between Cr(III) and Cr(VI), and results reported as Cr(VI) for upstream and downstream locations are consistent with previous river sampling results reported for total chromium.

The USGS method consisted of homogenizing the sediments in the laboratory and extracting pore water samples from the homogenized sediment slurry. By collecting the pore water in this manner, the method probably measured chromium in the dissolved and colloidal states. Additionally, the samples were analyzed by a research-level, non-USEPA approved cation exchange method. This method is not comparable to the direct measurement of Cr(VI) using USEPA Method 7199 and is likely to include Cr(III) in the results. Under the USGS method, all river sediment samples tested yielded detectable Cr(VI), ranging from 0.5 to 6.1 micrograms per liter in concentration, which indicates the unlikely universal presence of Cr(VI) in pore water upgradient, adjacent to, and downgradient of the site. The presence of organic-bound or colloidal fractions of Cr(III) (both very likely possibilities for pore water sampled from a sediment slurry) would have

yielded false-positive Cr(VI) values in this case; the analytical method would have recorded those fractions as Cr(VI) instead of Cr(III). The study results, particularly the ubiquitous presence of Cr(VI) upstream and downstream of the site, appear to be questionable. The USFWS reported that the chromium detected in their pore water samples was likely to be Cr(III) rather than Cr(VI) (presentation by Carrie Marr to the Consultative Workgroup [CWG], June 16, 2005).

## 1.2 Site Conceptual Model

The Topock site is located at the extreme southern end of the Mohave Valley, just above where the river enters the Topock Gorge. Bedrock outcrops to the south and west of the site create barriers to groundwater flow (Figure 1-1). In contrast to the overall trend of southerly groundwater flow throughout most of the Mohave Valley, groundwater flow directions at the Topock site are predominantly north to northwesterly. Groundwater at the Topock site is recharged primarily from local precipitation rather than from the Colorado River. Consequently, due to the limited amount of local recharge, the groundwater gradients at the Topock site are very slight.

Interaction of groundwater with the Colorado River is complex. The daily fluctuations in river stage, typically several feet each day, cause the surface water-groundwater interaction at this site to be very dynamic. Water levels in wells located several hundred feet from the river fluctuate on the order of feet due to fluctuations in river stage. In this way, the Colorado River switches between a gaining stream and a losing stream daily.

The stage of the Colorado River also varies seasonally in response to upstream dam discharge for resource management and electricity production. During winter and spring months, the river stage is higher than surrounding groundwater levels, and groundwater gradients indicate recharge to the aquifer occurs. During the late summer and fall, river levels drop several feet and groundwater gradients are generally towards the river. Metzger and Loeltz (1973) reported that the Colorado River is by far the principal source of recharge to groundwater in the Mohave Valley. However, this does not appear to be true across most of the Topock site, where the groundwater system is recharged from precipitation on the nearby mountains and infiltration from the intermittent flows in the desert washes.

The Colorado River affects groundwater levels at the Topock site. Wells completed in the fluvial sediments often show substantial influence due to river stage fluctuations, caused by Davis Dam release patterns. For a foot change in river level, some wells, such as the MW-34 wells, respond with a corresponding head change of over 0.6 foot. The head change observed at the well is in some cases clearly a function of distance from the river. Due to these river fluctuations, groundwater gradient shifts direction daily as well as seasonally in the floodplain area. The alluvial wells are also affected; seasonal river influences on groundwater hydraulic head have been observed as far away as well MW-16, located southwest of the evaporation ponds and more than 4,500 feet from the Colorado River.

## 1.3 Study Objectives

The primary objectives of this study, as outlined in the June 30 DTSC memorandum, are to:

- Evaluate the fate and transport of chromium observed in the floodplain area.
- Establish background levels of chromium in pore water.

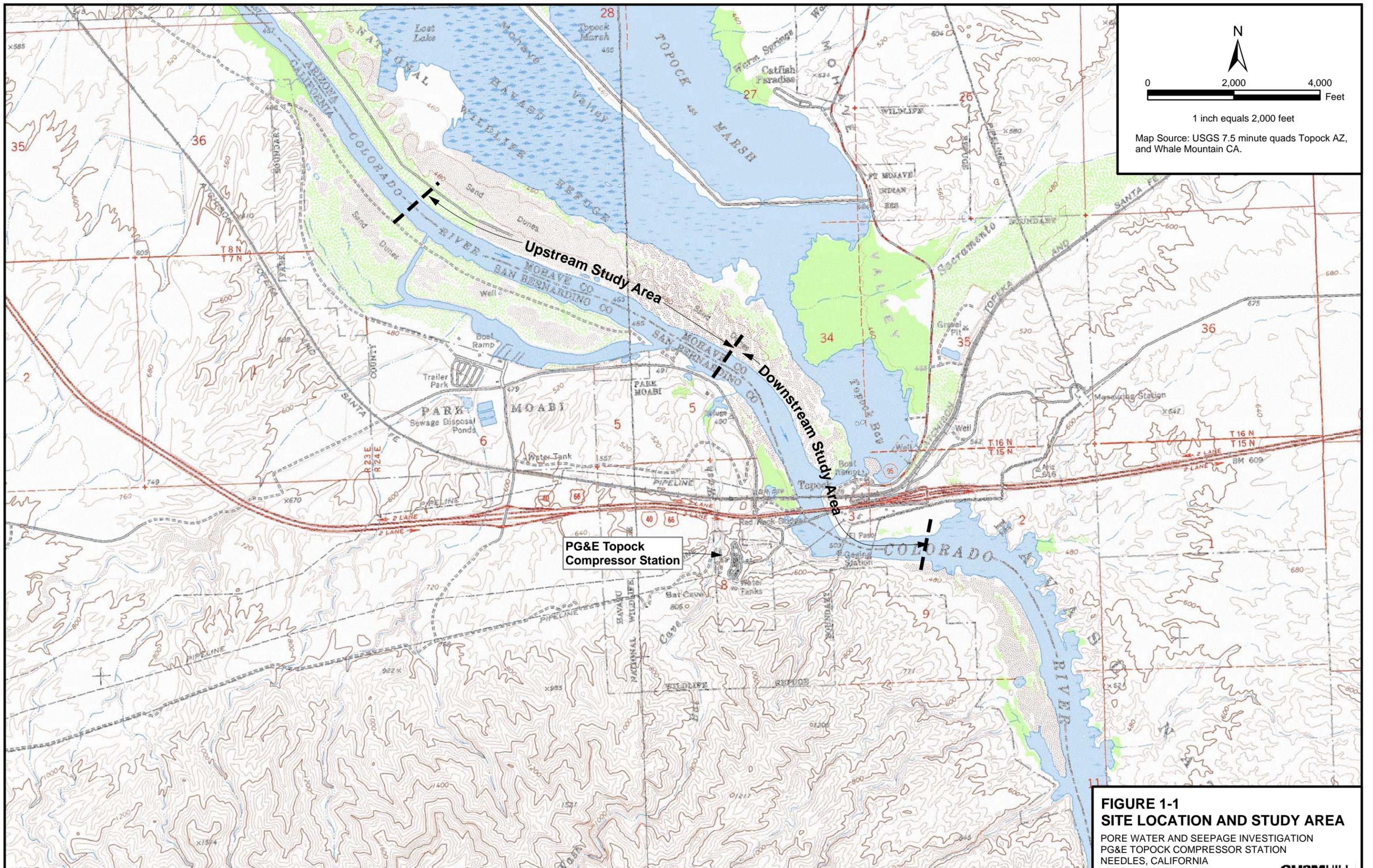
## 1.4 Data Interpretation and Considerations

Pore water sampling is generally performed as part of an ecological risk assessment on the benthic community, where microbial, meiofaunal, and macrofaunal receptors are the subject of analysis (SETAC 2001). These studies primarily focus on toxicity testing. The term “pore water” has a specific meaning to toxicologists; it refers to interstitial water in the uppermost 10 cm where the benthic organisms live. However, for the purposes of this memorandum, pore water is characterized as water in pore spaces immediately beneath the river.

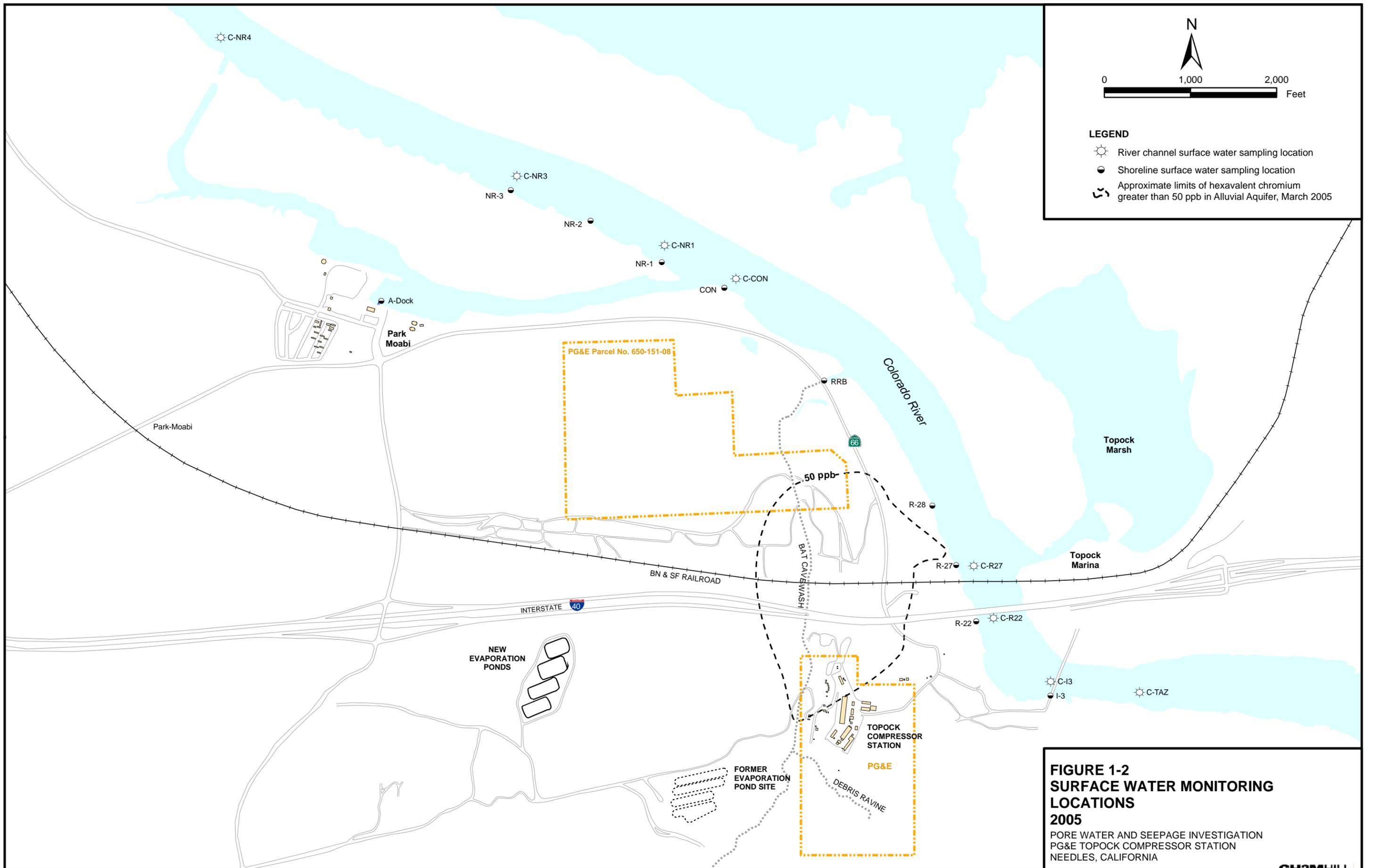
The presence of constituents of concern in pore water does not provide direct indication of any impact to the overlying surface water. In order to evaluate the surface water impact, it is necessary to quantify the constituents of concern concentration, the magnitude of pore water flux to the overlying surface water, and the geochemical environment in the river substrate. At the Topock site, a pump-and-treat/truck remediation system has been operating since March 2004 and is effectively controlling groundwater gradients in the floodplain near the river and for some distance under the river. Within the zone of influence of TW-2D pumping, located about 600 feet from the Colorado River, constituents in pore water (if present) would tend to migrate downward, away from the river.

Cr(VI) is also naturally occurring in groundwater in the Mohave Basin. Studies are currently underway to evaluate the concentrations of natural background Cr(VI) in the vicinity of the Topock site. Thus, Cr(VI) in pore water could be associated with naturally-occurring Cr(VI). A detection of Cr(VI) in pore water could indicate:

- There is naturally-occurring Cr(VI) in pore water.
- There is naturally-occurring Cr(VI) in discharging groundwater.
- There is naturally-occurring Cr(VI) in surface water.
- A sampling error occurred (many of the potential pore water sampling techniques are untested or could introduce interference).
- A laboratory error occurred or the limits of the laboratory precision methods were exceeded (e.g., the USFWS sampling).
- The Cr(VI) is associated with the Topock site.



**FIGURE 1-1**  
**SITE LOCATION AND STUDY AREA**  
 PORE WATER AND SEEPAGE INVESTIGATION  
 PG&E TOPOCK COMPRESSOR STATION  
 NEEDLES, CALIFORNIA



**FIGURE 1-2  
SURFACE WATER MONITORING  
LOCATIONS  
2005**  
PORE WATER AND SEEPAGE INVESTIGATION  
PG&E TOPOCK COMPRESSOR STATION  
NEEDLES, CALIFORNIA

## 2.0 Study Approach and Rationale

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### 2.1 Overview of Study/Work Plan Design

Per the DTSC letter dated June 9, 2005, a seepage evaluation and additional pore water sampling and measurements are requested to supplement the existing data set. The following activities are proposed to plan, permit, and execute the seepage and pore water study:

- Develop conceptual approach for the seepage evaluation and pore water sampling study based on the June 30 DTSC memorandum (included in this submittal).
- Compile technical information on available seepage evaluation and pore water sampling methods (included in this submittal).
- Discuss study approach and methods with DTSC and the TWG.
- Complete the screening of methods per study objectives and site conditions (to be performed in conjunction with the TWG).
- Contact agencies that may have jurisdiction over permitting, approving, and/or certifying this work.
- Prepare Draft Work Plan for the selected methodology for submittal to DTSC and the TWG.
- Initiate formal permitting based on the Draft Work Plan.
- Prepare Scope of Work for seepage evaluation and pore water sampling.
- Prepare Final Work Plan incorporating DTSC comments and TWG consensus.
- Procure subcontractors and equipment.
- Obtain all necessary permits, approvals, and certifications.
- Conduct seepage evaluation and pore water sampling work.

The study design will include a discussion of the approach and methods in consultation with the TWG, CWG, and DTSC, with the ultimate goal of a selection of seepage evaluation and pore water sampling method(s). This selection of methods to evaluate groundwater/surface water seepage and sample pore water should include a discussion of data quality objectives. At a minimum, these objectives will address:

- Appropriate methodology for collection of undisturbed samples.
- Appropriate methodology for maintaining sample redox conditions.
- Appropriate sample volume.
- Appropriate sample matrices (sediment and pore water sample or pore water only).

- Appropriate sampling depth.
- Appropriate timing of the sampling.

## 2.2 Study Design Considerations

The physical location of the sediment, its particle size distribution and level of compaction, and the final use of the data typically dictate the type of sampler used and the collection methodology that is chosen (USEPA 2001, SETAC 2001). Site conditions of particular importance include the depth of the water body overlying the sediment and the strength of the river current.

The potential sampling locations at the Topock site will be subject to water turbulence and high water velocities (2 to 3 ft/sec) where it may be difficult for a boat or diver to maintain a fixed position. The Colorado River level at the Topock site varies almost continuously in response to the variable release of water from Davis Dam, and to a lesser degree in response to changes in Lake Havasu level. Seasonally, the average river level at the I-3 gauge varies by about 5 feet. Daily variations at I-3 can exceed 4 feet.

As part of the Interim Measures (IM), at DTSC direction, PG&E has operated groundwater extraction at the MW-20 bench in the floodplain area of the site since March 2004. Currently, the IM extraction well (TW-2D) is pumping at approximately 70 gallons per minute. In May 2005, the monthly average groundwater gradient at three well pairs was directed landward at magnitudes generally between 2 and 3.5 times greater than the target value of 0.001 feet/foot. It is anticipated that an average landward gradient will be maintained within the TW-2D capture zone throughout the period during which future pore water sampling takes place.

## 2.3 Timing of Sampling and Seepage Surveys

In response to the daily river level fluctuations, the local gradient in the shallow sediments beneath the river is expected to shift each day. Thus, daily river fluctuations should be considered when selecting an appropriate sampling schedule. This short-term temporal variability in river water recharge rate suggests that a time-integrated sampling method may result in collection of more representative pore water data than a single point sampling method. If the United States Bureau of Reclamation (BOR) were able to stabilize the river levels before and during the sampling period, the concerns associated with the effects of daily river fluctuations on pore water characteristics could be negated. If it is determined that the daily river fluctuations affect the pore water quality at the depth of sample collection, it may be necessary to collect samples to during times of the day when river levels are declining.

The seasonal fluctuations are likely to result in long periods of time when there is no net groundwater discharge to the river. During spring and summer months when river levels are rising or at their seasonal high stand, a strong landward gradient is noted in floodplain wells, indicating that the river is recharging the groundwater system. To minimize the effects of surface water recharge on pore water characteristics, pore water sampling should be conducted during times of seasonally low river levels, which typically occur in the months of November through January.

The reach of Colorado River near the Topock site is subject to a significant amount of boat traffic. Any sampling strategy must address the health and safety of personnel during sampling, hazards to navigation, and the security of any dedicated equipment deployed on the river bottom. There have been collisions between boats, resulting in fatalities on the river near Topock in the past year. All of the possible sampling methods would require either divers in the water, boats or barges anchored in the channel, or both. Visibility underwater would be extremely limited during nighttime hours and diving risks would be greatly increased. Boats at anchor in the main channel would be much greater navigation hazard at night when anchor cables would not be visible. To minimize risk to sampling personnel and the boating public, it would be desirable to conduct sampling during daylight hours when visibility both above and below water is greatest.

For the Topock site, the evaluation of pore water sampling methods must consider the following objectives and constraints:

- Sample volume has to be large enough for analytical and quality assurance/quality control needs.
- Samples must be indicative of the dissolved Cr(VI) fraction in pore water and should not be biased by chromium in solid or colloidal form.
- The sampling method must be able to measure redox conditions in the pore water, which appear to be limiting the migration of Cr(VI) in the shallow floodplain sediments.
- Sample times may need to be carefully chosen to minimize the effects of daily and seasonal changes in river stage on pore water characteristics.

An aerial photograph of the Topock Compressor Station, Colorado River, and primary area of the PWSS is provided in Figure 2-1. The Colorado River in this area ranges from approximately 600 feet wide (north of Burlington Northern & Santa Fe [BN&SF] railroad bridge) to approximately 450 feet south of the I-3 gas transmission crossing. Based on a BLM verbal report (E&E 2004), the depth of the river is typically less than 9 feet, with a maximum depth of 21 feet. During upcoming July surface water sampling, river bottom depth data will be collected to define general river bottom profile in selected areas.



**FIGURE 2-1  
LOCATIONS OF SURFACE WATER  
MONITORING AND SITE FEATURES  
JULY 2005**

PORE WATER AND SEEPAGE INVESTIGATION  
PG&E TOPOCK COMPRESSOR STATION  
NEEDLES, CALIFORNIA

# 3.0 Methods for Identifying Areas of Groundwater/Surface Water Seepage

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## 3.1 Review of Methods

Table 3-1 provides a list of methods for identifying areas of groundwater/surface water seepage. This list allows for evaluation by the TWG and the screening of alternative seepage evaluation techniques. Additional or back-up seepage evaluation methods may be recommended by the TWG and incorporated into a draft Work Plan.

Chemical tracers are commonly used for tracing flow between surface water and ground water. However, practical constraints, as well as real and perceived issues regarding contamination, have limited the use and efficacy of chemical tracers. Differences between temperatures in streams and surrounding sediments are now being analyzed to trace the movement of groundwater to and from streams (USGS 2003).

Depending on the chosen technique, there are two modes of deployment available:

- **Boat Deployment.** A stable boat is used as a platform to deploy equipment and/or sample points into the river bottom.
- **Diver-assisted Deployment.** A support boat and custom underwater equipment facilitate diver access to the river bottom.

Procedures to ensure field quality control, data quality assurance, and the appropriate management of data will be described in the Draft Work Plan.

## 3.2 Seepage Evaluation Locations

The preliminary sampling locations envisioned for a seepage evaluation and pore water sampling investigation would include a set of appropriate **background stations**, located upstream of Bat Cave Wash, and a suitable set of **downstream stations**, located between the BN&SF railroad bridge and downstream (east) of the I-3 gas-transmission crossing. Refer to Figure 1-1 for the general areas where background and downstream pore water samples would be selected. As noted previously, pumping from TW-2D is likely preventing any net groundwater discharge over at least a portion of the downstream sampling area. It may therefore be difficult to identify any discrete zones of groundwater discharge in this area.

**Table 3-1**  
*Methods for Pore Water Sampling*  
*Pore Water and Seepage Study*  
*PG&E Topock Compressor Station, Needles, California*

Method	Installation	Sampling Depth Below River Bottom	Advantages	Disadvantages or Limitations	Proven Applications / References
Real - time temperature probe survey	Small-diameter probes driven into bottom from a boat	Up to 4 ft	Rapid collection of data allows for relatively large numbers of locations to be surveyed.	Diurnal fluctuations of river may limit working time to a few hours per day unless probes can be driven to depths below the zone where diurnal flow is dominant	Has been developed and successfully applied at similar sites by GSi/Water
Trident probe survey	Combined temp / conductivity / sampling probes driven into bottom from a boat	Up to 2 ft	Probe is able to measure both temperature and conductivity insitu plus collect groundwater samples.	Diurnal fluctuations of river may limit working time to a few hours per day unless probes can be driven to depths below the zone where diurnal flow is dominant. Triple probe may encounter more cobbles than a single, thermal probe. Technology only available through subcontract with Coastal Monitoring or Groundwater Seepage, Incorporated.	Developed by Space and Naval Warfare Systems Command (SPAWAR); has been used at numerous coastal, lake, stream, and river sites.
Temperature logging on river bottom	Strings of TidBits layed on river bottom using divers or boats	0 ft	Temperarure loggers provide more information on diurnal fluctuations than real-time probes and could be deployed without regard to river stage. Could provide an efficient method for preliminary survey to determine if temperature signal is detectable above river bottom.	Temperature signal would be muted by mixing with river water. Method would likely be less sensitive than methods that measure sub-bottom temperature. Strings of instruments on river bottom could be damaged by boat anchors or buried by moving sandbars.	Method suggested by USGS
Temperature logging in shallow sub-bottom	Divers bury TidBits in river bottom, either directly or inside temporary plastic casings.	Up to 2 ft	Buried temperature sensors more likely to see signal from GW seepage. Could be coupled with passive diffusion samplers to provide both temp and water quality measurements.	Need for deployment by divers would limit number of sites that could be surveyed. It may be difficult find and retrieve TidBits if sandbars shift.	None found
Bathymetric Survey	Boat-mounted equipment moving along survey lines	NA	Identification of coarse-grained zones where GW seepage is most likely. Knowledge of depth and bottom configuration could be used to help focus other investigation techniques.	Does not provide any direct measurement of seepage. Would need to be followed up by other methods.	Well proven technology widely used.
Aerial Thermal Infrared Survey	Supercooled detector mounted in small aircraft	NA	Can cover large areas efficiently	Only detects temperature differences in near surface waters. Unlikely to work well in deep, fast flowing river	

# 4.0 Pore Water Sampling

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## 4.1 Review of Methods

Table 4-1 provides a list of pore water sampling techniques. This list allows for evaluation by the TWG and the screening of alternative pore water sampling techniques. Additional or back-up pore water sampling methods may be recommended by the TWG and incorporated into a Draft Work Plan. Although the sampling techniques vary widely, there are three general approaches available to acquire pore water samples. A more detailed review of pore water sampling methods is provided in Section 4 of Chadwick et al (2003), which is included as Appendix A. Procedures to ensure field quality control, data quality assurance and the appropriate management of data will be described in the draft Work Plan.

**Drive-point (Discrete) Sampling.** With this methodology, drive-point samplers are advanced into the river sediments for collection of the pore water sample via a purge pump (i.e., a peristaltic pump). Advantages include low risk to personnel, somewhat deeper depth capabilities for sample collection, and the collection of water quality field parameters during sampling. Disadvantages include discrete sampling events that do not capture average conditions, difficulty in sealing the drive points from the river water infiltration, and difficulty in advancing drive points in coarse river bottom material. Appendix B provides information on the Trident sampler and the Harpoon sampler, two of the available discrete sampling methods.

**Passive Diffusion (Integrated) Sampling.** To best determine the average concentration present in pore water in a dynamic hydrologic environment, a sampling method that integrates concentrations over a period of time is advantageous. The method for collecting an integrated pore water sample would involve the use of passive diffusion samplers, buried in the sediments at the bottom of the river, that collect integrated samples over a period of up to a week. Advantages of this sampling technique include the time-integrated nature of the sampling and the placement of the samplers that are isolated from the overlying river water. Disadvantages include the difficulty of placing and retrieving the samplers (divers must be deployed in swift current in two mobilizations). Although diffusion sampling methods have been used most commonly for volatile organic compounds, recent field tests of diffusion sampling conducted by the USGS showed that diffusion samplers constructed with nylon mesh rather than membranes could be used for inorganics and metals (Vrobesky et al. 2002). Figure 4-1 shows a photo of the nylon mesh diffusion samplers tested by the USGS.



**FIGURE 4-1**  
Diffusion Samplers Tested by Vroblesky et al. 2002.

**Seepage Sampling Methods.** Seepage sampling involves the use of flux chambers set from a few inches to a few feet into the river bottom. The simplest seepage samplers (Lee-type samplers) can be made by cutting the upper third off a 55-gallon drum. The skirt of the sampler is pushed into the soft sediment, and groundwater discharge is collected in a polyethylene bag attached to a fitting installed on the top of the drum head. Seepage samplers collect water that is emerging into the river. Because the gradients causing the seepage to emerge are typically slight, seepage samplers can be adversely affected by current, which interferes with the sample collection bags and prevents the bags from filling. The most sophisticated sampler (Ultraseep®) includes a pump to fill the sample bags. In stronger currents, the eddies around the sampler can affect the rate of seepage. Scour may also occur around the sampler in sandy bottoms and affect the seal of the skirt to the sediments. These samplers work best in still waters. Successful use of seepage samplers requires seepage to be occurring. In zones where the river is recharging the groundwater, such as may be occurring within the capture zone of TW-2D, seepage samplers would be unable to obtain any pore water samples. Appendix B provides information and photographs of the Ultraseep® sampler.

## 4.2 Pore Water Sampling Locations

Similar to the sampling plan proposed for the augmented surface water sampling activity, the ideal pore water sampling locations would be sited in approximately the mid-channel area of the river (not the shoreline). The final locations would be based on actual channel depth and morphology for each target location and the condition of river sediment that would be suitable for pore water sampling (e.g., sandy and silty sediments). Pore water sampling adjacent to the central bridge piling of the BN&SF railroad would be included to assess pore water conditions at this location. To assist in the selection of pore water sampling locations, water depths and channel morphology will be evaluated during PG&E's upcoming July 2005 river channel surface water sampling activity. It is anticipated that mid-channel sites suitable for the pore water investigation can be refined based on the results of river depth profiling.

DTSC recommended in their June 30 letter that pore water samples be collected along seven transects – two upgradient and five downgradient from the Topock site. PG&E also proposes three additional upgradient sampling transects. Potential locations of these

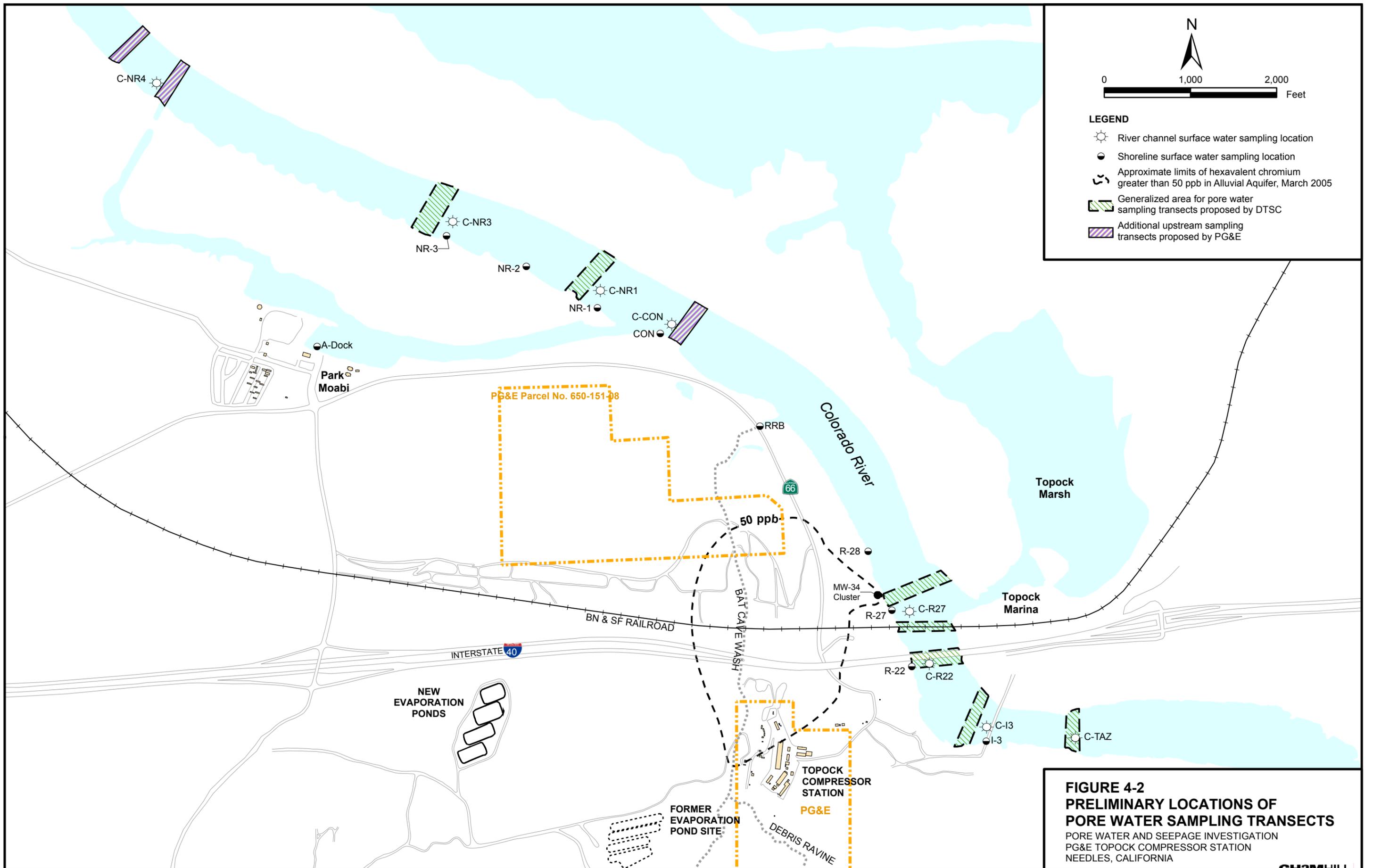
proposed transects are shown on Figure 4-2. These transects are located to comply with DTSC recommendations and approximately correspond to the July 2005 surface water monitoring locations. DTSC suggests that upgradient transects include three to four sampling locations each and downgradient transects include four to five sampling locations each. This would result in a total of between 26 and 33 sampling locations. This suggested sampling program is included for discussion purposes. Depending on the sampling methods chosen and the possible outcomes of a seepage survey, the sample numbers and locations may be revised in the Final Work Plan.

**Table 4-1**  
**Methods for Pore Water Sampling**  
**Pore Water and Seepage Study**  
**PG&E Topock Compressor Station, Needles, California**

Sampler Type	Description	Sampling Depth Below River Bottom	Sample Volume	Advantages	Disadvantages or Limitations	Proven Applications / References
<b>Discrete Sampling Methods</b>						
				<b>Provides the most representative sample of pore water at the time of sampling. Much faster and easier to deploy than either diffusion or seepage sampling methods.</b>	<b>Influence of diurnal fluctuations in river level may require sampling only during low water times and limit working hours per day.</b>	
Drive-point piezometers	1.5 to 2-inch diameter pipes driven by hand into river bottom from a boat	Up to 6 ft	Only limited by soil type	<ul style="list-style-type: none"> <li>- no sample volume limitations</li> <li>- field parameters (e.g., such as DO, ORP, etc.) can be measured with flow-thru cell; limited to suction lift;</li> <li>- could allow for repeat sampling at same locations if drive points were left in place</li> </ul>	<ul style="list-style-type: none"> <li>- Difficult to install in deep water or in swift currents</li> <li>- could not be installed in hard bottom sediments</li> <li>- large diameter of drive points may provide more chance of downward leakage of surface water</li> </ul>	Drive points commonly used for Sampling shallow groundwater and have been previously used for pore water sampling at Topock
Harpoon Sampler	1/4-inch diameter probes driven by hand into river bottom from a boat.	Up to 6 ft	Only limited by soil type	<ul style="list-style-type: none"> <li>- simple and low-cost sample tool</li> <li>- no sample volume limitations</li> <li>- field parameters (e.g., such as DO, ORP, etc.) can be measured with flow-thru cell; limited to suction lift;</li> <li>- could allow for repeat sampling at same locations if Harpoons were left in place</li> <li>- could allow for shore based sampling by routing tubing to river bank</li> </ul>	<ul style="list-style-type: none"> <li>- relatively new and unproven sampler design</li> </ul>	None found
Trident® Probe (temperature/conductivity/pore water probe)	Installed from boat; may require diver assist	Up to 2 ft	50-ml (syringe) or greater in sample bottle	<ul style="list-style-type: none"> <li>- Can be used manually near the shore or from a boat</li> <li>- provides real-time readout and profiling of temp and SC</li> <li>- can be used to estimate the location of the groundwater/surface water interface by looking at temperature gradients</li> <li>- air hammer allows installation in harder sediments</li> </ul>	<ul style="list-style-type: none"> <li>- limited to 2 ft sample depth</li> <li>- probe subject to damage if cobbles are encountered</li> </ul>	Developed by Space and Naval Warfare Systems Command (SPAWAR); has been used at numerous coastal, lake, stream, and river sites.
<b>Diffusion Sampling Methods</b>						
				<b>Diffusion sampling methods would provide integrated samples over a long period of time and could provide the most representative samples of the average concentrations present in pore water.</b>	<b>Diffusion samplers have not been widely used for metals. Because equilibration time is likely to be several days, the 24 hour holding time for Cr(VI) analysis could not be met.</b>	
Drive Point Piezometer with LDPE diffusion bottles and temperature loggers (TidBiT)	Boat and/or diver-installed	Up to 6 ft with samples collected at multiple depths	Up to 0.4 L in 10 vials	<ul style="list-style-type: none"> <li>- easy to construct 1.5-inch diameter drive point piezometers that can be stacked with multiple diffusion bottles and temperature loggers.</li> <li>- can be installed by hand in shallow water or by boat in deeper water (may need diver assist).</li> <li>- samples are time-integrated and can be at multiple depths.</li> <li>- temperature can be logged for the period of installation. for evaluation vertical groundwater flow conditions.</li> </ul>	<ul style="list-style-type: none"> <li>- may require diver assist for installation and will require diver assist for removal.</li> <li>- could allow for resampling at exact same location</li> <li>- not a commercially available product</li> <li>- permitting may be more difficult because pipes are left in river bottom</li> </ul>	PDB Demonstration at Grissom ARB, Indiana
LDPE Diffusion bottles buried with temperature loggers (TidBiT)	Diver-installed	Up to 2 ft	Up to 0.3 L in 3 x 100 ml plastic bottles	<ul style="list-style-type: none"> <li>- bottles may be placed at multiple depths depending on sediment type</li> <li>- temperature loggers can be placed with samplers for evaluation of vertical groundwater flow conditions</li> </ul>	<ul style="list-style-type: none"> <li>- divers required for installation and retrieval</li> <li>- doesn't allow for resampling at exact same spot</li> </ul>	Naval Industrial Reserve Ordnance Plant (NIROP), Naval Air Station, Fridley, MN; Fort Worth Joint Reserve Base (NAS Fort Worth JRB), Texas.

**Table 4-1**  
*Methods for Pore Water Sampling*  
*Pore Water and Seepage Study*  
*PG&E Topock Compressor Station, Needles, California*

Sampler Type	Description	Sampling Depth Below River Bottom	Sample Volume	Advantages	Disadvantages or Limitations	Proven Applications / References
<p><b>Seepage Sampling Methods</b></p> <p>Sampling bottom seepage provides a better measure of what is entering the river rather than just what is present in pore water. Seepage samplers can provide measurements of seepage rate.</p> <p>If no groundwater seepage is occurring at the location where the sampler is deployed, no samples would be obtained. The effects of currents may disrupt the samplers ability to accurately measure and collect seepage samples.</p>						
UltraSeep® (multi-sample seepage meter)	Boat and diver-installed	0 ft	Up to 3 L Dependent on seepage rate	<ul style="list-style-type: none"> <li>- direct measurement of groundwater and contaminant discharges at the sediment/surface water interface.</li> <li>- unit stores data and controls sampling events based on seepage rate, which is continuously monitored.</li> <li>- up to six samples can be collected for chemical analysis</li> <li>-can be programmed to sample when discharge rate or conductivity reaches a threshold value</li> </ul>	<ul style="list-style-type: none"> <li>- difficult to use and install in high currents</li> <li>- proprietary technology only available through U.S. Navy</li> <li>- sampler cost significantly greater than other methods</li> <li>- would require 24 - 48 deployment hours for each sample location</li> <li>- would only provide samples at locations where groundwater was discharging</li> </ul>	<p>U.S. Navy (numerous sites)</p> <p>Currently undergoing further technical evaluation under the DOD's ESTCP program</p> <p><a href="http://www.estcp.org/projects/cleanup/cu-0422.cfm">http://www.estcp.org/projects/cleanup/cu-0422.cfm</a></p>
Benthic Flux Sampler	Diver-installed	0 ft	Dependent on seepage rate	<ul style="list-style-type: none"> <li>- can operate unattended from a few days to months depending upon size and design</li> <li>- can operate in deep water</li> <li>- some are equipped with coring capabilities, advective flow volume measurement (from sediment to surface water), and current measurement instrumentation</li> </ul>	<ul style="list-style-type: none"> <li>- difficult to use and install in high currents</li> <li>- not able to program sample times to coincide with indications of groundwater discharge</li> <li>- would require 24 - 48 deployment hours for each sample location</li> <li>- would only provide samples at locations where groundwater was discharging</li> <li>- may not be commercially available</li> </ul>	<p>Developed by U. S. Navy and tested in several sites</p> <p>Certified by CalEPA.</p>
Lee-type Seepage Sampler	Diver-installed	0 ft	Dependent on seepage rate	<ul style="list-style-type: none"> <li>- low cost and light weight</li> <li>-low profile less likely to be tipped by current</li> </ul>	<ul style="list-style-type: none"> <li>- may not be usable in current velocity at Topock</li> <li>dynamic pressure on exposed sample bag</li> <li>- would require 24 - 48 deployment hours for each sample location</li> <li>- would only provide samples at locations where groundwater was discharging</li> </ul>	<p>Developed in 1970's and has been widely used</p>



# 5.0 Permitting and Procurement Activities

## 5.1 Permitting Agencies and Preliminary Permit Requirements

Table 5-1 provides a listing of potential permits and approvals that have been identified as applicable to the evaluation of seepage and sampling or pore water along the Colorado River, near the PG&E Topock Compressor Station (see Figure 1-1). Agencies will be contacted for general information as part of Draft Work Plan preparation. Based on prior experience, agencies will require the level of detail contained in a work plan to evaluate any necessary permits, approvals, and/or certifications. All applicable and necessary permits, approvals, and certifications will be documented prior to commissioning the seepage evaluation and pore water sampling work.

**TABLE 5-1**  
List of Potential Permits, Approvals, and Certifications for Sampling and Investigations in Colorado River  
*Pore Water and Seepage Study Work Plan, PG&E Topock Compressor Station, Needles, California*

Agency	Permits, Approvals, Certifications
United States Bureau of Land Management (BLM)	Action memorandum authorizing IM No. 2 activities on BLM land. Approval of the work plan required prior to commencing sampling activities.
BOR	To be determined.
USFWS	The lead federal agency (e.g., BLM or BOR) will consult with the USFWS regarding potential effects on sensitive fish species. Activities with the potential to affect sensitive fish species subject to formal consultation per Section 7 of the Endangered Species Act.
USFWS - Havasu National Wildlife Refuge	Authorization to occur via Action Memorandum, followed by Wildlife Refuge staff review and approval of the work plan.
United States Army Corps of Engineers	Potentially exempt from Clean Water Act, Section 404 requirements due to relation to Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA).
United States Coast Guard	To be determined
California DTSC	Review and approval of work plan required. Compliance with California Environmental Quality Act potentially to occur via categorical exemption.
California Regional Water Quality Control Board, Colorado River Basin	Potential exempt from Water Quality Certification (Section 401 of the Clean Water Act) due to relation to CERCLA.
California Department of Fish & Game	Alteration of river channel subject to Fish and Game Code section 1600 et seq. Potential requirement for a Streambed Alteration Agreement.

**TABLE 5-1**

List of Potential Permits, Approvals, and Certifications for Sampling and Investigations in Colorado River  
*Pore Water and Seepage Study Work Plan, PG&E Topock Compressor Station, Needles, California*

Agency	Permits, Approvals, Certifications
San Bernardino County	To be determined.
Arizona Department of Environmental Quality	Not applicable.
Arizona Department of Water Resources	If permanent facilities installed, a Notice of Intent will be filed with the Arizona Department of Water Resources.
Arizona State Department of Fish & Game	Potential need for consultation regarding sensitive fish species.
Mohave County Department of Health	To be determined.
Colorado River Board of California	To be determined.

## 5.2 Subcontractors and Procurement

Implementation of the methods outlined in Sections 3.0 and 4.0 will likely require specialty subcontractors and equipment. Procurement of appropriate subcontractor(s) and equipment will require a detailed Scope of Work, which will be prepared following submittal of the Draft Work Plan. Preliminary work scoping and scheduling will be conducted with subcontractors to ensure that work can proceed according to the preliminary schedule outlined in Section 6.0.

## 6.0 Schedule

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Based on the objectives, it is anticipated that the seepage evaluation and sampling will coincide with the end of the low river water period, which typically occurs in December.

The anticipated schedule includes:

- Submittals to DTSC: Conceptual Approach on June 27, 2005 and Study Overview on July 13, 2005.
- Review by DTSC and the TWG followed by seepage evaluation and pore water sampling methodologies initial screening and preliminary selection, TWG meeting July 20, 2005.
- Preparation and submittal of Draft Work Plan, based on DTSC and TWG guidance, for seepage evaluation and pore water sampling methodology.
- Review by DTSC and, if necessary, the TWG.
- Preparation and submittal of Final Work Plan.
- Initial planning followed by ongoing efforts to obtain permits, approvals, and certifications.
- Initial planning followed by procurement of specialty subcontractor(s) and equipment (subject to advanced lead time).

# 7.0 References

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Cooperation with the Air Force Center for Environmental Excellence and the Southern Division Naval Facilities Engineering Command.

## **Appendix A**

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**SPAWAR**  
*Systems Center*  
*San Diego*

TECHNICAL REPORT 1898  
June 2003

## **Coastal Contaminant Migration Monitoring Technology Review**

D. B. Chadwick  
M. Kito  
A. C. Blake  
**SSC San Diego**

B. Harre  
**Naval Facilities Engineering  
Services Center**

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SSC San Diego

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TECHNICAL REPORT 1898  
June 2003

# Coastal Contaminant Migration Monitoring Technology Review

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A. C. Blake  
**SSC San Diego**

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**Naval Facilities Engineering  
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**Commanding Officer**

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**ADMINISTRATIVE INFORMATION**

This report was prepared for the Naval Facilities Engineering Service Center by the Environmental Sciences Division (Code 236), SSC San Diego.

Released by  
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Under authority of  
S. Gagnon, Acting Head  
Environmental Sciences  
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## Executive Summary

The U.S. Navy is identifying, assessing, and remediating a large number of terrestrial hazardous waste sites. Many sites are located adjacent to harbors, bays, estuaries, wetlands, and other coastal environments. Approximately one-third of all U.S. Navy landfills have groundwater infiltrating the waste, and as a result the Navy must determine if contaminants from these sites are migrating into marine systems at levels that pose a threat to the environment.

Complex physical and geochemical processes arising from interactions between seawater, groundwater, soils, sediments, and contaminants affect the transport and mobility of contaminants from the waste site. As a result of chemical differences between groundwater and seawater, groundwater exchange between the waste site and the adjacent coastal water bodies is a likely migration pathway for dissolved nutrients and contaminants, particularly in areas with strong tidal influence. In coastal areas, tidal mixing zones may form from the movement of seawater into the aquifer (Figure 1, page 2). The tidally mixed zone may be important in estimating the amount of groundwater extracted due to a process referred to as tidal pumping (Moore, 1996). This is when higher density seawater mixes with groundwater at high tide, and then as the tide recedes, the mixture of seawater and groundwater is drawn out into the coastal waters. Because this process repeats at every tidal cycle, appreciable volumes of groundwater can be extracted over time. Increasingly, groundwater is recognized as a potentially significant, although poorly quantified, source of nutrients and contaminant materials to coastal ecosystems.

These problems are generally evaluated by making hydraulic head measurements in shore-side wells and/or numerical models that provide theoretical predictions of flow and contaminant migration. However, these models are of limited use in areas adjacent to marine systems where tides, waves, and strong density gradients make it difficult to establish boundary conditions. Few techniques are available to verify if the model predictions are accurate.

Growing evidence suggests that submarine groundwater discharge may represent an important migration pathway for natural and anthropogenic constituents entering coastal waters (Lendvay et al., 1998). To address this issue, a series of technologies were investigated for their applicability toward direct quantification of coastal contaminant migration via groundwater. Candidate technologies were divided into two categories: (1) technologies for quantifying groundwater flow to coastal waters, and (2) technologies for detecting contaminants in the groundwater-coastal water exchange zone.

The technologies evaluated for quantifying groundwater flow to coastal waters include seepage meters, thermal gradient flow meters, piezometers, thermal infrared aerial imagery, tracer injection, a colloidal borescope, and natural geochemical tracers.

The technologies for detecting contaminants in the groundwater–coastal water exchange zone include porewater probes, mini-wells, diffusion samplers, seepage meters, and in situ chambers.

A matrix was developed to evaluate these technologies. The factors for consideration of each technology include technical performance/applicability, developmental status, reliability, and cost. A panel of experts will fill out the matrix and the selected technologies will then be evaluated for a demonstration based on the panel results.

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## 1 Introduction

The U.S. Navy is identifying, assessing, and remediating a large number of terrestrial hazardous waste sites. Many sites are located adjacent to harbors, bays, estuaries, wetlands, and other coastal environments. Approximately one-third of all U.S. Navy landfills have groundwater infiltrating the waste, and as a result the Navy must determine if contaminants from these sites are migrating into marine systems at levels that pose a threat to the environment.

Complex physical and geochemical processes arising from interactions between seawater, groundwater, soils, sediments, and contaminants affect the transport and mobility of contaminants from the waste site. As a result of chemical differences between groundwater and seawater, groundwater exchange between the waste site and the adjacent coastal water bodies is a likely migration pathway for dissolved nutrients and contaminants, particularly in areas with strong tidal influence. In coastal areas, tidal mixing zones may form from the movement of seawater into the aquifer (Figure 1). The tidally mixed zone may be important in estimating the amount of groundwater extracted due to a process referred to as tidal pumping (Moore, 1996). This is when higher density seawater mixes with groundwater at high tide, and then as the tide recedes, the mixture of seawater and groundwater is drawn out into the coastal waters. Because this process repeats at every tidal cycle, appreciable volumes of groundwater can be extracted over time (Valiela and D'Elia, 1990; Moore, 1996). Increasingly, groundwater is recognized as a potentially significant, although poorly quantified, source of nutrients and contaminant materials to coastal ecosystems.

These problems are generally evaluated by making hydraulic head measurements in shore-side wells and/or numerical models that provide theoretical predictions of flow and contaminant migration. However, these models are of limited use in areas adjacent to marine systems where tides, waves, and strong density gradients make it difficult to establish boundary conditions. Few techniques are available to verify if the model predictions are accurate.

Growing evidence suggests that submarine groundwater discharge may represent an important migration pathway for natural and anthropogenic constituents entering coastal waters (Lendvay et al., 1998). To address this issue, a series of technologies were investigated for their applicability towards direct quantification of coastal contaminant migration via groundwater. Candidate technologies were divided into two categories: (1) technologies for quantifying groundwater flow to coastal waters, and (2) technologies for detecting contaminants in the groundwater-coastal water exchange zone.

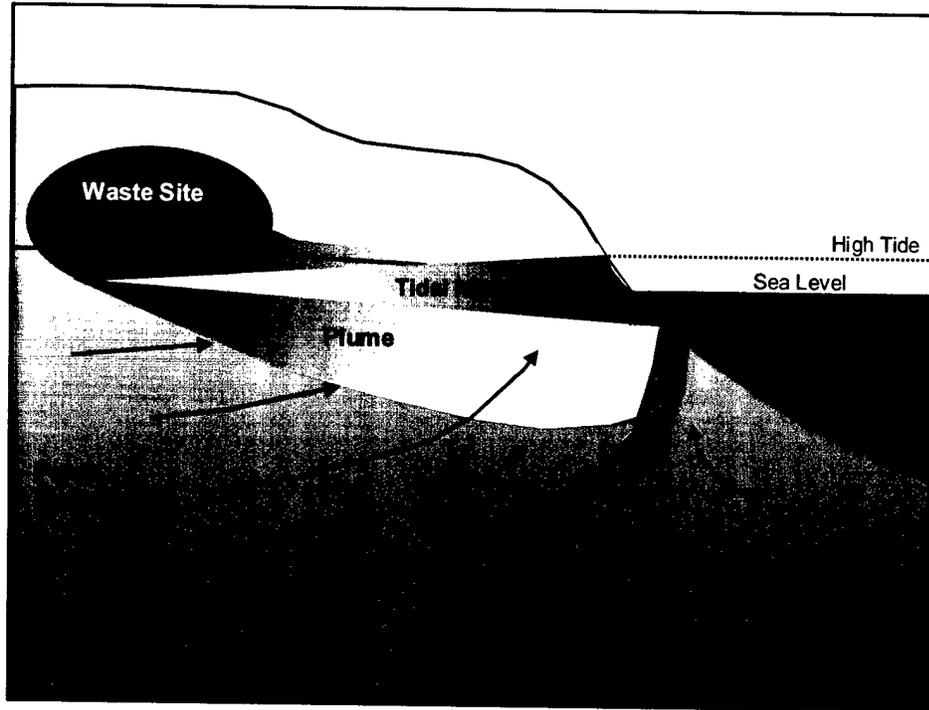


Figure 1. Conceptual representation of the coastal contaminant migration process and associated groundwater-surface water interaction.

## **2 Regulations**

### **Coastal and Landfill Regulations**

Many laws may govern a coastal waste site. The first comprehensive federal effort to deal with the solid-waste problem in general, and specifically hazardous waste, came with the Resource Conservation and Recovery Act (RCRA) of 1976. This act regulates anyone engaged in the creation, transportation, treatment, storage, and disposal of hazardous wastes (RCRA Subtitle C) and regulates the facilities for disposal of solid wastes (RCRA Subtitle D). However, many waste disposal sites were created before the passage of RCRA. The cleanup of these past waste disposal sites is principally regulated under the Comprehensive Response Compensation and Liability Act (CERCLA). In addition to these regulations, other regulations can be applied to a waste disposal site. These regulations include the National Environmental Policy Act; the Clean Water Act; the Safe Drinking Water Act; the Toxic Substances Control Act; the Clean Air Act; the Marine Protection, Research and Sanctuaries Act; the Coastal Zone Management and Improvement Act; the Fish and Wildlife Act; the Migratory Bird Treaty Act; the Rivers and Harbors Act; and the Endangered Species Act. Each measure, discussed in detail below, may be applicable to a coastal waste site.

### **National Environmental Policy Act**

---

The National Environmental Policy Act (NEPA) ensures that environmental impacts are considered before the final decision-making process. The law requires that environmental impact statements be prepared for major actions. Specifically, 42 U.S.C. 4332 et seq states that "All agencies of the Federal Government shall - (c) include in every recommendation or report on proposals for legislation and other major Federal actions significantly affecting the quality of the human environment, a detailed statement by the responsible official on - (i) the environmental impact of the proposed action."

The statements must address the environmental impact of the proposed action, address any unavoidable environmental effects of the proposed actions, and consider alternatives to the proposed actions.

### **Clean Water Act**

---

The Clean Water Act (CWA) limits pollutant discharges from point sources. The Environmental Protection Agency (EPA), or States with approved programs, issue pollution permits, known as National Pollution Discharge Elimination System (NPDES) permits. The CWA sets levels of technology that must be used to control various types of effluent; these limits must be incorporated into NPDES permits. EPA also promulgates nationwide effluent limitations for toxics and certain categories of new sources. NPDES permits must incorporate effluent limitations stringent enough to meet water-quality standards. States establish water-quality standards based on desired uses of the

particular water area. The CWA regulation of non-point source pollution is still in its infancy. States are developing and submitting for EPA approval non-point source pollution control plans.

#### **Safe Drinking Water Act**

---

The Safe Drinking Water Act (SDWA) protects the nation's drinking water supplies. The SDWA establishes national primary drinking water standards for public drinking water supplies for 83 contaminants. These standards are called maximum contaminant level standards, and each State enforces the standards.

#### **Toxic Substances Control Act**

---

The Toxic Substances Control Act (TSCA) allows EPA to require toxicity testing of chemicals if their effects are unknown. EPA can also prohibit the manufacture, sale, use, or disposal of a chemical if the compound represents an unreasonable risk to the environment or health. This act does not regulate pesticides, drugs, and nuclear materials.

#### **Clean Air Act**

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The Clean Air Act provides clean air to protect human health. The act is composed of many parts, but the two parts most relevant to landfills are the ambient air-quality standards and the emission standards. The ambient air-quality standards set levels for criteria pollutants that are not to be exceeded. If they are exceeded, the State or area must develop a plan to bring the area into compliance with the law. The Clean Air Act has also established emission standards for various compounds from a particular type of source. If emissions from the source are above the standard, emissions must be controlled and reduced to levels below that set by the standard.

#### **Marine Protection, Research, and Sanctuaries Act**

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The Marine Protection, Research, and Sanctuaries Act regulates ocean dumping. The act also establishes marine sanctuaries.

#### **Coastal Zone Management and Improvement Act**

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The Coastal Zone Management and Improvement Act encourages States to manage and conserve coastal areas as a unique, irreplaceable resource. The act requires each State with a coastal zone management program to address pollution of coastal waters and to encourage each coastal State to improve coastal wetlands protection, natural hazards management, public beach access, marine debris management, assessments of coastal growth and development, and environmentally sound siting of coastal energy facilities.

#### **Fish and Wildlife Act**

---

The Fish and Wildlife Act established the Fish and Wildlife Service (FWS) and authorized the Secretary of the Interior to develop, advance, manage,

conserve, and protect fish and wildlife resources. Such authority can be used to protect areas vital to many fish and wildlife species.

### **Migratory Bird Treaty Act**

---

The Migration Bird Treaty Act makes it unlawful at any time, by any means or in any manner to pursue, hunt, take, capture, kill, or attempt to take, capture, or kill any migratory bird, or any part, nest, or egg of any such bird administered by FWS, unless permitted.

### **Rivers and Harbors Act**

---

The Rivers and Harbors Act requires that permits be obtained from the Army Corps of Engineers for dredge, fill, and other activities that could obstruct navigable waterways.

### **Endangered Species Act**

---

The Endangered Species Act conserves endangered and threatened plants, animals, and their habitats. This act prohibits any federal agency from undertaking or funding a project that will threaten a rare or endangered species. The act can be used to restrict development or alterations of an area that is critical to a species.

### **Groundwater Monitoring Regulations and Requirements**

Groundwater from a coastal waste site may require monitoring. A summary of the groundwater monitoring requirements for a landfill shows that monitoring a coastal site can be extensive. The Federal regulation references that govern monitoring for a landfill are as follows:

RCRA Regulations: 40 CFR, Subtitle C, Parts 264 and 265, Subpart F

RCRA Regulations: 40 CFR, Subtitle D, Part 258, Subpart E

CERCLA Regulations: 40 CFR, Part 300

TSCA Regulations: 40 CFR, Part 702

RCRA Groundwater Monitoring Technical Enforcement Guidance Document

RCRA Groundwater Monitoring Systems

Each regulatory program has the same basic groundwater monitoring components; however, they may differ somewhat in monitoring frequencies and periods, required constituents for analysis, and unique State requirements or regulations.

With limited exceptions as stated in the various regulations, all owners and operators (O/Os) of hazardous and solid-waste facilities (including containers, tanks, surface impoundments, waste piles, land-treatment facilities, landfills, and incinerators) must implement and conduct a monitoring and response program. The groundwater-monitoring program must include a sampling and analysis plan that detects contaminants in the groundwater above background conditions. When hazardous constituents are detected in the groundwater at

the facility, the O/O must implement a compliance or assessment-monitoring program. Whenever a groundwater protection standard is exceeded, the O/O must implement a corrective action program.

The following sections provide a brief summary of the basic requirements for a site characterization and groundwater-monitoring program.

### **Site Characterization**

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The adequacy of an O/O's groundwater monitoring program hinges on the quality and quantity of the hydrogeologic data used in designing the program. Two basic objectives must be met before the site is considered to be adequately characterized: (1) Collect enough hydrogeologic information to adequately characterize, at a minimum, the uppermost aquifer at the site, including the identification of potential contaminant migration pathways, and the groundwater flow path and flow rates, and (2) use appropriate data collection, sampling, and analysis techniques in obtaining the hydrogeologic data to support of the design of the groundwater monitoring program. Site-specific factors must be considered at each location.

Various investigative techniques are available that all O/O's should use to characterize their sites. Initially, all available literature regarding the hydrogeology of the site should be reviewed before conducting a site-specific investigation. The following list of hydrogeologic investigative techniques may be used to characterize a site:

- Survey existing geologic information/aerial photographs
- Install soil borings/rock corings
- Perform material tests/grain size analyses and/or standard penetration tests
- Perform geophysical well logging (resistivity, electromagnetic conductance, gamma, etc.)
- Perform permeability and/or hydraulic conductivity measurements of soil samples/cores
- Perform soil gas/geoprobe/hydropunch surveys
- Install groundwater monitoring wells/piezometers at different aquifer depths/locations
- Perform slug and/or pumping tests at monitoring wells
- Consider tracer studies and other methods to determine lateral and vertical migration pathways

Using these investigative techniques, the following data presentations and assessment outputs should be created:

- Narrative description of the hydrogeology of the site
- Geologic cross-sections
- Soil boring/coring logs

- Structure contour maps of the aquifer and/or confining layers
- Raw data and analysis of geophysical investigations
- Raw data and analysis of material testing
- Groundwater well completion logs
- Narrative description of the groundwater flow and migration characteristics
- Groundwater table potentiometric surface map
- Raw data and analysis of tracer studies and slug and/or pump tests

The soil boring/well installation program should be adequate to characterize the site and to determine the potential contaminant migration pathways. Initial boreholes should be installed at a density that provides information to determine the presence and migration of contaminants. Initial boreholes should be drilled into the first confining layer beneath the uppermost aquifer. Boreholes should be placed at strategic locations to adequately characterize the site and may be located based on indirect or geophysical techniques. Initially, continuous coring should be performed at the site to characterize the geology. Sufficient laboratory analyses and material testing should be performed to verify the field determination of the geologic logging.

#### Groundwater Detection Monitoring

Placement and screening of groundwater wells at a site is based on the result of a thorough site characterization investigation. This information (geologic strata, groundwater flow direction, gradient, velocities, etc.) is the foundation for the entire groundwater-monitoring program. Up-gradient well(s) must be located in a position where background water-quality conditions in the uppermost aquifer can be detected, and are unaffected by any potential site contaminants. A sufficient number of down-gradient monitoring wells (usually a minimum of three) will detect any potential contaminant release from the regulated unit (i.e., landfill).

It is important to remember that potential contaminant pathways are three-dimensional (3-D), and detection monitoring wells may be required at different depths in the uppermost aquifer and sometimes in lower aquifers. The horizontal and vertical (screened intervals) placement of the detection monitoring wells depends on site hydrogeologic conditions. The wells should typically be placed immediately adjacent to the hazardous waste management unit (i.e., landfill) and predicated on the ability to intercept contaminant migration. Another factor in determining the location and depth of the monitoring wells is the physical and chemical characteristics of the hazardous waste constituents (i.e., dispersion, solubility, non-aqueous phased liquids, etc.).

When designing and constructing groundwater monitoring wells, factors such as drilling methods, well construction materials, filter packs, sealant materials,

well intakes (screen/perforation sizes, depth intervals, and lengths), well development, and appropriate documentation should be considered.

A written sampling and analysis plan should include procedures and techniques for groundwater sample collection, sample preservation, field and laboratory quality assurance/quality control (QA/QC) procedures, sample shipment and analytical procedures, and chain-of-custody control.

Once the analytical data from the laboratory have been validated, a statistical analysis should be performed on the data to determine if the constituents from the hazardous waste management unit have potentially or significantly affected the groundwater quality.

### Groundwater Assessment or Compliance Monitoring

Once contaminant leakage has been detected as a result of the groundwater-monitoring program, the O/O must undertake a more aggressive groundwater-monitoring program. The O/O must also establish the rate and extent of contaminant migration. This information is needed to evaluate the need for any corrective action requirements.

Assuming the contamination is not the result of false positives, a site that has detected statistically significant groundwater contamination requires a written assessment-monitoring plan. Any combination of additional monitoring wells, additional analytical constituents, or an increased frequency of monitoring may be required. The assessment plan should describe any potential migration pathways and implement a plan to fully characterize the rate and extent of contamination. A combination of direct methods (installing additional groundwater wells) and indirect methods (groundwater fate and transport or mathematical modeling) may be used to predict the extent of contamination. Additional site characterization may also be required.

Once the additional assessment or compliance monitoring data have been collected and evaluated, it should be determined if any groundwater protection standards have been exceeded and if a site requires a corrective action program.

### 3 Site Summaries

This section provides information about sites that have groundwater migration issues.

#### Summary of Landfills with Tidal Influence

Table 1 is a summary of the results found at the various Engineering Field Activities and Engineering Field Divisions from the initial decision report on coastal landfill remediation—subsurface barriers. Approximately one-third of the 465 landfill sites have groundwater contamination and groundwater infiltrating the waste, and it is estimated that one-fifth of the landfills have a tidal influence.

Descriptions of sites with groundwater migration issues are included to illustrate these issues. These sites are spread throughout the country, from the East Coast to Hawaii.

Table 1. Navy landfill summary.

EFA/EFD	Groundwater Contamination	Tidal Infiltration	Groundwater Infiltration
Atlantic Division	29	14	16
EFA Chesapeake	14	4	10
Northern Division	20	10	18
EFA West	29	14	31
South West Division	19	15	13
EFA Midwest	3	0	3
EFA North West	6	8	10
Pacific Division	5	10	8
Southern Division	27	26	50
TOTALS	152	101	159

#### Naval Fuel Depot Point Molate

*Site 3 Treatment Pond Area.* Site 3 (Figure 2) is located on a flat, filled area adjacent to the San Francisco Bay and is approximately the size of a football field. The site consists of three stormwater treatment ponds (300 to 400 feet long), a stormwater treatment plant, a groundwater containment wall and extraction trench, a groundwater treatment plant, and a domestic sewage treatment plant, all constructed over a former sump pond. Weathered diesel and heavier, tar-like, number 6 bunker fuel exist throughout the site. Free product varies from 0 to 3.6 feet.

In 1995, the Water Board required the installation of a 25-foot-deep sheet pile containment wall, 10 to 20 feet from the San Francisco Bay shoreline. Four extraction wells pump free product and water into an extraction system; the water is treated and then discharged to the Bay.

The stormwater treatment plant captures stormwater runoff from the fuel storage tanks and catch basins. The stormwater first passes through an oil/water separator and then to the three treatment ponds that are above ground bioreactors. After 2 to 4 weeks, the stormwater is pumped through a treatment plant that consists of sand filtration and granular-activated carbon before it is discharged to San Francisco Bay.

*Site 4 Shoreline Perimeter.* Site 4 (Figure 2) includes the entire perimeter along San Francisco Bay. This site was included as an Installation Restoration site because of concerns over historical fuel spills and leaks, which may have impacted bay waters and sediment. Investigations at Site 4 included soil and groundwater sampling along the shoreline.

Site 4 soil samples were collected during the site investigation and the shoreline investigation. Chemical analytical results indicated total petroleum hydrocarbons (TPHs), benzene-toluene-ethylene-xylene (BTEX), and polycyclic aromatic hydrocarbons (PAHs).

Groundwater samples were collected from shoreline wells during the four quarterly groundwater-sampling events in 1994. TPH, BTEX, and chlorinated volatile organic carbons (VOCs) were the most commonly detected contaminants in Site 4 groundwater. Detections in groundwater samples consistently included contaminants. Free product has also been identified in wells within Site 4.

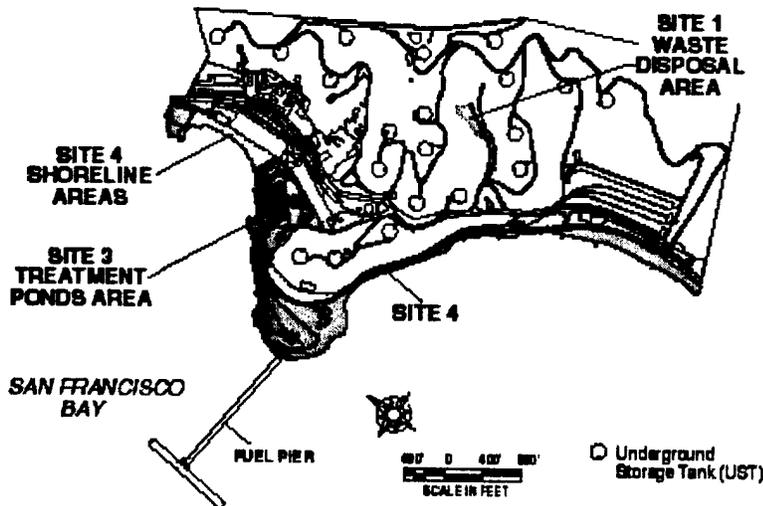


Figure 2. Site map of Naval Fuel Depot Point Molate.

### Naval Station Treasure Island

Base-wide areas are impacted by diesel and gasoline from fuel lines, Underground Storage Tanks (USTs), and TPH plumes (Figure 3). Investigation of the fuel lines proceeded by using screening levels previously developed from bioassay data for aquatic receptors. At Naval Station (NS) Treasure Island, a tiered approach was used to evaluate TPH-affected areas. Based on facility-specific bioassay results and modifications proposed by the Regional Water Quality Control Board (RWQCB), TPH concentrations below  $1.4 \text{ mg}\cdot\text{L}^{-1}$  in groundwater and  $447 \text{ mg}\cdot\text{kg}^{-1}$  in soil have been determined to be protective of aquatic receptors (it is noted that exposure of aquatic receptors is the principal pathway of concern at Treasure Island). These values are used as first tier TPH screening levels. TPH concentrations exceeding the first tier screening levels were subsequently evaluated using TPH constituent- and site-specific data (for example, fate and transport modeling) and examined as part of NS Treasure Island monitored natural attenuation program. TPH concentrations that are determined to still exceed the  $1.4 \text{ mg}\cdot\text{L}^{-1}$  TPH criterion at the shoreline (the proposed NS Treasure Island point of compliance) are then evaluated for cleanup. This NS Treasure Island TPH approach parallels the tiered protocol being developed by the Navy TPH working group and has been ongoing.

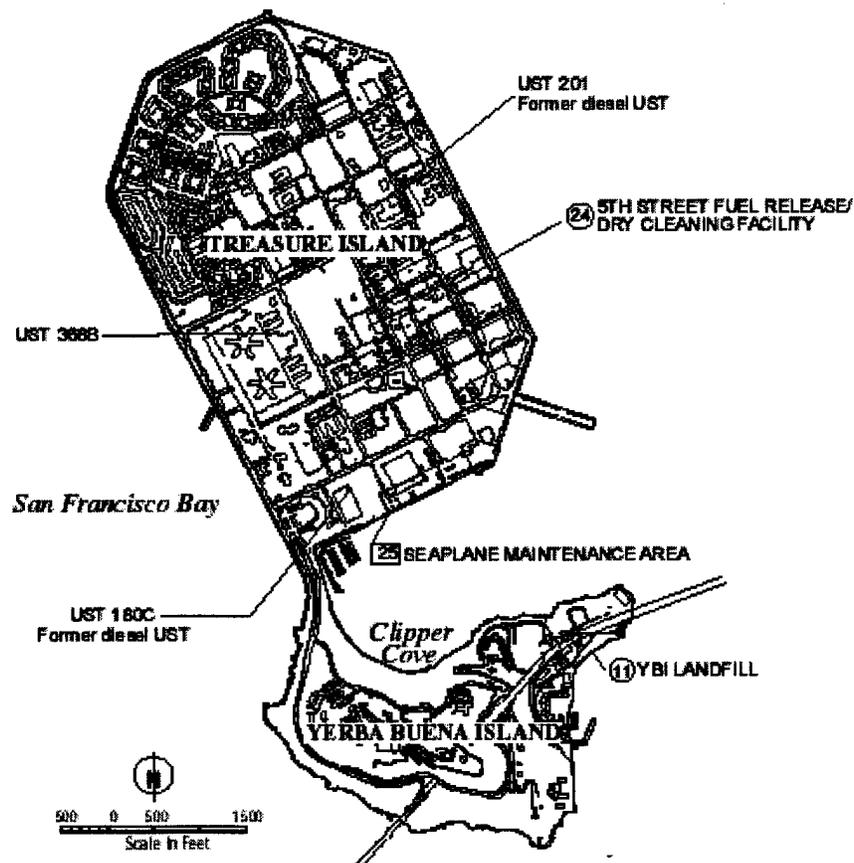


Figure 3. Site map of Naval Station Treasure Island.

The U.S. Navy uses modeling to evaluate whether TPH constituents will reach the shoreline. Previous modeling at one site, with conservative parameters, indicated TPH constituents (such as BTEX) would reach the shoreline at concentrations in excess of corresponding EPA ambient water-quality criteria.

Site 24 (5th Street Fuel Releases) exists because of a fuel line spill and sumps leading directly to the soil from a former dry-cleaning facility (Figure 3). By 1960, operation at the dry-cleaning facility had stopped, but current groundwater measurements still show solvents. A very conservative groundwater model shows that chlorinated solvents will reach the shoreline at a concentration that will exceed ambient water-quality criteria.

### Naval Air Station North Island

*Site 9, Chemical Waste Disposal Area.* This site is a 38-acre parcel that operated as a waste disposal area from the 1940s to the late 1970s, before the Industrial Waste Treatment Plant (Site 11) began operation (Figure 4). It consisted of three major waste disposal operations: a shallow pit used for disposal of liquid wastes from portable tanks; four parallel trenches, each containing different types of wastes (solvents, caustics, acids, and semisynthetics consisting of ceramic and metallic compounds); a low-level radioactive material storage yard; and a large unimproved area used for burying drums containing unidentified wastes.

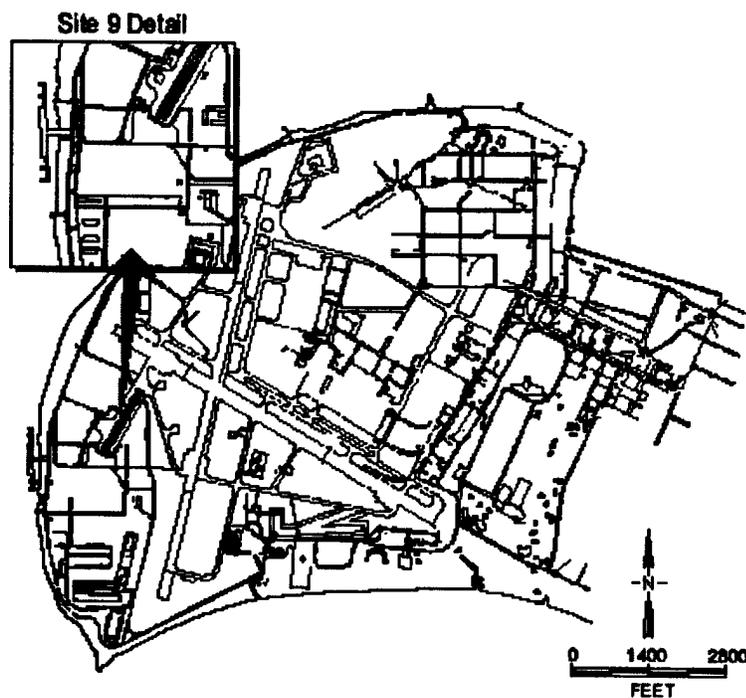


Figure 4. Naval Air Station North Island Site 9.

Previous modeling and measurements indicate VOCs are migrating into San Diego Bay from groundwater sources originating at Site 9. Groundwater modeling indicates that groundwater flow is directed from Site 9 toward the bay, and elevated concentrations of chlorinated solvents have been identified in sampling wells located along the western shore of North Island.

Several demonstrations of innovative cleanup technologies are also operating at Site 9. Space and Naval Warfare (SPAWAR) Systems Center, San Diego (SSC San Diego) has performed measurements with porewater probes and seepage meters to determine high flux areas.

### Naval Base Ventura County NAS Point Mugu Site 1 - Lagoon Landfill

This site was a 25-acre landfill, trash-burning area, and dredge spoil storage area since 1952 (Figure 5). The landfill is no longer used and was closed in 1978. The eastern boundary of the landfill, adjacent to a lagoon, was partially contained by a berm composed of rubble and dredged material. However, this material was subject to erosion by tides and flooding of Calleguas Creek.

The Remedial Investigation phase that was performed at the site during Fiscal Year 1996 indicated the immediate need to perform a time-critical removal action (TCRA) to reduce the erosion. The decision was made to perform the TCRA. During the removal action, approximately 7 acres of the site were graded and capped with a chip seal surface. This surface is used as a laydown

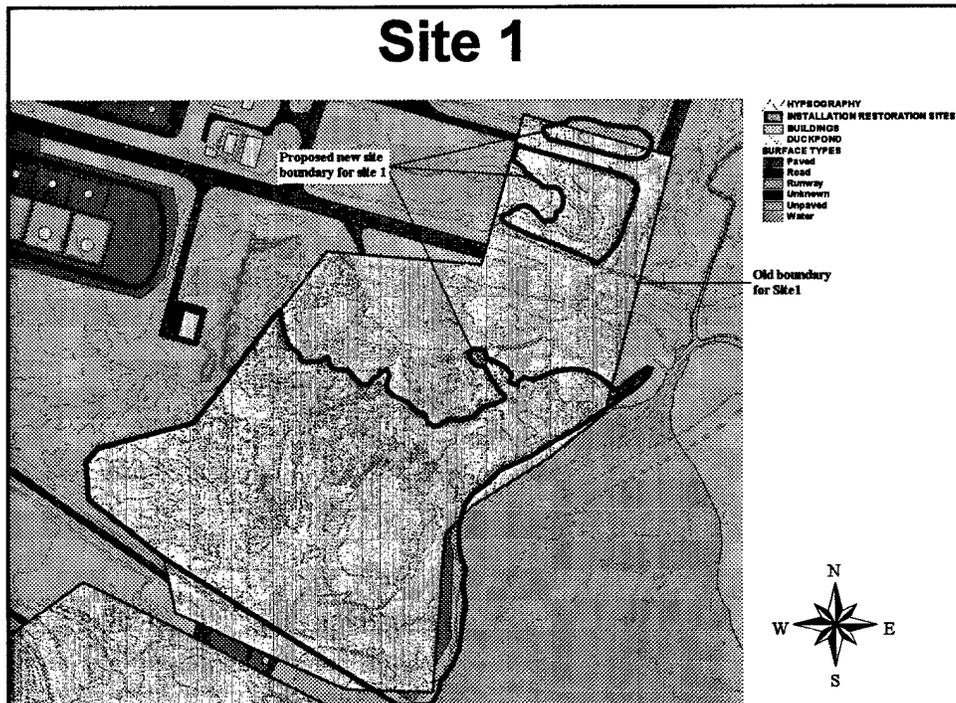


Figure 5. Naval Air Station Point Mugu Installation Restoration Site 1.

area. A rip-rap wall was also constructed to reduce further erosion of the shoreline and transport landfill materials into the lagoon.

A base-wide groundwater study was funded to address any concerns with the migration of contaminants from terrestrial sites on NAS Point Mugu to the lagoon, ocean, or lower aquifers. New monitoring wells were installed, quarterly groundwater data were collected, and tidal influence was studied. This information was used to perform modeling of Site 1 to determine any impacts to the lagoon.

### Portsmouth Naval Shipyard

The 25-acre Jamaica Island Landfill (JILF) was used for hazardous and non-hazardous waste disposal from 1945 to 1978 (Figure 6). The landfill was created by filling tidal flats between the original Seavey's and Jamaica Islands from north to south, and forms the north and west shore of Clark Cove. According to archive records, the tidal flats that were inundated with disposal material appear to have supported various estuarine habitats including shell-fishing beds, fringing marshes along the shores of Seavey and Jamaica Islands, a benthic invertebrate habitat, a rocky shoreline habitat, and possibly eelgrass beds in adjacent subtidal areas. The filling activities, which took place over several decades, completely covered the estuarine resources where the landfill now resides and altered the river currents around Jamaica Island. Remnants of the old habitat found during the JILF investigations included an 8- to 30-ft thick layer of organic-rich silt and clay underlying most of the landfill, and extensive beach and tidal flat deposits under the overburden (McLaren/Hart Environmental Engineering Corp., 1992). The direct disposal of materials into the tidal area would have resulted in significant releases of contaminants through surface runoff, windblown dust, and refuse being pushed directly into the river.

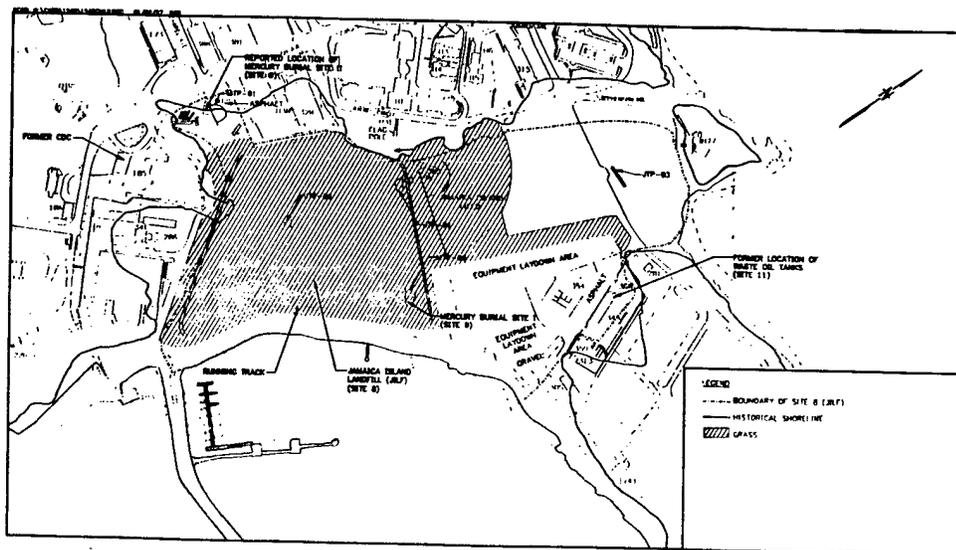


Figure 6. Portsmouth Naval Shipyard Jamaica Island Landfill Restoration Site 1.

Various materials, including sludges, solvents, asbestos, blasting grit, incinerator ash, and mercury-contaminated wastes contained within concrete vaults were disposed in the landfill. Waste oils containing polychlorinated biphenyls (PCBs) may also have been disposed in the landfill before 1972. In 1978, more than 82,571 cubic yards of sediments were dredged from Berths 6, 11, and 13 at the western end of the island and were disposed of over the landfill. This material was contained and capped by a clay barrier. Currently, the JILF is maintained as an open space and recreational area.

The presence of the marine silt and clay layer underlying the landfill could serve as a confining layer and would prevent the movement of contaminants due to the low porosity and high sorptive capacity of the clay material. Regional groundwater flow appears to be discharging upward from the bedrock, likely resulting in the flow being diverted "laterally beneath the clay layer toward the estuary" without coming into contact with the landfill material (McLaren/Hart Environmental Engineering Corp., 1992). Migration of landfill contaminants could be further hindered by the fill and cap materials used when the landfill was closed. However, there is evidence of tidal exchange and tidal influence on groundwater elevations near the southeastern edge of the landfill (along the shore of Clark Cove). Estuarine water has been detected in monitoring wells (McLaren/Hart Environmental Engineering Corp., 1992) and seepage samples (Johnston et al., 1994) taken along the edge of the landfill. Based on the available hydrogeological information, it is expected that most metals and organic compounds would be tightly sorbed to particles and would not readily migrate. This expectation is consistent with results of seepage sampling, which show that no organic contaminants have been detected (McLaren/Hart Environmental Engineering Corp., 1992; Johnston et al., 1994) and that most inorganic contaminants in the seep samples were below ambient water-quality criteria standards (Johnston et al., 1994). However, a "potential exists for inorganic contaminants to migrate via groundwater from JILF to [the] estuary...and...based on tidal influence... organic compounds may [also] be entering the estuary..." from the JILF (McLaren/Hart Environmental Engineering Corp., 1992).

Marine sediments collected along the face of JILF contained elevated concentrations of chromium, nickel, and lead. Algae (*Fucus vesiculosus*) samples were elevated in chromium, cadmium, lead, and nickel. Blue mussels (*Mytilus edulis*) had elevated levels of nickel, lead, and PCBs. Sediment and water sampling in Clark Cove conducted by McLaren/Hart Environmental Engineering Corp. during the Resource Conservation and Recovery Act facility investigation found no detectable levels of PCBs, pesticides, semivolatiles, or volatile compounds (except for unidentified aliphatic hydrocarbons and VOCS associated with laboratory solvents—acetone, chloroform, and carbon-tetrachloride). Measurements of TPH concentration ranged from 140 to 780 ppm, and metal including arsenic, chromium, copper, lead, mercury, and nickel



The Waiawa Unit is an intensely managed wetland that covers approximately 25 acres immediately northwest of the landfill. Two shallow ponds occupy most of the area. The ponds are supplied with fresh water from the Waiawa Spring Complex (located approximately 1000 feet to the north) and drain into Pearl Harbor. Ecological risk assessment results indicate that landfill groundwater is unlikely to threaten the ecological receptors that inhabit the Unit. Groundwater discharged from the landfill represents only a small fraction of the total volume of water flowing through the ponds. Contaminated surface and groundwater sources up-gradient of the landfill apparently contribute the bulk of the contamination load entering the ponds.

Elevated dioxin/furan, PCB, and arsenic concentrations were detected in surface and subsurface soil samples from an ash layer in the southeast corner of the landfill. The ash layer is apparently not restricted to U.S. Navy property; dioxins/furans have also been detected in soil on adjacent City and County of Honolulu-owned property occupied by an inactive STP. Human health risk assessment results indicate that direct exposure to ash and contaminated soil is the only mechanism likely to threaten human health. Ecological receptors in Waiawa Stream may be at risk due to the potential for surface runoff to erode and transport ash and contaminated soil to Waiawa Stream. The contaminants of concern are not readily leachable in soil due to their very low solubility and strong tendency to sorb to soil particles; therefore, surface water infiltration is a minor concern, and contaminant migration to groundwater is unlikely.

Investigations completed since landfill closure have not concluded that contaminants from the site are threatening human health and the environment. However, potential threats include direct exposure of humans to contaminated soils on-site and exposure of off-site ecological receptors to landfill-derived contaminants through direct contact with surface water and sediment.

The recommended option, Long-Term Monitoring Only, proposes a 5-year groundwater-monitoring program using 16 wells or piezometers along the landfill boundary. Landfill gas would be monitored in gas monitoring wells installed around the perimeter of the landfill. The program may be modified if sampling results indicate the need for a change in the monitoring schedule, duration, or parameters. The recommended option also proposes a 10-year monitoring program to detect future increases in the Waiawa Unit surface water and sediment toxicity or contaminant concentrations. The monitoring program may be suspended or discontinued if toxicity is not increasing or if the concentrations of contaminants known to occur in the landfill are not increasing in Waiawa Unit surface water or sediments. To better define baseline conditions within the Unit, additional ecological sampling would be implemented. Potential up-gradient or off-site contaminant sources would also be investigated to confirm that landfill contaminants are unlikely to threaten

the Waiawa Unit. The additional sampling programs would be developed in cooperation with concerned stakeholders.

## 4 Coastal Contaminant Migration Monitoring Technologies

Groundwater models are currently the method of choice for evaluating whether groundwater is impacting a coastal zone such as a bay or estuary. While this review focuses on measurement technologies, it is important to mention the role of models and their relationship to measurements and flow prediction.

### Groundwater Models

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#### Technology Description

Groundwater modeling is a computer-based method for mathematical analysis of the mechanisms and controls affecting groundwater systems (Van der Heijde, El-Kadi, and Williams, 1988). Analytical and numerical models are used extensively in simulating groundwater flow (Fetter, 1994), with applications ranging from one-dimensional, steady-state, flow prediction to 3-D, time-dependent flow, transport, and partitioning simulation (Van der Heijde, 1996). Models were developed for the hydrogeological processes of flow, transport, and transformation with many specific applications. These applications have increased enormously, parallel to the advancements in computer software technology. For example, models have been developed specifically for estimation of leachate generation at a waste facility, evaluation of various remedial activities, risk assessment, biodegradation, waste classification, etc. Models are often used in an integrated approach with measurements. Model loading terms, initial conditions, boundary conditions, calibration, and validation may all require measurement data.

#### Developmental Status

Many different types of models are available to simulate different groundwater systems, depending on the purpose of the study. Model selection generally depends on the complexity of the groundwater system. If the system is in steady-state condition during simulation, a simple analytical model may be sufficient to simulate a flow and transport. However, systems with transient conditions, heterogeneities, anisotropies, and multi-aquifer flow and transport can only be simulated accurately with numerical models.

Common numerical models include MODFLOW, GMS, VS2DT, 3DFEMFA, SEEP/W, and SUTRA. MODFLOW is a U.S. Geological Survey (USGS)-developed, modular, 3-D groundwater flow model used to simulate systems for water supply, containment, remediation, and mine dewatering. VS2DT is another USGS-developed program for flow and solute transport in variably saturated, single-phase flow in porous media. Simulated regions include one-dimensional columns, two-dimensional (2-D) vertical cross-sections, and axially symmetric, 3-D cylinders. The proprietary model, 3DFEMFAT (Scientific Software Group), is a 3-D finite-element model of flow and

transport through saturated–unsaturated media. Typical applications include infiltration, well-head protection, agriculture pesticides, sanitary landfill, radionuclide disposal sites, hazardous waste disposal sites, density-induced flow and transport, and saltwater intrusion. 3DFEMFAT supports simulations of flow only, transport only, combined sequential flow and transport, or coupled density-dependent flow and transport. SEEP/W is a proprietary finite-element software product (Geo-Slope International) that models seepage problems involving movement and porewater pressure distribution within porous materials such as soil and rock. SUTRA (developed by USGS) is a coupled groundwater flow and quality model. The model simulates energy and solute transport in saturated and unsaturated media and may also account for variability of density with temperature when simulating the heat transport.

### **Applications and Limitations**

Groundwater models are practical, descriptive, and predictive problem-solving tools that assess the response of subsurface systems to variations in existing and potential environmental stresses. Groundwater models have various applications, including simulating and evaluating natural attenuation, optimizing groundwater remediation systems, designing pumping well capture zones, and studying watershed management. Where precise aquifer and contaminant characteristics have been reasonably well-established, groundwater models may also provide a viable method to predict contaminant fate and transport in complex subsurface systems.

Simulation of complex groundwater systems often requires the characterization of the hydrology, physical transport processes, geochemistry, contaminant chemistry, and biochemistry of the system, making groundwater modeling highly multidisciplinary (Van der Heijde and Elnawawy, 1993). Groundwater models also depend on several factors such as geology and parameters. Documentation for groundwater models can often be insufficient in determining the implementation of boundary conditions in the model. Most groundwater modeling software packages also address only a limited number of conditions that are actually encountered in the field (Van der Heijde, 1996). While groundwater models are only estimations used to describe complex systems, they can provide realistic, quantitative information for efficient resource use when additional field data collection is required and financial resources are limited.

The costs associated with groundwater modeling can be estimated from a recent contract task order (CTO) to assess groundwater migration. CTO 149 for NAS Point Mugu involved the installation of new monitoring wells, the collection of quarterly groundwater data, a tidal influence study, and the modeling of nine sites. The cost of this CTO was \$1,850,952. The cost per site was \$205,661. Other U.S. Navy bases have performed the same type of study, such as the Naval Construction Battalion Center (NCBC) Port Huenme, but their costs per site were even higher. Therefore, the cost of \$205,661

represents a minimum number for the costs associated with groundwater modeling.

### **Flow Detection**

The advective flow of groundwater to coastal water is called submarine groundwater discharge (SGWD) (Simmons et al., 1992). In freshwater systems, the exchange of water between surface waters and groundwater is generally referred to as hyporheic flow. A number of technologies exist or are under development to detect SGWD and hyporheic flow. These technologies range from the more quantitative detection methods such as seepage meters (Lee, 1977; Chadwick et al., 1999) and 3-D thermal gradient flow meters (Ballard, Barker, and Nichols, 1994) to indirect techniques such as piezometers (Lee and Cherry, 1978) and dye tracer injection (Turner Designs, 2000), and generalized detection techniques such as thermal plume mapping by infrared (IR) detection (Portnoy et al., 1998; Urish, 1999) and naturally occurring tracers. These techniques may be used together or in concert with analytical or numerical models. The following subsections describe each technology, its developmental status, applicability, and limitations.

### **Seepage Meters**

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#### **Technology Description**

Seepage meters were originally developed in the 1970s to assess SGWD in lakes and estuaries (Lee, 1977). The prototype instrument described by Lee (1977) consisted of a bottomless cylinder vented to a deflated plastic bag (Figure 8). The cylinder is implanted into the sediment, allowed to stabilize, and then the sampling bag is attached to the vent.

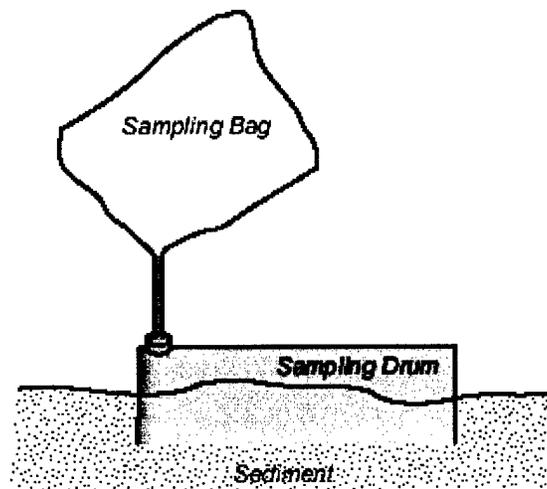


Figure 8. A traditional seepage meter showing typical placement in the sediment (adapted from Lee and Cherry, 1978).

Groundwater migrating across the interface is then channeled by the cylinder into the bag. The seepage velocity is determined by the equation,  $v = A \cdot V / t$ , where  $v$  is the seepage velocity,  $A$  is the area of sediment covered by the seepage meter,  $V$  is the net volume of water collected in the bag, and  $t$  is the elapsed time that the bag was in place. If the bag is pre-filled with water, then seepage from the surface water into the sediment can also be detected.

### Developmental Status

Seepage meters continue to be refined and applied in various settings. Recent developments include adaptation for automated multiple sample collection (Chadwick et al., 1999), continuous flow detection using mechanical flow meters (Linke et al., 1994), thermistor flow meters (Linke et al., 1994), tracer injection (Tyron and Brown, 1999), and ultrasonic travel-time flow meters (Paulsen, Smith, and Wong, 1997). The following subsections describe each adaptation.

*Multi-Sample Seepage Meter:* Chadwick et al. (1999) describe a modified seepage meter system based on the standard seepage meter geometry used in previous studies. However, instead of a single sampling bag, a multi-port sampling configuration was used (Figure 9). The system incorporated two rotary selector valves that allowed six samples bags to be attached. A control system attached to the valves allowed sampling at pre-selected intervals. As a result, the meter can delineate variations in seepage over tidal cycles in coastal waters.

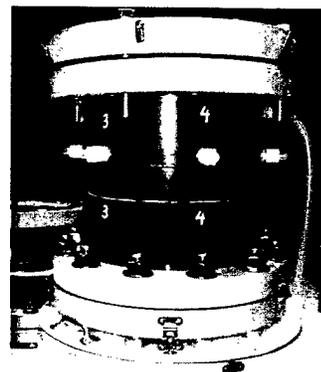


Figure 9. The multi-sample seepage meter showing the polyethylene drum (bottom) and multiport sampling module (top). Sampling bags connect to each of the six sampling ports on the meter.

*Mechanical Flow Meter:* Linke et al. (1994) describe a seepage meter with a mechanical flow meter in place of sampling bags. A

Bernoulli-type mechanical flow meter was attached to the exhaust port on the top of the seepage drum and a camera recorded the flow reading. The calibrated flow meter provides a measurement range of about 0.01 to 4.0 ml  $\text{min}^{-1}$ . The meter requires careful calibration to compensate for fluid viscosity (as a function of temperature, salinity, and pressure), and for the back pressure induced by the small diameter of the exhaust port (3 mm<sup>2</sup>).

*Thermistor Flow Meter:* Linke et al. (1994) also describe a thermistor (hot-bead) flow meter connected to a seepage meter. The thermistor flow meter measures flow rates from about 0.01 to 50 cm  $\text{s}^{-1}$ , and data can be recorded directly to a data logger.

*Tracer Injection Flow Meter:* Tryon and Brown (1999) present the design and initial results from a seepage meter equipped with a tracer-injection flow

meter. The water-and-geochemical flux meter (WGF-meter; Figure 10) measures fluid velocities through the sediment surface on the order of 0.1 to 100 mm y<sup>-1</sup>. The WGF-meter is similar to traditional seepage meters; it channels groundwater flow at the sediment–water interface through an inverted-drum type chamber. The technology differs significantly in the manner in which it detects the flux rate and chemical properties of the flow. The meter uses the dilution of a chemical tracer to measure flow through the chamber. The tracer solution is injected into the seepage meter exhaust stream by two osmotic pumps. The same pumps are then used to sample the vent fluid/tracer mixture from downstream of the tracer injection port. The seepage rate is then quantified by analysis of the tracer concentration in the sample volume. This method allows direct measurements at low flux-rate vents and regions of slow diffuse flow.

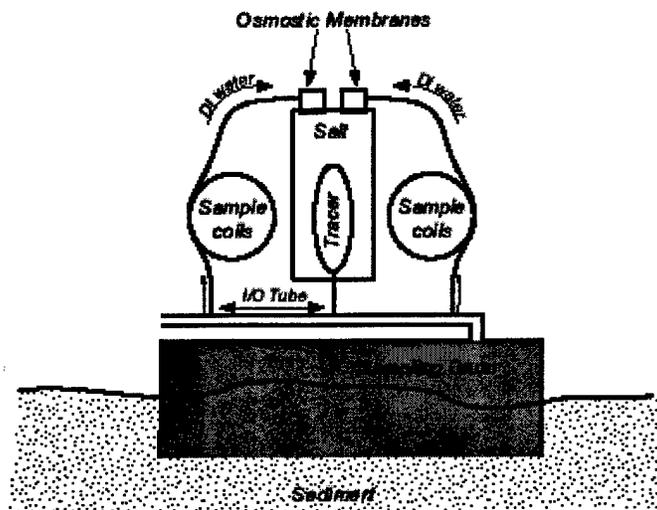


Figure 10. The WGF seepage meter showing schematically the tracer injection flow meter technique (adapted from Tryon and Brown, 1999.)

*Ultrasonic Flow Meter:* Paulsen et al. (1997) describe an ultrasonic flow meter that uses continuous flow monitoring (Figure 11). The flow from the sampling drum is led to a flow tube equipped with two ultrasonic piezoelectric transducers. As water passes through the ultrasonic beam path, the difference in travel times of the ultrasonic signals is directly proportional to the direction and velocity of the flow and can be used to determine the flow rate. The meter also detects reversals of flow such as a negative groundwater flux across an interface. In the field, the data logger and a backup battery are often housed in a buoy anchored to shore so that long-term, continuous measurements are made with a minimal risk of equipment damage. The battery life of the logger is approximately 12 hours, while the backup battery lasts approximately 48 hours.

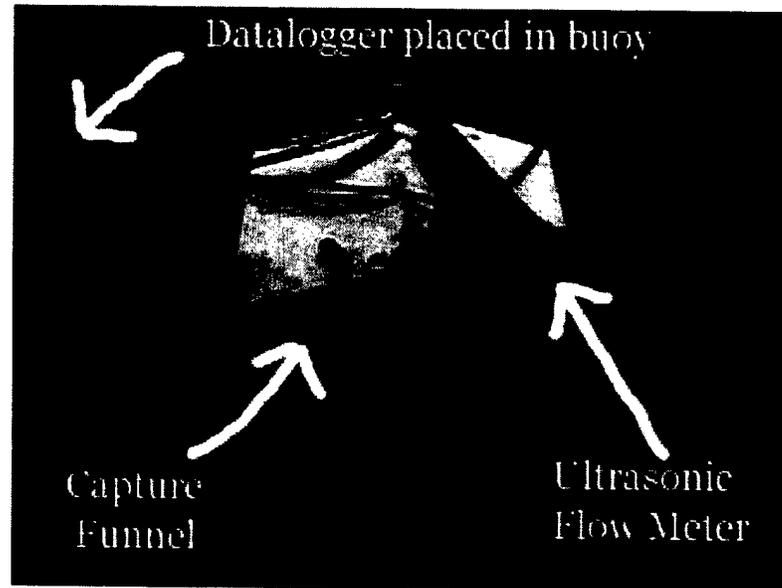


Figure 11. Seepage meter with ultrasonic flow detection.

### Applications and Limitations

Seepage meters detect groundwater flow in a wide variety of settings including lakes and streams (Lee, 1977; Lock and John, 1978; Brock et al., 1982; Belanger and Mikutel, 1985; Cherkauer and McBride, 1988; Shaw et al., 1990), estuaries and bays (Lee, 1977; Bokuniewicz, 1980; Zimmerman, Montgomery, and Carlson, 1985; Simmons et al., 1991; Simmons et al., 1992), coral reefs (D'Elia, Web, and Porter, 1981; Lewis, 1987; Simmons and Netherton, 1986), and continental shelf waters (Simmons et al., 1992; Linke et al., 1994).

Traditional seepage meters are limited in detecting small seepage rates. They are also subject to errors associated with flow-field deflection, frictional resistance, head loss, and anomalous short-term influx when sampling bags are not pre-filled (Belanger and Montgomery, 1992; Shaw and Prepas, 1989). As described above, many limitations may be overcome by using improved sampling and flow measurement techniques.

### Thermal Gradient Flow Meters

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#### Technology Description

Heat-pulse groundwater flow meters have been used to measure groundwater flow in monitoring wells (Kerfoot and Massard, 1985). These meters heat the groundwater in a pulsed mode and then detect the 2-D horizontal flow components by measuring the thermal bias created as water flows through the meter. The linear relationship between the thermal conductance bias and flow rate determine the velocity (Kerfoot, 1982). Ballard et al. (1994) describe the In Situ Permeable Flow Sensor, a similar technique for direct, in situ measurement of groundwater flow (Figure 12). In this method, the probe is installed

directly into the saturated soil media (not a well) and a thermal perturbation technique detects flow. The meter uses a resistance heater to heat a groundwater volume of  $\sim 1 \text{ m}^3$  around the probe. An array of 30 thermistors located beneath the skin of the probe detects small-scale perturbations in the temperature distribution that arise from the flow of groundwater past the device. This technique provides magnitude and direction of groundwater flow in three dimensions, with theoretical detection as low as  $\sim 1 \text{ m}\cdot\text{yr}^{-1}$ .

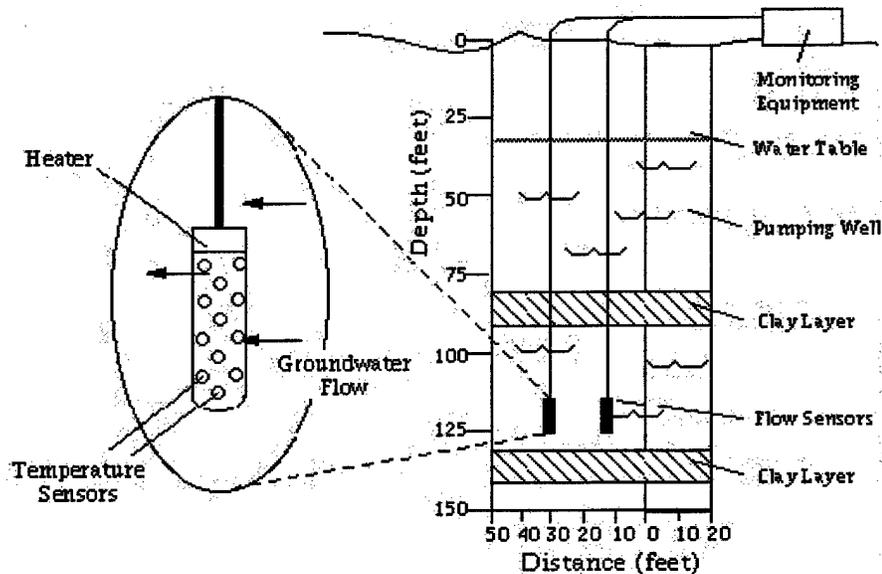


Figure 12. A schematic view of the In Situ Permeable Flow Sensor (from U.S. Department of Energy, 1995).

### Developmental Status

Thermal flow probes have been demonstrated at a number of terrestrial sites. Recent publications indicate that further testing is still required, but initial test results appear promising (Ballard, 1996; Ballard et al., 1994).

### Applications and Limitations

Thermal flow probes may have application in a wide variety of groundwater flow detection studies; however, the number of groundwater-surface water interaction applications attempted appears limited. The probes have advantages over traditional hydraulic gradient measurements because they can measure either 2-D or 3-D flow from a single installation, eliminate the need for additional slug/pump testing for hydraulic conductivity, and provide point measurements as opposed to average flow estimates over large areas. Thermal flow probes that are installed directly into the saturated soil avoid problems associated with screening effects on flow measurements observed in well-type probes. The probes can be left in place for up to about 1 year. Some drawbacks of the In Situ Permeable Flow Sensors are that they generally cannot be

removed once installed (at a cost of about \$2500/probe) and convection associated with heating the water may affect flow.

## **Piezometers**

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### **Technology Description**

A piezometer is a small-diameter well with a short-screened section at its end that measures the hydraulic head in an aquifer. In the field, a polyvinyl chloride (PVC) or stainless steel tube is typically used with evenly spaced small holes at the bottom of the tube to allow free-flowing groundwater to enter. Piezometers are placed at different depths to measure flow (Barnard and McBain, 1994). At least two piezometers must be used to determine the groundwater flow. According to Darcy's Law, the rate of water flow through a bed of specified strata is proportional to the difference of the heights of water between two piezometers and inversely proportional to the lengths of the flow path between piezometers (Fetter, 1994). In the field, the difference in pressure is measured by the difference of the water elevations in the tubes. These measurements may be done with an electric interface measuring tape, pressure transducer, or other methods.

### **Developmental Status**

Piezometric methods for measuring hydraulic head are well developed. Recent developments indicate that substrate permeability can also be estimated with piezometers (Barnard and McBain, 1994). Drive-point piezometers for direct-push applications have become popular for water-level and water-quality monitoring (Cherry et al., 1993). For applications to groundwater-surface water interaction, miniature piezometers have been described for use directly in shallow coastal water for determining hydraulic head relative to surface water levels (Lee and Cherry, 1978; Winter, LaBaugh, and Rosenberry, 1988; Simmons et al., 1992).

### **Applications and Limitations**

Piezometers have been used to evaluate water groundwater-surface water interactions in lakes and streams. If several piezometers are placed at different depths below the shoreline on the down-slope side of a lake, and they all have hydraulic heads higher than the elevation of a lake, a stagnation point is present, which means the lake will not leak from the bottom (Fetter, 1994). Piezometers are frequently used to evaluate the magnitude and landward extent of tidal influence on groundwater elevations in coastal regions (Ferdowsian and Ryder, 1997). Application is limited to sites where piezometers can be driven into the ground. Piezometers work best in unconsolidated deposits such as sands and gravels. This often proves problematic in developed coastal areas where shorelines have been stabilized with rip-rap or other impenetrable fill materials. Direct-push methods do not require a drill rig but will not work well in hard soil beds (Pitkin, Ingleton, and Cherry, 1994). Piezometers do not provide a direct measurement of

groundwater flow and rely on good estimates of lithology and hydraulic conductivity between the measurement points to allow accurate flow estimates.

## **Thermal Infrared Aerial Imagery**

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### **Technology Description**

Thermal infrared aerial imagery has been used to detect groundwater discharge along shorelines of marshes and embayments in coastal New England (Portnoy et al., 1998). A super cooled detector mounted on a small aircraft measures the difference of thermal spectral response of the water along the coastline. Groundwater can be detected because it may sometimes be as much as 10 to 15° C colder than the surface water, especially in the summertime (Urish, 1999). If the groundwater is fresh, it will also have a lighter density than saltwater, making the temperature difference easier to detect because the freshwater tends to float above the saltwater.

### **Developmental Status**

Thermal IR imagery is a well-developed technology that has been commercially available for many years. A number of platforms and detectors exist, ranging from hand-held to airborne to satellite-based systems. Using this technique to evaluate groundwater flow into surface waters is relatively new and has not been widely applied.

### **Applications and Limitations**

This technology may find application in coastal sites with predominately good weather. The technique can only be used during good weather (cloud-free sky with very calm wind). Optimal time is immediately after sunset when the effect of direct solar effect is minimal and water temperature difference is still strong (Urish, 1999). Optimum time may also occur during low tide because the greatest discharge of groundwater often occurs at, or just after, low tide. In tests reviewed, two flight surveys were run about 1 hour apart to distinguish between fixed coastal features, which may also give a thermal response, and the moving plume of discharging freshwater. The method appears efficient and cost effective for detecting groundwater discharge under the proper circumstances. However, it is strictly qualitative and only indicates that discharge is occurring, but provides no information on flow magnitude. The number of published applications is also limited.

## **Tracer Injection**

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### **Technology Description**

The tracer injection technique generally involves the introduction of an easily detectable constituent at one or more fixed points in the study area, and subsequent monitoring of the surrounding area to determine where the tracer migrates, and over what period of time. Common tracers include dyes

(Rhodamine WT, Fluorescein, Pontacyl brilliant-pink B) and dissolved salts (sodium bromide, sodium chloride, potassium chloride, lithium chloride) (Turner Designs, 2003; Goel, 1994; Replogle et al., 1976; Wright and Collins, 1964). The tracer is generally introduced via an existing monitoring well and may consist of a slug input or a continuous input for an extended period of time. Measurements of dye concentration are sampled at different wells downstream over a given period of time to predict the approximate subsurface flow of the groundwater (Kimball, 2000).

#### **Developmental Status**

While there have been a number of applications, the use of injected tracers in typical groundwater systems has not been thoroughly investigated (Turner Designs, 2003), particularly the effects of sorption of tracers on soil or subsurface strata.

#### **Applications and Limitations**

Tracer injection has been used in a variety of applications to groundwater flow detection including determination of flow path, flow velocity, travel time (residence time), water budget, hydraulic conductivity, dispersivity, and effective porosity (Cohen et al., 1994; Turner Designs, 2003). In applications to measurement of groundwater flow, adsorption of the tracer may confound results (Turner Designs, 2003). In a study of groundwater flow within a constructed fen, Goel (1994) found that sorption of Rhodamine WT on silty-loam material led to a retardation factor of about 7.2, indicating that the tracer movement would significantly underestimate the actual flow. In areas where the groundwater flow impinges on surface water, detection of the tracer may be difficult due to strong dilution, especially if the surface water is well-mixed by tidal, river, or wind-driven currents. In areas where groundwater flow is very slow, travel time measurements with tracers may require excessive time to achieve results, depending on the spatial separation of the injection and monitoring points. The appropriate tracer should be used based on their properties (toxicity, mobility, sorption) and the availability of reliable analytical techniques. The appropriate amount of tracer should be used based on background conditions, detection limit, and expected degree of tracer dilution (Cohen et al., 1994).

### **Colloidal Borescope**

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#### **Technology Description**

The colloidal borescope is an in situ observation system that determines groundwater flow velocity based on the movement of natural colloids in groundwater wells. The system consists of a charge-coupled device camera, an optical magnification lens, an illumination source, and a compass, all housed in a watertight stainless steel casing (Figure 12) (Kearl, 1997). The instrument transmits an electronic image to the surface through a cable and a special particle-tracking software program reads the borescope and analyzes

the images to calculate groundwater flow. The system is capable of measuring flow at selected depths within a well and has the ability to measure flow from individual fractures (Kearl et al., 1999). Flow direction and velocity in low- and high-permeability materials can be measured at velocities up to  $3 \text{ cm}\cdot\text{s}^{-1}$  (Kearl and Roemer, 1998).

### Developmental Status

The colloidal borescope (Figure 13) has been tested and demonstrated at many sites, including the Sandia Mountains in New Mexico (Kearl et al., 1999), the Department of Energy Kansas City Plant, the Portsmouth Gaseous Diffusion Plant, North Island Naval Air Station, Fallon Naval Air Station, the Fernald Plant, Hanford Reservation, the Savannah River Plant, Lawrence Livermore National Laboratory, and the Paducah Gaseous Diffusion Plant (Kearl and Roemer, 1998).

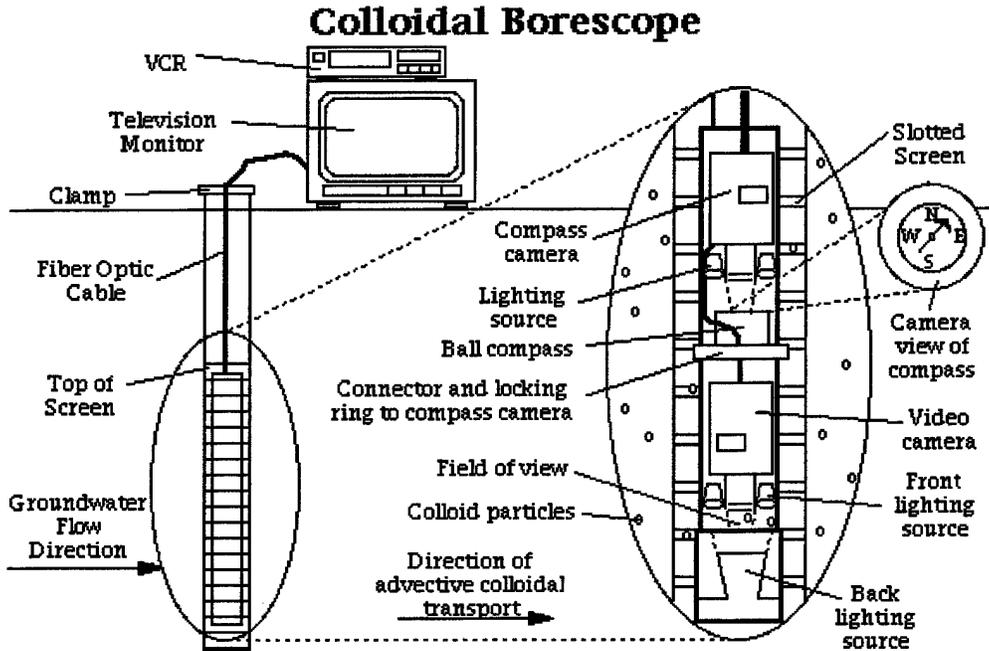


Figure 13. The colloidal borescope provides a direct means of determining groundwater flow direction and velocity. Reprinted from *Journal of Hydrology*, vol. 200, 1997, pp. 323–324, P. M. Kearl, "Observations of Particle Movement in a Monitoring Well Using the Colloidal Borescope," Copyright © 1997, with permission from Elsevier.

### Applications and Limitations

The colloidal borescope system provides a direct measurement of groundwater flow direction and velocity. The technique is generally applicable to sites with existing monitoring wells or where wells can be installed. Current applications include the following:

- Site characterization by determining preferential flow paths and fractures
- Assessing heterogeneities associated with porous media
- Establishing the existence of immiscible contaminant layers and their associated flow properties
- Assessing the efficiency of groundwater remediation programs by determining the effective radius of influence of groundwater extraction systems
- Determining the amount of biological activity present in a bioremediation system
- Evaluating the effects of sampling on colloidal concentrations.

Potential applications include providing physical observation capabilities necessary to develop and confirm new, more accurate theoretical models of the porous media flow process and assessing the effects of water-sampling techniques on natural colloidal concentrations.

Boreoscope measurements are limited to horizontal flow (2-D) and may be hampered by vertical flow and/or well screen effects. Applications for the assessment of groundwater–surface water interaction appear limited. Additional work is underway to address variability observed in a well bore.

### Natural Geochemical Tracers

#### **Technology Description**

Naturally occurring geochemical tracers represent a promising approach for regional scale assessment of groundwater–surface water interaction. Previous studies have used  $^{222}\text{Rn}$  (Cable et al., 1996; Moore and Shaw, 1998; Hussain, Church, and Kim, 1998),  $^{226}\text{Ra}$  (Moore, 1996; Moore and Shaw, 1998; Hussain et al., 1998), and barium (Moore and Shaw, 1998; Shaw et al., 1998) to estimate groundwater inflow rates (Figure 14). These tracers are favored because they are typically enriched in groundwater, often 3 to 4 orders of magnitude above coastal seawater. Nutrients and salinity have also been shown to be useful tracers in some areas (Moore and Shaw, 1998; Simmons et al., 1992). Most applications of natural tracers have been to evaluate the importance of submarine groundwater discharge in overall water or chemical budgets. The quantification of flow is generally based on measurement of surface water inventories of groundwater tracers and subsequent calculation of the groundwater discharge necessary to maintain the surface water budget.

Studies suggest that  $^{226}\text{Ra}$  may be more useful for quantifying tidal pumping of groundwater due to its longer half-life, while  $^{222}\text{Rn}$  may be more applicable as a tracer for groundwater discharge of freshwater (Hussain et al., 1998). Barium may be a good indicator of saline intrusion (Shaw et al., 1998).

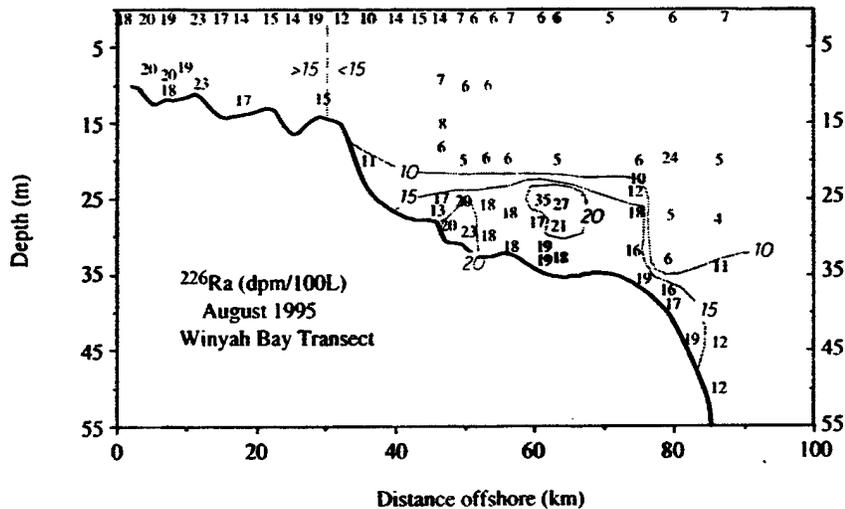


Figure 14. Offshore section of  $^{226}\text{Ra}$  showing evidence of submarine groundwater discharge to the South Atlantic Bight. W. S. Moore and T. J. Shaw. "Chemical Signals from Submarine Fluid Advection onto the Continental Shelf," *Journal of Geophysical Research*, 103(C10), p. 21545, 1998. Published 1998, American Geophysical Union. Reproduced/modified by permission of American Geophysical Union.

### Developmental Status

Natural tracers have gained acceptance as markers for groundwater–surface water interaction over the last 10 years based on a number of published studies. The methodologies, applications, and types of tracers continue to develop.

### Applications and Limitations

Natural tracer techniques have application in coastal areas or bays near groundwater with a natural enrichment or deficit of the selected tracer. Examples include estimates of atmospheric and benthic exchange to San Francisco Bay (Hammond and Fuller, 1979), submarine spring discharge off the coast of Florida (Fanning et al., 1981), groundwater discharge to the South Atlantic Bight, groundwater discharge in the Gulf of Mexico (Cable et al., 1996), benthic exchange along the Southern California coast (Berelson, Hammond, and Fuller, 1982), and groundwater discharge in the Chesapeake Bay (Hussain et al., 1998).

Previous studies have primarily been limited to regional scale assessment based on overall water and chemical budgets. This approach has potential limitations in identifying source locations, and depends somewhat on

measuring or eliminating other tracer sources from the budget. Other possible tracer sources include diffusion from sediments, bioirrigation of sediments, and bubble ebullition. Many tracer techniques also depend on rather specialized isotope chemistry that may be unavailable.

## **Contaminant Detection**

### **Pore Water Probes**

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#### **Technology Description**

The direct measurement of sediment pore water is generally done using one of four different methods: squeezing, centrifugation, vacuum filtration, and dialysis (Bufflap and Allen, 1995). The first two methods are considered ex situ techniques, requiring the extraction of sediments from their natural environment. These are the oldest and most widely used methods; however, the direct handling of sediment and porewater samples may lead to contamination and oxidation of the samples. The last two methods are considered in situ techniques. Because a sediment sample is not required, the potential for contamination is greatly decreased. Bufflap and Allen (1995) compared these four sampling methods and concluded that vacuum filtration had the best potential for producing artifact-free samples. However, this technique is limited at increased depths due to the high pressures that required extracting the samples.

#### **Developmental Status**

Several different techniques are used to extract sediment pore water. The type of techniques used generally depends on the type of environment in which a study occurs.

#### *Squeezing Methods*

Squeezing methods of pore water extraction either employ a means of pressurizing a section or an entire sediment core sample. This method usually uses gas pressure (Hartman, 1965; Lusczynski, 1961) or pistons that force pore water from the sample through an exit port (Lusczynski, 1961; Hartman, 1965; Jahnke, 1988). Jahnke (1988) describes an example of this method, where a simple porewater sampler was used that consisted of an acrylic core barrel with holes drilled at 1-, 2- and 3-cm spacings. The core barrel is inserted into a box core and pistons are placed at the top and bottom of the core barrel to pressurize the sample, forcing pore water out of the holes through 0.45- $\mu$ m filters and into plastic syringes. This device is simple, fast, and cost-efficient, and is effective when in situ methods are not practical; however, handling of sediments may contribute to oxidation artifacts.

#### *Centrifugation*

Centrifugation is another ex situ method of extracting sediment pore water. Extracted samples are centrifuged to separate sediments from pore water. Batley and Giles (1979) have also used an inert fluorocarbon (FC-78) during

centrifugation to replace the pore water in the space between particles and force pore water to the surface. This method provides a greater percentage of pore water removal and alleviates the need for filtration of the extracted sample.

#### *Vacuum Filtration*

For in situ measurements, Watson and Frickers (1990) have developed a multilevel porewater sampler with a compact design that allows it to be deployed unattended in intertidal sediments, either inside benthic field chambers or aboard ship for porewater sampling in deeper cores. The unit is a solid acrylic cylinder with a series of five vertical holes drilled into the cylinder with their centers equally spaced around a 3.6-cm diameter circle, each fitted with a porous polyfluoro-tetraethylene (PFTE) insert. Pore water is extracted from each hole using a vacuum pump system. Watson and Frickers have also designed and tested a 10-hole unit, which they expect could easily be extended to 15 or 20 sampling intervals.

Chadwick et al. (1999) have developed an in situ collection method where pore water is extracted through a small-diameter, stainless steel probe using a syringe. Divers insert probes into the sediment and 100-mL samples are extracted and placed in pre-acidified vials for analysis.

#### *Mini-Well*

Mini-wells/mini-piezometers (Figure 15) can be installed permanently or temporarily and are very economical. Water levels are measured with a pressure manometer and samples are recovered using a peristaltic pump. Dean et al. (1999) developed a robust system of multilevel pore water sampling to investigate temporal and spatial effects of lake-aquifer interactions along an active beach face. Each array consists of a series of eight samplers made up of polyethylene tubing fitted with stainless steel screens. In situ pore water samples in the region of the sediment-water interface were extracted using a peristaltic pump to draw water from eight discreet depths. The arrays are inexpensive and easy to install; however, significant maintenance is required when they are used in a high-energy sampling site.

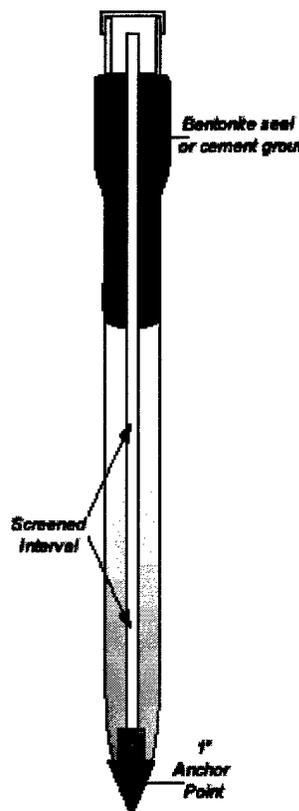


Figure 15. An example of a mini-piezometer/mini-well.

#### *Dialysis*

Dialysis is another in situ method for extracting pore water. Dialysis samplers, sometimes referred to as “peepers,” usually consist of a sample chamber filled with distilled water and covered with a dialysis membrane that allows

chemical species to pass through the membrane until equilibrium with the ambient water is achieved (Carignan, 1984; Belzile and Tessier, 1990; DiToro et al., 1990). Dialysis samplers have also been developed that use a thin layer of ion exchange resin or gel (Davidson et al., 1991; Davidson and Zhang, 1994). Equilibrium times for thin-film resin and gel samplers are much shorter (< 1 hour) than for water-filled samplers (1 to 27 days).

#### **Applications and Limitations**

The analysis of sediment pore water has become increasingly important in determining and assessing sediment contamination and the contribution of sediment to the pollution of the overlying water column (Bufflap and Allen, 1995). Porewater samplers have applications in a wide range of environments, including intertidal sediments (Watson and Frickers, 1990), inside benthic field chambers (Watson and Frickers, 1990), and dynamic beach environments (Dean et al., 1999).

Sources of error that may alter trace metal concentrations in porewater samples are oxidation of anoxic pore waters, improper sediment sampling techniques, metal contamination, temperature artifacts, and lack of filtration (Bufflap and Allen, 1995).

#### **Diffusion samplers**

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##### **Technology Description**

Several types of diffusion samplers are available for making in situ measurements of contaminants: vapor-diffusion samplers, water-to-water samplers, and diffusive gradients on thin films (DGTs). The vapor and water-to-water diffusion samplers consist of either air or deionized water, respectively, inside a polyethylene membrane. Each sampler is placed directly in the sediment and tied to a flag and a cable for easy retrieval (Lyford et al., 1999). These samplers are based on the ability of polyethylene to readily allow diffusion of VOCs such as aromatic petroleum hydrocarbons and chlorinated solvents while preventing the movement of water across the membrane. After sufficient equilibration time ( $\geq 14$  days recommended), VOC concentrations of air or water in the sampler achieve equilibrium with VOC concentrations in the ambient water outside the sampler (Vroblesky, 1997). A field or laboratory gas chromatograph can then determine VOC concentrations in the contained air or water samples.

DGTs were designed in 1994 at Lancaster University to quantitatively measure in situ metal concentrations (ranging from  $\sim 0.1$  ppb to 10 ppm) in sediment pore water (Windsor Scientific, Ltd., 2003; Davidson and Zhang, 1994). The probe is inserted directly into the sediment where trace metals are accumulated on a selective binding resin (sequestration layer) after passage through an open-pore gel (diffusive layer). As the DGT probe is continuously accumulating metal during deployment, the final measured mass is an integration of all metals in solution in contact with the device during the

deployment. The original probe developed by Davidson and Zhang (1994) used an acrylamide gel as a diffusion layer and Chelex as a sequestering plate. McCarthy et al. (1998) developed a similar device that uses a glass fiber filter for the diffusional layer, as this material does not adsorb either PAHs or dissolved organic matter (DOM).

The U.S. Geological Survey's Columbia Environmental Research Center recently developed a similar device, the Semi-Permeable Membrane Device (SPMD) (Figure 16). The SPMD was designed as a passive sampling technique for monitoring and assessing trace levels of organic compounds, including polychlorinated dioxin and furans, PAHs, PCBs, organochlorine insecticides, herbicides, and industrial chemicals. The SPMD is typically constructed from a layer of nonporous, low-density polyethylene that surrounds a sequestration medium. The sequestration medium generally consists of a thin film of large molecular weight lipid such as triolein, which mimics the absorption of contaminants into the fatty tissues of aquatic organisms (Figure 15) (Huckins et al., 1999).

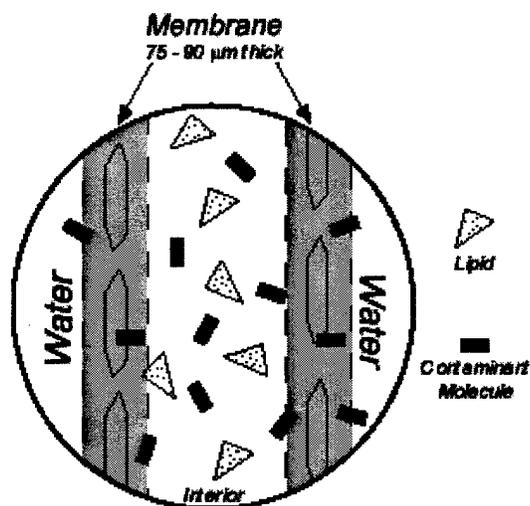


Figure 16. The Lipid-Containing Semi-Permeable Membrane Device (SPMD).

### Developmental Status

Vapor-to-water and water-to-water diffusion sampling methods for determining groundwater concentrations of VOCs are relatively new. However, studies by Vroblesky (1997) and Vroblesky and Hyde (1997) suggest that this type of sampling method is a much more cost-efficient alternative to conventional purging and sampling.

DGTs and SPMDs are also very recent developments in measuring trace metal concentrations in sediment pore water. DGTs provide a much better spatial resolution than other technologies (i.e., dialysis peepers) and can be deployed

in large numbers because of relatively low cost and rapid equilibration time (Yu et al., 2000). The DGT probe also measures a much greater vertical resolution than other technologies by retaining vertical concentrations gradients in the pore water. SPMDs have primarily been used to measure contaminant concentrations in the water column; however, Huckins et al. (1999) and Axelman et al. (1999) imply that this device does have applications for measuring pore water contaminant concentrations.

#### **Applications and Limitations**

Diffusion samplers can be used to measure VOC concentrations in streambeds (Noonkester et al., 2000; Lyford et al., 1999; Vroblesky, 1997; Vroblesky and Hyde, 1997), wells (McClellan AFB/EM, 2000; Vroblesky, 1997; Vroblesky and Hyde, 1997), or other bodies of water where the samplers can be placed in an undisturbed area. A study by Vroblesky and Hyde (1997) shows similar concentrations obtained from diffusion samplers to those measured using traditional purging and sampling approaches (within ~12%). The lower cost of the diffusion sampling technique makes it a viable option for monitoring large well networks; however, the long equilibration period ( $\geq 14$  days) must be considered when time is a factor. This method is also not applicable for measuring metals and other contaminants that do not readily diffuse across the semi-permeable membrane.

DGT probes have applications in a wide variety of aquatic environments, including rivers, lakes, estuaries, mudflats, and the deep sea. They have been interpreted to provide in situ information on labile metal species in seawater, remobilization fluxes, and concentration profiles at high resolution (1 mm) in freshwater, ultra-high resolution (100- $\mu\text{m}$ ) profiles in microbial mats, and remobilization fluxes in soils (McCarthy et al., 1998). The DGT probe is also not limited to measuring trace metals and can measure any component with a selective binding agent.

#### **Seepage Meters**

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##### **Technology Description**

Seepage meters, previously described, have primarily been used to measure seepage rates of groundwater into aquatic environments. However, these instruments also have applications in measuring concentrations of various nutrients, gases, and contaminants in seepage water. Seepage meters consist of a cylinder with a large opening at the bottom and an exhaust port at the top that vents into a deflated plastic bag. The chamber is placed into the sediment to measure the rate of groundwater seepage across the sediment-water interface, based on the net volume of water collected in the bag. Samples from the collection bags are then analyzed for selected nutrient concentrations.

**Developmental Status**

Seepage meters have primarily been used to measure nutrient concentrations in groundwater seepage (Linke et al., 1994; Lewis, 1987; Belanger and Mikutel, 1985; Lee, 1977). However, Chadwick et al. (1999) have modified the traditional seepage meter to measure the concentration and fluxes of VOCs (primarily TCE, 1,2-dichloroethene (DCE), 1,1-DCE, and vinyl chloride (VC) migrating out of the sediment. Instead of a single sampling bag, a multiport sampling configuration was used. The system incorporated two rotary selector valves that allowed attachment of six sample bags. A control system attached to the valves allowed sampling at pre-selected intervals.

**Applications and Limitations**

Seepage meters have been used to measure nutrient and contaminant concentrations from groundwater seepage in many different environments, including the deep sea (Linke et al., 1994), coral reefs (Lewis, 1987), lakes (Belanger and Mikutel, 1985; Lee, 1977), and bays (Chadwick et al., 1999). Seepage meters are an excellent measurement tool for groundwater seepage; however, measurements of nutrient concentrations may be questionable if anaerobic conditions are allowed to occur in the enclosed portion of the cylinder (Belanger and Mikutel, 1985). This condition greatly enhances the release of nutrients from the sediment, thus overestimating the actual concentrations present in sediment pore water.

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<b>14. ABSTRACT</b> Growing evidence suggests that submarine groundwater discharge may represent an important migration pathway for natural and anthropogenic constituents entering coastal waters. To address this issue, a series of technologies were investigated for their applicability toward direct quantification of coastal contaminant migration via groundwater. Technologies were divided into two categories: (1) technologies for quantifying groundwater flow to coastal waters, and (2) technologies for detecting contaminants in the groundwater-coastal water exchange zone. The technologies evaluated for quantifying groundwater flow to coastal waters include seepage meters, thermal gradient flow meters, piezometers, thermal infrared aerial imagery, tracer injection, a colloidal borescope, and natural geochemical tracers. The technologies for detecting contaminants in the groundwater-coastal exchange zone include porewater probes, mini-wells, diffusion samplers, seepage meters, and in situ chambers. A matrix was developed to evaluate these technologies. The factors for consideration of each technology include technical performance/applicability, developmental status, reliability, and cost. A panel of experts will fill out the matrix and the selected technologies will then be evaluated for a demonstration based on the panel results.					
<b>15. SUBJECT TERMS</b> Mission Area: Environmental Science groundwater contaminants                      submarine groundwater discharge measurement techniques					
<b>16. SECURITY CLASSIFICATION OF:</b>			<b>17. LIMITATION OF ABSTRACT</b>	<b>18. NUMBER OF PAGES</b>	<b>19a. NAME OF RESPONSIBLE PERSON</b>
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## **Appendix B**

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**NAS NORTH ISLAND - NAVY REGION SOUTHWEST**

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**NAVY ENVIRONMENTAL LEADERSHIP PROGRAM**

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**CLEANUP****BENTHIC FLUX SAMPLING DEVICE****LEAD ACTIVITY**

Southwest Division Naval Facilities Engineering Command (SWDIV)

**STATUS**

Complete

**MISSION**

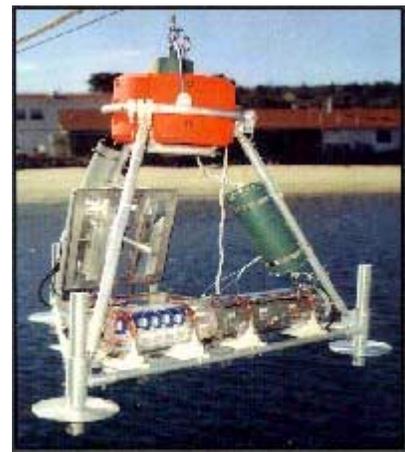
Use innovative pore water sampling technology, coupled with specially designed seepage meters for benthic flux sampling, to identify the area in San Diego Bay where contaminated groundwater discharges to the bay and quantify the amount of contamination being released into San Diego Bay

**REQUIREMENT**

Contaminated sites at many Navy facilities have the potential to impact bays and estuaries. These types of sites include locations where contaminated sediments are present, as well as sites located inland where contaminated groundwater has the potential to migrate to surface waters. The Benthic Flux Sampling Device (BFSD) and companion seepage meter and pore water sampling technologies have been developed by Space and Naval Warfare (SPAWAR) Systems Center in San Diego to meet the requirement of identifying whether contamination is being released from contaminated sediments and where contaminated groundwater may be discharging to surface waters.

**DESCRIPTION**

Naval Air Station (NAS) North Island Site 9 was identified as potentially discharging groundwater contaminated with chlorinated solvents to San Diego Bay. SPAWAR Systems Center was tasked by SWDIV to conduct a two-phase approach to delineate the area of discharge and to quantify the amount of contamination being released to San Diego Bay. The first phase consisted of using innovative pore water sampling techniques to identify the locations where contaminated groundwater migrated to the bay through pore water. Pore water sampling consisted of a metal-tip hollow rod being driven into the sediment to a desired depth. A syringe placed on the end of the rod was used to pull water up through the rod to obtain a sample. Samples were extracted from depths of 1 foot and 5 feet. Based on the results of phase 1, the second phase used a modified BFSD, deployed to six locations, to determine the seepage rate of pore water to the bay, and to quantify the amount of contamination reaching the bay. Pore water sampling



**BFSD**

results indicated large concentrations of VOCs 5 feet into Bay sediments with much lower concentrations 1 foot into Bay sediments. Seepage samples were analyzed for VOCs and results indicated VOCs are entering San Diego Bay from the Bay sediments.

### **BENEFITS**

- The BFSD, seepage, and pore water studies provided a direct, quantitative assessment of the amount of contamination reaching the bay. The BFSD technology has been designed to also quantitatively demonstrate that some contaminated sediments do not release detectable concentrations of contaminants to the water. Use of the technology can provide data to demonstrate which sediments may be left in place with no adverse effects on the environment, and which sediments may require remediation

### **ACCOMPLISHMENTS/CURRENT STATUS**

<b>Date</b>	<b>Activity</b>
FEB 1998	Pore Water Sampling at Site 9
APR 1998	Seepage Sampling and Analysis at Site 9
JUN 1998	BFSD Demonstration at Naval Station San Diego – Paleta Creek
NOV 1998	The results of the work at Site 9 are currently being reviewed by SWDIV and SPAWAR Systems Center, and a report will be completed
NOV 1998	The BFSD technology was used at the Alameda Point (formerly NAS Alameda) Seaplane Lagoon to assess the potential for contaminant release from contaminated sediments in the lagoon
JUN 1999	Following a successful demonstration of the BFSD in Pearl Harbor NSY, and review of the data from San Diego Bay (NS San Diego) in 1998, the technology was certified by Cal/EPA

### **FUTURE PLAN OF ACTION & MILESTONES**

Not Applicable

### **COLLABORATION/TECHNOLOGY TRANSFER**

This project was a collaborative effort between NAS North Island, SPAWAR Systems Center, SWDIV, and Bechtel National, Inc. SPAWAR Systems Center developed and provided the Benthic Flux sampling device demonstrated at NAS North Island.

### **BIBLIOGRAPHY**

- Bechtel National, Inc. Draft Work Plan Addendum for the Additional Remedial Investigation Sampling Effort at Site 9, Naval Air Station North Island, San Diego, CA.

### **RELATED GOVERNMENT INTERNET SITES**

[SPAWAR Systems Center Home Page](#)

### **RELATED NAVY GUIDEBOOK REQUIREMENTS**

- 08029 Water Quality/Sediment Studies

*UPDATED: 01/23/02*

The Harpoon is the newest in the line of PushPoint sediment pore-water sampling tools.

This tool incorporates the function of a PushPoint Extreme sampler into a device that can be used from a boat

or through the ice in 20+ feet of water to sample sediment pore water. If the bottom is composed of loose

sediment, the sampler can be pushed 15+ feet into sediments to gather pore water samples. One of the

advantages of the tool is that the investigator can purchase commonly available materials to custom configure

the sampler to meet their sampling depth requirements. The extendable body of the sampler is made of 1/2" EMT

conduit (~\$2/10 foot), and the sampling tubing is 3/8" OD polyethylene tubing. Multiple lengths of 3/8"

polyethylene tubing inside lengths of 1/2" EMT may be connected together as needed to form a very long,

remotely-operated PushPoint sampler that can be connected to a peristaltic pump to collect sediment pore

water.



MHE PushPoint Harpoon installed in the Harpoon Holder, clamped together by EMT compression coupler nut.

This is the MHE Harpoon assembly ready to go.

Attach the Shuttle Cable, 3/8" poly tubing and 1/2" EMT conduit and you're ready to sample.

Pore water sampling is possible from a boat or through the ice at depths of 20+ feet of water

and through 20+ feet of loose sediments..

**Caution:** the tip of the Harpoon is very sharp to facilitate penetrating sediments. When you are working with the Harpoon, especially when disassembling the Harpoon Holder, be careful not to poke anything (or anyone) with the point of the Harpoon. During disassembly, when pulling off the compression sleeve from the Harpoon Holder, it can suddenly pull free from the nylon jaws as you are pulling the assembly apart, and the tip of the Harpoon has been known to stick into things like car seats, etc.



EXPLODED VIEW

- The MHE Harpoon system:
- 1) stainless steel Shuttle Cable with clasp on one end and loop on the other
  - 2) top jaw of nylon Harpoon Holder assembly
  - 3) 3/16" OD polyethylene Shuttle with stainless steel support
  - 4) 316 SS body of the 24" MHE Harpoon
  - 5) bottom jaw of nylon Harpoon Holder assembly
  - 6) split compression sleeve is the outer sleeve of Harpoon Holder
  - 7) 1/2" EMT conduit compression-type coupler



This is how the Harpoon Holder attaches to the EMT compression coupler. Note that the Shuttle has been installed in the Harpoon body (only a small amount of the Shuttle poly tubing is visible) and the loop of the Shuttle the ready for attachment to the Shuttle Cable.



Tighten the EMT coupler to the MHE Harpoon, leaving the other EMT coupler nut that will connect to the long length of EMT loose.



Before you attach the Shuttle Cable and the poly tubing to the Harpoon you will need to feed the

looped end of the Shuttle Cable through your 3/8" poly tubing until only the clasp of the Shuttle

Cable sticks out of poly tubing.

It is far easier to feed the Shuttle Cable through the poly if the poly tubing is straight rather than coiled.

Shuttle Cable lengths of up to 30' are available.

Sometimes it's helpful to just have a bunch of Shuttle Cables already strung inside poly tubing for

quick and easy attachment to a single Harpoon. I recommend leaving as little of the clasp of the

Shuttle Cable exposed as you need to attach to the Shuttle Screw; this will reduce the effort needed

to push the poly tubing over the barbed fitting at the sampling port of the Harpoon.



Make sure that the poly Shuttle is fully inserted into the Harpoon body.  
Only friction holds the Shuttle in place within the Harpoon body.  
Attach the clasp end of the Shuttle Cable to the loop of the Shuttle Cable Screw.  
Do not disturb the Shuttle position in the Harpoon or pull the Shuttle Cable attached to the Shuttle  
until you have deployed the sampler and you are ready to sample as you may pull the Shuttle from the  
Harpoon and expose the inside of the screened-zone of the Harpoon to the sediments during insertion  
- this may clog the sampler.



Push the 3/8" OD poly tubing past the barb at the sampling port of the Harpoon, at least 1/4" (6mm).

It is nearly impossible to pull the poly tubing off after it has been pushed much past the barb.

After that, it will be necessary to cut the poly off to remove it (more on this later). Slide the loose end of the poly through a length of 1/2" EMT conduit and connect to the

EMT coupler on the Harpoon Holder.

If you are having a lot of trouble pushing the poly past the barb, try heating 1/2" of the end of the poly

in the flame of a butane lighter for 1 or 2 seconds to soften the polyethylene a little.



MHE Harpoon attached to a 10' piece of EMT and ready to go into the water. You can add additional lengths of EMT, poly tubing and Shuttle Cable as needed to reach the desired depth. Shuttle Cables have a loop at the end so that they may be joined end-to-end to achieve longer lengths. We recommend using a 1.25 inch piece of 3/8"ID clear vinyl or Tygon tubing to connect successive lengths of 3/8" poly together if a longer sampler is needed to push through deeper water or deeper into the sediments than originally anticipated. Use a nylon wire-tie (zip-tie) or other means to clamp both connections to the poly.



Push the Harpoon straight down into sediments to the desired depth.

Once the sampling system is inserted into the sediments, I usually cut off the EMT at a convenient height and then slip the excess EMT off the poly.

Cut the poly so that approximately 3 inches of the poly extend past the top of the EMT. This reduces the amount of curve that the will be in the poly. The Shuttle Cable likes straight poly tubing to travel through – each curve adds quite a bit of friction.

Be careful to not cut the Shuttle Cable when you cut off the excess poly tubing. To sample the sediment pore water, have a peristaltic pump ready with enough tubing on it to allow for movement

of the boat during sampling without pulling the sampler sideways.

Hold the end of the EMT and then pull the Shuttle Cable with the attached Shuttle completely out of the 3/8" poly.

Immediately attach the peristaltic pump tubing to the end of the 3/8" poly and pump the pore water – don't waste any

time getting the development water out of the system.

Do your sampling as you would with any PushPoint sampler.



To easily remove the poly tubing from the Harpoon, take a sharp knife and cut the poly tubing until you reach the flat back-end of the barb. Do the same on the other side of the sampler. The tubing should come off easily.



If you have several Harpoon bodies and several Shuttles and Shuttle Cables, you can pre-assemble the cores of the

Harpoon sampling systems to lengths of poly tubing, and have them ready (locked-and-loaded) for easy deployment.



In this way, all you need is one Harpoon Holder which would be interchangeable to all the preassembled Harpoon cores.



# UltraSeep / Trident

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## Subsurface Seepage Monitor and Water Sampler



The UltraSeep seepage monitor system allows you to survey, quantify, record and analyze fluid seepage from the bed into a body of water. The system monitors conductivity, temperature and fluid seepage rate. It then conditionally samples the seeping fluid for later laboratory analysis.

The UltraSeep system consists of two instruments: a survey probe (the Trident) and an integrated insitu seep monitor/water sampler (The UltraSeep). The Trident probe is used to map the area where seepage is likely, based on anomalous conductivity and temperature measurements. After mapping the extent of potential seepage using the included GIS software, the UltraSeep monitor/sampler is deployed for longer-term measurement and sample collection.

The Trident probe carries temperature and conductivity sensors and a water sampler. These are mounted on a lance that is pushed into the bed from a small boat with a 12-m push rod. Ambient C and T are measured with a second sensor set mounted above the sub-bottom sensors. The GPS is mounted on the top of the probe's deployment pushrod. C and T values, deviation from ambient, and position are recorded. Included is a GIS software package that maps the anomalies.

Using the resulting map of C and T deviation, the UltraSeep monitor is deployed. The seepage through the instrument is measured with a specially developed flow meter. Seep fluid is conditionally sampled when threshold levels of T,C or flow are exceeded. Data is recorded with an onboard logger.

System training classes are offered. A complete data package that includes survey, monitoring and data reports can be supplied.

This system was developed by the US Navy and Cornell University for investigation of seepage from contaminated terrestrial sites into estuaries.



Trident Probe

## UltraSeep Seepage Monitor System Components

- Underwater controller with integrated water sampler
- Battery housing
- 316 stainless deployment frame with sample bag compartments
- Interface funnel with sensors

### Specifications

#### *UltraSeep Controller with integrated water sampler*

- Construction Acetyl and marine grade aluminum
- Water sampler path PTFE
- Pump Pressure compensated, peristaltic pump
- Pumping rate Flow-proportional or manually set
- Pump capacity 0 - 13ml per minute
- Valve 10 port rotary
- Clock Battery backed real-time
- Data protocols available Analogue (16 bit resolution) and digital signals (RS232, SDI-12, frequency)
- Software Latest version of SeepTalk for Windows
- Spares Replacement peristaltic pump tube
- Data cable 2-m cable (switched communication between either flow meter or UltraSeep controller)
- Sample bag size 1 liter
- Standard system depth rating: 70 m

#### *Conductivity and temperature sensor*

- Construction PTFE body, titanium sensor rings.
- Temperature resolution 0.001 Deg C
- Conductivity output Specific conductance @25 Deg C
- Conductivity resolution 0.01 mS/cm
- Conductivity range 0 to 80 mS/cm

#### *Underwater Battery Housing*

- Construction Marine grade aluminum, anodized
- Capacity 3 x 12 volt 12 amp/hr gel cell batteries
- Includes Charging cable plug adaptor

#### *Funnel*

- Sensor ports Conductivity/temperature sensor, water sampler inlet filter
- Gas trap
- Dimensions 508mm diameter x 176mm high
- Construction 316 grade stainless steel, fully Teflon plated on all internal surfaces

Additional sensors or mounts may be supplied as custom options.

## Trident Underwater Groundwater Seep Detection System

### *System includes:*

- Water sampling probe
- Standard filter cartridge
- Sand pack filter system
- Conductivity and temperature sensing probe
- Reference conductivity and temperature probe
- Depth control plate
- GPS unit with antenna
- Deck unit
- Latest version TridentTalk for Windows software
- 12 meter total length push rod, 2 meter sections

### Specifications

#### *Conductivity/temperature sensors*

- Depth rating 150 meters
- Temperature resolution 0.001 Deg C
- Conductivity output Specific conductance @25 Deg C
- Conductivity resolution 0.01 mS/cm
- Conductivity range 0 to 80 mS/cm
- Connectors Wet mateable

#### *GPS*

- WAAS capable

#### *Deck Unit*

- Connectors Wet mateable
- Power Internal battery or external 12V DC

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