# Overview of Groundwater Monitoring Technologies to Support Groundwater Monitoring in California Oil and Gas Fields

Murray Einarson
Haley & Aldrich
Oakland, CA

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HALEY ALDRICH

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- Dr. Beth Parker
- Steve Chapman
- Dr. Jessica Meyer

## *Recommendations on Model Criteria for Groundwater Sampling, Testing, and Monitoring of Oil and Gas Development in California*


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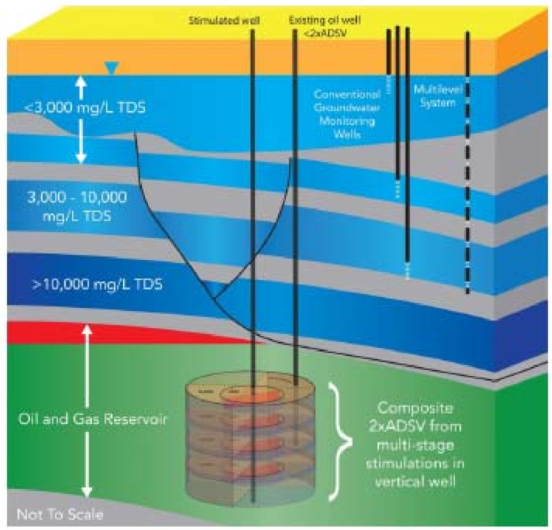



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http://www.waterboards.ca.gov/water_issues/programs/groundwater/sb4/docs/llnl_recommendations_report.pdf

# 11 Appendix: Overview of Depth-Discrete Multilevel Groundwater Monitoring Technologies: Focus on Groundwater Monitoring in Areas of Oil and Gas Well stimulation in California

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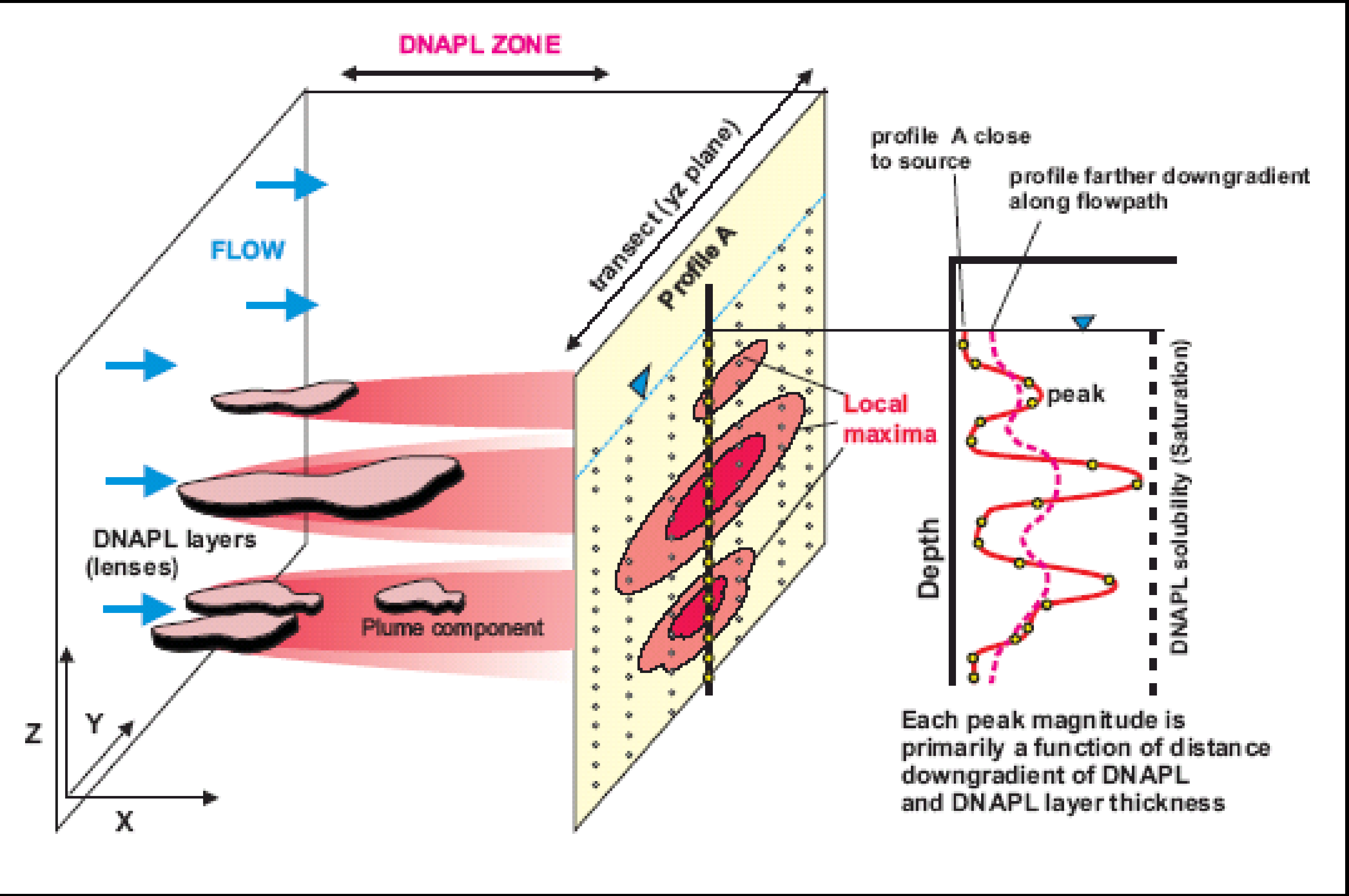
For the SB4 Groundwater Monitoring Expert Advice Project

June 29, 2015

# Why multilevel groundwater characterization & monitoring?

- Solute concentrations, hydraulic properties, and head distribution are spatially variable in the subsurface, particularly in the vertical dimension

# Conceptual Model for Dissolved Plumes Emanating from DNAPL Source Zones




(Source: Guilbeault, Parker, & Cherry, 2005)

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# Direct-push geochemical profiling for assessment of inorganic chemical heterogeneity in aquifers

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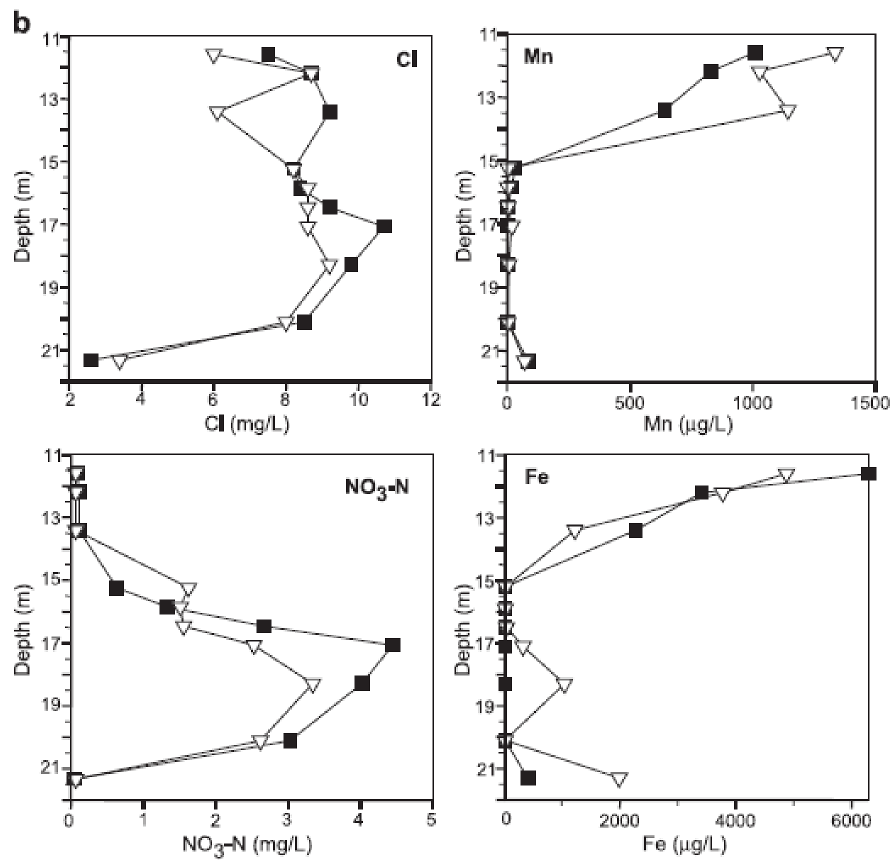
**Abstract**

Discrete-depth sampling of inorganic groundwater chemistry is essential for a variety of site characterization activities. Although the mobility and rapid sampling capabilities of direct-push techniques have led to their widespread use for evaluating the distribution of organic contaminants, complementary methods for the characterization of spatial variations in geochemical conditions have not been developed. In this study, a direct-push-based approach for high-resolution inorganic chemical profiling was developed at a site where sharp chemical contrasts and iron-reducing conditions had previously been observed. Existing multilevel samplers (MLSs) that span a fining-upward alluvial sequence were used for comparison with the direct-push profiling. Chemical profiles obtained with a conventional direct-push exposed-screen sampler differed from those obtained with an adjacent MLS because of sampler reactivity and mixing with water from previous sampling levels. The sampler was modified by replacing steel sampling components with stainless-steel and heat-treated parts, and adding an adapter that prevents mixing. Profiles obtained with the modified approach were in excellent agreement with those obtained from an adjacent MLS for all constituents and parameters monitored (Cl, $NO_3$, Fe, Mn, DO, ORP, specific conductance and pH). Interpretations of site redox conditions based on field-measured parameters were supported by laboratory analysis of dissolved Fe. The discrete-depth capability of this approach allows inorganic chemical variations to be described at a level of detail that has rarely been possible. When combined with the mobility afforded by direct-push





ground water

# Temporal Changes in the Vertical Distribution of Flow and Chloride in Deep Wells

by John A. Izbicki[1], Allen H. Christensen[2], Mark W. Newhouse[2], Gregory A. Smith[2], and Randall T. Hanson[2]

**Abstract**

The combination of flowmeter and depth-dependent water-quality data was used to evaluate the quantity and source of high-chloride water yielded from different depths to eight production wells in the Pleasant Valley area of southern California. The wells were screened from 117 to 437 m below land surface, and in most cases, flow from the aquifer into the wells was not uniformly distributed throughout the well screen. Wells having as little as 6 m of screen in the overlying upper aquifer system yielded as much as 50% of their water from the upper system during drought periods, while the deeper parts of the well screens yielded 15% or less of the total yield of the wells. Mixing of water within wells during pumping degraded higher-quality water with poorer-quality water from deeper depths, and in some cases with poorer-quality water from the overlying upper aquifer system. Changes in the mixture of water within a well, resulting from changes in the distribution of flow into the well, changed the quality of water from the surface discharge of wells over time. The combination of flowmeter and depth-dependent water quality data yielded information about sources of high-chloride water to wells that was not available on the basis of samples collected from nearby observation wells. Changing well design to eliminate small quantities of poor-quality water from deeper parts of the well may improve the quality of water from some wells without greatly reducing well yield.

## Introduction

Fluid velocity in the screened interval of production wells measured under pumping conditions using standard geophysical tools, such as impeller flowmeters, electromagnetic flowmeters, or heat-pulse flowmeters, provides a direct measure of the depths at which water enters a well. Flowmeter data are more accurate than are indirect estimates of the depth at which water enters a well made on the basis of geologic, geophysical, or well-construction data. Flowmeter data also may be more accurate than other types of data, such as packer tests, because these other data may not represent flow to the well under actual pumping conditions.

Flowmeter data collected within wells under pumping conditions can be used to determine the distribution of hydraulic properties in aquifer materials (Schimschal 1981; Keys 1987; Rehfeldt et al. 1989; Molz et al. 1989; Molz and Young 1993; Kabala 1994; Hanson and Nishikawa 1996; Paillet 2001; Paillet and Reese 2000; Paillet et al. 2002), improve well-construction and design practices (Gossel et al. 1999), and distribute pumping from long-screened wells to different aquifers represented in regional ground water flow models (Hanson et al. 2003). Flowmeter data also can be used with fluid conductivity profiles (Tsang et al. 1990) or depth-dependent water-quality data collected from wells under pumping conditions (Gossel et al. 1999; Izbicki et al. 1996, 2003) to evaluate changes in ground water chemistry with depth.

The combination of flowmeter data and depth-dependent water-quality data is especially effective for determining the distribution of poor-quality water in complex aquifer systems where wells are screened in different aquifers having different hydraulic properties and different water quality (Tsang et al. 1990; Izbicki et al. 1999). In these complex aquifer systems, it is possible that the depths at which water enters a well may change with time as a result of changing hydraulic conditions related to changes in pumping rates, changing pumping patterns and interference from nearby wells, changing hydraulic conditions within the well resulting from corrosion, or

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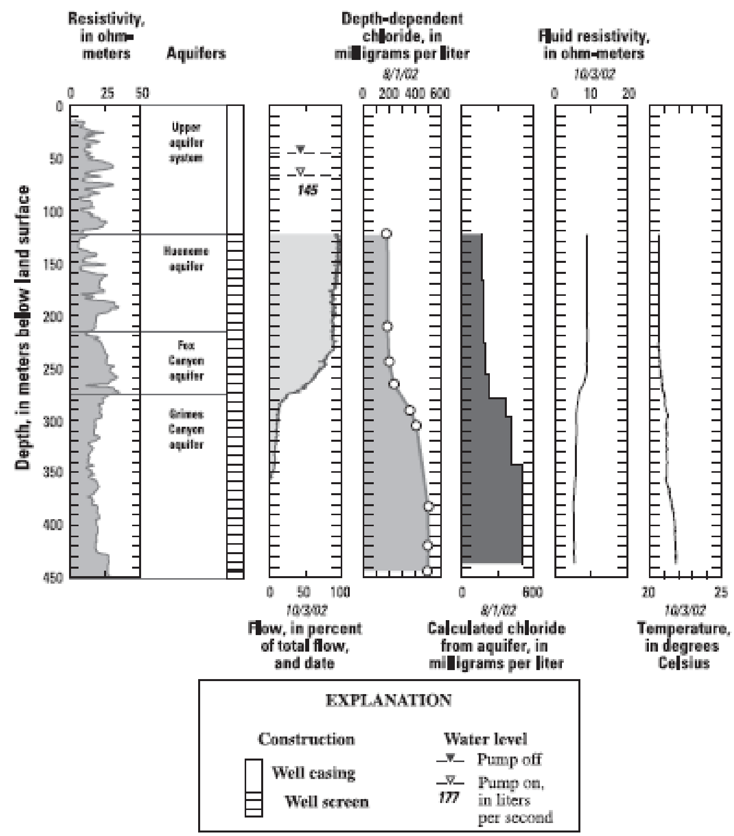
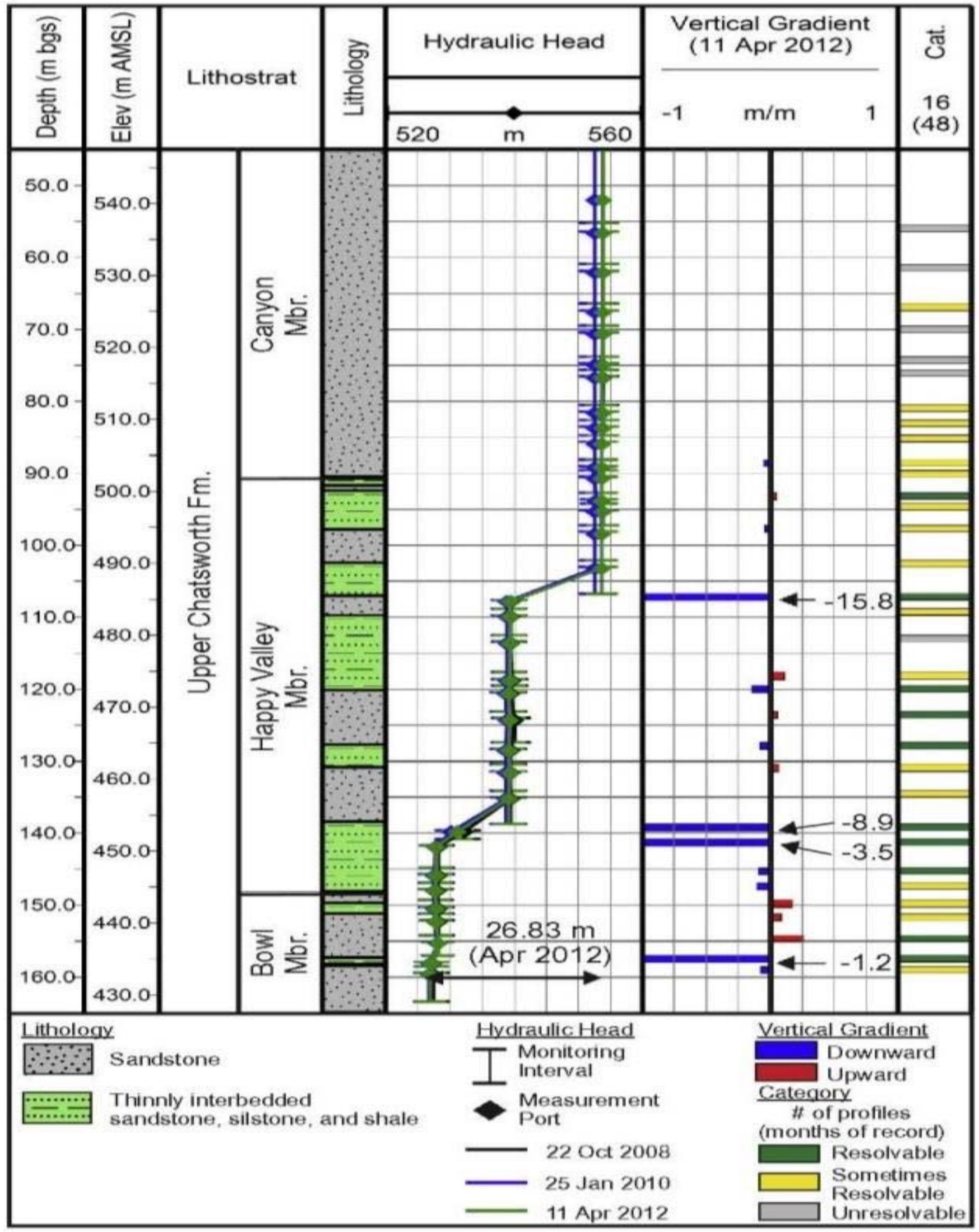


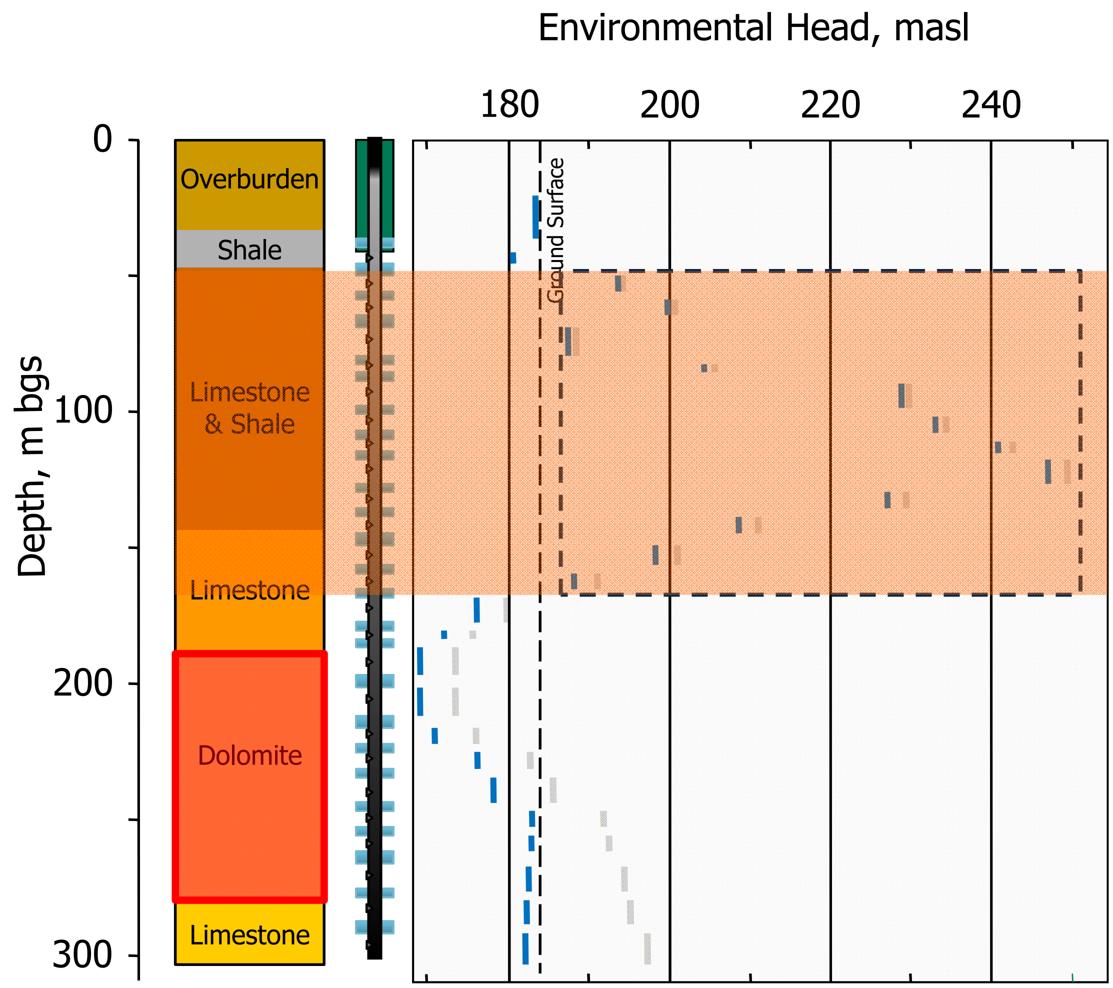

**Figure 5. Depth-dependent chloride-concentration data, fluid-resistivity data, and fluid-temperature data from well 2N/21W-34G1 (PV-2), Pleasant Valley, California.**

# What about hydraulic head?




(Source: Meyer et al., 2014).

# Wastewater Injection Site, Ontario, Canada

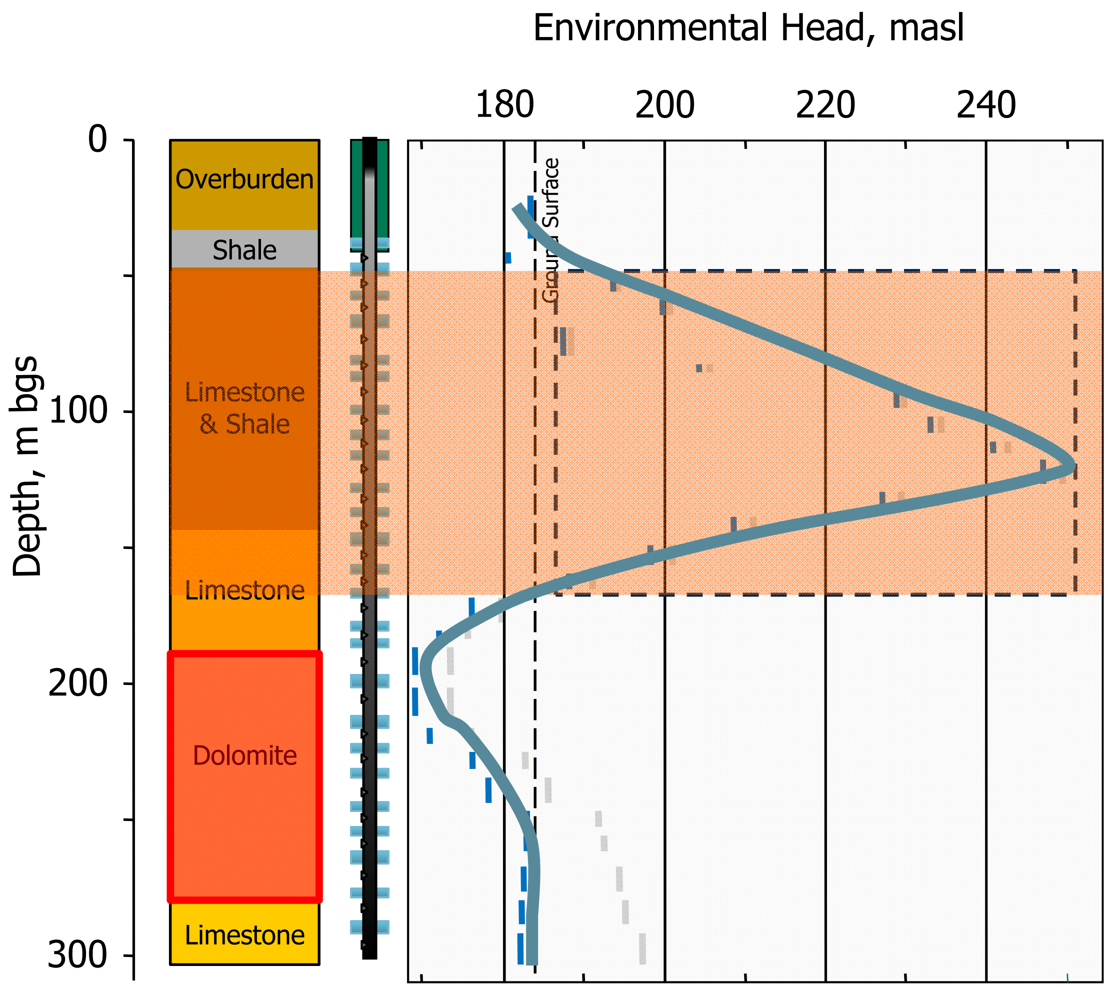



After Raven et al., 1990

NOVA METRIX

Westbay Instruments

# Wastewater Injection Site, Ontario, Canada




After Raven et al., 1990

# Should we expect variations in water chemistry and hydraulic head in California oil and gas fields?

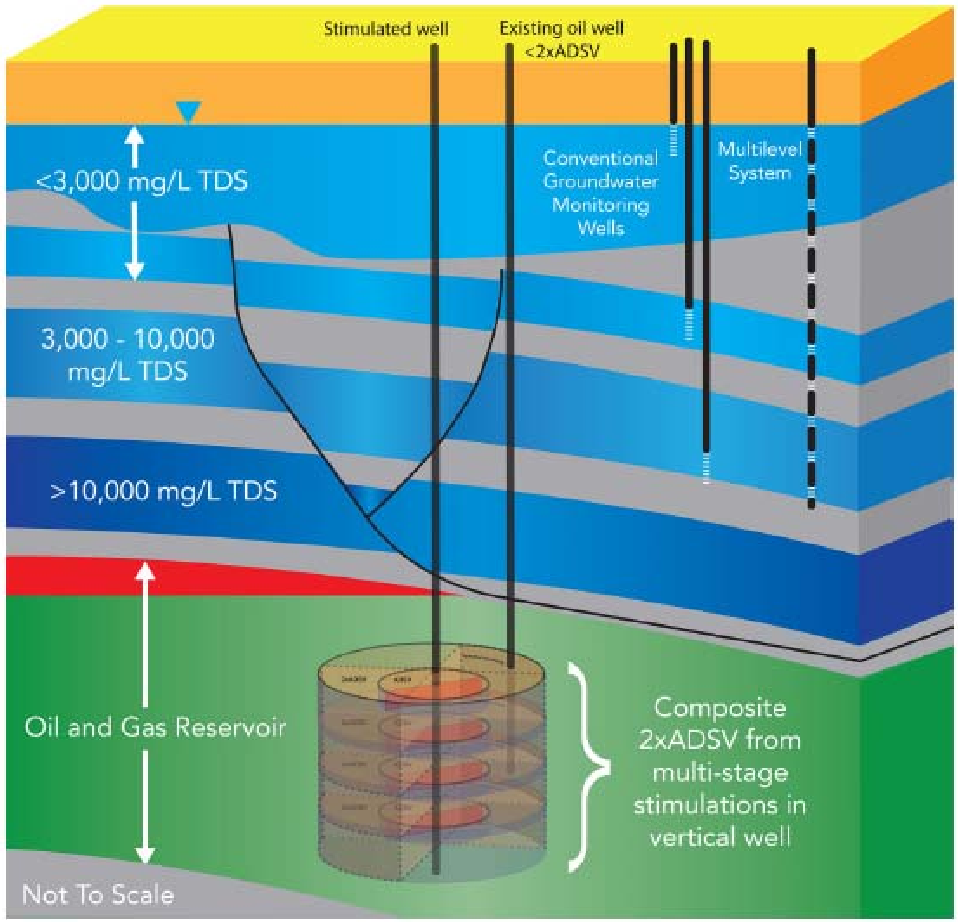
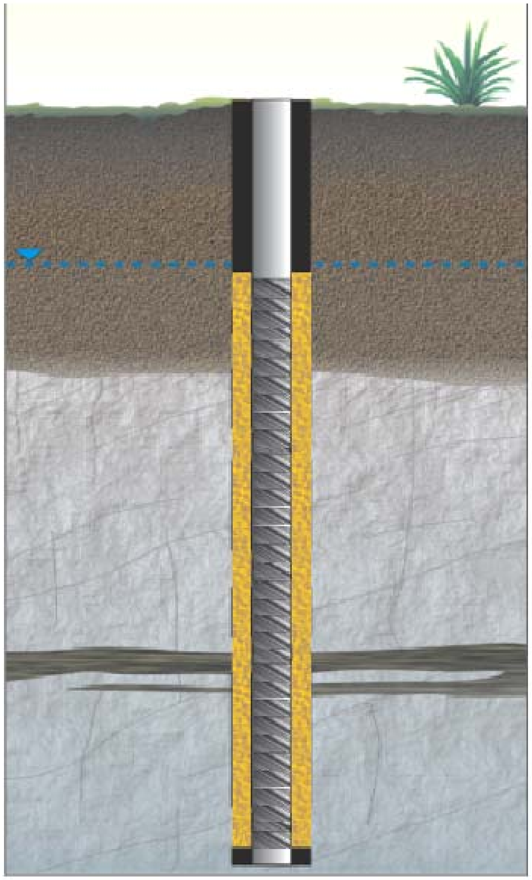



*Figure 6.4. A view showing one monitoring location with the installation of three conventional groundwater monitoring wells or one multi-level system well. Graphics by Sascha Madrid.*

# Issues and biases with single-interval, long-screened wells

- Blended concentrations and heads
- Measured concentrations in samples a function of flux into well
- Dilution of some target compounds below MDL
- Incongruent geochemical data (e.g., redox-sensitive compounds, GW age)
- Bias associated with ambient vertical flow in well



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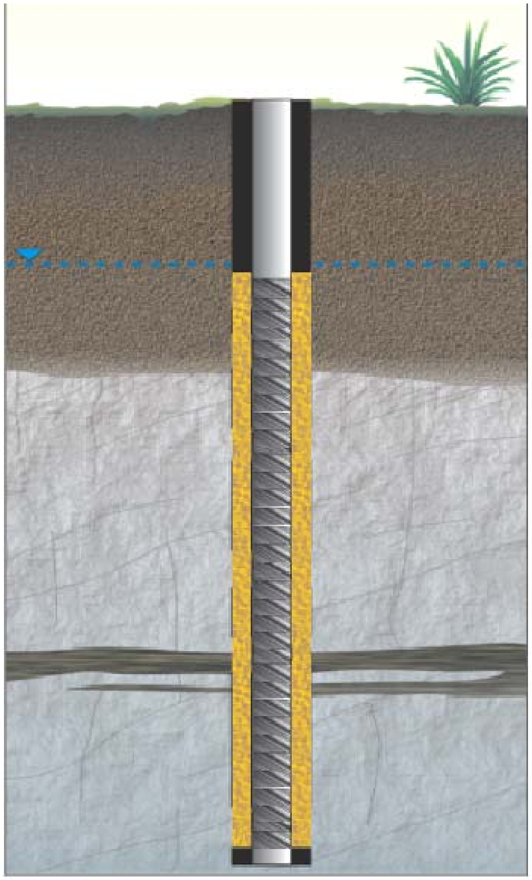


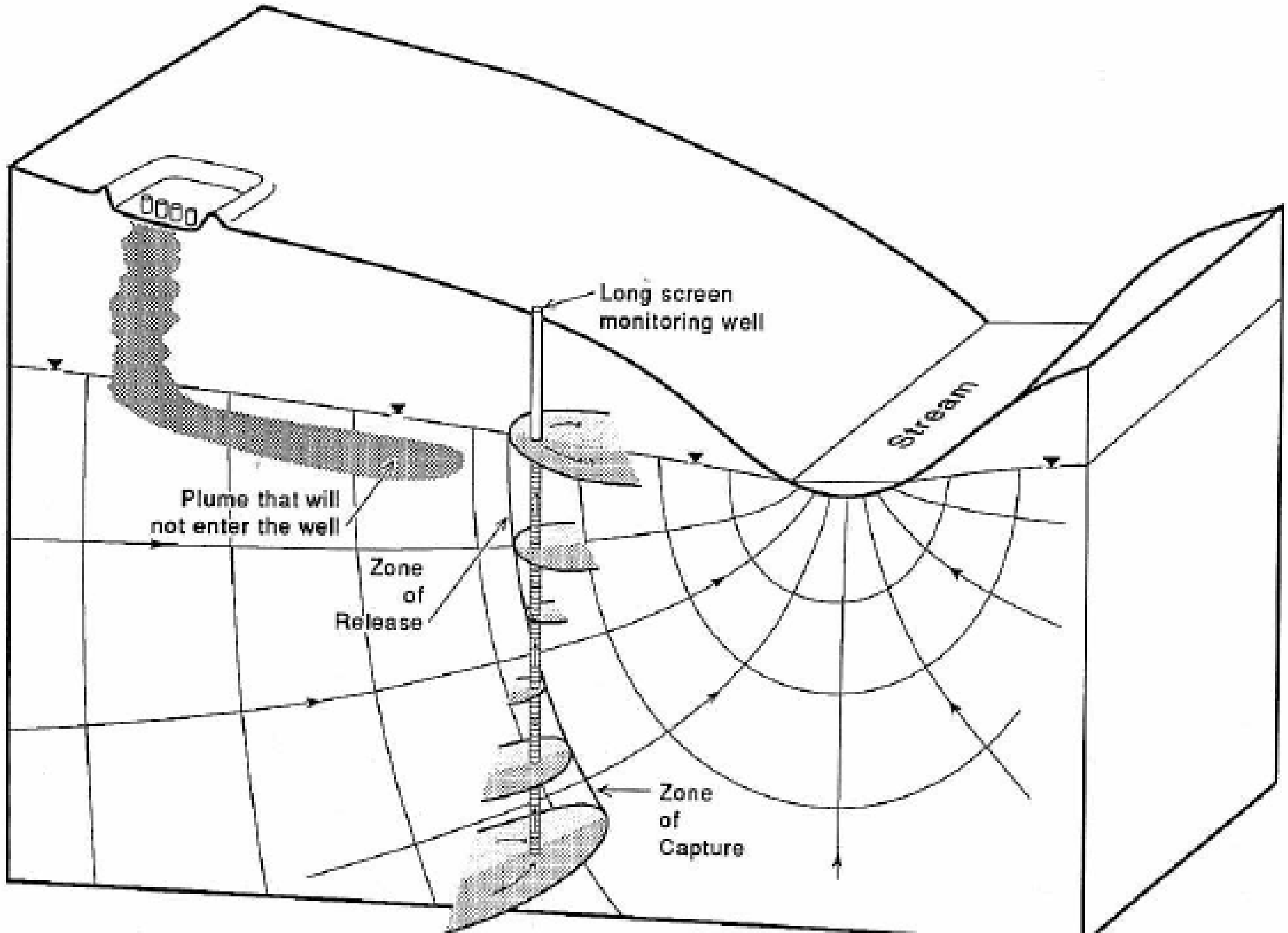



Figure 5. Flow Through a Long Screen Monitoring Well In a Thick, Unconfined Aquifer

(Source: McIlvride et al. 1988).

# Implications of Observed and Simulated Ambient Flow in Monitoring Wells

by Alper Elci[1], Fred J. Molz III[2], and William R. Waldrop[3]

## Abstract

A recent paper by Hutchins and Acree (2000) has called attention to ground water sampling bias due to ambient (natural gradient-induced) flows in monitoring wells. Data collected with borehole flowmeters have shown that such ambient flows are ubiquitous in both confined and unconfined aquifers. Developed herein is a detailed three-dimensional model of flow and transport in the vicinity of a fully penetrating monitoring well. The model was used to simulate a measured ambient flow distribution around a test well in a heterogeneous aquifer at the Savannah River Site (SRS) near Aiken, South Carolina. Simulated ambient flows agreed well with measurements. Natural flow was upward, so water entered the well mainly through high K layers in the lower portion of the aquifer and exited through similar layers in the upper portion. The maximum upward discharge in the well was about 0.28 L/min, which implied an induced exchange of 12 $m^3$/month from the bottom half of the aquifer to the upper half. Tracer transport simulations then illustrated how a contaminant located initially in a lower portion of the aquifer was continuously transported into the upper portion and diluted throughout the entire well by in-flowing water. Even after full purging or micropurging, samples from such a well will yield misleading and ambiguous data concerning solute concentrations, location of a contaminant source, and plume geometry. For all of these reasons, use of long-screened monitoring wells should be phased out, unless an appropriate multilevel sampling device prevents vertical flow.

## Background

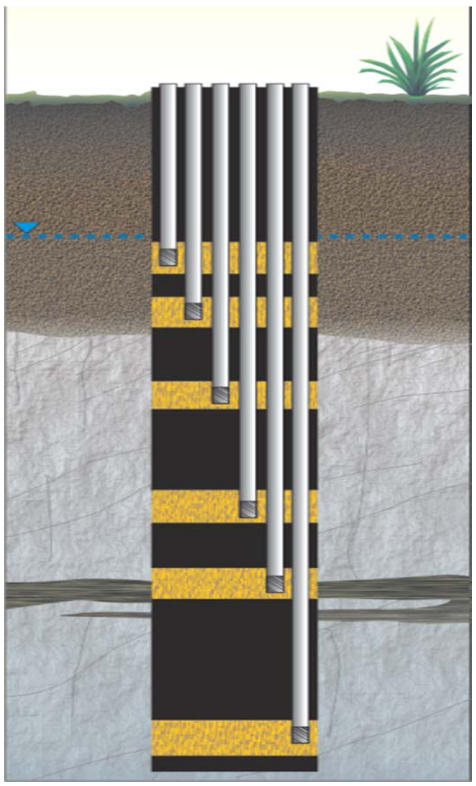
Conventional monitoring wells are often used to obtain information about ground water chemistry and plume geometry. The gathering of information is accomplished by collecting ground

past studies (Molz and Young 1993; Molz et al. 1994; Church and Granato 1996; Boman et al. 1997; Hutchins and Acree 2000; Crisman et al. 2000). For most of the wells listed in Table 1, whether the well screen penetrated the aquifer fully was not documented. The last five wells shown in Table 1 were selected from

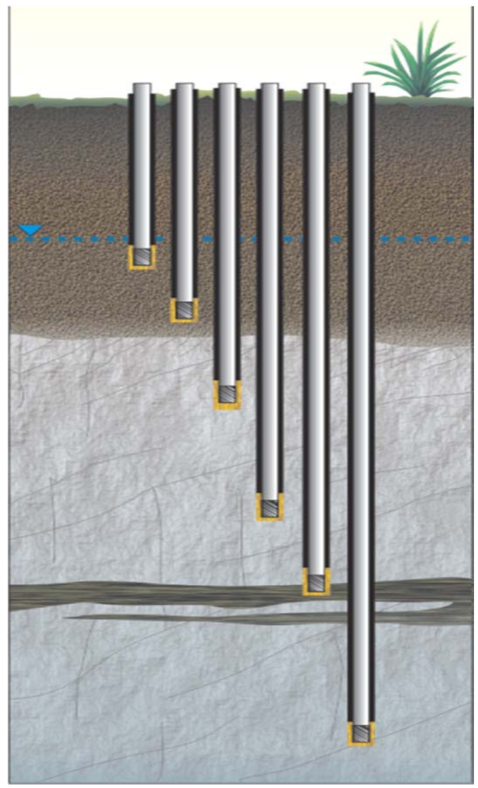
(Source: Elci, A., F. Molz and W. R. Waldrop (2001). "Implications of observed and simulated ambient flow in monitoring wells." Ground Water **39(6): 853-862.**

# Options for depth-discrete groundwater monitoring

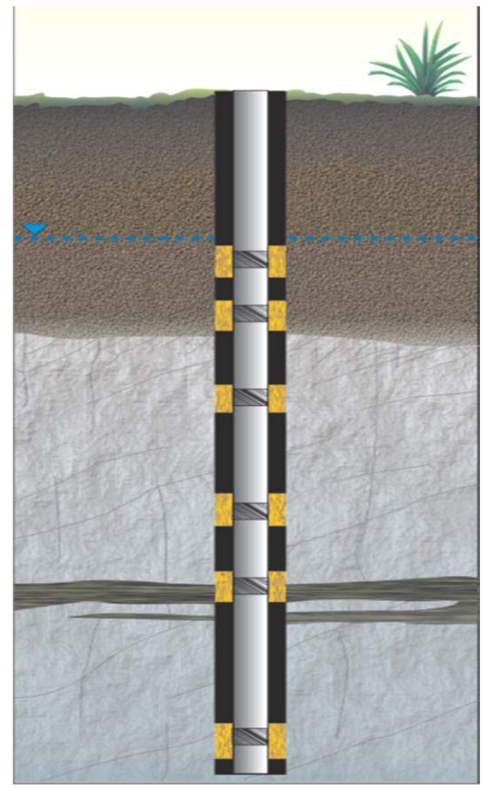
(a) **Nested Well**



(b) **Well Cluster**

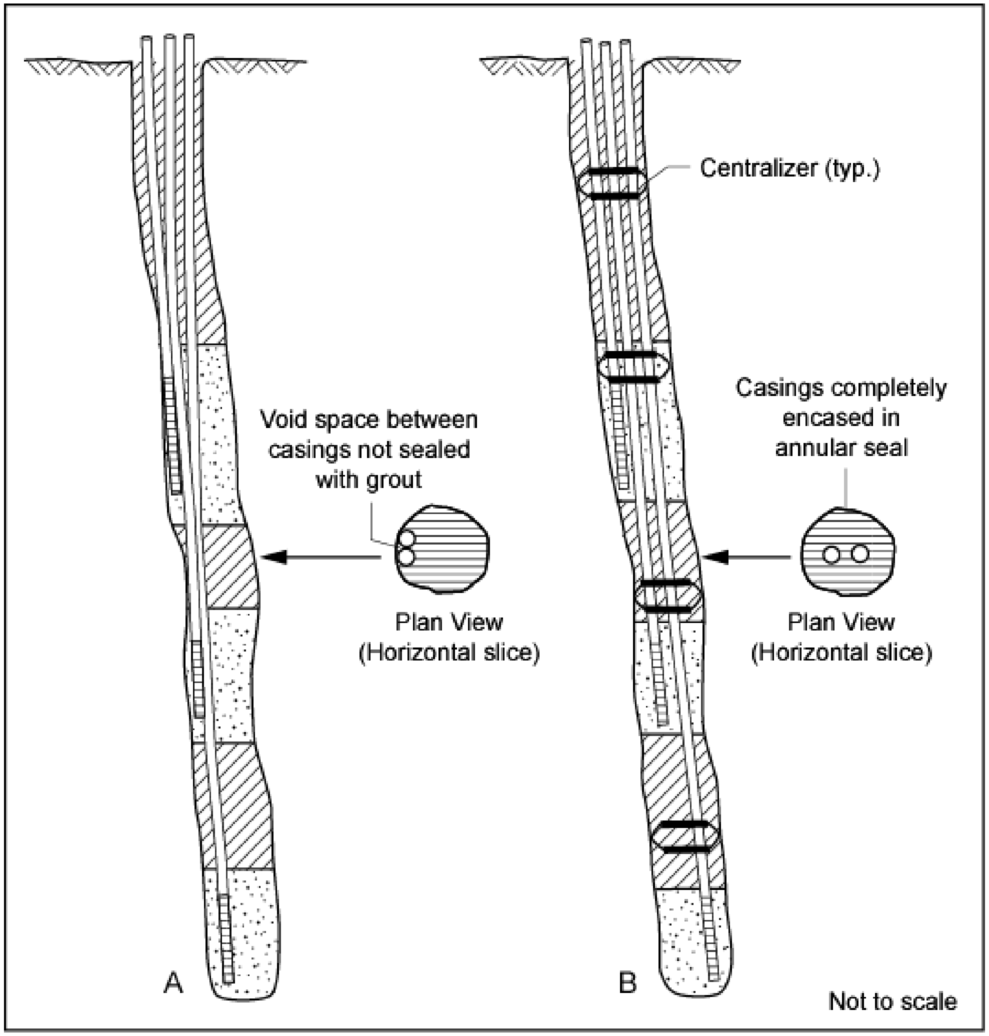


(c) **Engineered Multilevel System (MLS)**



(Source: adapted from Einarson 2006).

# A “real” nested well




A) without centralizers; B) with centralizers

Source: Nielsen, 2005 Practical Handbook of Ground-Water Monitoring, Second Edition

(a)

(b)

(c)

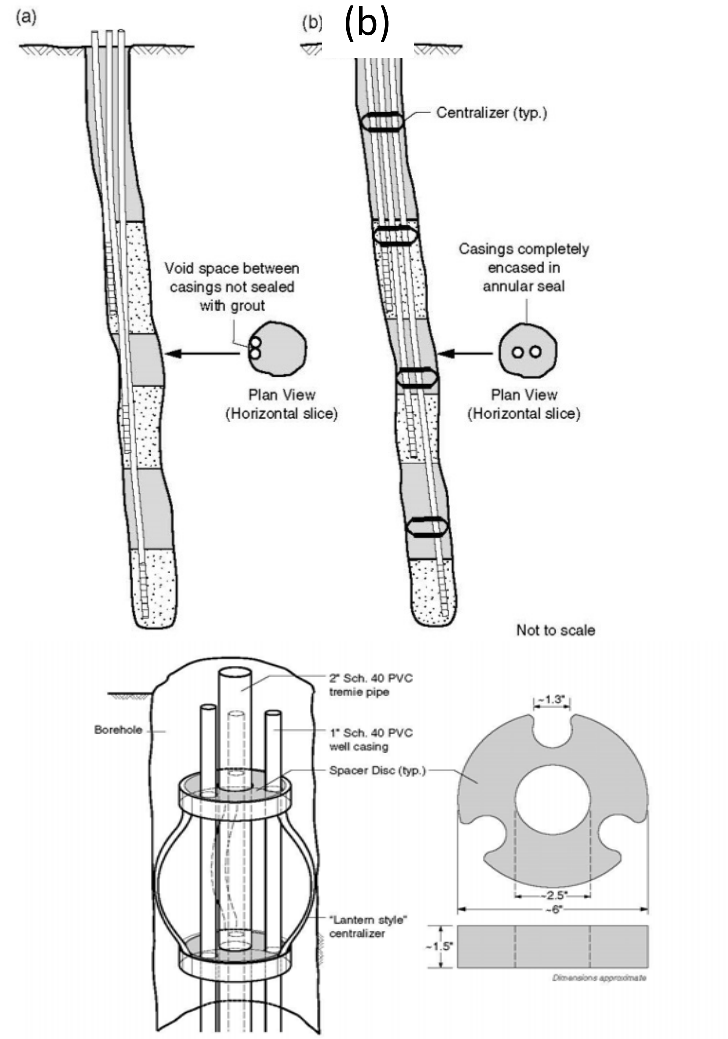


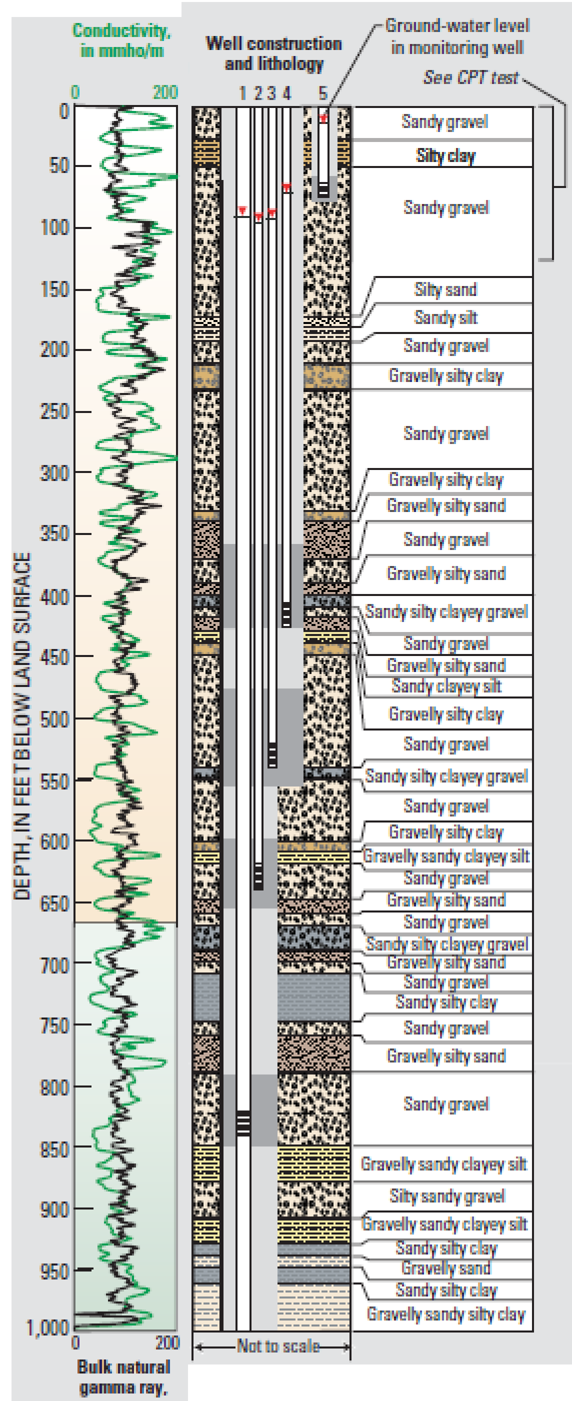

**FIGURE 11.10**
Design of a centralizer for a three-zone nested well. See text for further discussion.

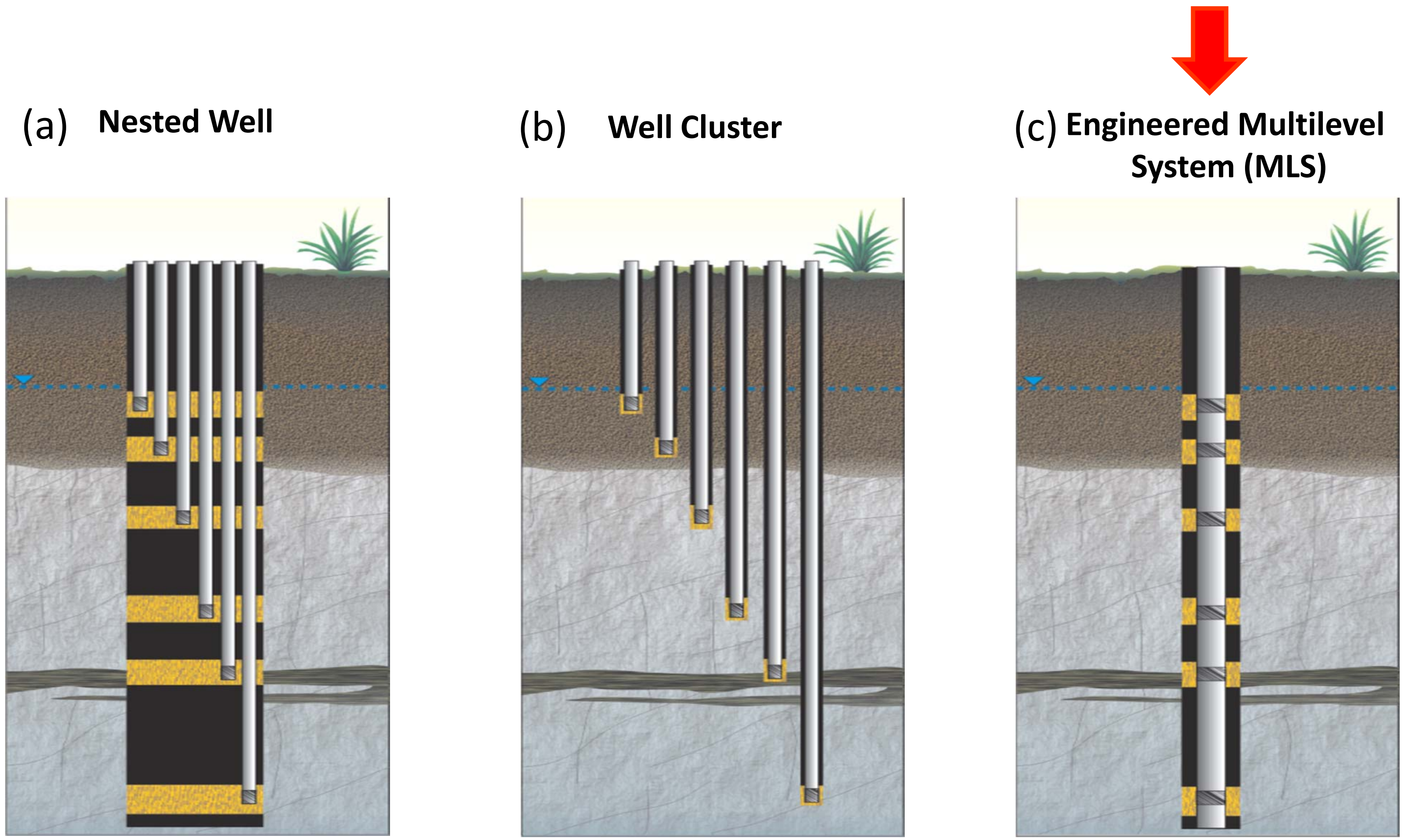
Source: Nielsen, 2005 Practical Handbook of Ground-Water Monitoring, Second Edition

## There is a resurgence in the number of nested wells being installed in the U.S.

- Successful installations have large sealed intervals
- Same head values measured in adjacent zones may indicate a failed seal
- Effective centralizers are very important but are often an afterthought. Centralizers should be considered and specified in the well design

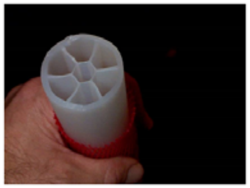
(Source: Hansen et al. 2002)

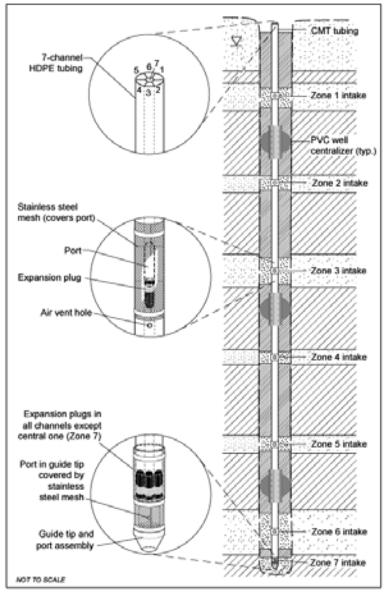




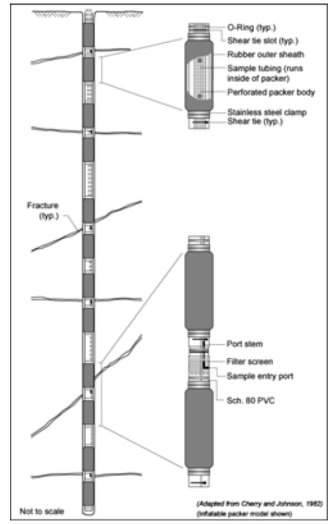

(Source: adapted from Einarson 2006).

# Solinst CMT™ System



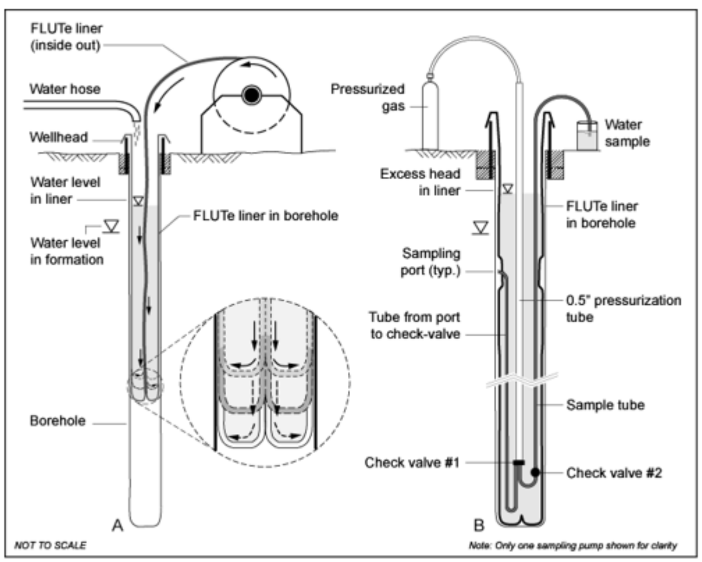



# Solinst Waterloo System





# Water FLUTe™ system




# Westbay System

1 – packer

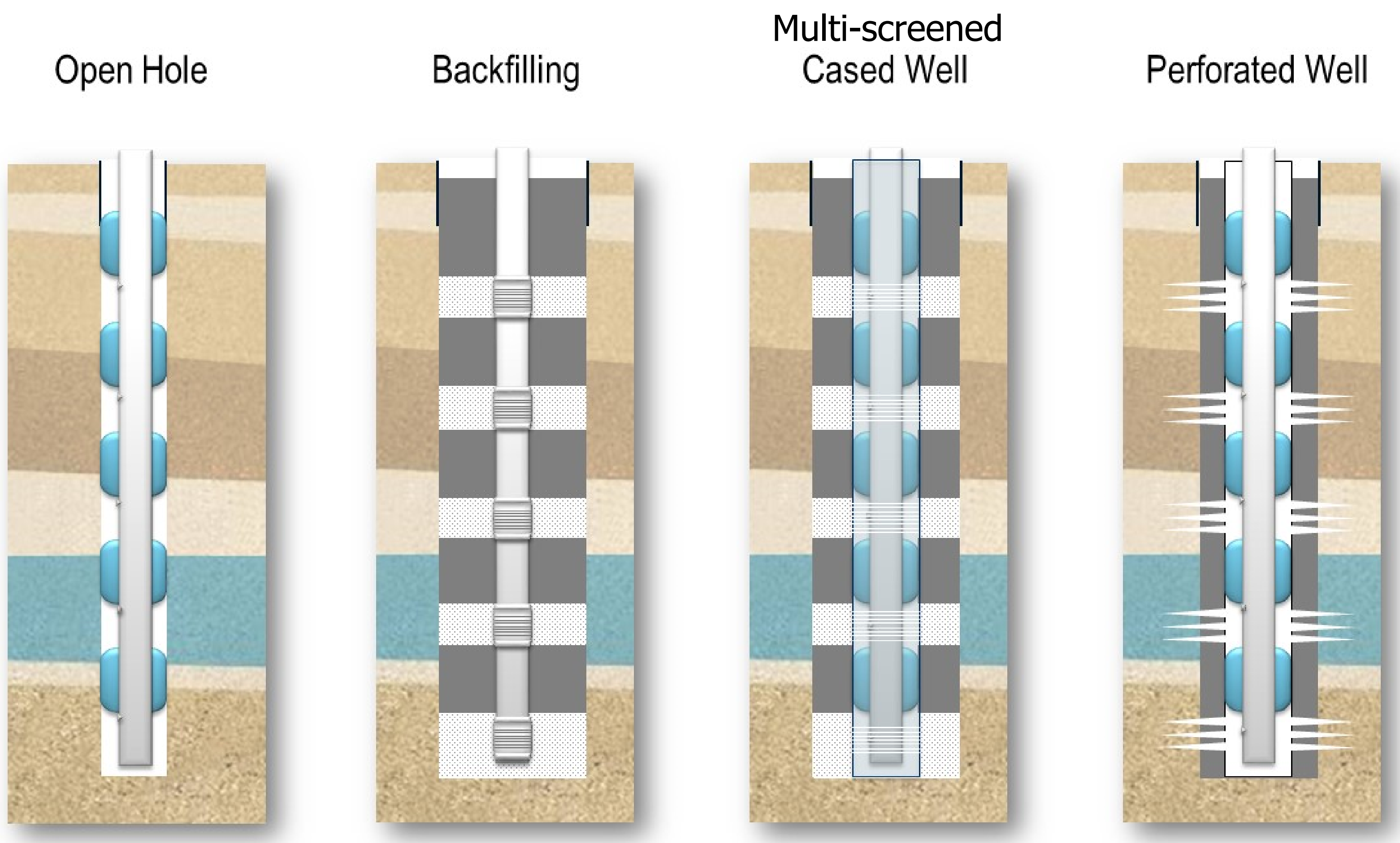
2 – measurement port (pressures, groundwater sampling, limited hydraulic testing)

3 – pumping port (development and hydraulic testing)

# Engineered multilevel monitoring systems (MLS)

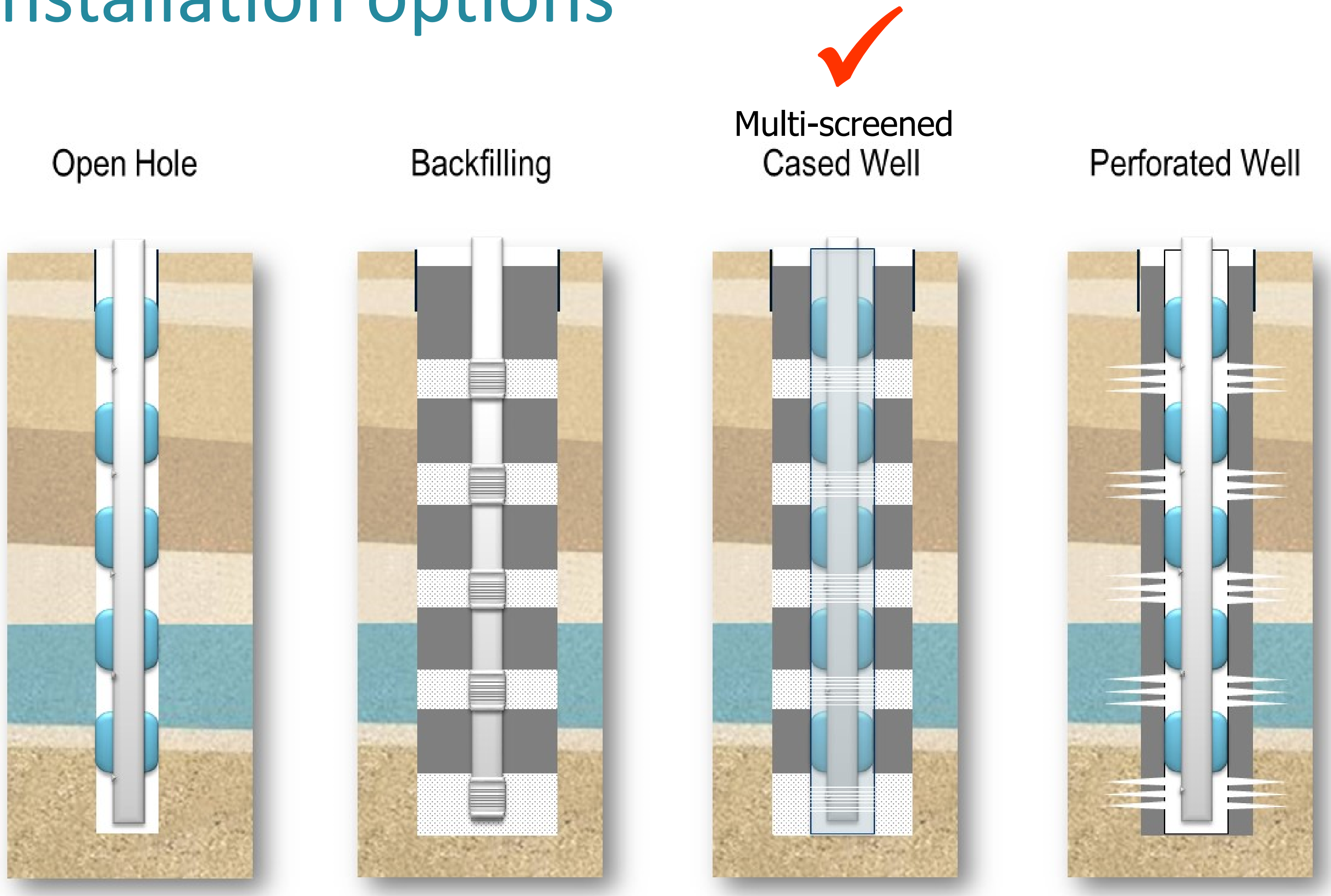
1. Continuous Multichannel Tubing (CMT™) http://www.solinst.com/products/multilevel-systems-and-remediation/403-cmt-multilevel-system/
2. Solinst Waterloo System http://www.solinst.com/products/multilevel-systems-and-remediation/401-waterloo-multilevel-system/datasheet/
3. Water FLUTe™ http://www.flut.com/index.html
4. Westbay System http://www.novametrixgm.com/groundwater-monitoring/multilevel-well-system/westbay-system-multilevel-groundwater-monitoring

# Installation options




(Source: provided by Westbay Instruments,
A Division of Nova Metrix Ground Monitoring (Canada) Ltd.).

# Installation options




(Source: provided by Westbay Instruments,
A Division of Nova Metrix Ground Monitoring (Canada) Ltd.).

# Benefits of installing MLS in multi-screened PVC or steel wells

- Familiar technology
- Smooth interior (high-quality seals; low risk of failure during installation of MLS)
- Standard well development (mud rotary no issue)
- Standard geophysical logging
- Hydraulic testing
- Can verify integrity of seals
- Removable/ease of decommissioning (simplifies permitting)

# Key MLS advantages

- Head and hydrochemical data from multiple depths in a single borehole
- Only one pipe/tube in the borehole. Enhances reliability of seals
- Total project costs lower
- Small system volume results in more accurate head measurements
- Small footprint
- Reduced permitting costs
- Seals can be verified

# MLS disadvantages

- Fewer options for sampling; collecting large volumes of water can be time consuming
- Specialized training required
- Can be more difficult to decommission than conventional monitoring wells
- Fewer options for hydraulic testing

# Engineered MLS systems are no longer "novel" in California and can play an important role in Oil & Gas monitoring

- First system installed in an oil & gas field in Kern County in 1986
- 2,000 MLS systems installed in California in the last 30 years
- More than 200 Westbay wells installed in California, most in Southern California to depths up to 2,000 feet. (Deepest Westbay well is 7,000 feet in Decatur, IL)
- Several FLUTe and Westbay wells to ~500 feet at SSFL near Simi Valley
- 60 Westbay wells installed in Orange County to depths up to 2,000 feet in the 1990s
- Six Westbay wells installed recently for Mojave Water Agency
- Many Westbay wells installed at San Gabriel Valley Superfund sites

# Thank you!

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