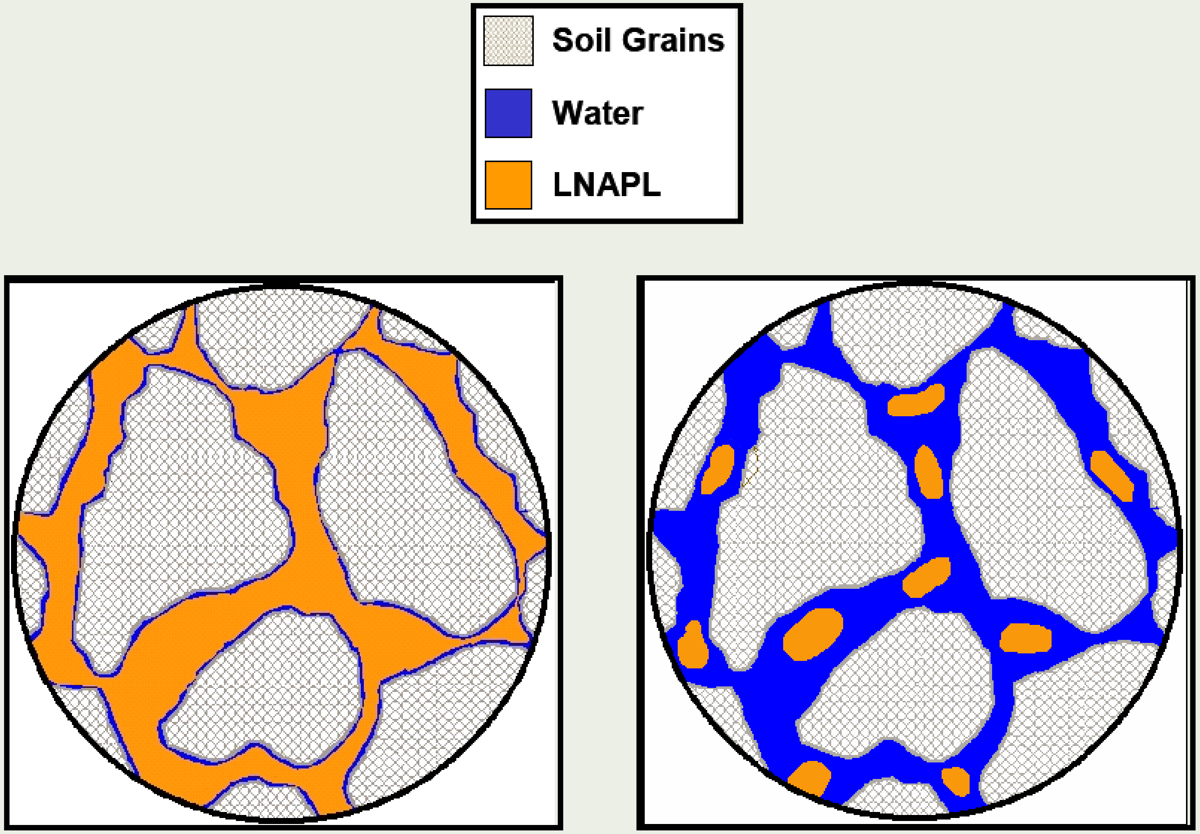
Tidal Influence on LNAPL & Aqueous Phase Distribution

EPA
United States
Environmental Protection
Agency

Tidal Influence On NAPL Movement

- **Overview**
  - Poorly studied with limited literature available
  - Oscillations in groundwater along a shoreline:
    - Produce a natural buffer zone
    - Inhibits LNAPL migration toward the open water body

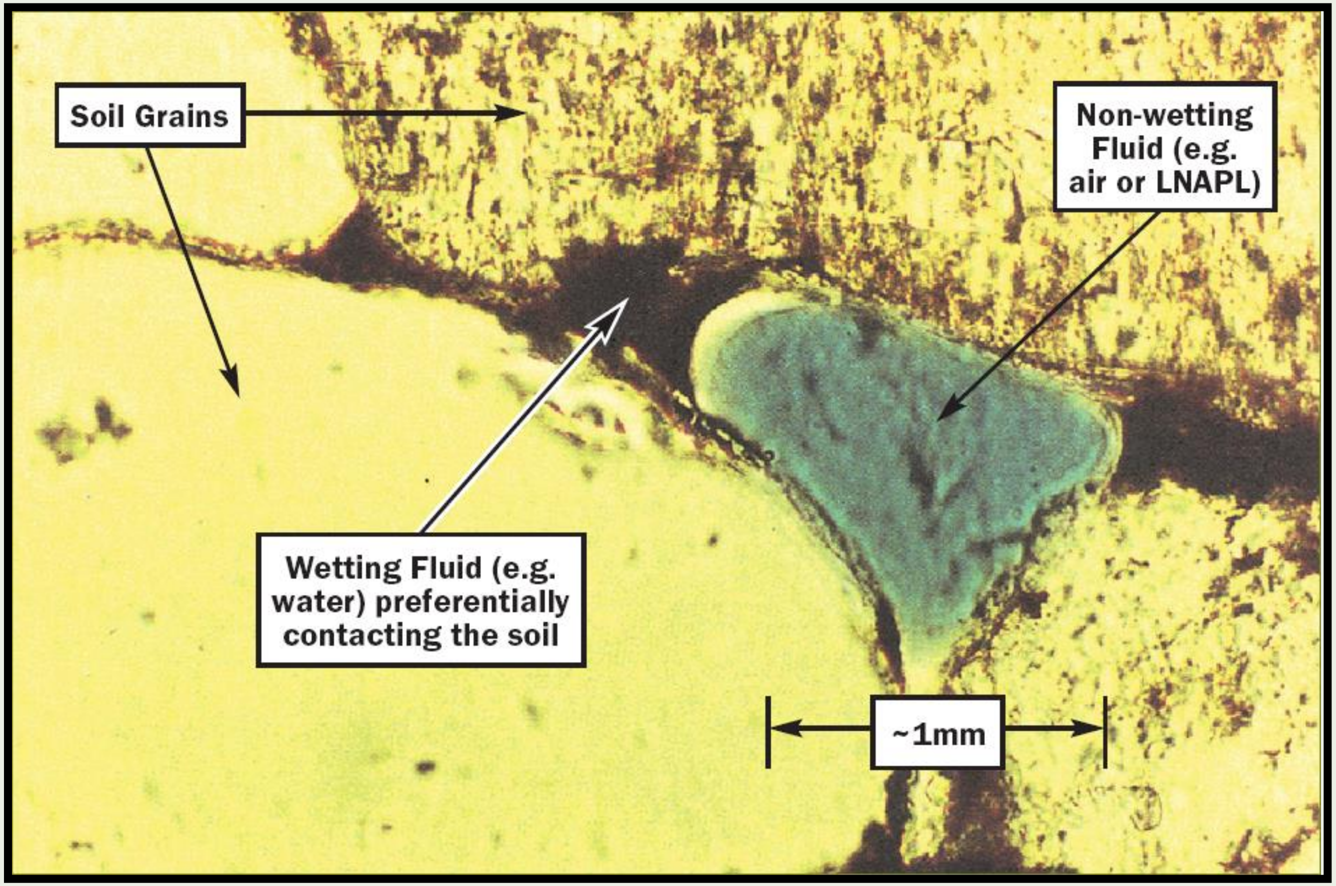
LNAPL Saturation



High Saturation
(Mobile LNAPL in pore network)

Low Saturation
(Residual LNAPL in pore network)

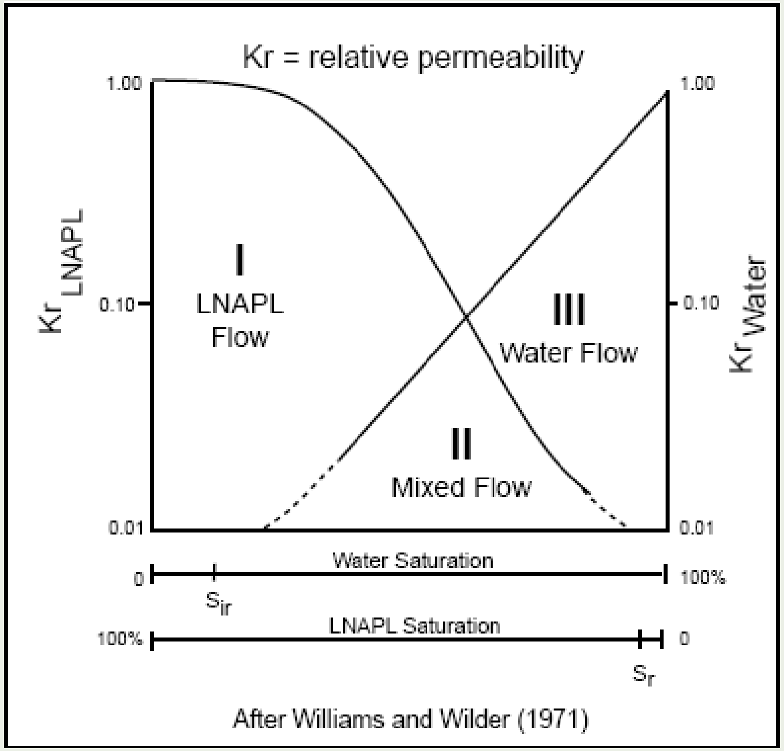
Multiple fluids



Source: Wilson et al., 1990.

Multiple fluids in the pore space of a granular porous media.

Hypothetical relative permeability



Hypothetical relative permeability curves for water and an LNAPL in a porous medium.

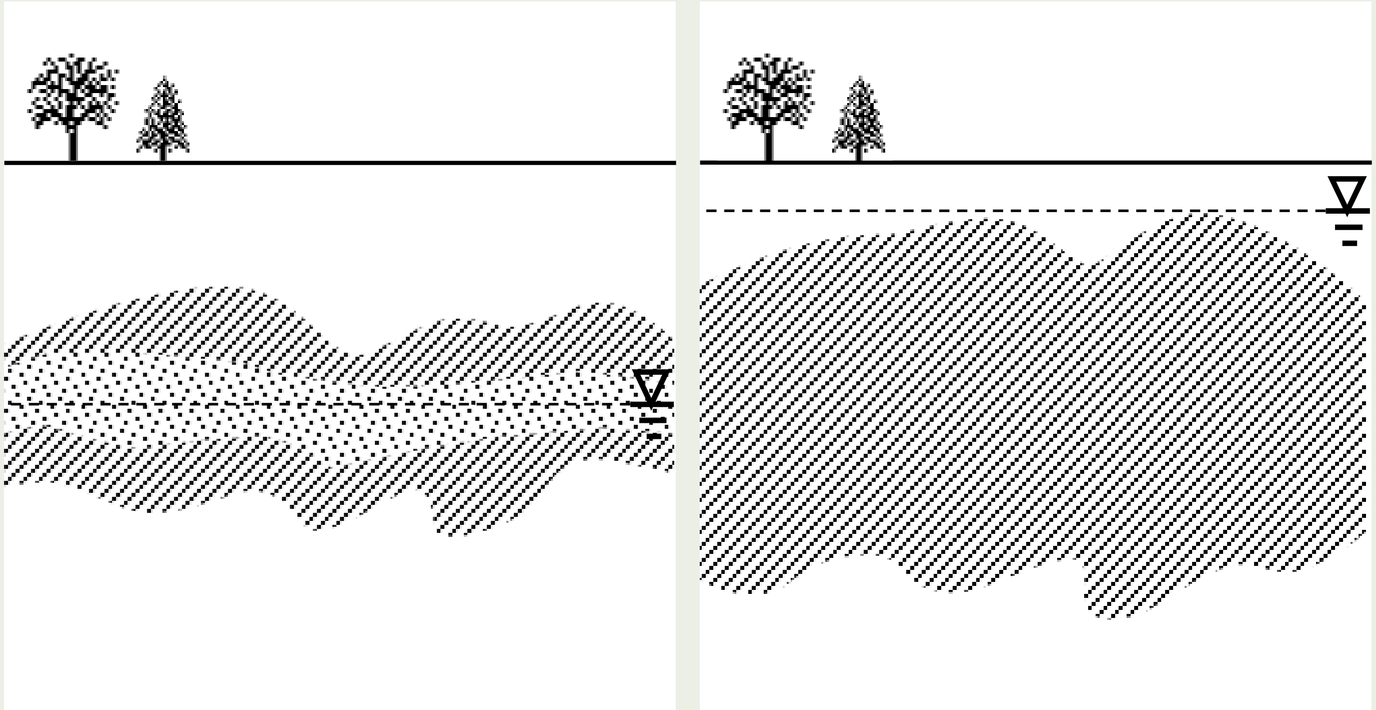
Zone I: small	LNAPL occurs as a potentially mobile, continuous phase and saturation is high. Water is restricted to pores. The relative permeability of water is low. Such conditions may be observed within large mobile product accumulations.
Zone II: Such	Both LNAPL and water occur as continuous phases, but, generally, do not share the same pore spaces. However, the relative permeability of each fluid is greatly reduced by the saturation of the other fluid. conditions may be representative of zones of smaller mobile product accumulations at the water table.
Zone III:	LNAPL is discontinuous and trapped as residual in isolated pores. Flow is almost exclusively the movement of water, not LNAPL. Examples of such conditions may be found within zones of residual LNAPL retained below the water table.

Source: Newell, et al., 1995.

Tidal Influence On NAPL Movement

- **Buffer zone results primarily from the large smear zone that is produced due to the increased fluctuations in groundwater closer to the shore**
- **As an oil plume migrates toward the shore:**
  - Ultimately intersects the zone of tidally induced groundwater fluctuation
  - Any mobile LNAPL will become trapped as a residual as the oil plume is smeared vertically within the aquifer
- **The potential for vertical smearing increases toward the shoreline as the magnitude of the fluctuations increases**

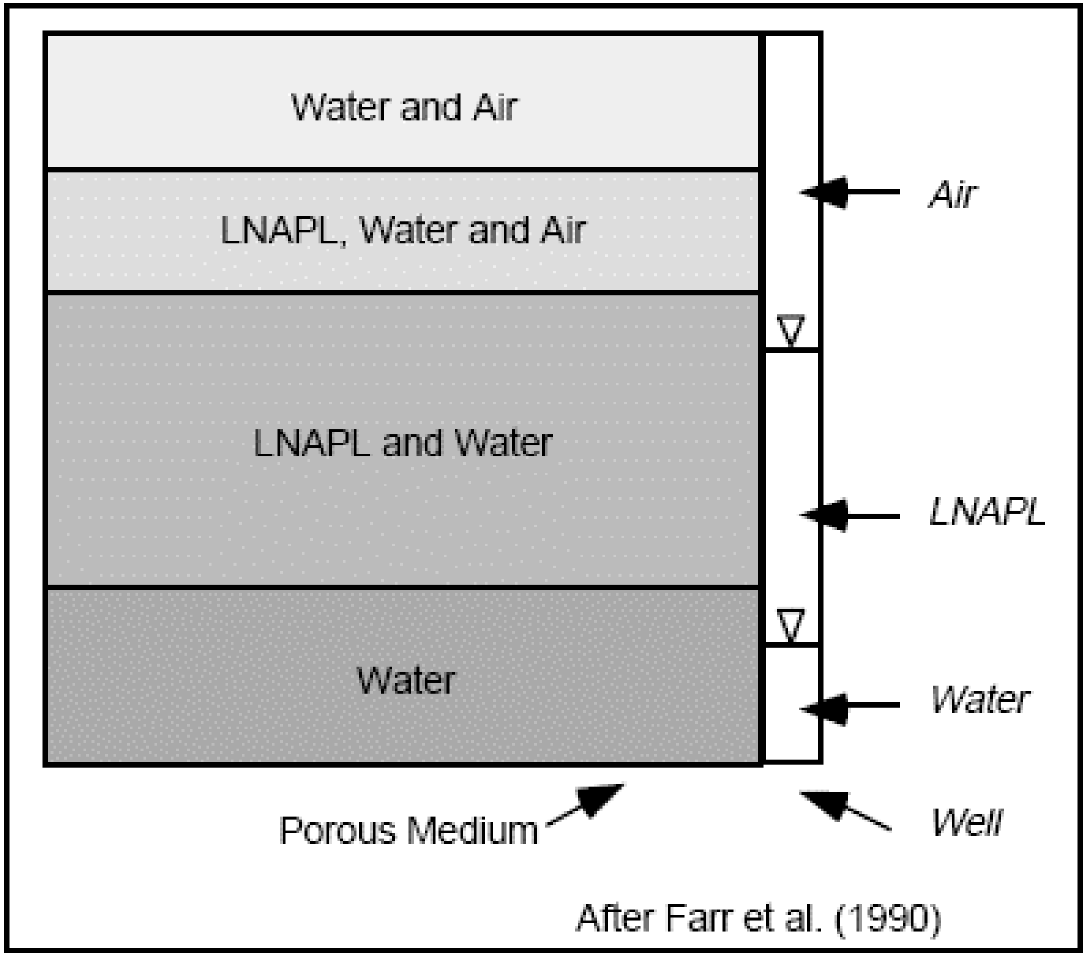
Smearing of LNAPL



Effect of rising water table on LNAPL distribution in porous medium. A similar effect may be seen with a falling water table.

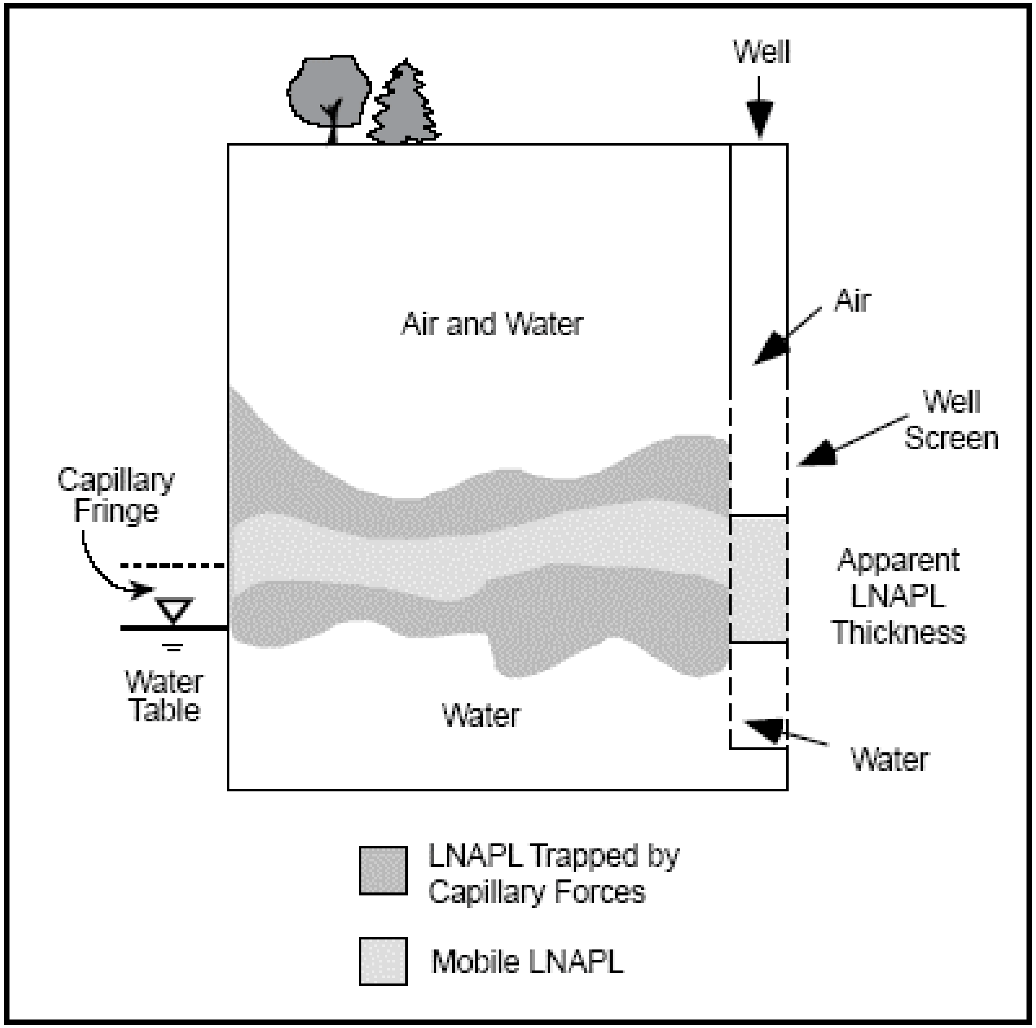
Source: Newell, et al., 1995.

Multiphase fluid distribution



Conceptualization of a multiphase fluid distribution in porous medium and monitoring well screened within the medium.

LNAPL Thickness in Well



Simplistic conceptualization of LNAPL thickness measured in well and LNAPL distributed information.

Tidal Influence On NAPL Movement

- Regular fluctuations in the water table act to produce "snap-off", which breaks up the plume into isolated droplets within the soil pore network
- As groundwater fluctuations occur daily and consistently, it becomes difficult for the LNAPL to coalesce into a consistent plume of any significant thickness
- Because the oil transmissivity decreases within the tidally influenced smear zone, the rate of migration of any potential mobile oil decreases as well
- Hence, the tidally influenced smear zone is an effective barrier inhibiting oil migration

Tidal Influence on Aqueous Phase Contamination

- **Will result in an increase of dissolved contamination.**
  - Product is continually being trapped and released with the water table changes
  - New LNAPL surfaces in contact with water increase and facilitate mass transfer from the LNAPL phase to the aqueous phase
- **Groundwater concentrations will commonly be higher in areas of large water table fluctuations**






Hull Dye & Print Works Oil Spill Site

Evaluation of Groundwater Hydraulics in a Tidally Influenced Shallow Aquifer

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United States
Environmental Protection
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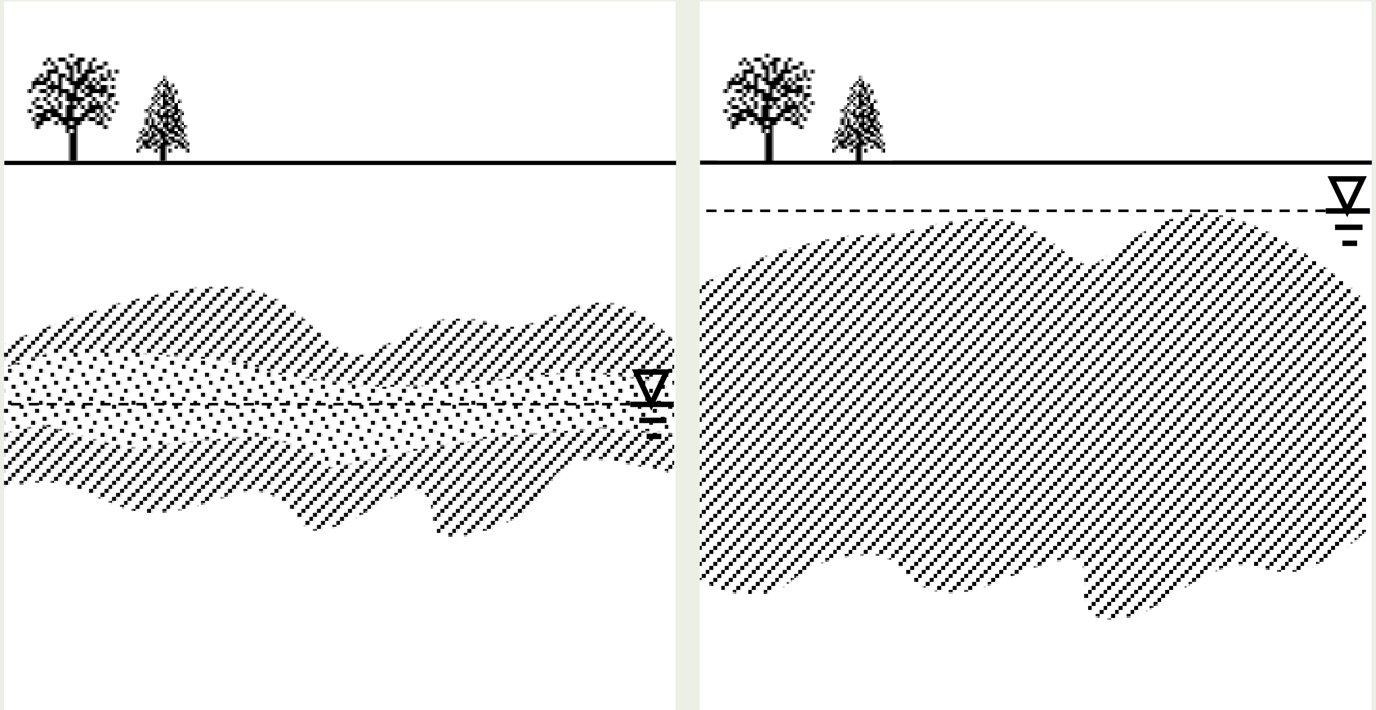
Thanks to:
Terrence Johnson, PhD
U.S. EPA, ERT

LNAPL Smear Zone



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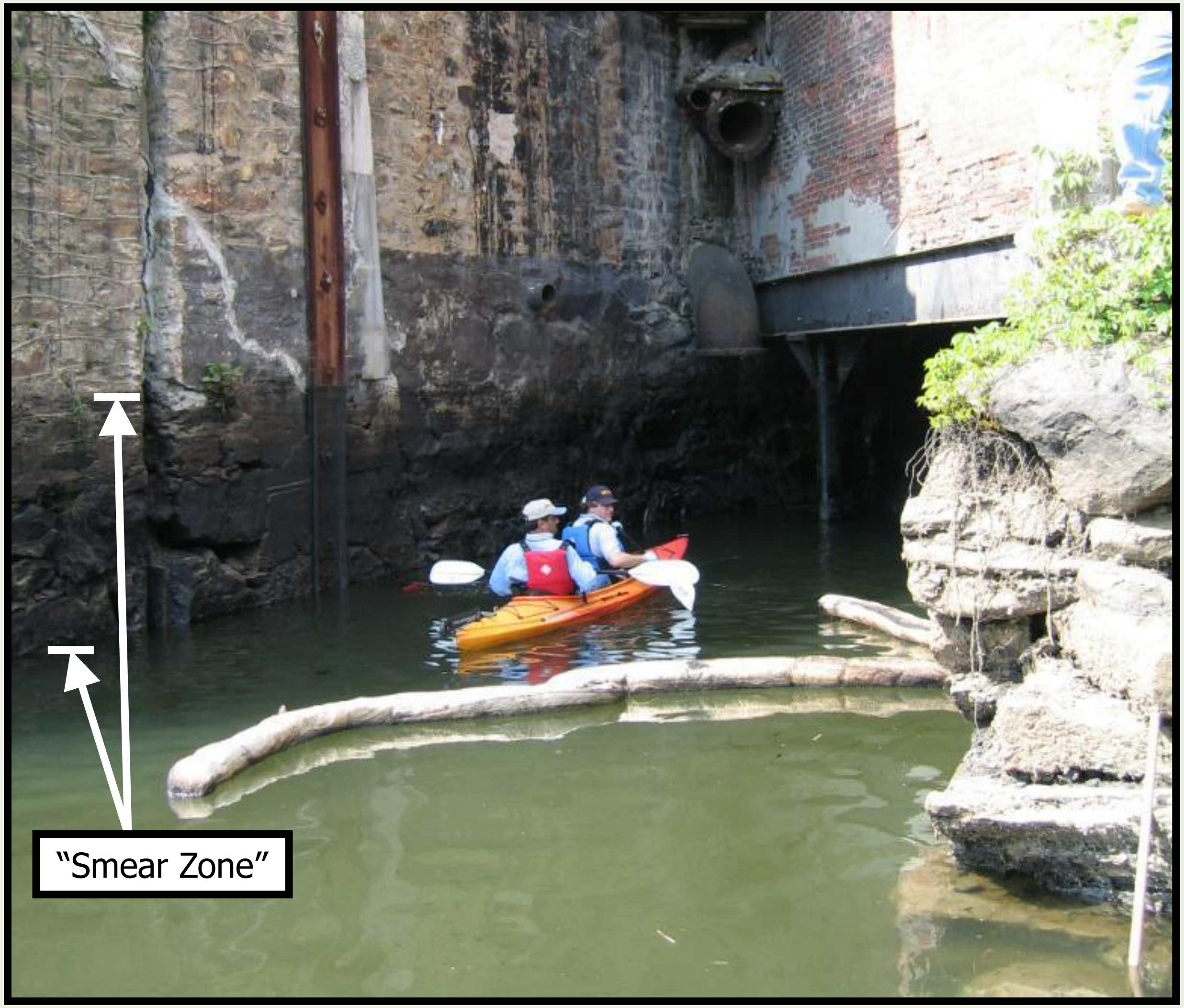
Source: Newell, et al., 1995.

Hull Dye & Print Works Oil Spill Site



Hull Dye & Print Works Oil Spill Site

- The Works is located on the eastern bank of the Housatonic River in Derby, Connecticut, USA.
- #6 fuel oil was discovered seeping into the river.
- The U.S. EPA Environmental Response Team was activated to evaluate the extent of the LNAPL plume as well as options for its recovery.
- In order to make these assessments, the site's groundwater hydraulics had to be determined.

Hull Dye & Print Works Oil Spill Site

- **Problem:**
  - Develop groundwater contours to access flow directions in a tidally influenced environment

- **Solution:**
  - Apply filtering algorithm to remove tidal effects
    - The filtering algorithm uses 71 consecutive hourly fluid pressure readings to calculate three sequential means, filtering out the tidal effects in the process.
    - The third mean in the sequence is the effective fluid pressure head for the median hour; i.e., the 36th hour.

Solution

- Sixteen monitoring wells across the site were equipped with fluid-pressure transducers.
- Hourly fluid-pressure fluctuations from the initial pressure readings were monitored across the site over a one-week period.
- Hourly fluid-pressure head readings were smoothed by applying a algorithm.

Filtering Algorithm

- Smooth the tidal effects and generate effective fluid pressures

- Uses 71 consecutive hourly fluid pressure readings to calculate three sequential means

Filtering Algorithm

$$M_j^1 = \sum_{i=1}^{24} \frac{p_i}{24}$$

- **First smooth mean pressure head in feet.**

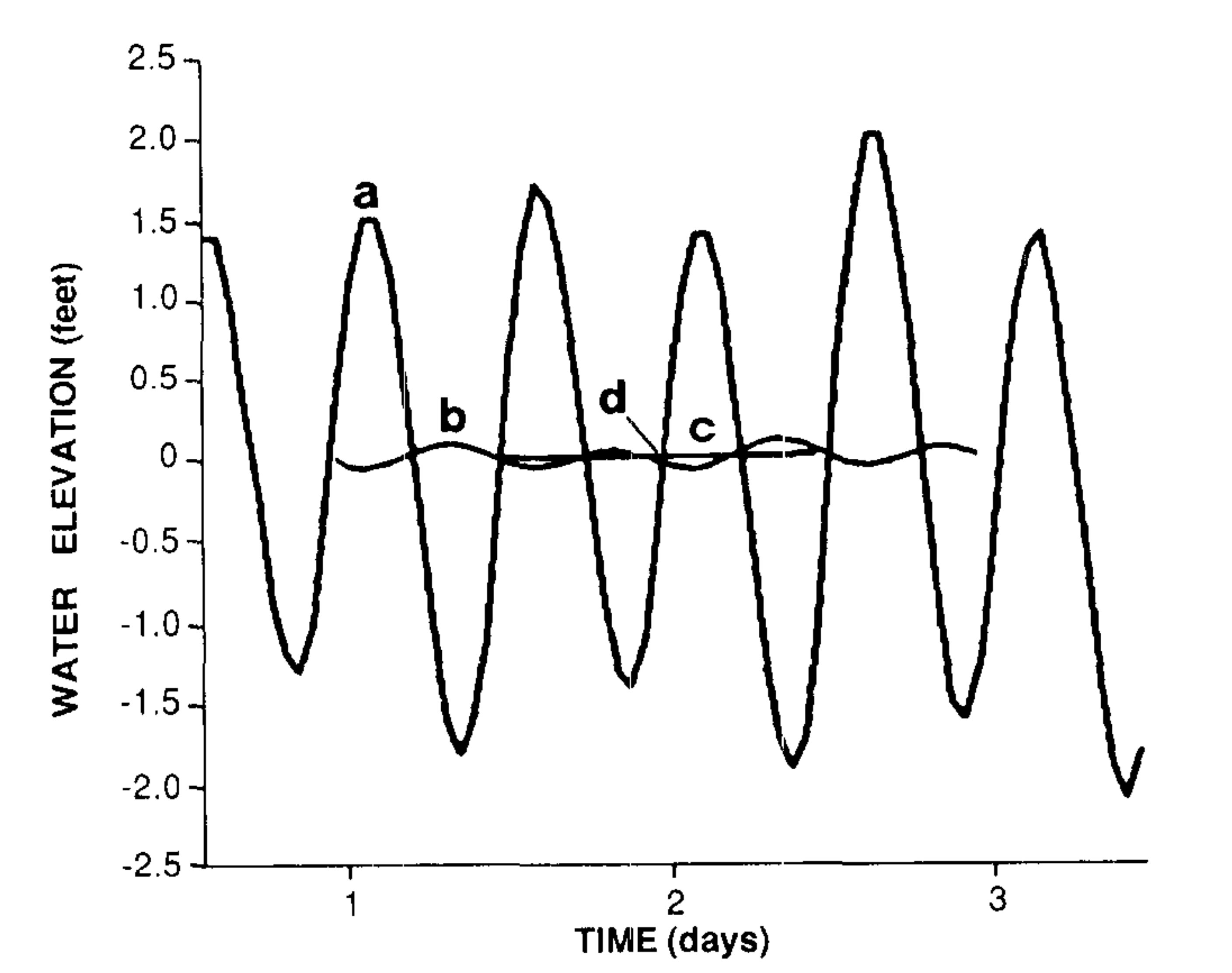
$$M_k^2 = \sum_{j=1}^{24} \frac{M_j^1}{24}$$

- **Second smooth mean pressure head in feet.**

$$M_l^3 = \sum_{k=1}^{24} \frac{M_k^2}{24}$$

- **Third smooth mean pressure head in feet with the tidal effects removed.**

Filtering Algorithm

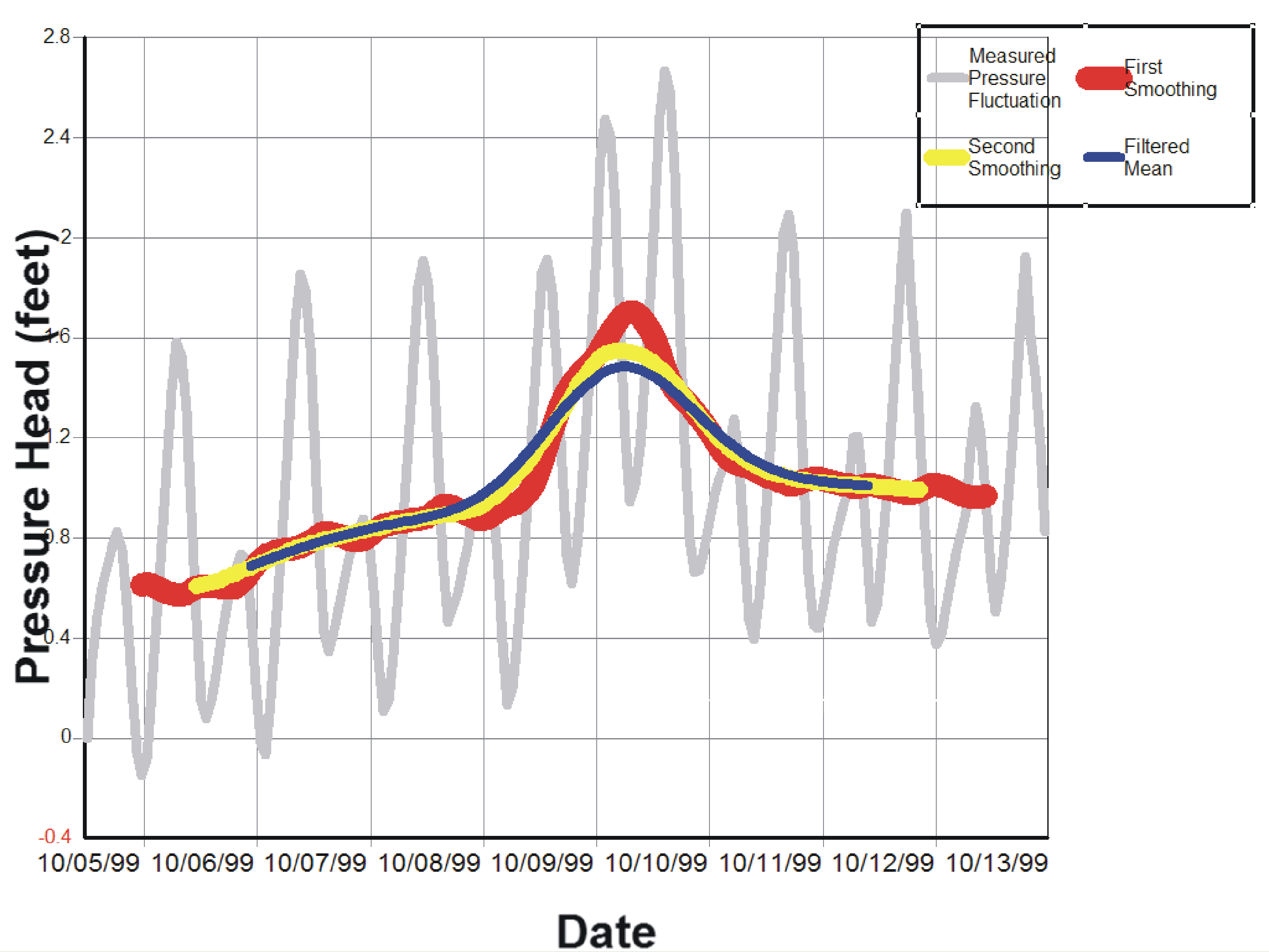


Solution

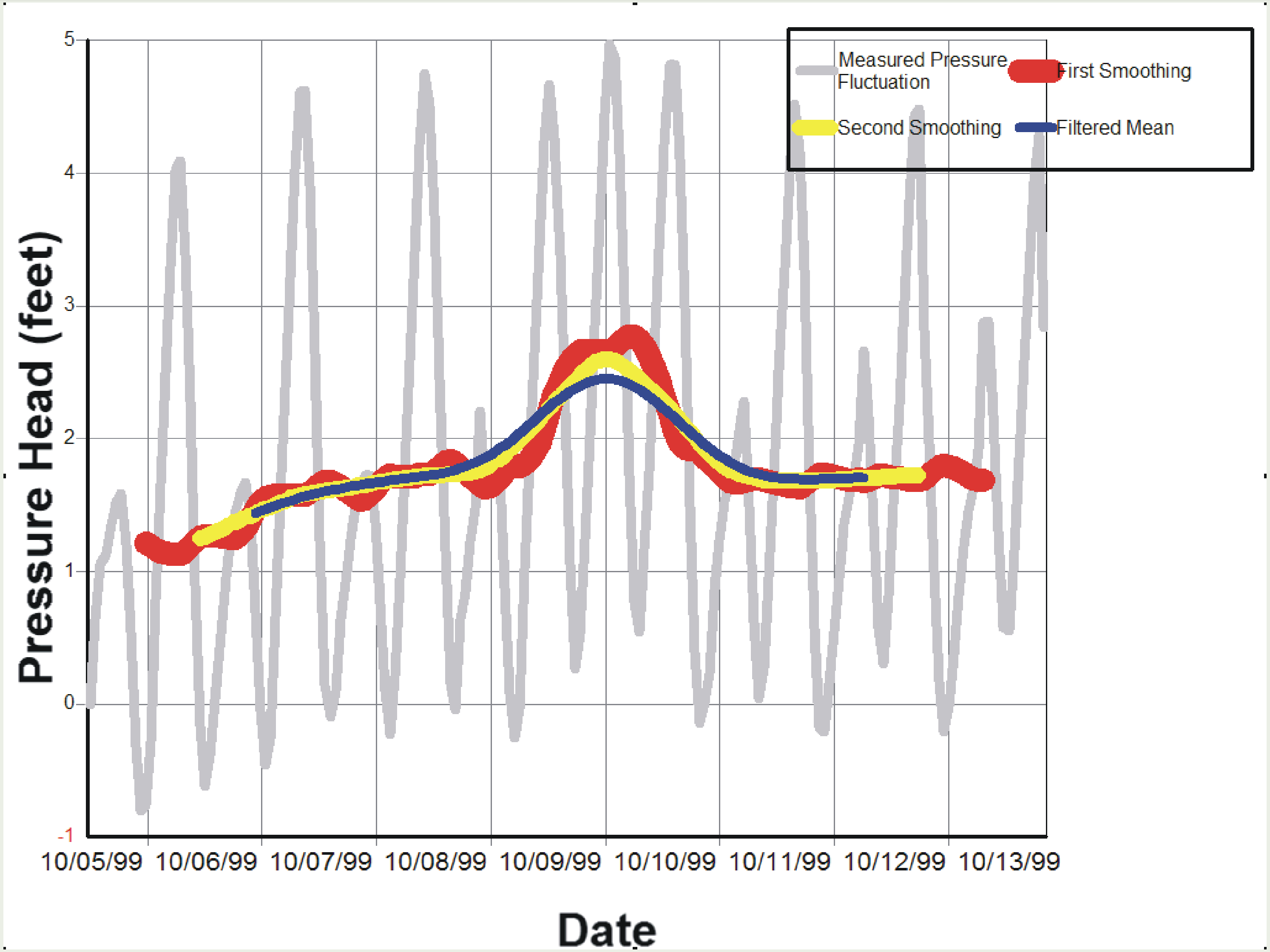
- From the elevation of the transducers (Z_t) and the effective fluid pressure head (M_l^3), the effective groundwater table elevation (H_l) at an instant was calculated as:

$$H_l = Z_t + P_o + M_l^3$$

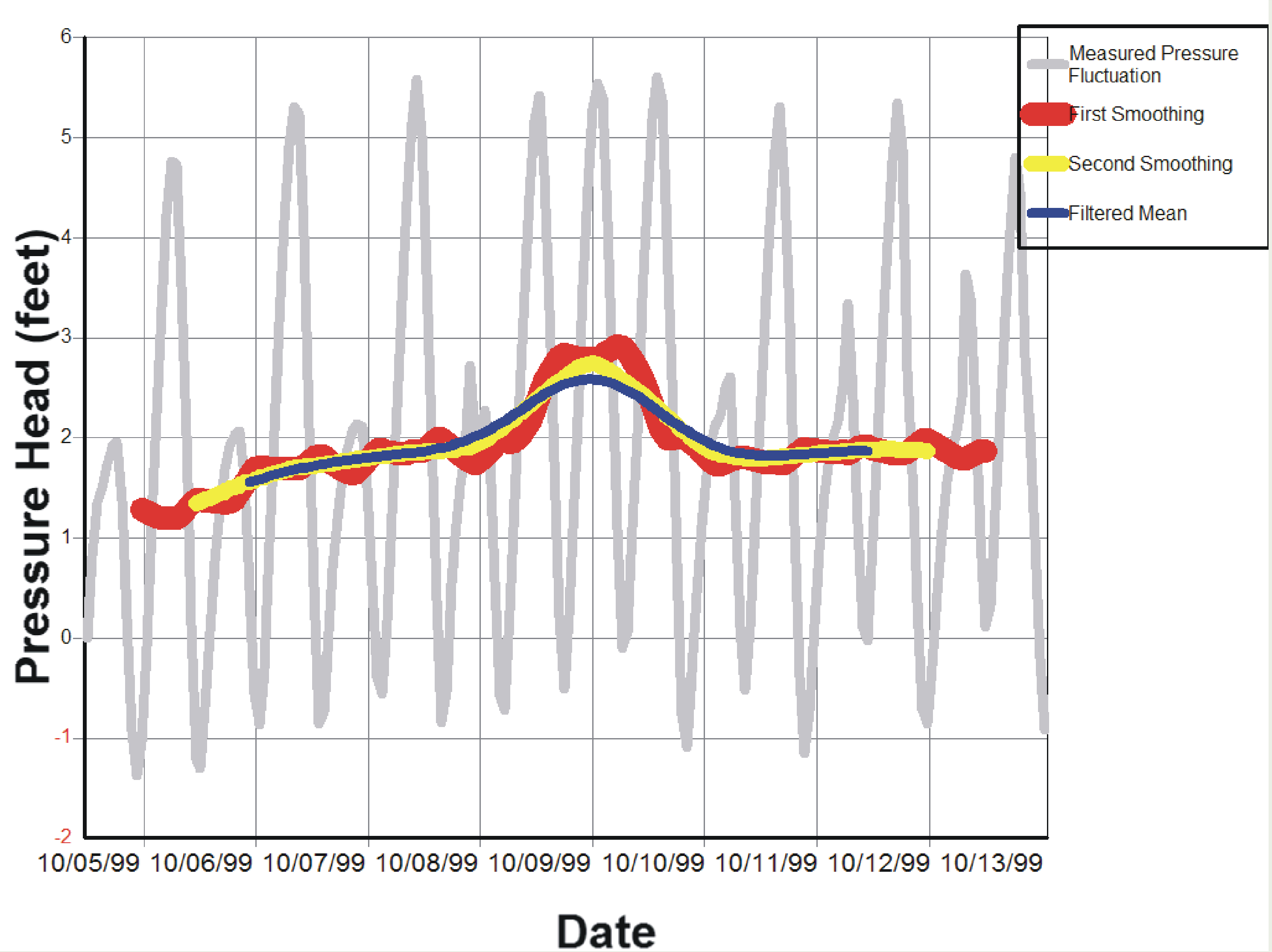
Hydrograph of Monitoring Well MW 1



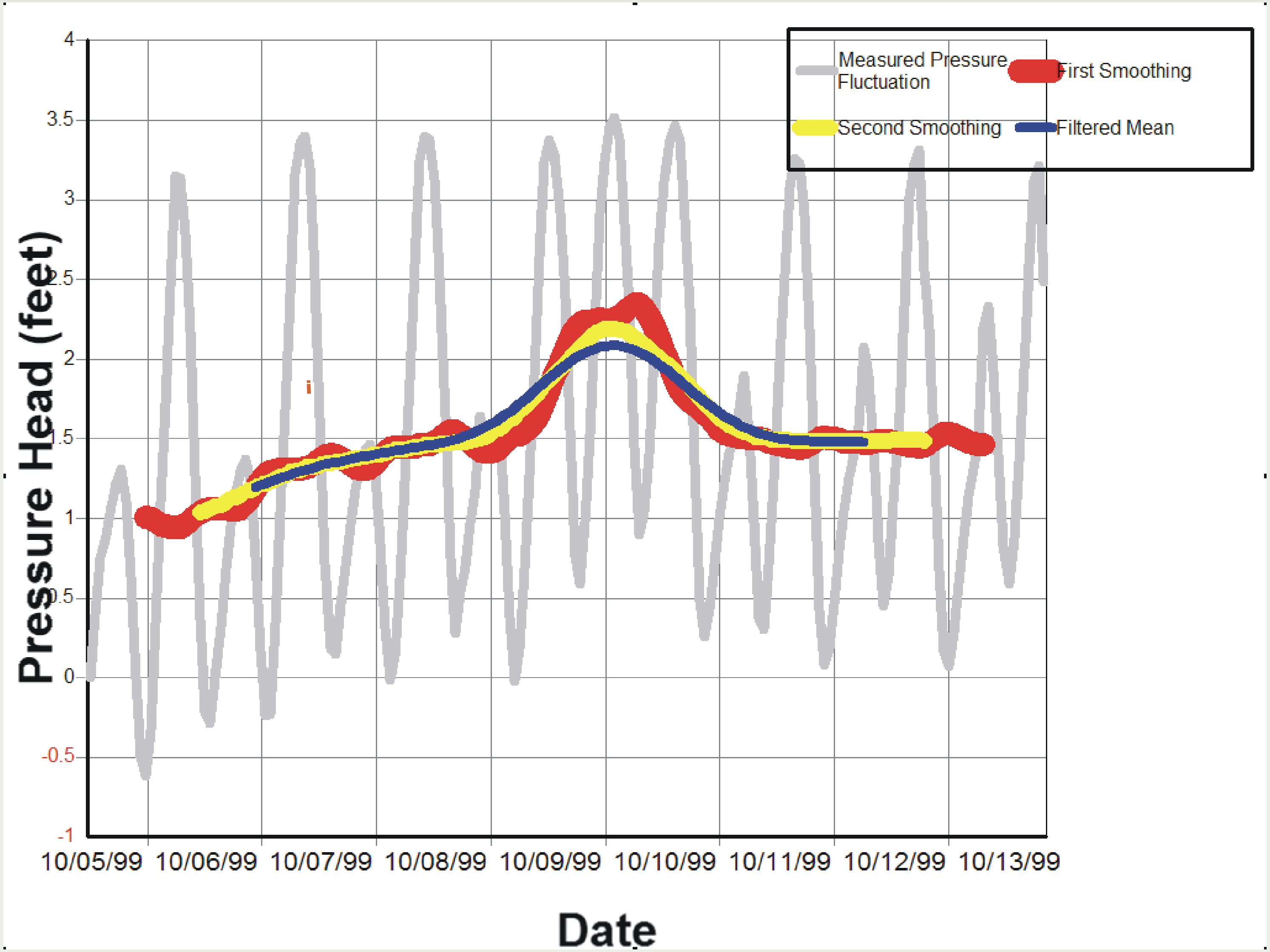
Hydrograph of Monitoring Well HD6



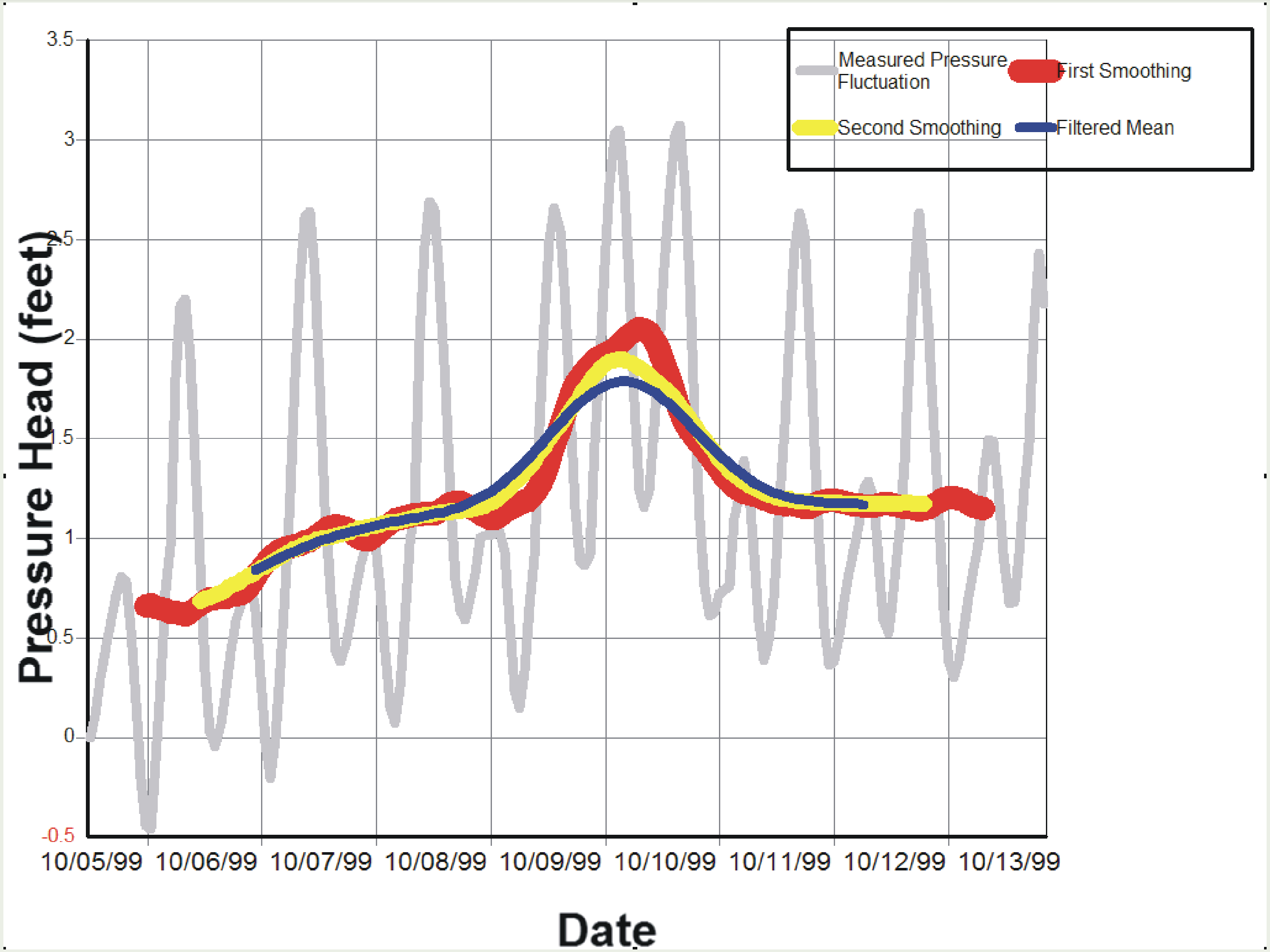
Hydrograph of Monitoring Well HD 3



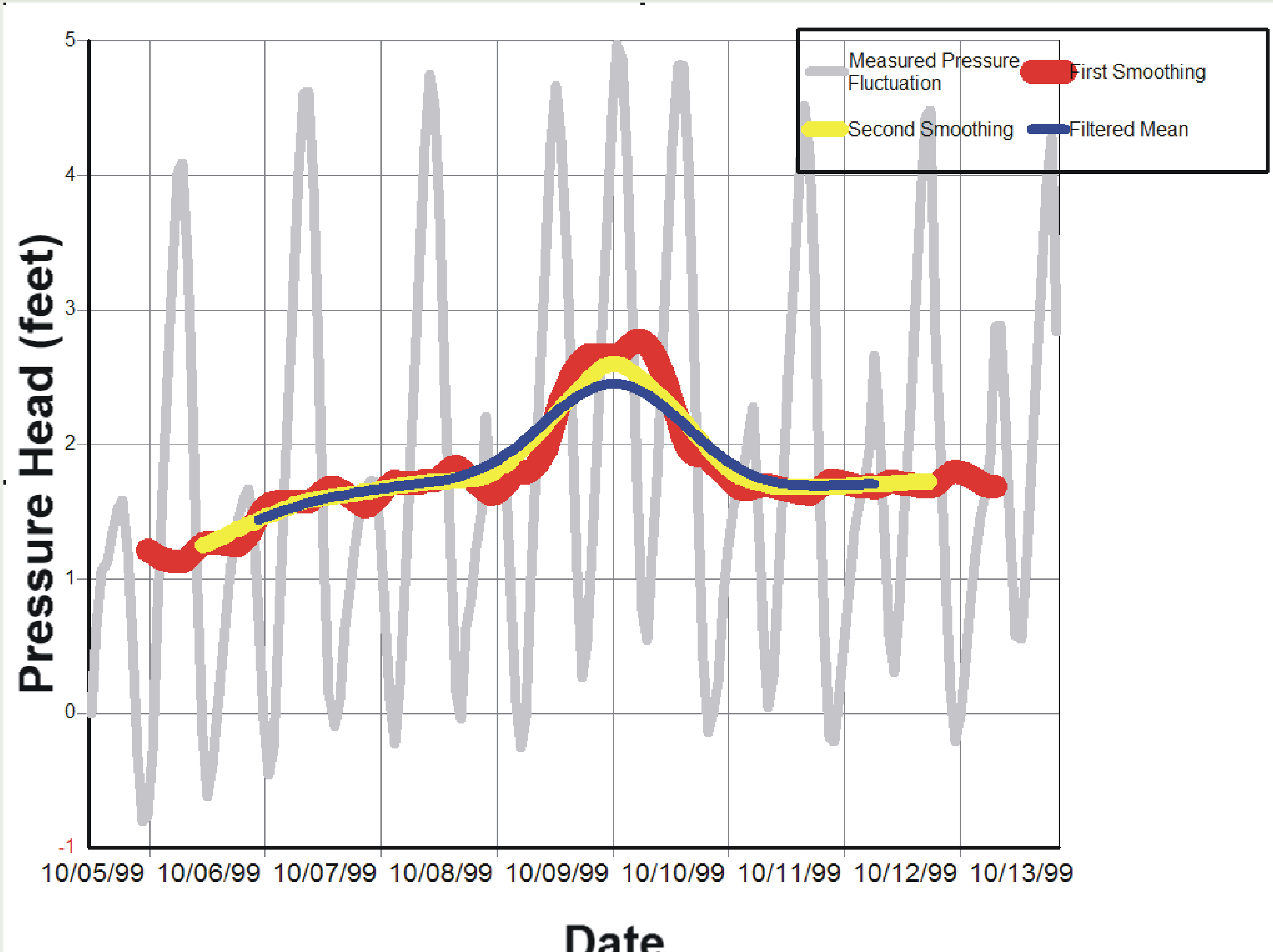
Hydrograph of Monitoring Well HD 9



Hydrograph of Monitoring Well DCP 2



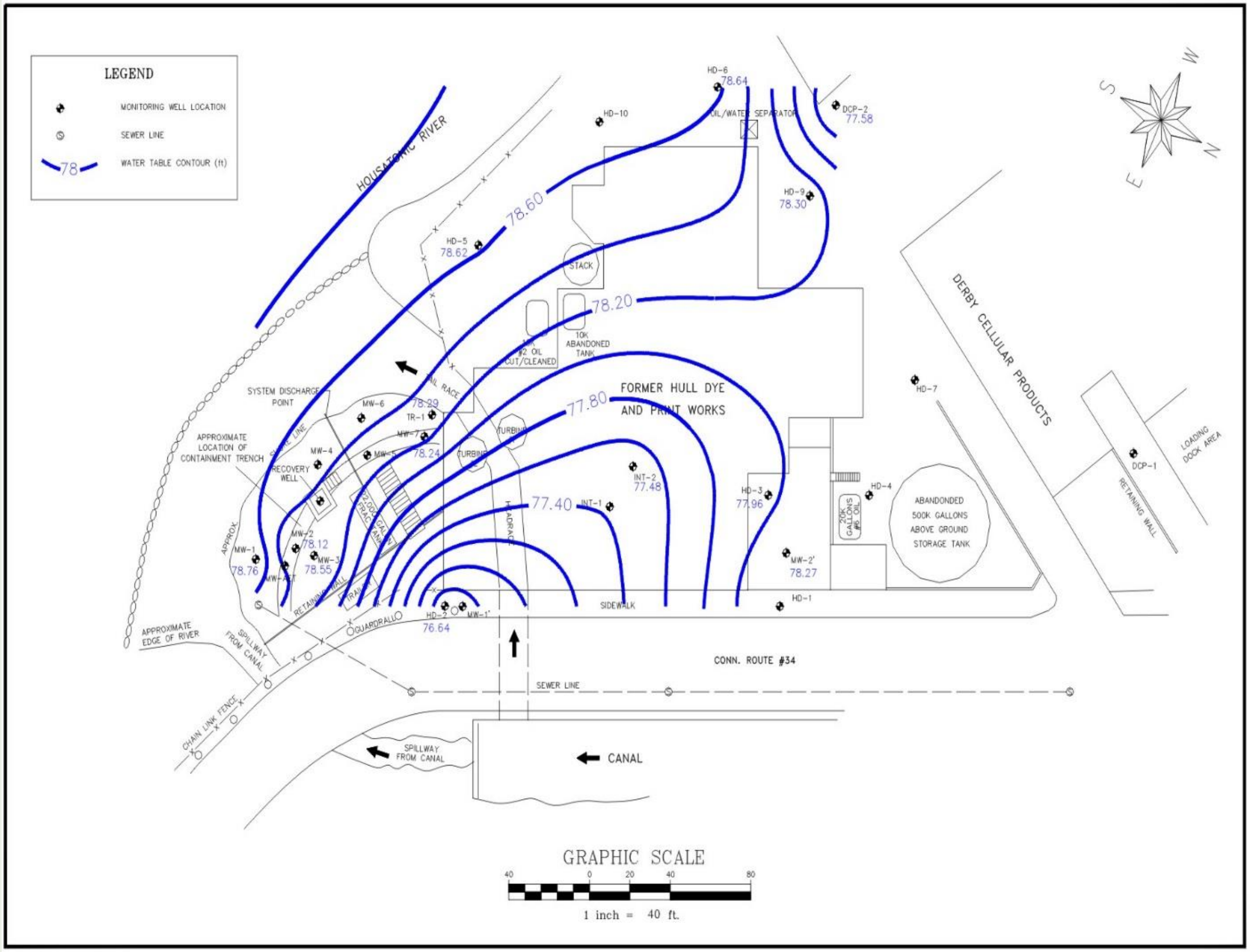
Hydrograph of Monitoring Well HD 6



Effective groundwater table elevation

- Contouring of the groundwater table elevations allowed an assessment of the groundwater flow direction and hydraulic gradient across the site.

Effective groundwater table elevation



Questions?

Measuring NAPL Thickness in Monitoring Well

- **Problem:**
  - » Determine the thickness of a viscous oil

- **Solution**
  - » Install monitoring well-piezometer pair within the same well bore.

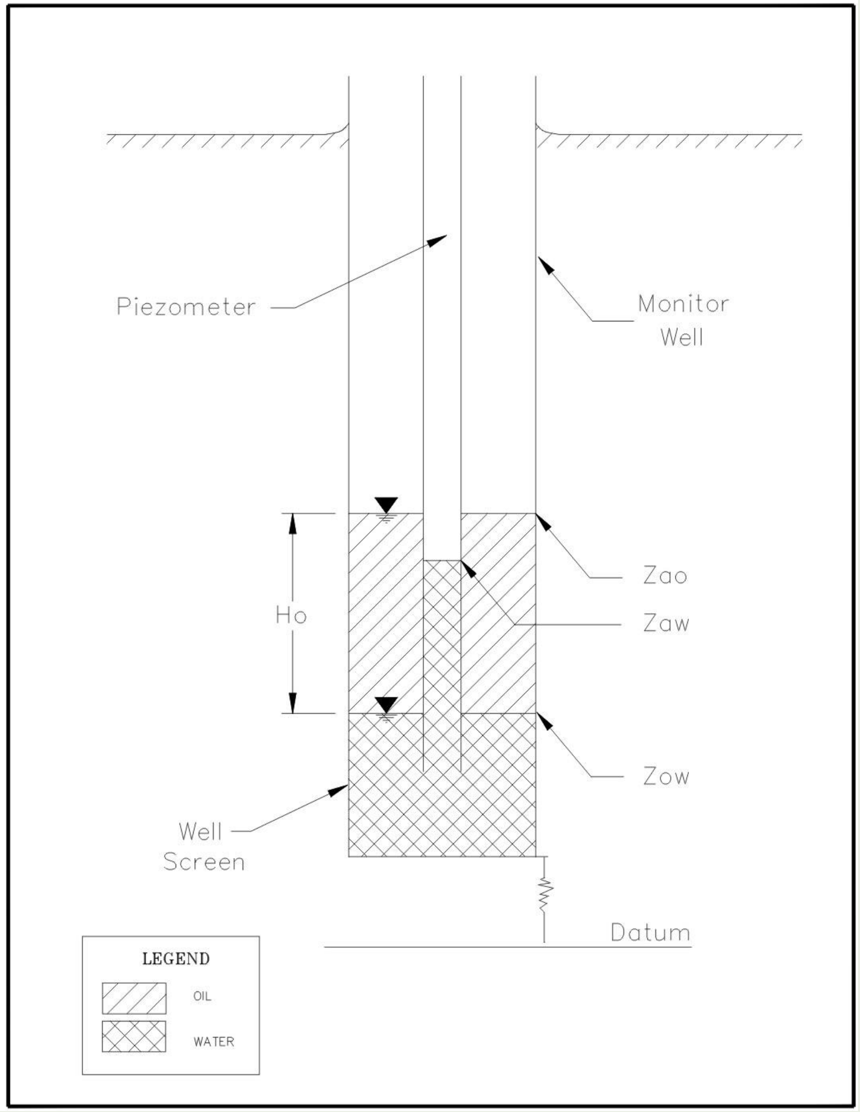
Problem

- **Estimation of extent of the viscous LNAPL**
  - » Product plume extent and volume are typically estimated from monitoring well-product thickness measurements made using an oil-water interface probe.
  - » However, due to the high viscosity and surface tension of the product at the site, these probes could not be used.

Solution

- **An alternate approach for estimating well-product thickness was developed.**
  - The theory of this approach involved the vertical hydrostatic pressure distribution within an air-oil-water system.
  - Piezometers were installed within monitoring wells such that only water was inside the piezometer, and water and oil in the outer monitoring well.
  - The depth to oil in the outer well and water in the inner well were then measured.

Monitoring Well and Piezometer Construction Details



Solution

$$H_o = \frac{Z_{ao} - Z_{aw}}{(1 - \rho_o)}$$

Where:

Z_{ao} is the depth to the air-oil interface

Z_{aw} is the depth to the air-water interface

ρ_o is the oil's specific gravity

Apparent oil thickness