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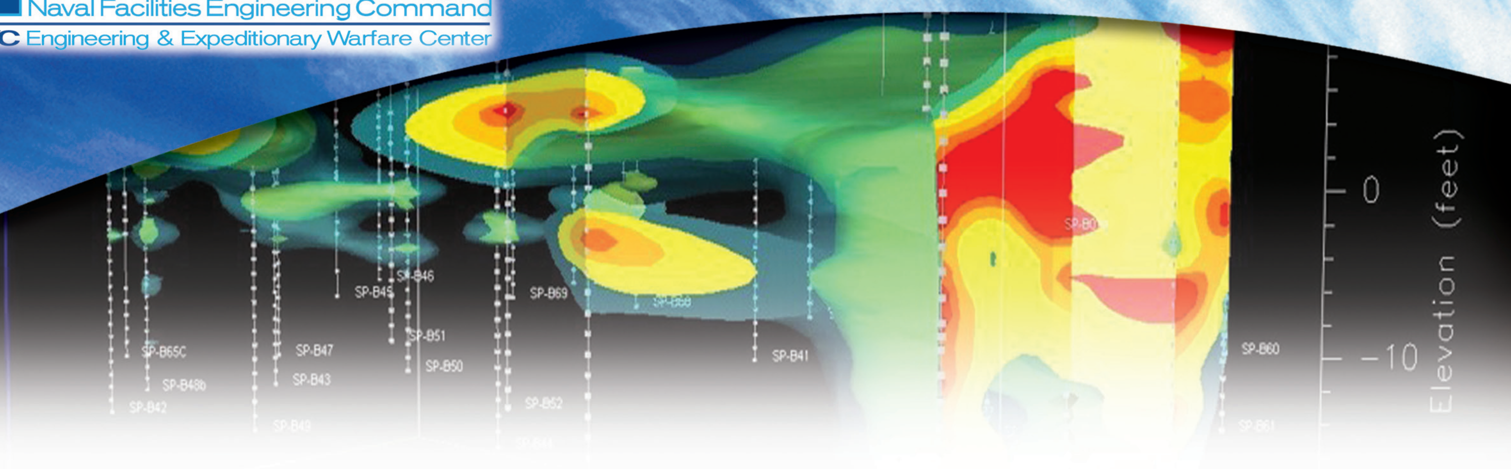

ENVIRONMENTAL RESTORATION

Repeatable Multilevel Groundwater Sampling

Introduction

Repeatable multilevel groundwater sampling (RMGS) refers to any method of groundwater sample collection from a single location, but at multiple depths below ground surface, repeatably over time. RMGS differs from "one-time" or "snap-shot" groundwater sampling in that groundwater samples can be repeatedly collected from the same depth at the same location over time without the need to reinstall a temporary sample point (such as a direct push groundwater sampling tool).

RMGS is not a replacement for temporary or traditional groundwater sampling techniques, but an additional tool to help to characterize the site. Temporary groundwater samplers are valuable, and frequently used during environmental investigations as screening tools to assess the nature and extent of contamination. Temporary groundwater samplers are often combined with real-time sample analysis (such as a mobile laboratory) to allow for field decisions – selecting each sample location based on the results of preceding locations.

In contrast, RMGS is a tool for tracking contaminant concentration trends over time at fixed locations, but at depth-discrete intervals within an aquifer. RMGS can be thought of as a "traditional" groundwater monitoring well, but with the additional feature of providing results from multiple discrete depths. The data from RMGS methods can be integrated with other sampling results to improve the conceptual site model (CSM) and the understanding of contaminant distribution in both a vertical and horizontal sense.

Assessing whether to consider the use of RMGS at a site is based on the need for temporal data regarding:

- Vertical distribution of contaminant concentrations or conventional chemistry parameters in groundwater – how do these values at various depths within an aquifer change over time (for example, during implementation of a remedy)?
- Vertical head gradients – is there a time-dependent factor to a measured upward or downward vertical gradient (for example, adjacent to a seasonal stream)?

Methods for Multilevel Groundwater Sampling

Repeatable groundwater samples can be collected from discrete depths within an aquifer by:

- Constructing nested or clustered "traditional" groundwater monitoring wells
- Placing samplers at specific depths within a "traditional" groundwater monitoring well
- Installing a system specifically engineered to isolate discrete intervals of an aquifer and then sampling those isolated intervals

Nested or Clustered Traditional Groundwater Monitoring Wells

In this fact sheet, "traditional" monitoring wells refer to those constructed with a single screened interval and blank riser casing to the ground surface, with a sand pack around the well screen and a seal above the screened interval in the well bore annulus. One method of obtaining repeatable groundwater samples from different discrete depth intervals in an aquifer is simply to install a group, or cluster, of traditional monitoring wells, each with a well screen targeting a specific depth range in the aquifer. However, this approach has several disadvantages:

- Drilling many well bores and constructing many wells in a small area can be costly and cumbersome, while creating a relatively large footprint at the site. Also, more investigative derived waste (IDW) tends to be generated.

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- Overlapping screened intervals and sand packs must be avoided to preserve the vertical isolation of each zone, both from a contaminant concentration perspective and a hydraulic head perspective.
- Wells in the cluster must be close enough together to be relatively representative of the same lateral position in the aquifer, but far enough apart to allow for the integrity of each well bore and seal. For some sites where contaminant concentrations vary substantially over small distances (e.g., 5 to 10 feet), creating a well cluster representative of a single lateral location in the aquifer is essentially impossible. Results from adjacent wells could also vary depending on the lateral and vertical continuity of the sedimentary layers.

The technique of "nesting" wells in a single well bore was common in the 1970s and late 1980s (Einarson, 2006). It consisted of drilling a single well bore, but installing multiple well screens with independent risers, with each well screen at a different depth in the well bore. Isolation of the multiple vertical zones in a nested well is complicated by the crowded annular space of the well bore, which makes placement of a competent seal between zones very challenging. The zone isolation can easily be compromised by leakage between zones occurring along the well casings and the walls of the well bore. For this reason, several states discourage or prohibit the construction of nested wells (California Department of Toxic Substances Control [DTSC], 2014 or Washington Administrative Code [WAC] 173-160-420[3], respectively).

Depth-Discrete Samples from within a Traditional Monitoring Well

It is possible to collect depth-discrete samples from traditional monitoring wells, and to discern differences in contaminant concentrations with depth (Vroblesky et al., 2001). However, because this method does not isolate each discrete sampling interval from the rest of the aquifer, the degree to which each sample represents only the targeted interval is uncertain. These methods rely on relatively laminar, horizontal flow through the aquifer to retain the vertical contaminant profile during sampling. If legacy traditional monitoring wells are present at a site, these methods, although somewhat uncertain, can be useful to assess the vertical contaminant profile at a screening level of data certainty. Sampling devices for depth-discrete sampling within traditional monitoring wells include:

- A low-flow pump can be placed with its intake at multiple depths within the screened interval and multiple samples collected.
- Passive diffusion bags (PDBs) can be installed at discrete depths within the screened interval, allowed to equilibrate over time and then retrieved and replaced.
- A series of Snap Samplers® can be installed at discrete depths within the screened interval, allowed to equilibrate over time, "snapped" shut, and then retrieved and replaced.

Both PDBs and the Snap Sampler are "no-purge" sampling methods, with their own advantages and disadvantages that are beyond the scope of this fact sheet.

Engineered Systems

Several engineered systems are available that are designed specifically to allow for RMGS applications. These systems are intended to isolate discrete zones of an aquifer, while providing a mechanism to repeatedly sample each isolated zone for chemical parameters or make measurements (such as groundwater head). Engineered systems differ fundamentally from nested wells in that they utilize a single casing or liner, which greatly reduces the challenges of filter pack and sealant placement encountered with nested wells. Engineered systems include, but are not limited to the systems below:

- Solinst Continuous Multi-Channel Tubing (CMT)™
- Solinst Waterloo™ Sampler
- Water FLUTe™ System
- WestBay MP® System

Engineered systems for RMGS have both advantages and limitations when compared to clusters of conventional wells or nested wells as summarized in Table 1 below. These four systems are compared in Figure 1 and Table 2. In general, the relative cost of installing engineered RMGS systems versus multiple conventional wells is lower due to reduced drill footage and reduced IDW generation and disposal needs. However, site-specific cost comparisons should be made prior to RMGS selection. In addition, upon installation, there are no specialized maintenance, repair, or rehabilitation actions needed for these types of wells, beyond actions that might be required for traditional monitoring wells. See Einarson (2006) and Cherry et al. (2015) for a more detailed comparison of these engineered systems.

Table 1. Advantages and Limitations of Engineered Systems

Advantages	Limitations
• Use of a single casing in the well bore greatly improves seal integrity between zones, and the systems provide for integrity testing of the seals. • Because only one well bore is required, the footprint of the sampling location is substantially reduced compared to a cluster of multiple wells, making the results more representative of a single location. • It is more practical to sample a greater number of vertical zones, because only one well bore is required. • The reduced drill footage, reduced waste volume, and reduced purge water volume result in a lower cost compared to the installation of multiple conventional wells.	• Specialized pumps and monitoring devices are required. • Additional training for installation and sampling is required. • The small diameters of the sampling tubing preclude the use of these wells as extraction wells, or pumping wells for pumping tests (but they can be used as monitoring points during pumping tests). • The components cannot withstand high temperatures and therefore aren't compatible with thermal remediation. • The small sampling ports can be susceptible to smearing with clay during installation and the short-screened interval requires precise placement in the well bore to ensure that the permeable target zone is screened. • Some states require variance from well regulations to allow for installation.

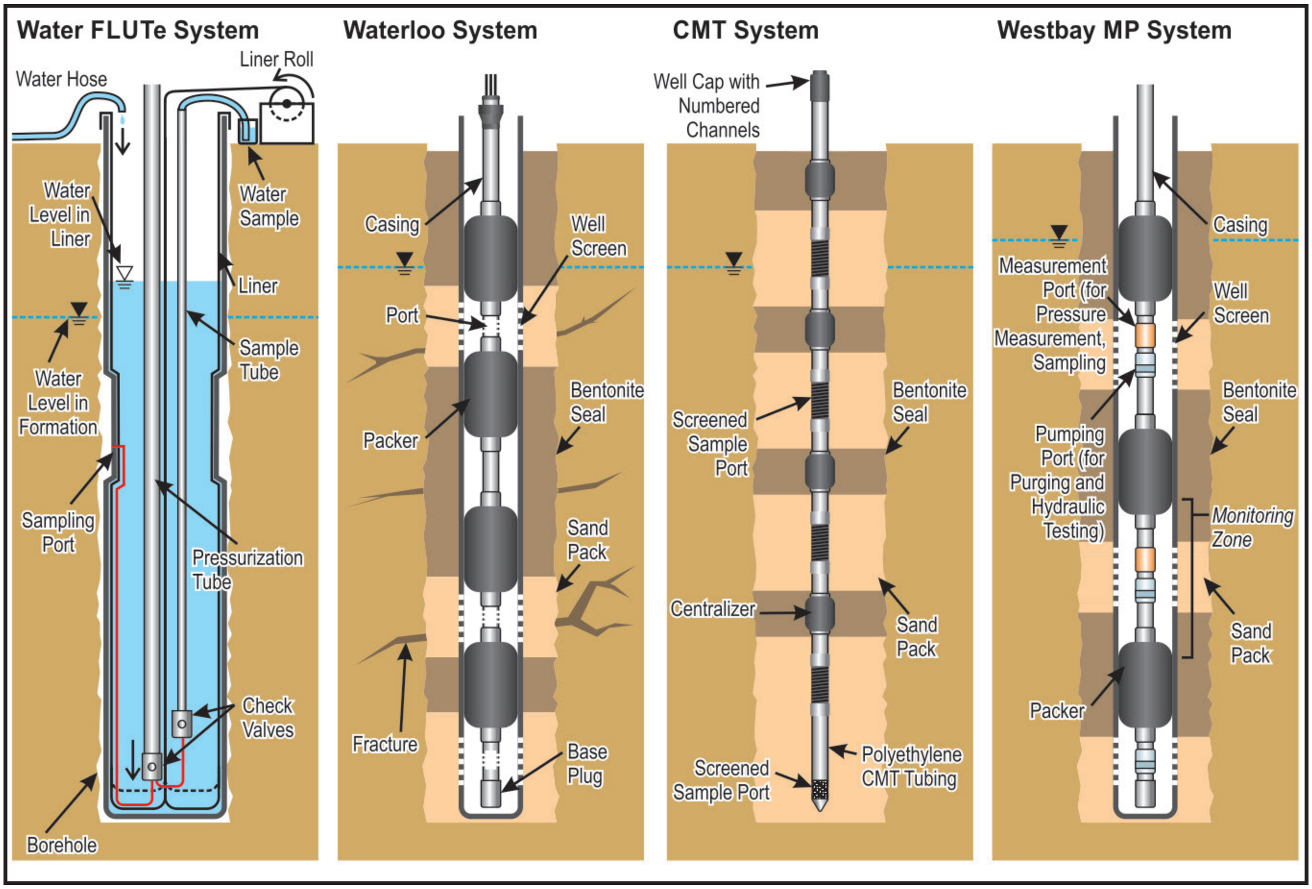

Figure 1. Schematic of Engineered Systems ***(Reproduced with Permission)***

Table 1. Comparison of Engineered Systems for RMGS Applications *(Reproduced with Permission and Modified from Einarson, 2006)*

Description	Westbay MP® System	Solinst Waterloo™ System	Solinst CMT™ System	Water FLUTe™ System	Comments
Summary	Includes both specialized casing and customized probes and tools that integrate with the casing. The casing itself is manufactured of rigid plastic or stainless steel and consists of modular components – packers, valved port couplings, and casing.	2-inch diameter schedule 80 polyvinyl chloride (PVC) casing with depth-discrete sampling ports connected to the surface with small-diameter tubes within the PVC casing.	Flexible HDPE tubing divided into either three or seven interior channels, and associated components (e.g., foot screen, port screens, wellhead caps, channel plugs, centralizers)	A flexible impermeable liner of polyurethane-coated nylon fabric is used as the well casing. The liner comes from the factory with the sampling ports and tubes pre-assembled on a roll, inside-out. The liner is everted from the roll into an open well bore, with water pressure inside the liner used to seal the liner against the well bore.	
Materials	PVC, polyurethane, Viton, and stainless steel	PVC, stainless steel, Viton, rubber, and polyethylene tubing	Polyethylene and stainless steel	Polyurethane-coated nylon, stainless steel or brass, and and polyethylene or PVDF tubing	Materials vary depending on sealing and pumping options
Maximum depth (ft)	4,000	750	300	1,000	Maximum depth for routine installations
Maximum number of sampling points	20 per 100 ft of well	15	7	20+	With exception of Westbay system, depends on diameter of system and size of sampling tubes
Allows use of pressure transducers to monitor hydraulic pressure	Yes	Yes	Yes	Yes	Westbay MP system uses a specialized tool for sample collection and pressure measurement. Dedicated pressure sensors can also be installed.
Maximum sampling points when dedicated pressure transducers are used in each monitored zone	See comments	8	3	20+	With Westbay MP system, dedicated pressure sensors must be removed prior to collecting groundwater samples from the same zones
Sampling methods	Uses a specialized tool for sample collection and pressure measurement	Peristaltic pump, inertial-lift pump, double-valve pump, bladder pump	Peristaltic pump, inertial-lift pump, double-valve pump	Peristaltic pump, inertial-lift pump, double-valve pump, bladder pump	

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Description	Westbay MP® System	Solinst Waterloo™ System	Solinst CMT™ System	Water FLUTe™ System	Comments
Optimal borehole diameter (in.)	3 – 6	3 – 6	3 – 6	3 - 10	
Built-in features for well development and hydraulic testing	Yes	No	No	No	
Can be installed immediately after well designed; that is, no delay due to shipping customized well components to site from factory	Yes	Yes	Yes	No	It is still recommended that at least an initial well design be completed for all systems prior to ordering materials.
Removable system	Yes	Yes	No	Yes	Solinst Waterloo system removable when deflatable packers used. Deflatable packers under development for Solinst CMT system. Successful removal depends on borehole conditions
Can be installed in open holes in bedrock and massive clay deposits	Yes	Yes	Yes	Yes	
Can be installed in unconsolidated deposits	Yes	Yes	Yes	Yes	
Can be installed in multi-screened wells	Yes	Yes	Yes	Yes	
Seals and sand pack can be installed by backfilling from surface	Yes	Yes	Yes	Yes	FLUTe system seals borehole; other annular seals are therefore not needed
Inflatable packers available for sealing borehole in bedrock or multi-screened wells	Yes	Yes	No	No	Inflatable packers under development for Solinst CMT system. Water FLUTe system can be thought of as one long packer
Can be installed with direct push equipment	No	No	Yes	Yes	

Regulatory Framework

Several states discourage or prohibit the construction of nested wells (e.g., California or Washington, respectively). In some states, the installation of engineered multilevel groundwater monitoring wells requires that a written variance be obtained from the state regulatory authority. There is no known state regulation absolutely prohibiting the installation of engineered multilevel systems. State-specific requirements should be determined prior to the selection of RMGS for a given site.

Key Considerations for Repeatable Multilevel Groundwater Sampling

Key points to consider when assessing whether to implement RMGS at a site are noted below:

- If there is a need to obtain temporal data at discrete vertical depths within the aquifer, RMGS may be appropriate;
- Target data (e.g., contaminant concentrations) that may vary substantially over short distances point towards use of an engineered multilevel system rather than a well cluster;
- For engineered systems, consider the system advantages and limitations listed above;
- Assess state well construction regulations and the need for a written variance for installation of a multilevel system;
- Establish the target sampling depths prior to ordering well materials;
- Assess borehole stability in advance to select the installation method (open borehole versus cased);
- Be cognizant of the groundwater chemistry and the potential for biofouling of relatively small ports and tubes in engineered systems, though the system vendors have no reports of biofouling in installations to date; and
- Prepare for the extra care needed for ensuring competent seals between each monitored depth zone.

Naval Base Kitsap Keyport Case Study

Three CMT wells were installed within a chlorinated solvent hotspot at the former landfill at Naval Base Kitsap Keyport to provide vertically discrete monitoring of contaminant concentrations over time. As shown in Figure 2, contaminant concentrations in the hotspot vary substantially over short distances both vertically and laterally.

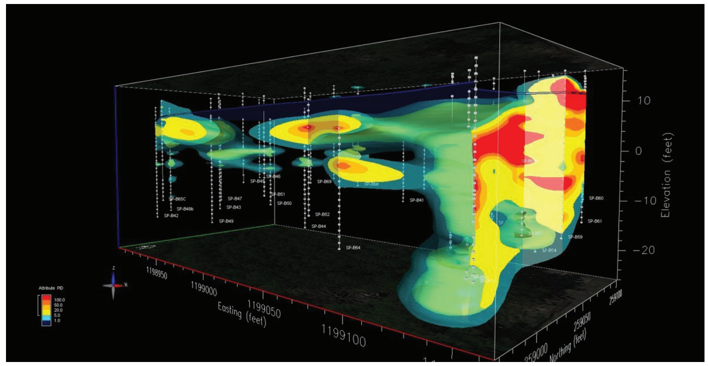

Figure 2. Chlorinated Solvent Hotspot at Former Landfill, Naval Base Kitsap Keyport, WA ***(Courtesy of Battelle)***

The contaminant distribution within the hotspot was first mapped using a membrane interface probe (MIP) followed by grab soil and groundwater sampling from direct-push borings. The planned sample port depths for the three CMT wells were then selected, and a well construction variance was obtained from the Washington State Department of Ecology. A comparison of the MIP data, grab sample data, and CMT well data from one of the three locations is shown in Figure 3 below.

All three of the CMT wells were successfully installed at the planned intervals. Repeatable depth-specific samples from single boreholes can now be obtained over time in this hotspot. The wells may also be used to assess the vertical vacuum profile during high-vacuum extraction pilot testing. Some of the disadvantages at this site were:

- Obtaining the variance from the State for installation required help from the State regulator;
- The deepest interval in one of the wells was smeared with clay from the aquitard below, preventing sampling;
- The CMT wells were more time consuming to install than single-screened conventional wells;
- The wells have a more limited use because of the very small channels, and require the long-term monitoring (LTM) contractor to bring specialized water level monitoring and sampling equipment; and
- The wells would not be able to withstand high temperatures should electrical resistance heating be selected as the remedy for treatment of this hotspot.

The drilling contractor also provided feedback regarding the installation of CMT wells:

- Handling long lengths of CMT is challenging – the driller built a spool to help manage longer lengths;
- Pre-grouting of unused channels prior to installation is required by the State, which can take several hours with long lengths to pump in super-fine grout;
- Grout itself is hard to use, and requires a bucket pump or small high-pressure pump;
- Drillers need experience and Solinst training to install CMT wells, however the Solinst manual is a helpful document;
- Generally, plan 1 to 2 hours for grouting and assembly of CMT;
- Installation using sonic rather than auger is slightly easier;
- Use centralizers;
- Use slow-release bentonite pellets (not chips) between zones to avoid bridging;
- Plan time for materials order and shipment, which must pass customs from Canada; and
- Parts are specialized – order extra plugs, screens, and anchors.

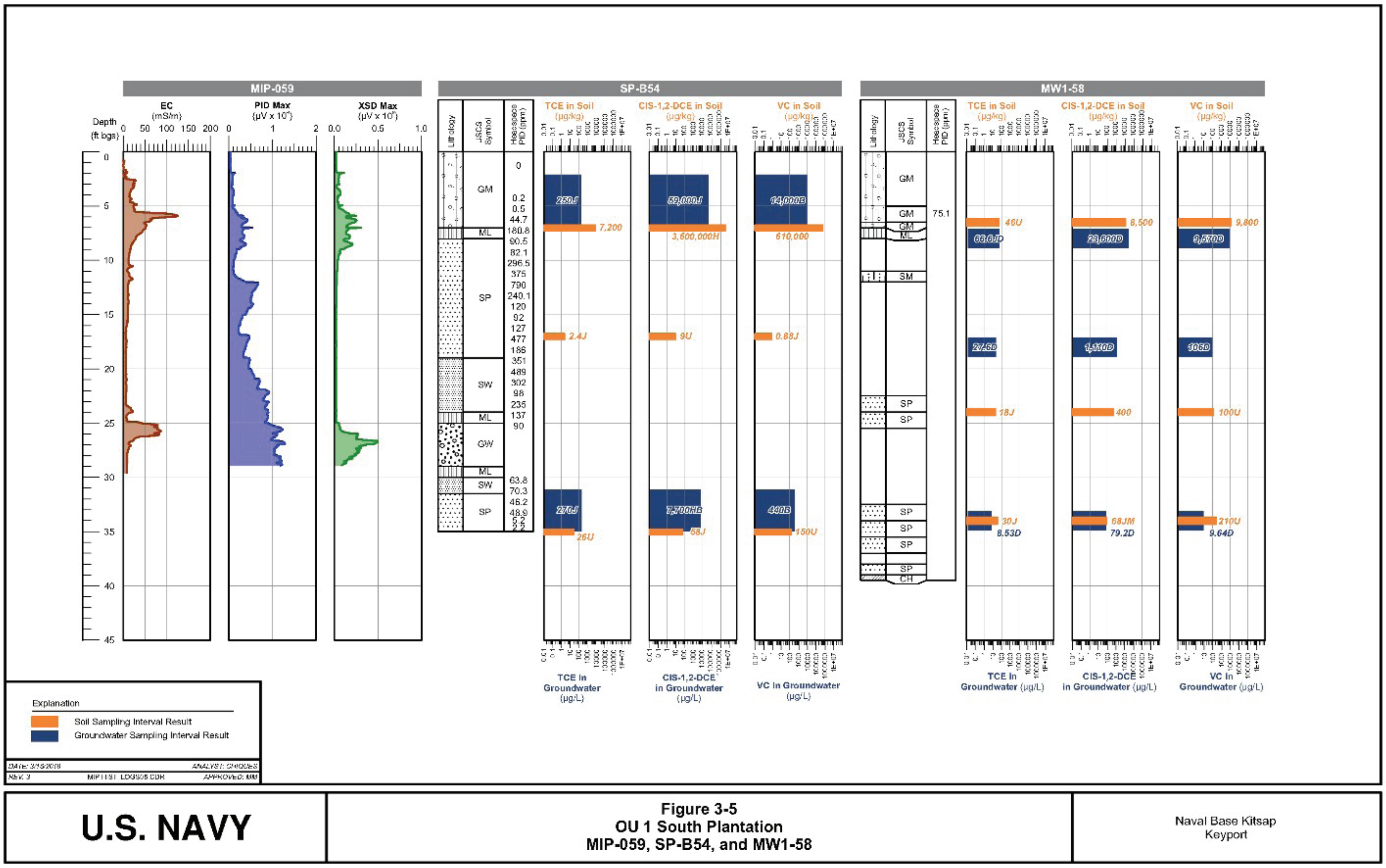

Figure 3. Comparison of MIP Data, Grab Sample Data, and CMT Well Data ***(Courtesy of Battelle)***

Resources

Cherry, J., B. Parker, M. Einarson, S. Chapman, J. Meyer. 2015. *Overview of Depth-Discrete Multilevel Groundwater Monitoring Technologies: Focus on Groundwater Monitoring in Areas of Oil and Gas Well Stimulation in California.* In: Recommendations on Model Criteria for Groundwater Sampling, Testing, and Monitoring of Oil and Gas Development in California. LLNL-TR669645. June 29, 2015.

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Vroblesky, Don A. and Brian C. Peters. 2001. *Diffusion Sampler Testing at Naval Air Station North Island, San Diego County, California, November 1999 to January 2000.* USGS Water-Resources Investigations Report 00-4182.

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