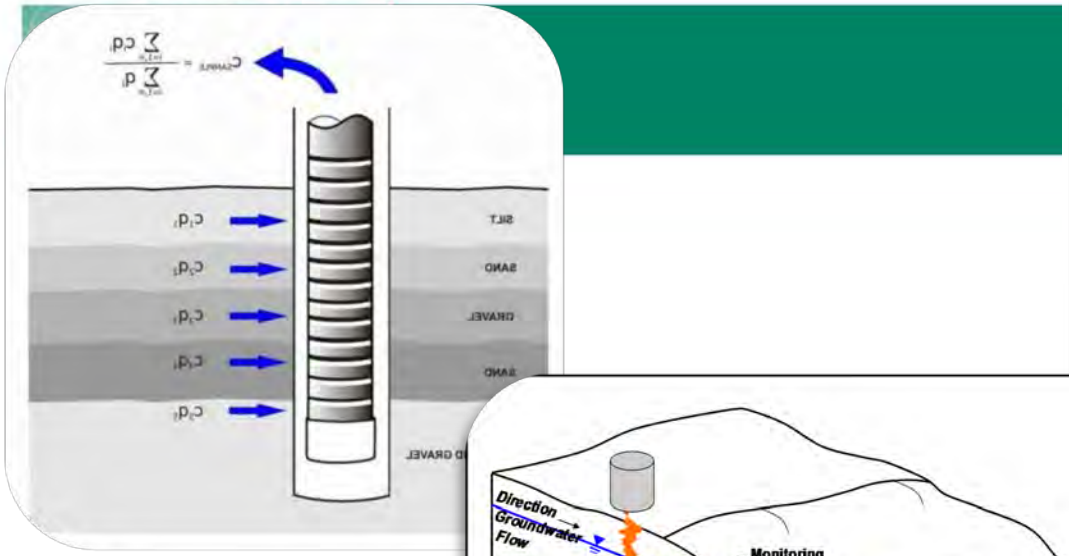
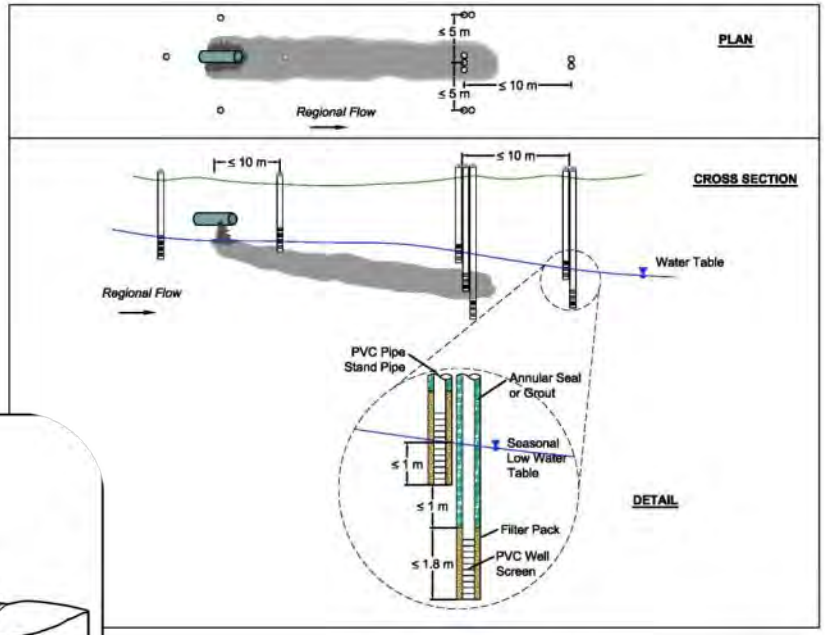
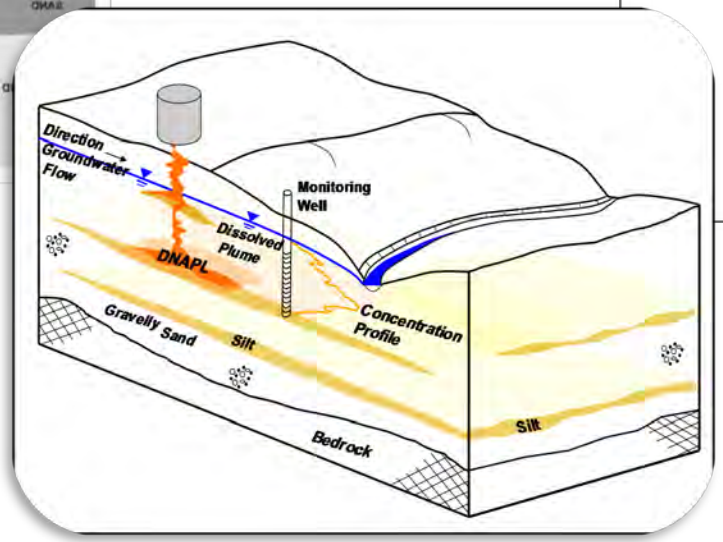






British Columbia's New Guidance for Groundwater Site Characterization –

Technical Guidance #8

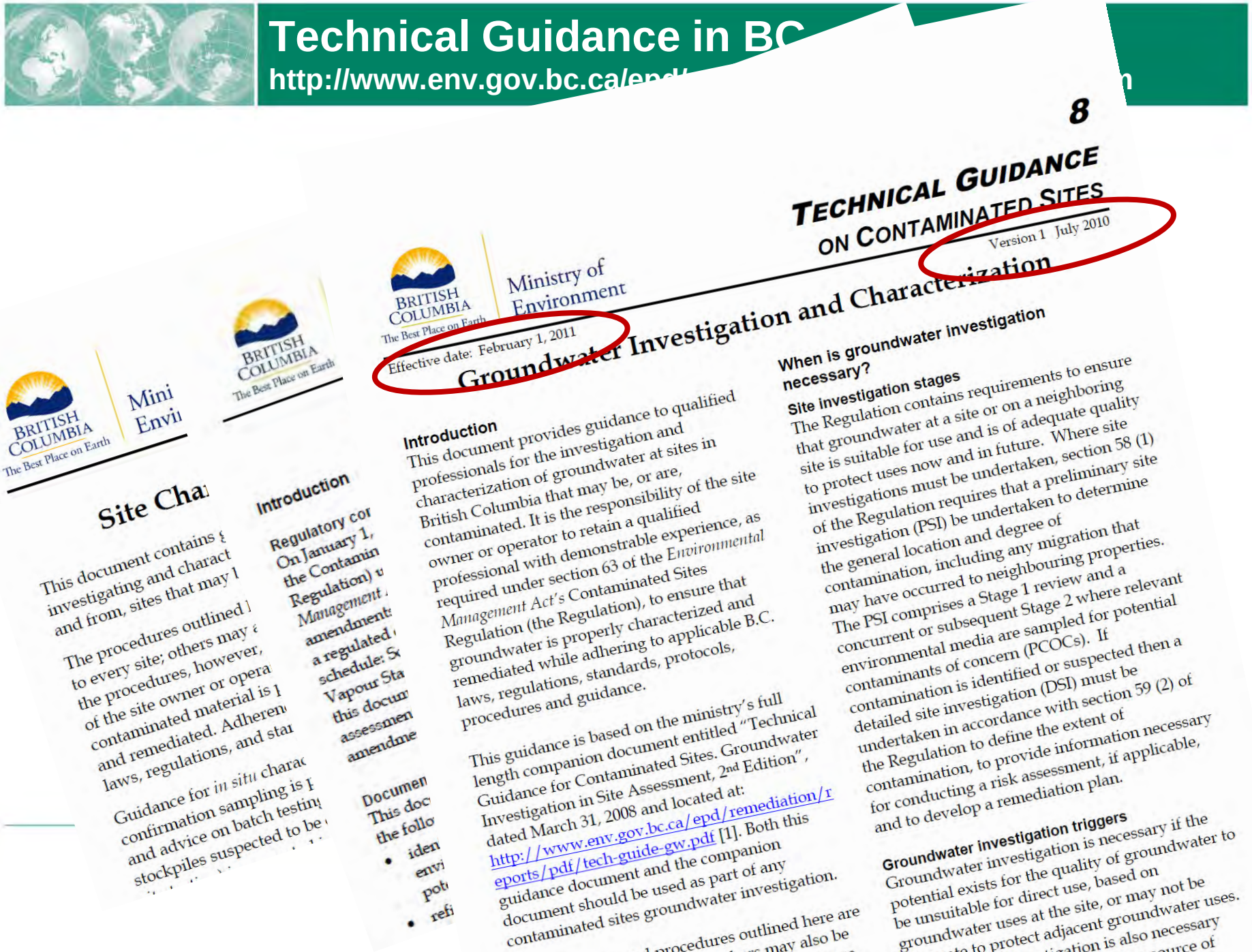
Guy C. Patrick
Victoria, BC

February 18, 2011

Golder Associates

Technical Guidance in BC

http://www.env.gov.bc.ca/epd/



BRITISH COLUMBIA
The Best Place on Earth

Ministry of Environment

Site Cha

This document contains g
investigating and charact
and from, sites that may l

The procedures outlined l
to every site; others may a
the procedures, however,
of the site owner or opera
contaminated material is l
and remediated. Adheren
laws, regulations, and stan

Guidance for *in situ* charac
confirmation sampling is l
and advice on batch testin
stockpiles suspected to be

Introduction

Regulatory cor
On January 1,
the Contamin
Regulation) u
Management
amendment:
a regulated
schedule: S
Vapour Sta
this docum
assessmen
amendme

Documen
This doc
the follo
• iden
envi
pot
• refi

BRITISH COLUMBIA
The Best Place on Earth

Ministry of Environment

Effective date: February 1, 2011

Groundwater Investigation and Characterization

Introduction

This document provides guidance to qualified professionals for the investigation and characterization of groundwater at sites in British Columbia that may be, or are, contaminated. It is the responsibility of the site owner or operator to retain a qualified professional with demonstrable experience, as required under section 63 of the *Environmental Management Act*'s Contaminated Sites Regulation (the Regulation), to ensure that groundwater is properly characterized and remediated while adhering to applicable B.C. laws, regulations, standards, protocols, procedures and guidance.

This guidance is based on the ministry's full length companion document entitled "Technical Guidance for Contaminated Sites. Groundwater Investigation in Site Assessment, 2nd Edition", dated March 31, 2008 and located at: http://www.env.gov.bc.ca/epd/remediation/reports/pdf/tech-guide-gw.pdf [1]. Both this guidance document and the companion document should be used as part of any contaminated sites groundwater investigation.

procedures outlined here are
may also be

When is groundwater investigation necessary?

Site investigation stages

The Regulation contains requirements to ensure that groundwater at a site or on a neighboring site is suitable for use and is of adequate quality to protect uses now and in future. Where site investigations must be undertaken, section 58 (1) of the Regulation requires that a preliminary site investigation (PSI) be undertaken to determine the general location and degree of contamination, including any migration that may have occurred to neighbouring properties. The PSI comprises a Stage 1 review and a concurrent or subsequent Stage 2 where relevant environmental media are sampled for potential contaminants of concern (PCOCs). If contamination is identified or suspected then a detailed site investigation (DSI) must be undertaken in accordance with section 59 (2) of the Regulation to define the extent of contamination, to provide information necessary for conducting a risk assessment, if applicable, and to develop a remediation plan.

Groundwater investigation triggers

Groundwater investigation is necessary if the potential exists for the quality of groundwater to be unsuitable for direct use, based on groundwater uses at the site, or may not be
to protect adjacent groundwater uses.
ation is also necessary
ource of

8

TECHNICAL GUIDANCE ON CONTAMINATED SITES

Version 1 July 2010

What's in this Guidance?

- When is groundwater investigation necessary?
- How do you design the field program?
- What is a conceptual site model?
- What are acceptable methods and approaches?
- What about LNAPL and DNAPL?

What's in this Guidance (cont.)?

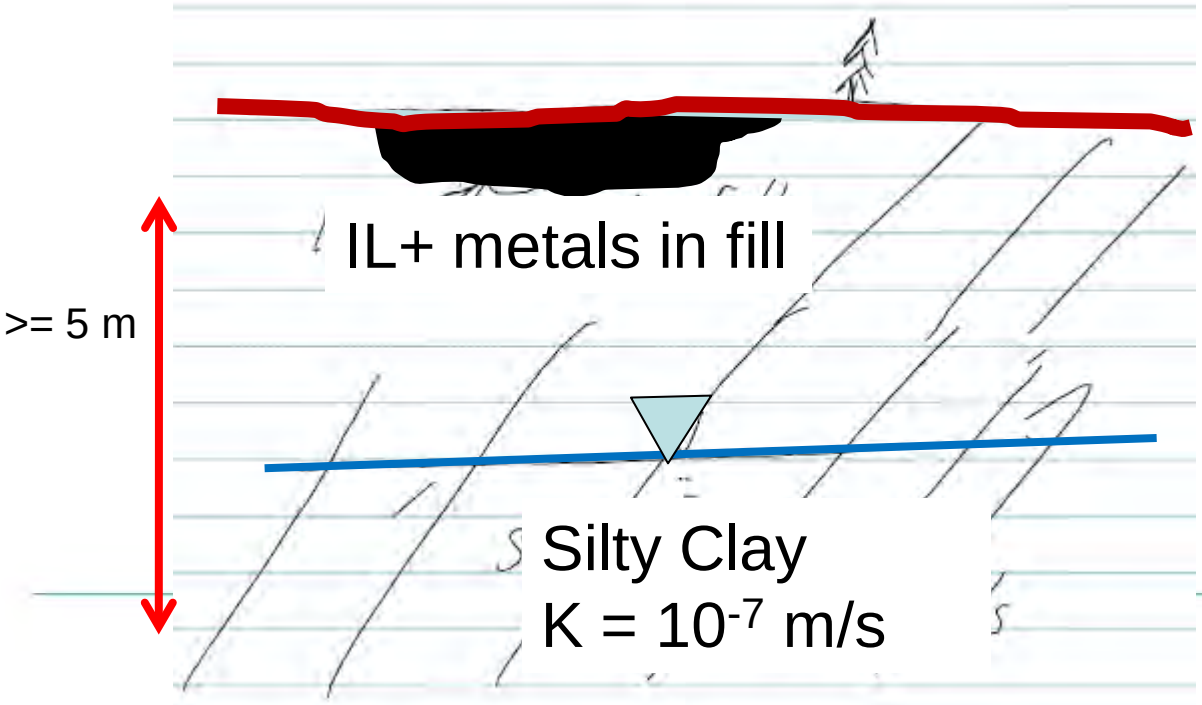
- What level of investigation is necessary for:
  - a Stage 1 PSI (Phase 1 ESA)?
  - a Stage 2 PSI (Phase II ESA) ?
  - Remediation Planning?
  - Confirmation of Remediation?
- When is long-term groundwater monitoring necessary, and when can you stop?
- How do you de-activate or close your monitoring wells
- What needs to go into the report? Any useful "checklists"?

When is Groundwater Investigation Necessary?

- Groundwater investigation begins during the Stage 1 PSI
- When areas of potential environmental concern ("APECs") are found, recommendations should be provided to investigate ***all relevant media*** for each APEC.
- If groundwater is to be excluded, ***"detailed supporting rationale must be provided"***

Examples Where Groundwater Investigation May Not Be Necessary

- Example Scenario #1 - Shallow metals
  - shallow metals in fill
  - underlying extensive low K material
  - metals are not leachable



Caution: highly fractured clays may have K > 10^{-6} m/s and a yield > 1.3 L/min

Examples Where Groundwater Investigation May Not Be Necessary

- Example Scenario #2 – Petroleum Hydrocarbons
  - Depth of contamination defined in soil
  - No mobile NAPL
  - Water table several metres deeper than soil contamination
  - Extensive low K materials

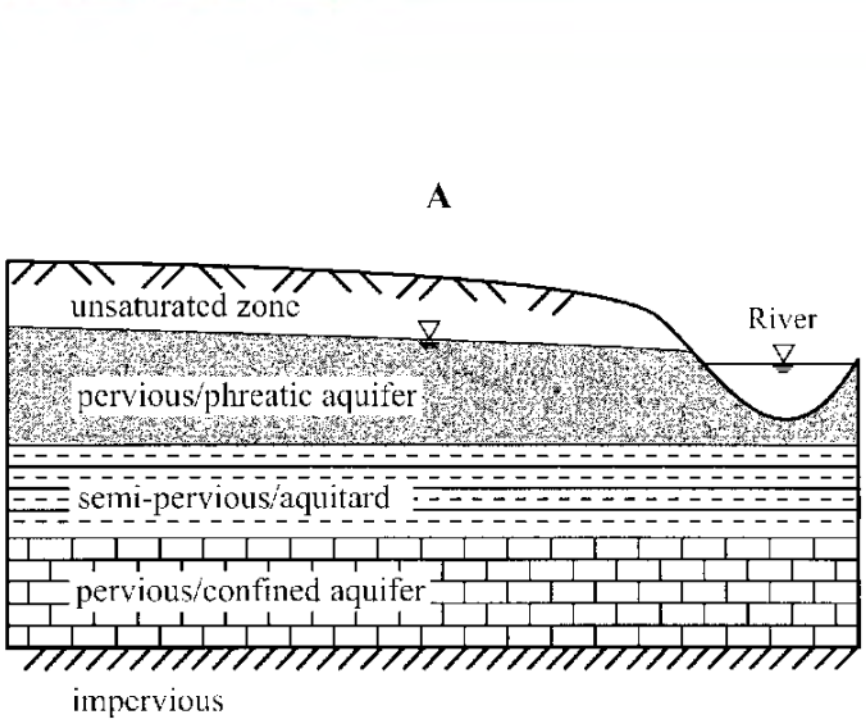
What About Bedrock?

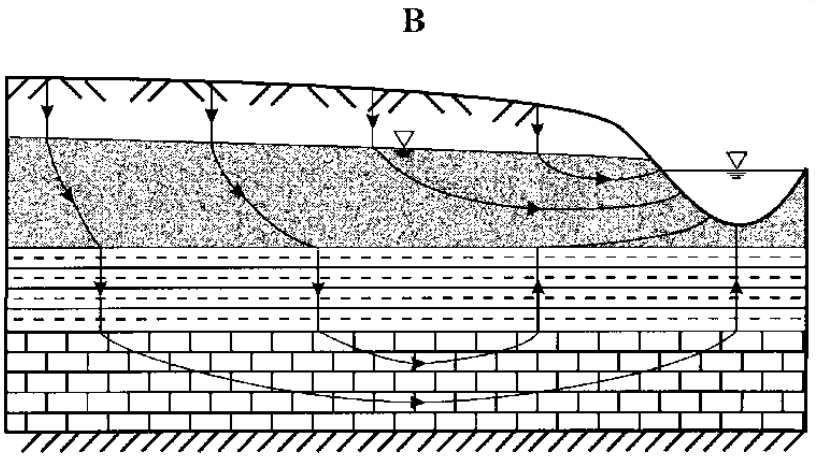
- Assume groundwater is present
- Has contamination penetrated to bedrock?
- If so, investigate to determine yield

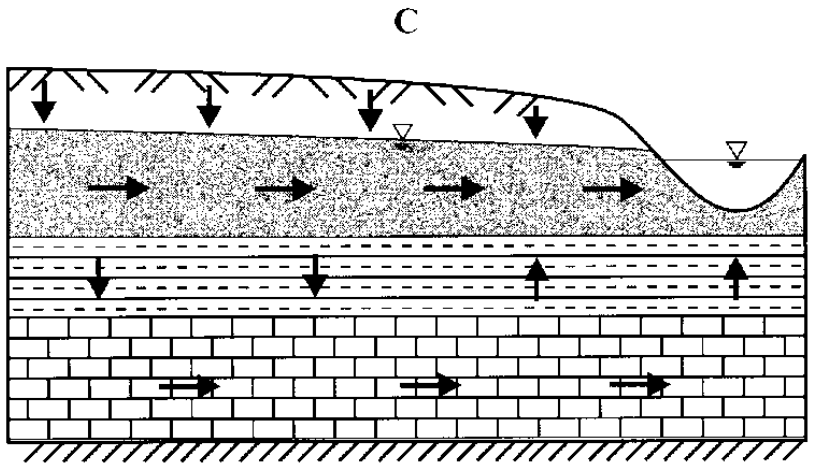
Conceptual Site Model Groundwater Focus

- **Key Elements**
  - Geology and Stratigraphy
  - Aquifers and Aquitards
  - Groundwater Levels/Elevations and Hydraulic Gradients
  - Boundaries (physical and hydrogeologic)
  - All Potential Source Zones
  - All Plumes
  - All Pathways for Contaminant Transport
  - Relevant Transport and Fate Processes
  - All Receptors

Aquifers, Aquitards, and Flow

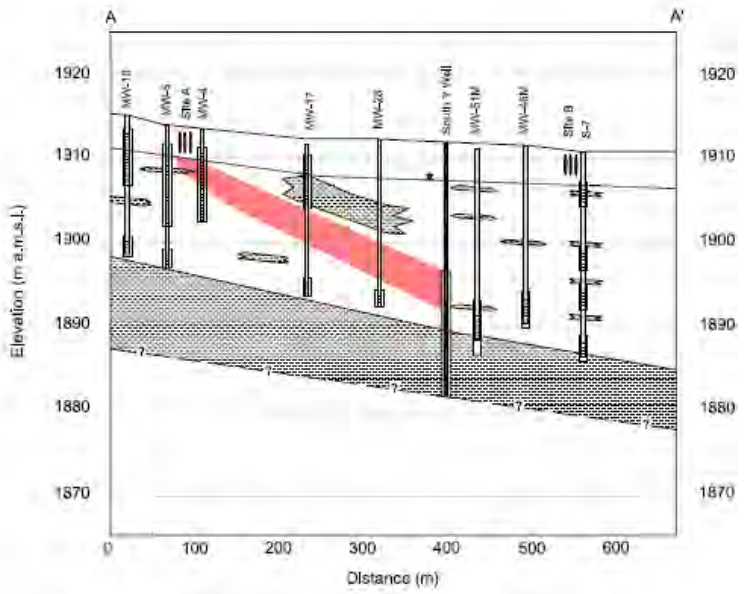




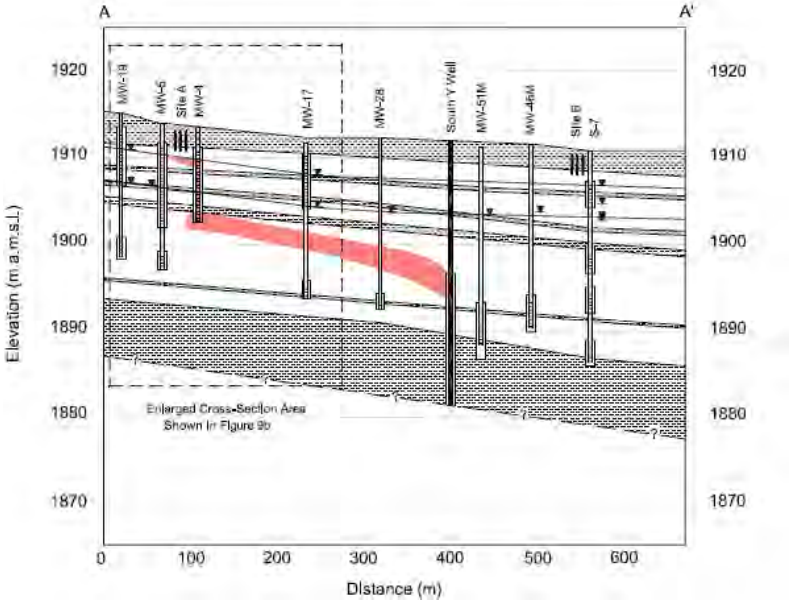


(from Delleur, 1999)

Diving Plumes – Long Screens



Conceptual Model A



Conceptual Model B

Morgan et al. (2008)

Hydrogeology Journal (2008) 16: 981–994

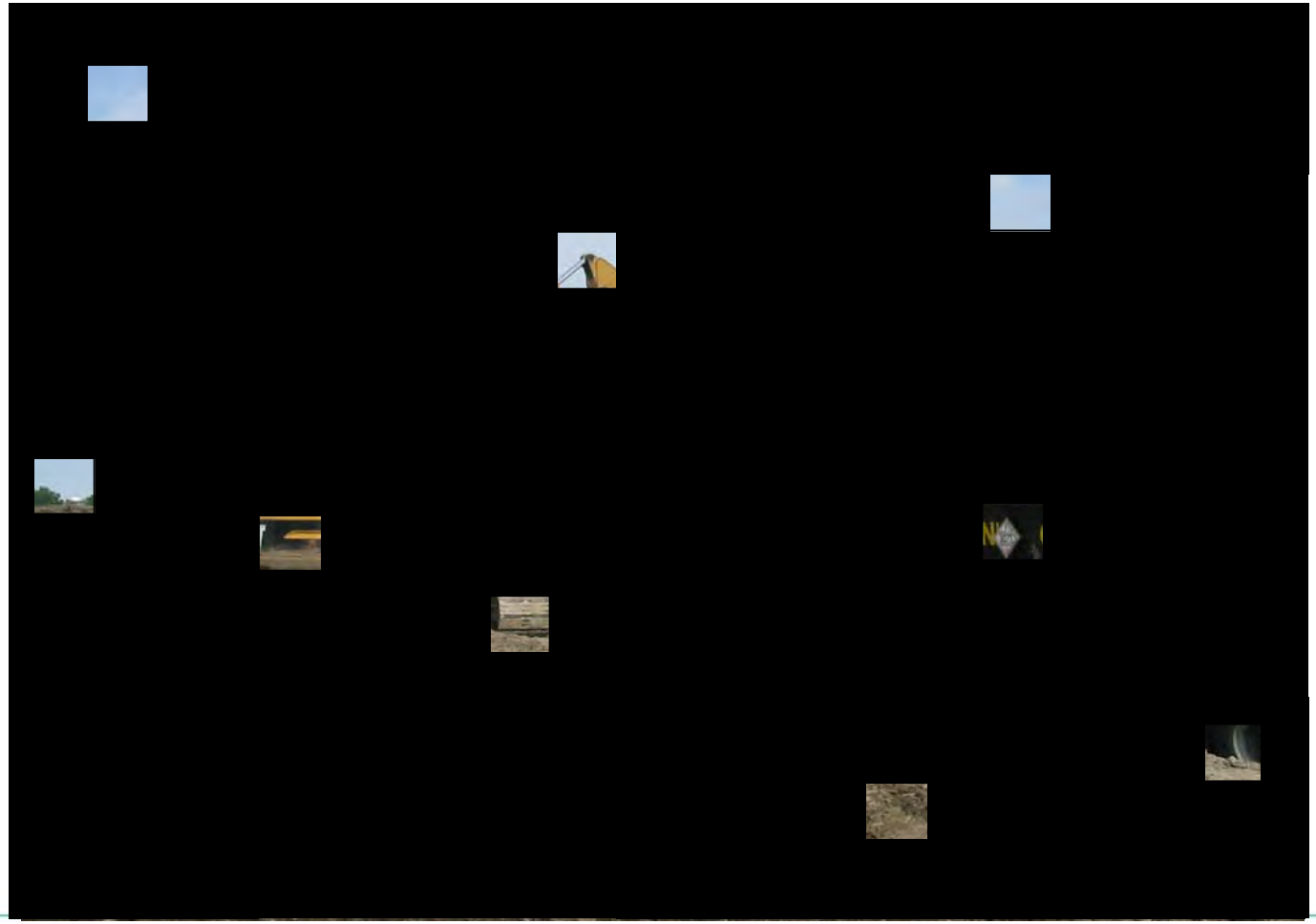
Groundwater Characterisation Approach

- Preference for approaches that will ***increase:***
  - ***spatial data density***
  - ***temporal data density***
  - ***chemistry***

- Objective - a ***larger three-dimensional data set***

Golder Associates

Precise Data, Limited Extent



Less Precise Data, Greater Extent

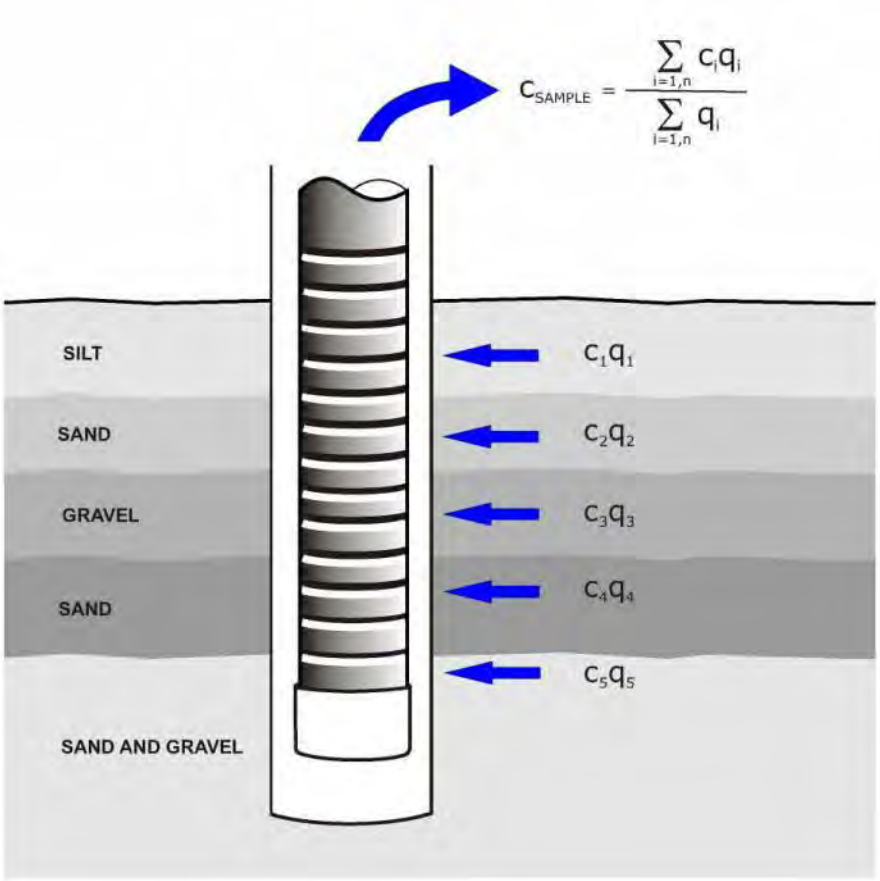
Conventional Monitoring Wells

Drill cuttings as backfill is to be avoided

Golder Associates

Averaging at the Well Screen

Patrick and Thomas (2007)



c_i =concentration in stratum *i*

q_i = flow to well in stratum *i* during sampling

Acceptable Well Screen Lengths

Stage 2 PSI

- Long screens okay, BUT
  - If screen plus filter pack ***>1.8 m***, then ***cannot compare chemistry data*** directly with standards
  - Exceptions – must provide ***detailed supporting rationale***
    - Examples of rationale:
      - Soil or groundwater profiling indicates that contamination is uniformly distributed with depth through aquifer

Acceptable Well Screen Lengths

DSI

- Maximum screen interval ***1.8 m***
- Preference for smaller intervals (*e.g.*, using profiling technologies)
- Maximum screen interval below lowest water table depth, ***1.0 m***

How many wells?

Stage 2 PSI

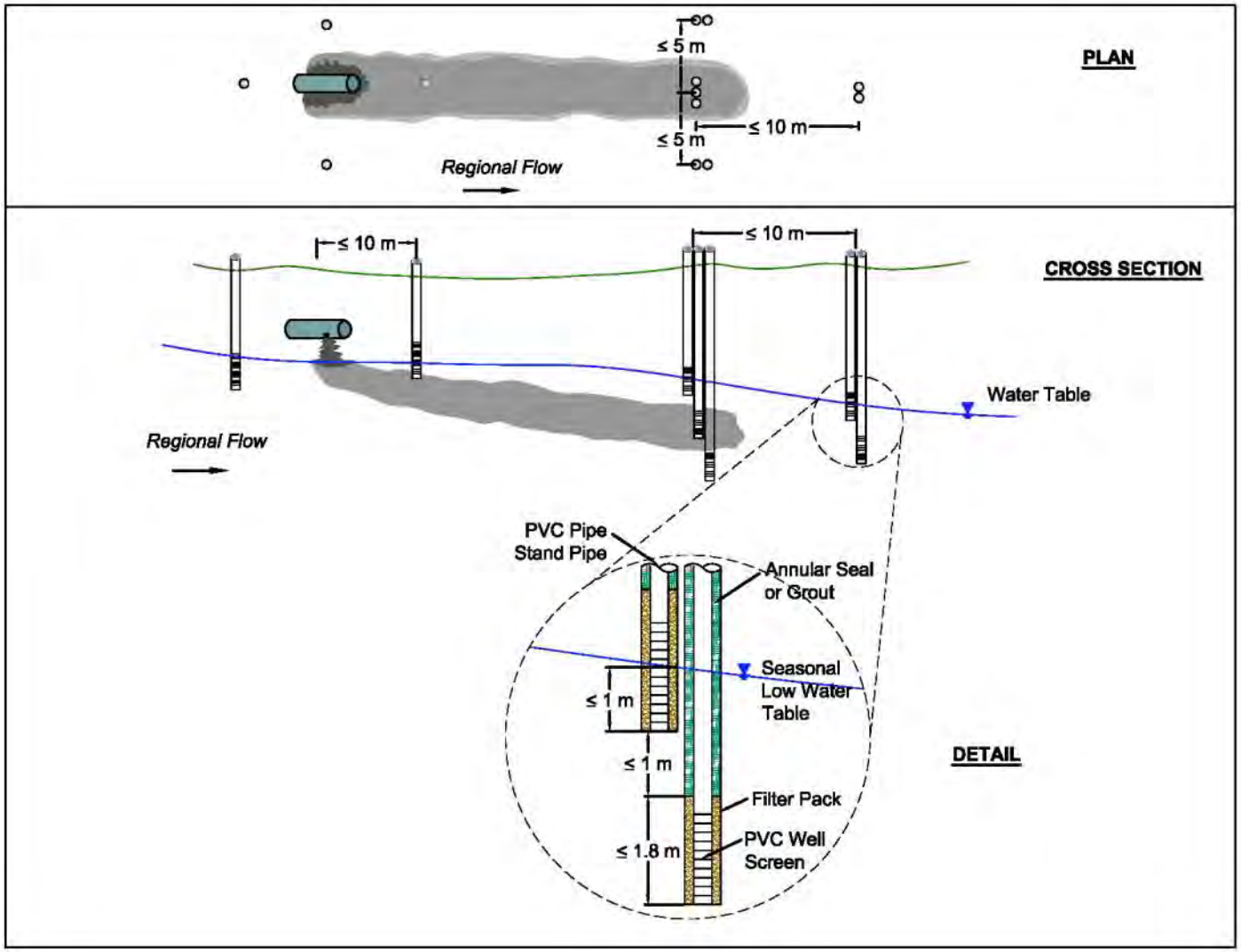
- Additional wells necessary if new information suggests that highest concentrations may have been missed

How many wells? DSI

DSI

- Identify all groundwater plumes of *significant size:*
  - Longitudinal: 10 m or longer
  - Vertical: 0.1 m or thicker
  - Lateral: 5 m or wider
- Bound the extent, using Figure 1 as a guide.

How many wells? DSI



Do I need all of those wells?

- ***NO***
- *Deviation from the guidance is acceptable* provided that:
  - the deviation from the requirements is identified, together with *supporting rationale* and consequent *implications on the uncertainty* of the acquired data set.

Golder Associates

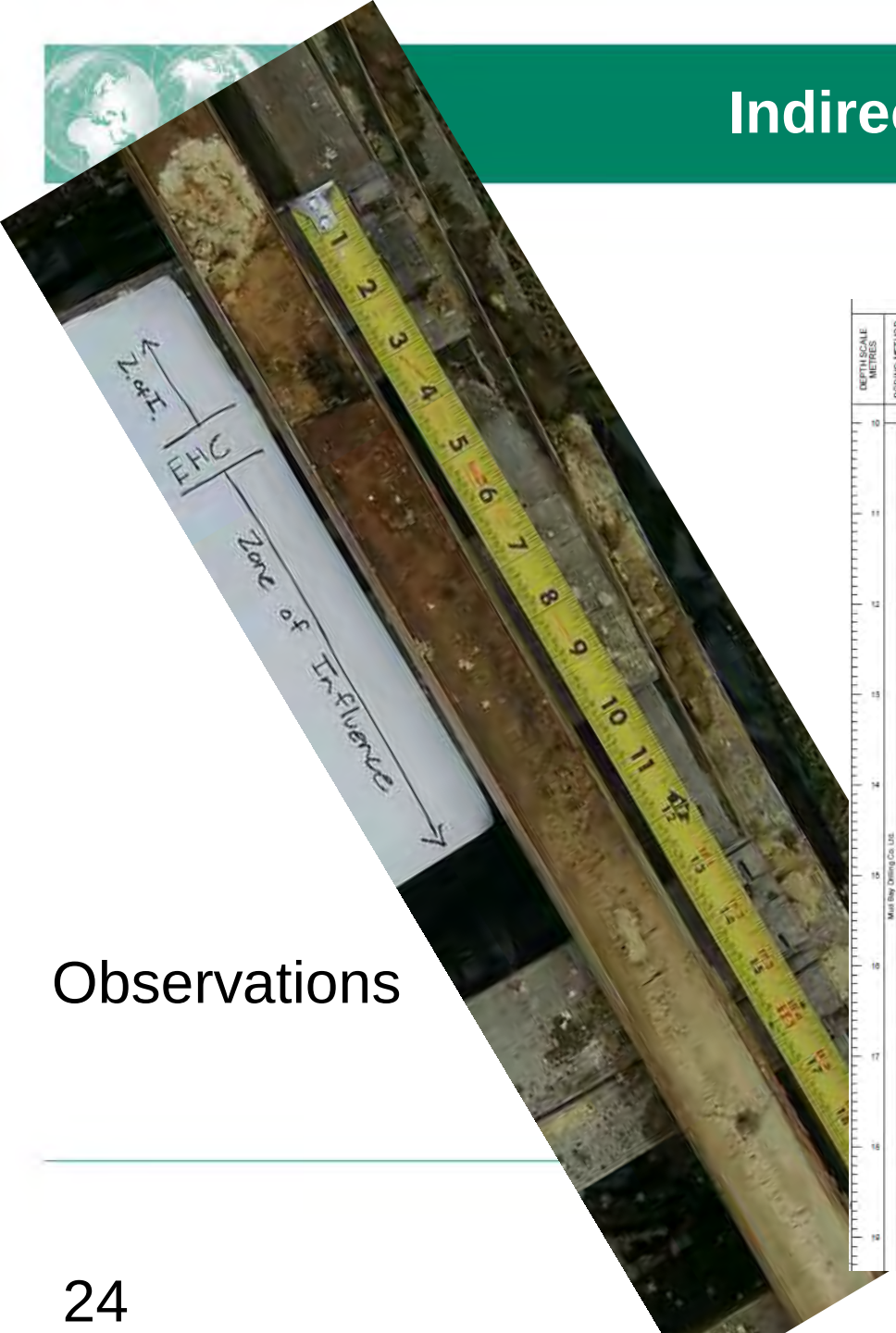
How Can I Use Fewer Wells?

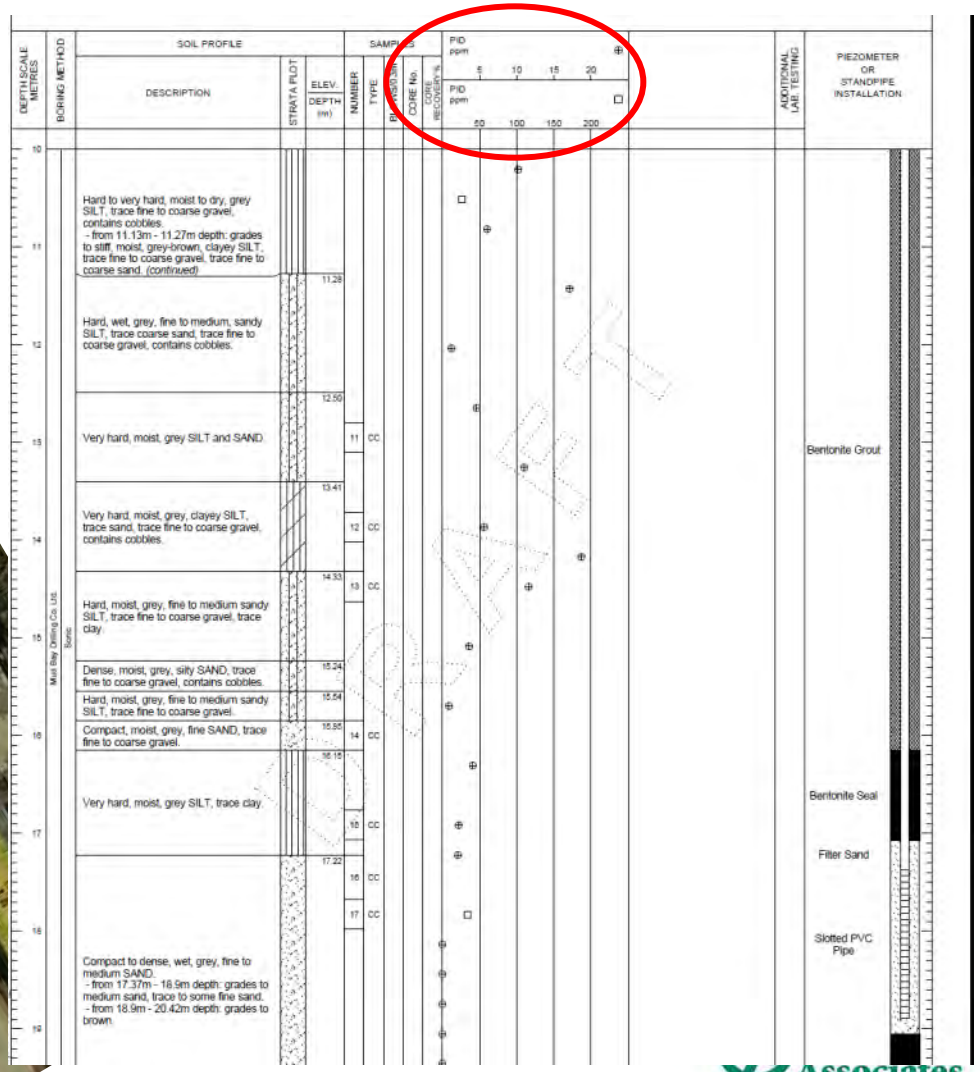
- Develop and ***use your conceptual model:***
  - contaminant properties (*e.g.*, volatility, electrical conductance)
  - known local site conditions (*e.g.*, stratigraphy, hydraulic gradients)
- Draw together the lines of evidence
  - Indirect
  - Direct
- Consider other technologies and approaches

Golder Associates

Indirect Lines of Evidence

Organic vapour screening





Observations

Mapping PERC Plumes

Treecore analysis

Groundwater analysis

Tree Coring for VOCs

- **Coredrill (100*4 mm)**
- **Vial 50 ML (airfilled)**
- **Head-Space analysis for VOC**

Golder Associates

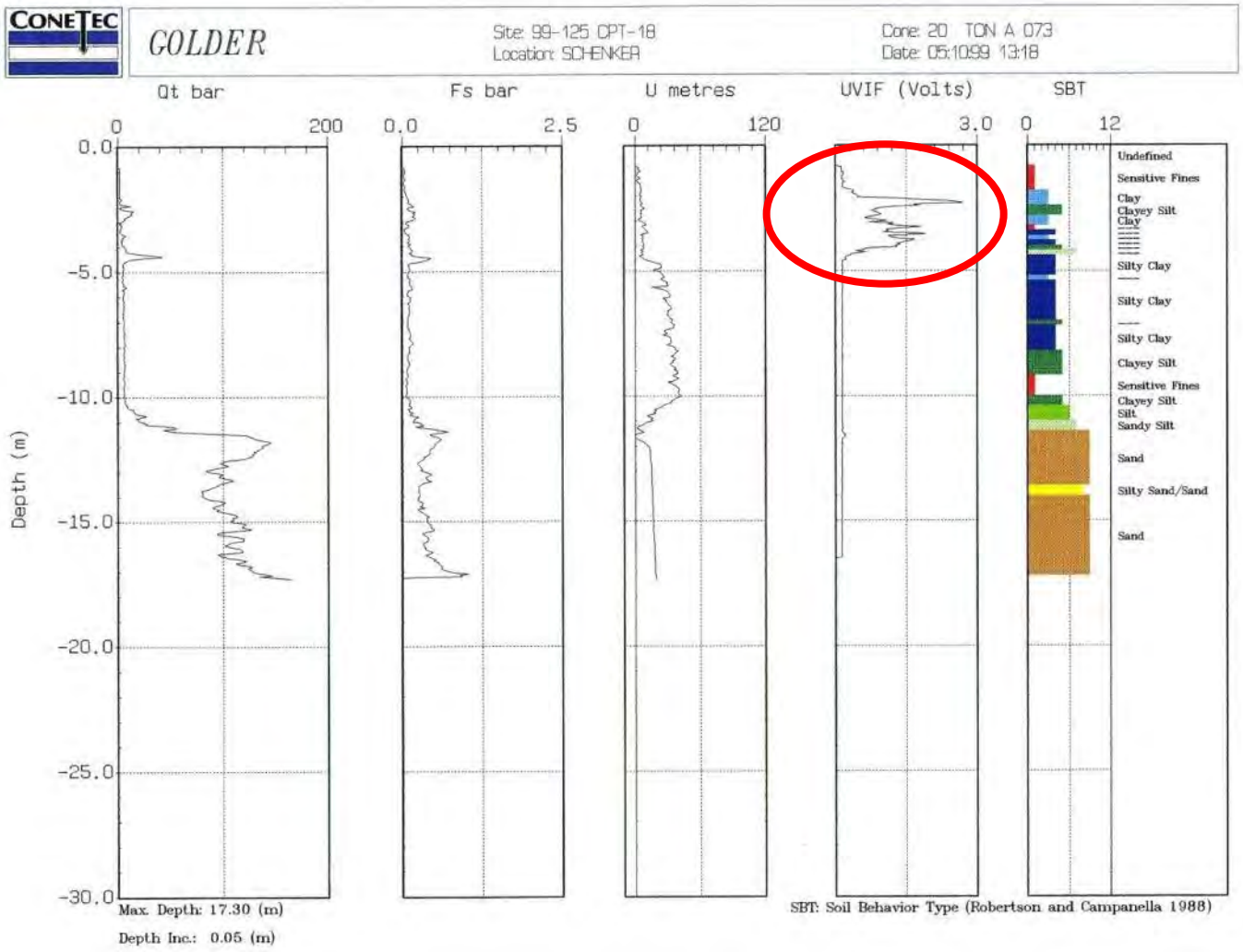
Acceptable Approaches for Groundwater Investigations

- Direct-Push Technologies
  - Waterloo Profiler™
  - Laser-Induced Fluorescence (LIF)
  - Membrane Interface Probe (MIP)
  - Others...
- The Concept:
  - One or two vertical profiles may be sufficient to demonstrate:
    - Where highest concentrations reside
    - Heterogeneity of homogeneity of the plume
    - Where well screens should be placed
    - *Etc.*

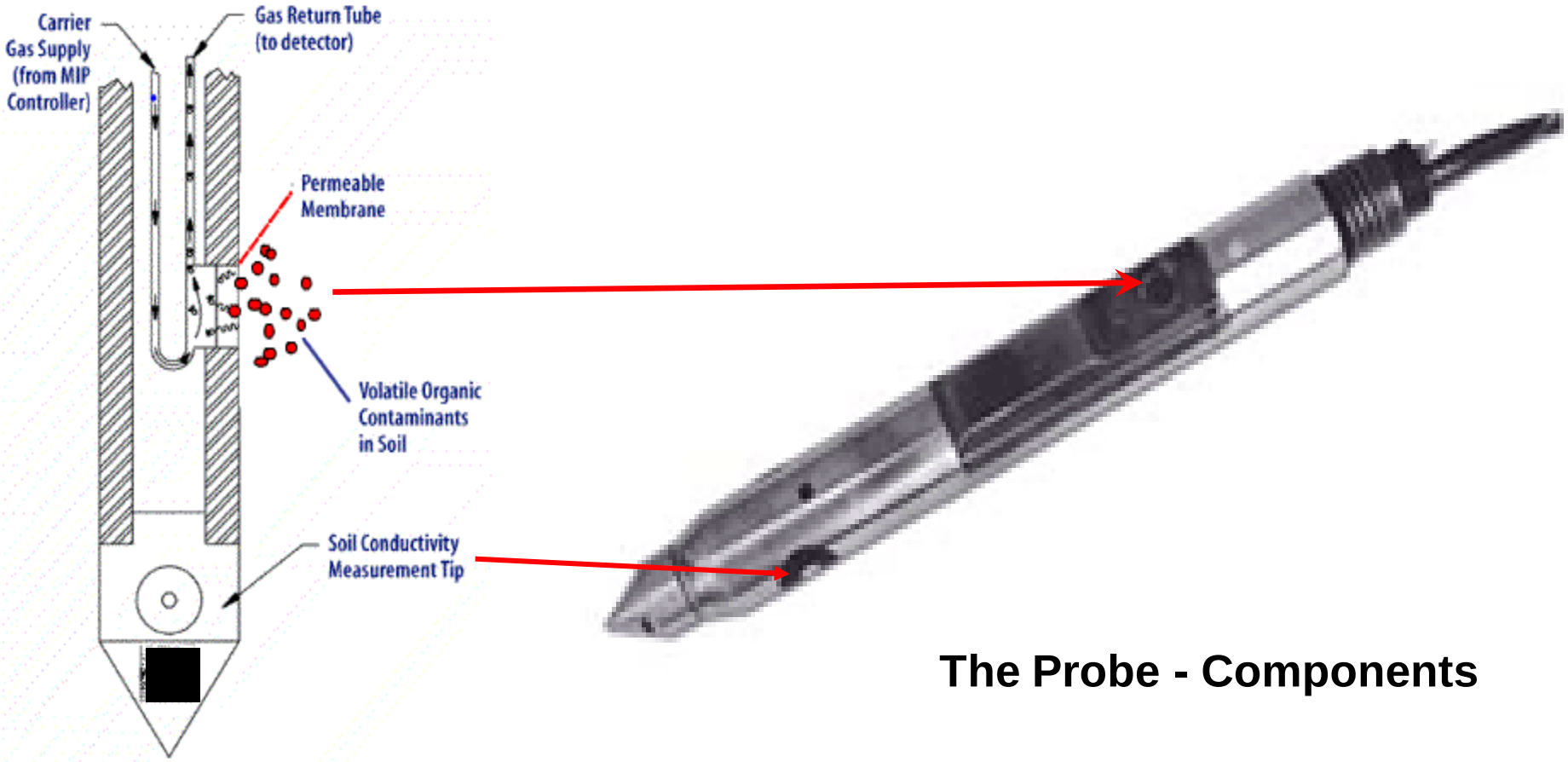
UVIF Cone Penetrometer Tool

Example of UVIF

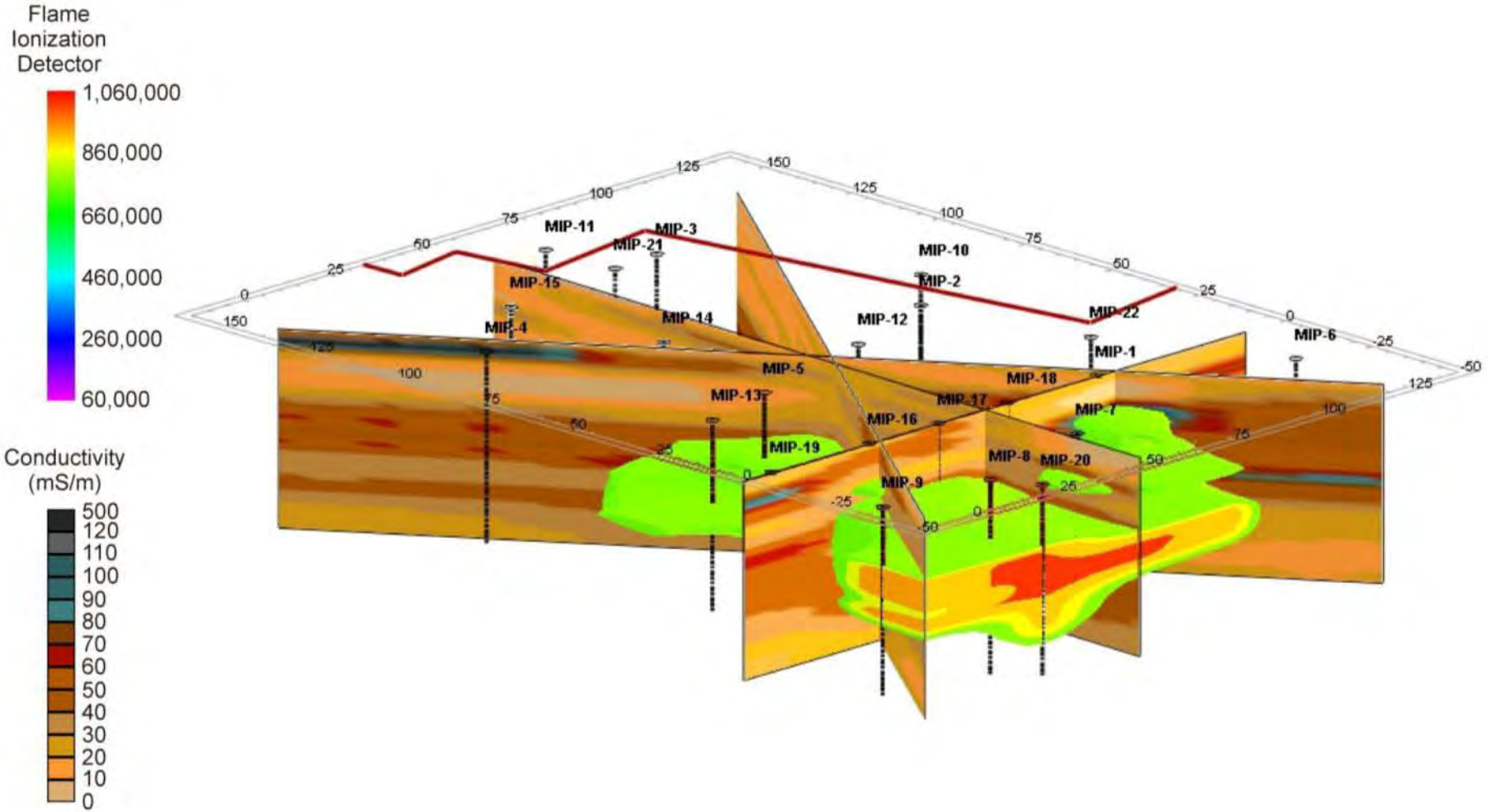
Ultraviolet fluorescence (UVIF) responding to creosote DNAPL



Membrane Interface Probe



The Probe - Components



Example Conceptual Model –
Membrane Interface Probe (MIP) Results

Direct Push for Groundwater Sampling

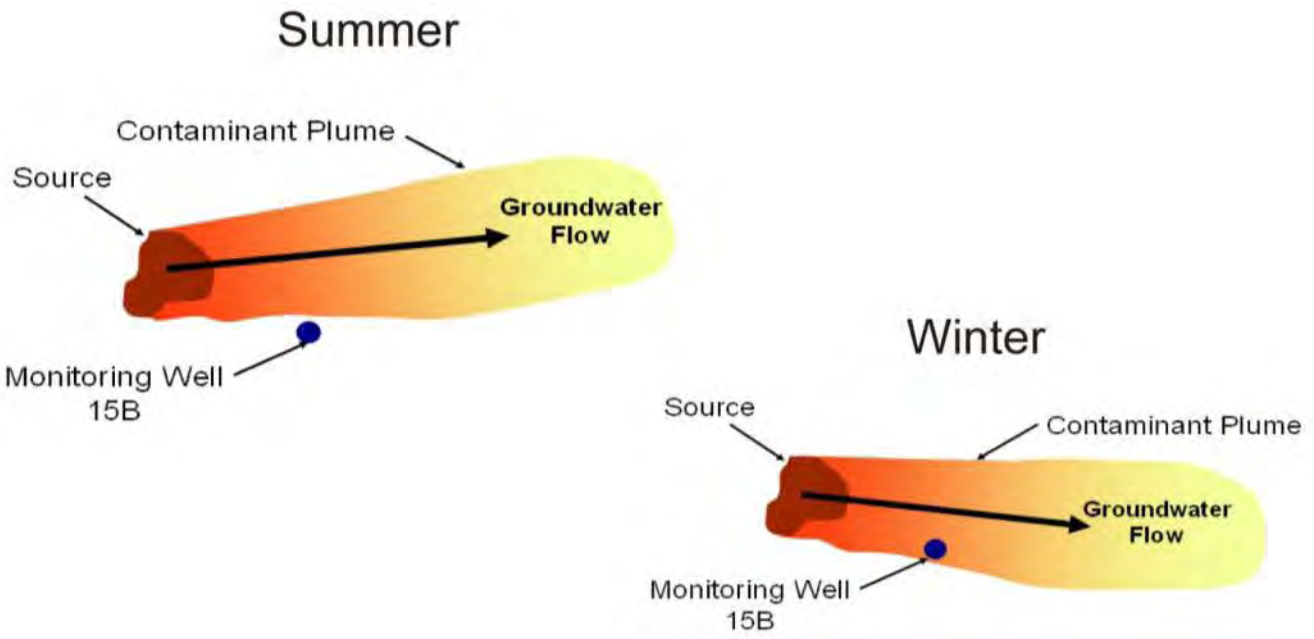
So Now What??

- Use screening data to reduce # of wells:
  - Define NAPL and/or plume extent w/o wells
  - Target a few locations to
    - confirm screening results
    - provide conservative (highest) concentration data

- Use profile data to reduce # of wells:
  - Target sampling to specific zones and locations (*i.e.*, most likely to carry the contamination)
  - Justify limiting # of wells outside of the plume
  - Strategically locate long-term monitoring wells

How many samples are necessary?

- Where seasonal effects are likely to vary, sample at a *minimum quarterly* for at least one year.



LNAPL Monitoring

- Well screen should straddle the water table
- At least one well should be placed in expected thickest NAPL zone
- Extent of LNAPL zone should be resolved at a scale of 5 m to 7 m or less
- Monitor for LNAPL at least 24 hours after installation, and preferably after at least one week

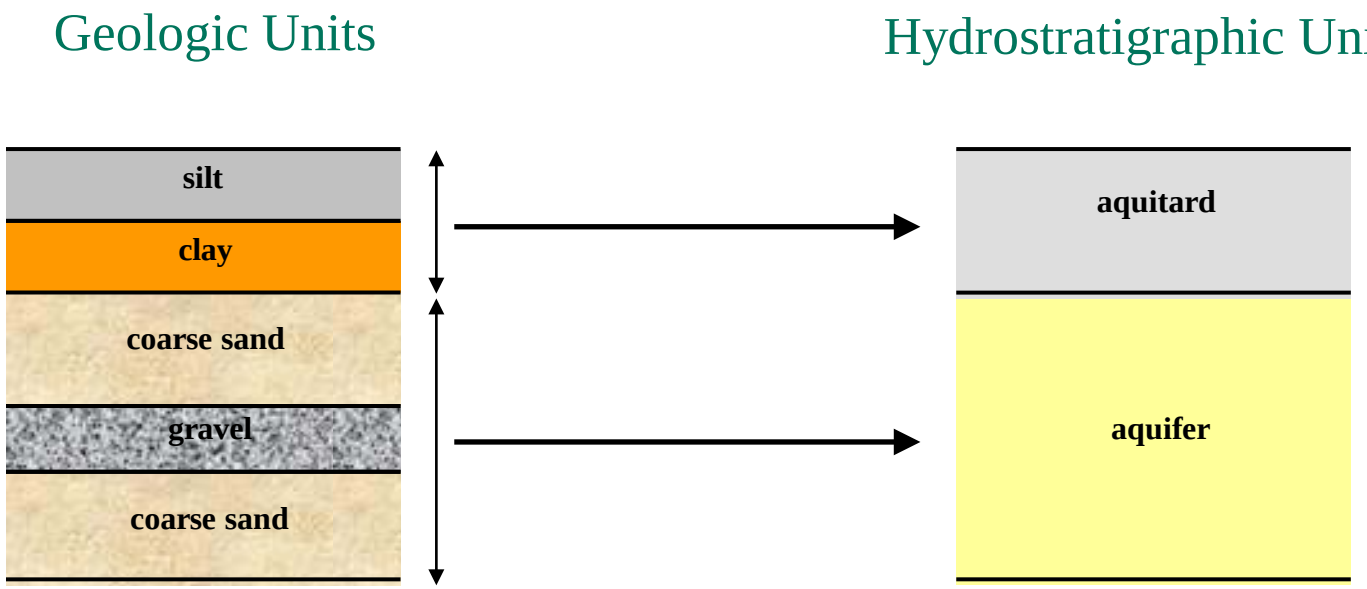
LNAPL Monitoring

- Continue regular monitoring until:
  - NAPL migration is confirmed or absent (at least 12 months)
  - Remediation is complete, or
  - LNAPL is demonstrated to be immobile
- Monitoring Frequency
  - Minimum once every two months
  - Preferably, monthly
- Must maintain integrity of well during monitoring period

DNAPL Monitoring

- Avoid drilling directly through DNAPL
- Use indirect data and inference to resolve the likely extent of a DNAPL source:
  - Horizontal - resolve to 5 m to 7 m
  - Vertical - resolve to 1 m to 2 m

What About “Hydrogeology”?



Hydrogeologic Information

- Characterise aquifers and aquitards
  - estimate hydraulic conductivity
  - establish vertical and lateral hydraulic gradients
- estimate groundwater flow direction and, if relevant, groundwater velocity
- determine confined and unconfined aquifers
- determine physical and hydrogeologic boundaries (recharge, no-flow, discharge, etc.)

Hydrogeologic Information

- At a minimum:
  - All wells should be surveyed for reference or geodetic elevation
  - Static water levels should be measured on the same day (or smaller interval if tidal)
  - Elevation data should be calculated and tabulated

Guidance for Data Presentation

- a scaled ***regional location plan*** and ***site plan***
  - showing relevant hydrological, topographical and physiographic features
- a ***contour plan of piezometric heads*** in each aquifer of interest
  - data points posted at measurement locations on each drawing
- ***stratigraphic cross sections***
  - longitudinal and transverse with respect to the known or estimated groundwater flow direction
- ***contours****, in plan and cross section, of chemical concentrations*
  - for each COC in on-site and off-site soil and groundwater
- ***sample locations*** with corresponding analytical results used to develop each figure
  - shown on the figure and in tabular form with reference to applicable criteria

Confirmation of Remediation

Minimum Requirements:

- ***at least three*** monitoring locations within each affected aquifer
- Locate wells strategically within remediated zone or along immediate perimeter of zone
- Monitor indicator parameters (e.g., pH, conductivity, dissolved oxygen) to verify that conditions are static
- Obtain ***at least two sets of groundwater samples*** at least 24 hours apart, and preferable two weeks apart
- Analyse for all contaminants of concern plus any possible newly created contaminants.

Post-Remediation Monitoring

When is Post-Remediation Monitoring Complete?

- Remediation Standards are achieved
- “Rebound” approaching or exceeding standards is no longer likely

Well De-Activation

- Don’t Forget about this!!

- Where well does not cross-communicate between flow zones:
  - pull casing, grout borehole using tremie pipe
  - If borehole collapse, re-drill and grout
  - where completion zone is less than one metre, simple grouting of casing to surface may be acceptable

- Where well may cross-communicate between flow zones:
  - re-drill and grout
  - inject grout into the well under pressure to inject grout through the well screen and into the surrounding filter pack.