ARCADIS
Improving Quality of Life

Risk Management Solutions

VIJAY KALLUR, M.Sc., P.Eng., FEC, CSAP
Client Program Manager

The 12th Annual SABCS Conference on Contaminated Sites

September 22, 2022

SCIENCE ADVISORY BOARD FOR CONTAMINATED SITES IN BC

AGENDA

- Introduction of Arcadis
- Risk Mitigation Options
- Requirements of a Conceptual Site Model (CSM)
- Tools that can be used for Better Characterization
- Case Studies
- Conclusions

Creating a sustainable future since 1888

ARCADIS at a Glance

€ 3,378m
Gross Revenues

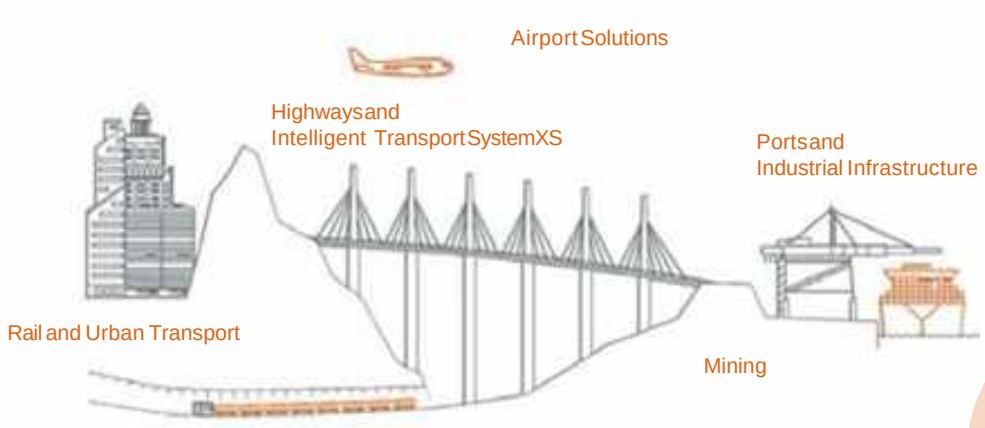
29,000+
People Globally

35,000+
Projects Annually

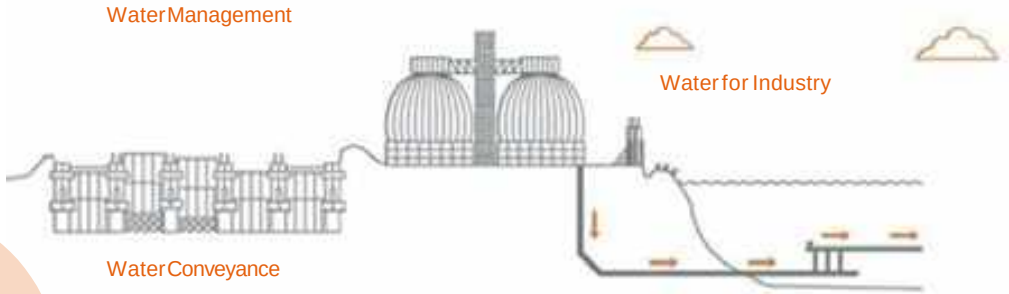
#1 In our industry
Sustainalytics
ESG Risk Rating score

Our solutions are delivered cross sector

Infrastructure (24% net revenues)

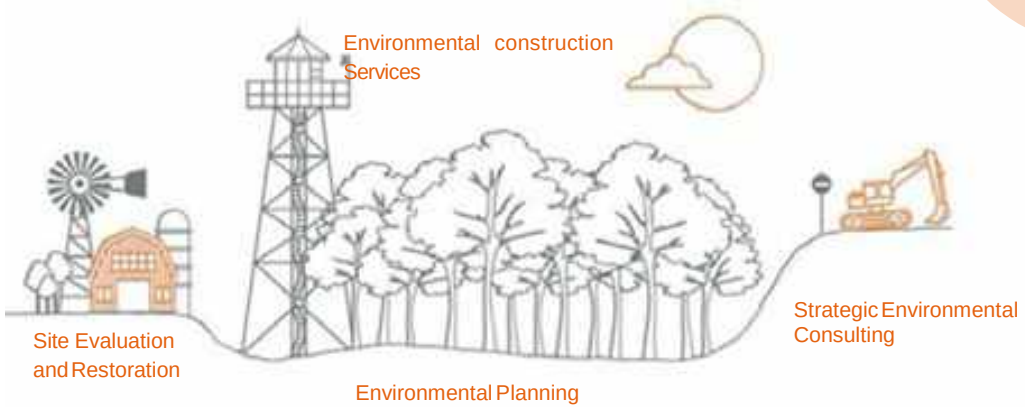


Water (12% net revenues)

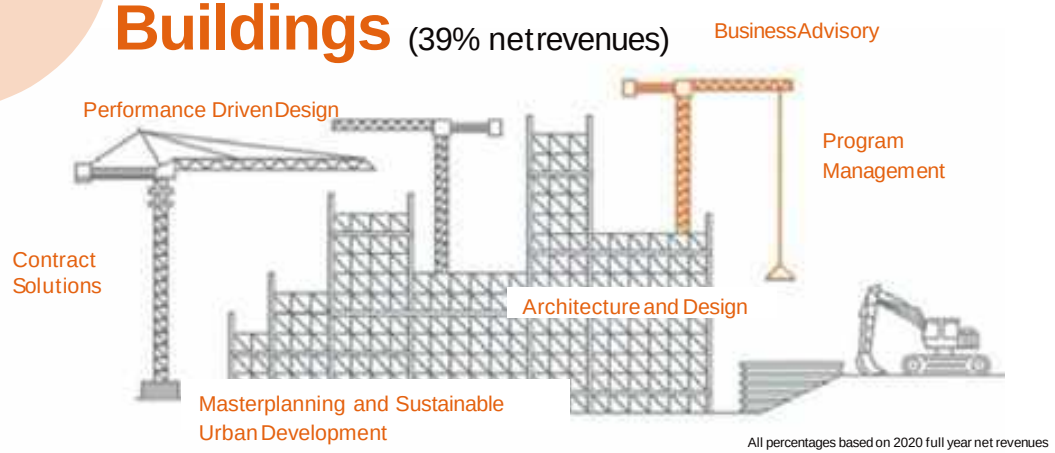


Local expertise
Global reach

Environment (25% net revenues)



Buildings (39% net revenues)

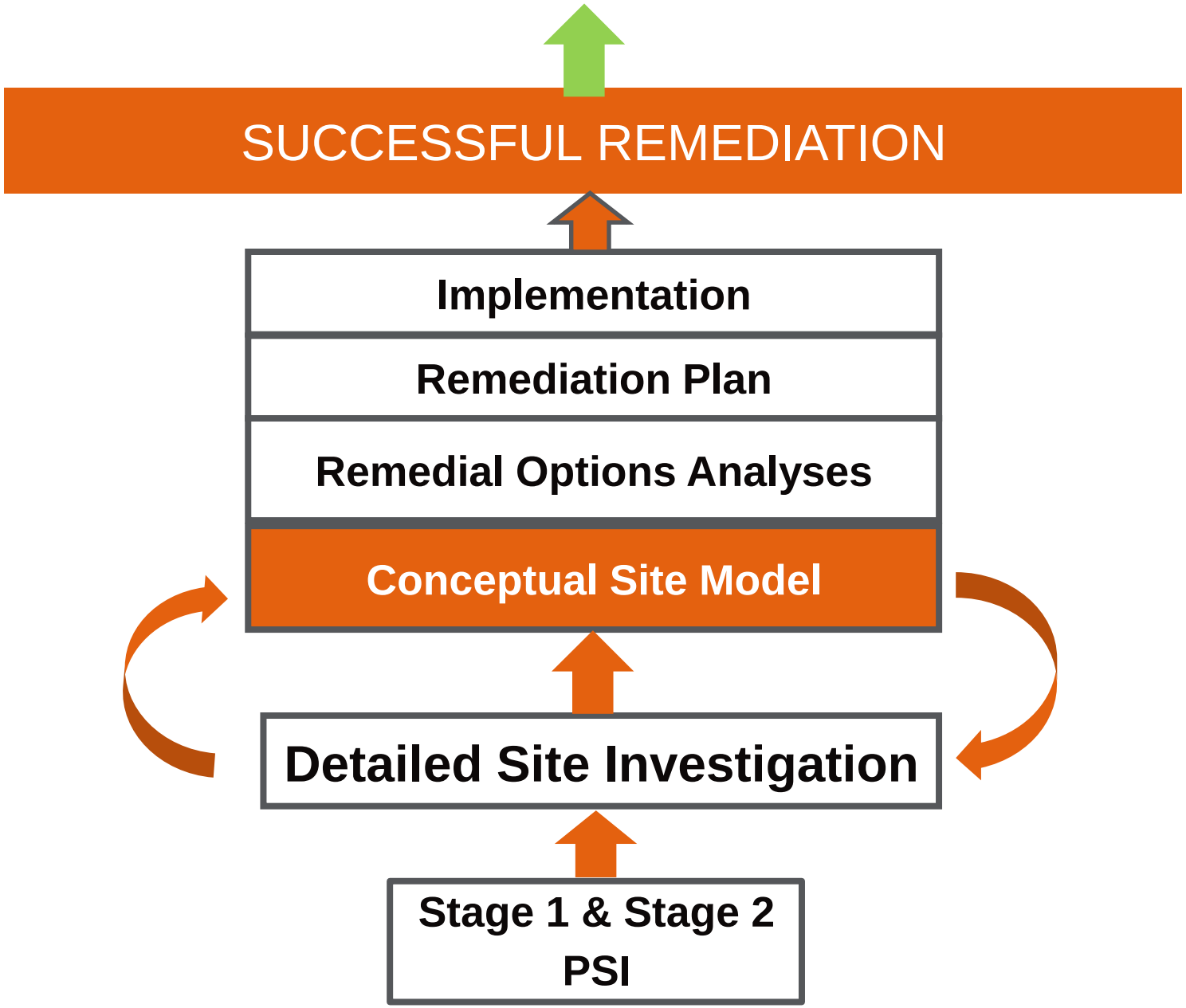


All percentages based on 2020 full year net revenues

RISK MITIGATION OPTIONS

1. **Exsitu**
   - **Excavation**
2. **Insitu**
   - **Groundwater Pump & Treat**
   - **Air Sparging and Soil Vapour Extraction with Thermal Oxidation**
   - **Dual Phase Extraction with Thermal Oxidation and Water Treatment**
   - **Chemical Oxidation**
   - **Enhanced Bioremediation**

RISK MITIGATION



CONCEPTUAL SITE MODEL

A CSM is defined as a written or pictorial representation of an environmental system and the biological, physical, and chemical processes that determine the transport of Contaminants of Concern (COCs) from sources through environmental media to environmental receptors within the system (ASTM 2014).

For effective planning of any site investigation, the historical, physical, chemical and biological components that define a problem should be drawn together into a conceptual site model (CSM). In a hydrogeological context, the CSM should comprise a three-dimensional understanding of the site to be investigated. (ENV Technical Guidance 8).

Requirements of a CSM

Site Characteristics

- Size – small or large Site
- Location – Inland, Shoreline or Water, Potential Eco and Human Receptors
- Past Use – Imported Fill, Infilling?
- Hydrogeology, Contaminants
- Risk classification
- 3rd party issues

Client Requirements

- Redevelopment plans
- Risk Tolerance / Liability Management
- Legal Agreements
- Policies - Sustainability

Regulatory Requirements

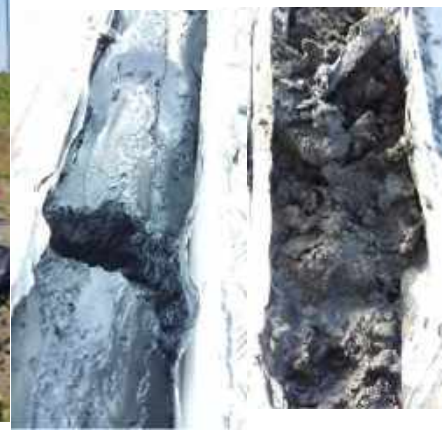
- Data Collection
- Modelling
- Tidal Influence
- Background Assessment
- Remedial standards
- Risk Classification
- Processes for Reviews (NIR or AIP or CoC)

CSM Challenges

- **Inconsistent Data and Logging – Silty Sand or Sandy silt ?**
- **Stratigraphy onsite – Fill, Bedrock (siltstone or sandstone), Till with gravel/sand lenses?**
- **Depth of Groundwater or multiple aquifers**
- **Plume Size (Vertical and Areal) – LNAPL, DNAPL, GW and Soil Vapour**
- **Preferential Pathways – Utility Corridors, Buried Stream Beds, Fractures in Bedrock**

Tools

- Drilling logs, Grain Size Analyses
- Bail tests, Pump tests
- Data logging of tidal influence
- Analytical data
- Models



Tools

- Shelby Tube samples
- Soil Moisture Characteristic Curves
- Vertical Aquifer Profiling

Geo-Slope International

Fredlund, D.G. (2002)

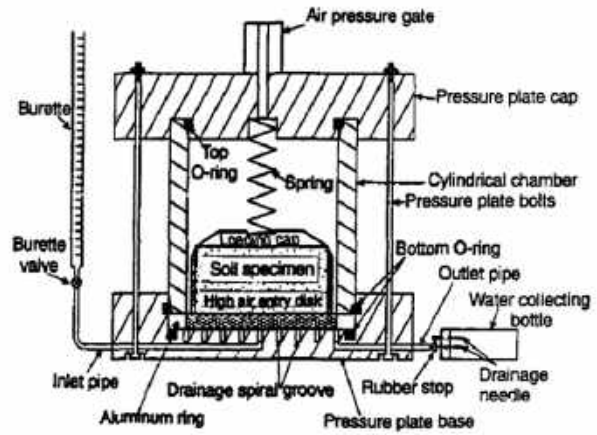


Figure 2. A single specimen, pressure plate cell developed at the University of Saskatchewan, Saskatoon, Canada.

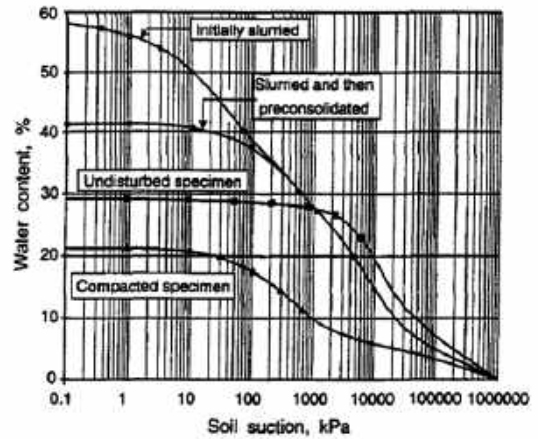
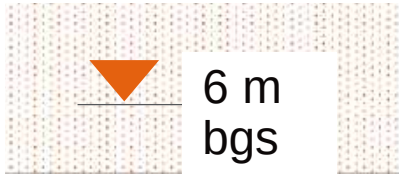


Figure 5. Shrinkage curves corresponding to typical soil specimens prepared in various manners.

CASE STUDY 1

- A Site with an active fuelling facility (gas station) at a busy intersection in urban area.
- Native soil – “Capilano Sediments and Vashion Drift comprised of lenses and interbeds of glaciolacustrine laminated stony silt and glaciofluvial sand and gravel over lodgment and minor flow till”.

Silt and clay - 34% to 65%
Sand - 17% to 59%
Gravel – 7% to 20%



K = 1.6 x 10^{-04} cm/s to 8.7 x 10^{-06} cm/s

- Investigations - 62 boreholes over 5 years
- LNAPL detected onsite and offsite
- LNAPL Recovery - Manual Bailing over 8 months yielded 1275 L
- Depth of Contamination in soil – 2 m to 8 m bgs

Table 1. Pre-DPVE Contaminant Distribution

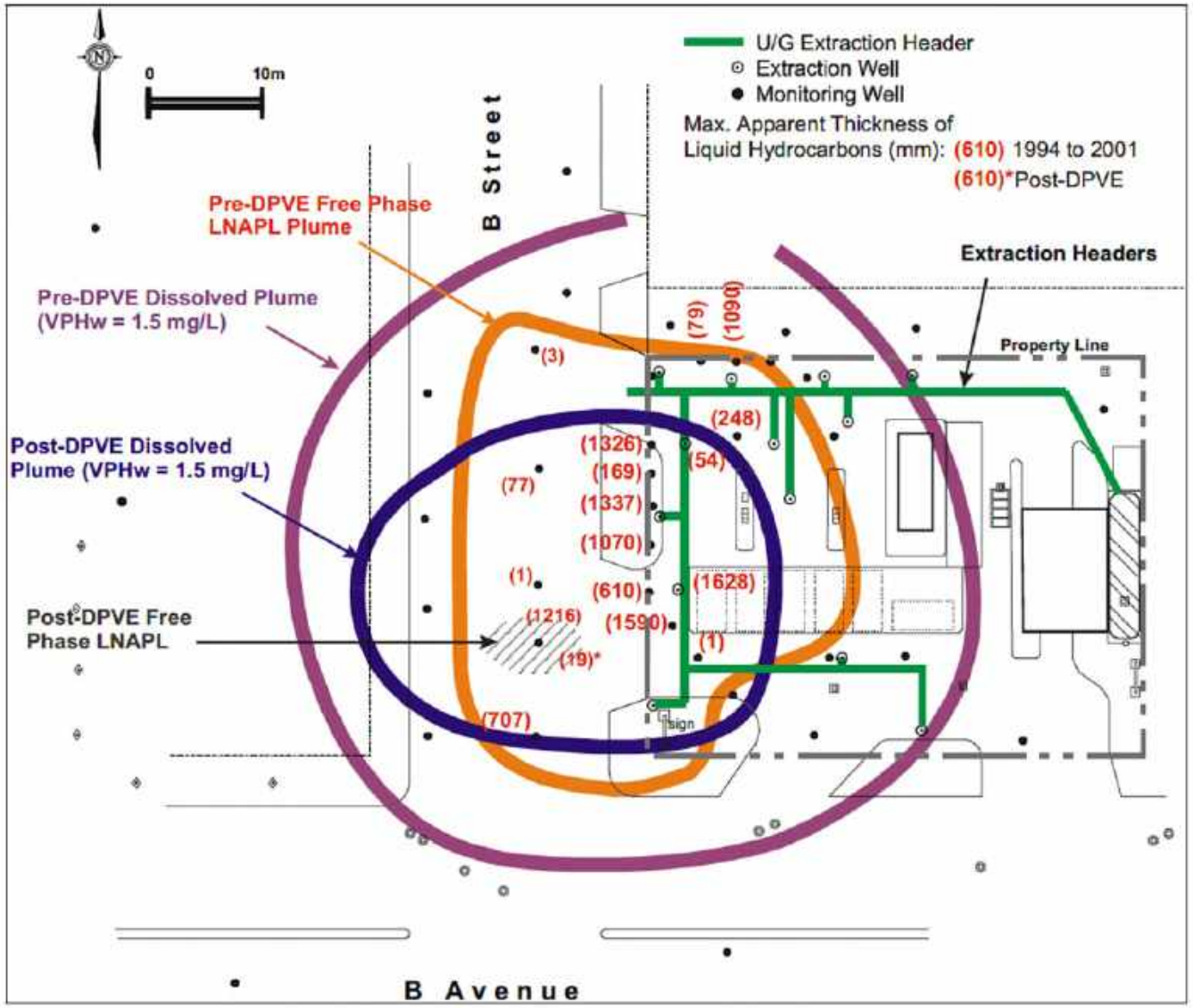
Phase	Measured Values
Max. Apparent LNAPL Thickness (mm)	Onsite: 3777
	Offsite: 1219
Max. PHC Concentration in Soils 3.7m to 6.7m bgs (mg/kg)	VPH: 1155 to 8788
	BTEX: 50 to 1670
Max. Dissolved PHC Concentration (mg/L)	VPHw: 45 to 70

CASE STUDY 1

- Mitigate further offsite contamination
- Recover LNAPL
- Soil and GW Remediation

Table 3. Design Parameters for the DPVE System

Parameter	Design Value
No. of Wells / Spacing	13 at 8 m
LRP Size / Capacity	50 h.p. / 700 acfm
Inlet Vacuum (“ Hg)	18 to 22
Wellhead Vacuum (“Hg)	8 to 10
Air Extraction Rate per Well	21 scfm
Thermal Oxidation Unit Capacity	750 cfm
Max. Water Flow Rate	100 L/min
Max. BTEX Conc. In Water	100 mg/L



Kallur, et. al. (2003)

CASE STUDY 1

Table 4. DPVE System Performance Data

Description	Result
Volume of LNAPL Recovered (L): Vapour / Liquid / Dissolved Phase	18 000 / 1 / 35
Volume of Water Extracted (m^3)	1117
Vacuum in Drop-Tubes (“Hg)	11 to 14
Vacuum at Wellheads (“Hg)	5 to 14
Initial Rate of LNAPL Recovery (L/d)	538
Finial Rate of LNAPL Recovery (L/d)	<10
Residual VPH in Soil prior to deactivation (mg/kg)	205 to 8 878
VHw in Groundwater (mg/L)	66

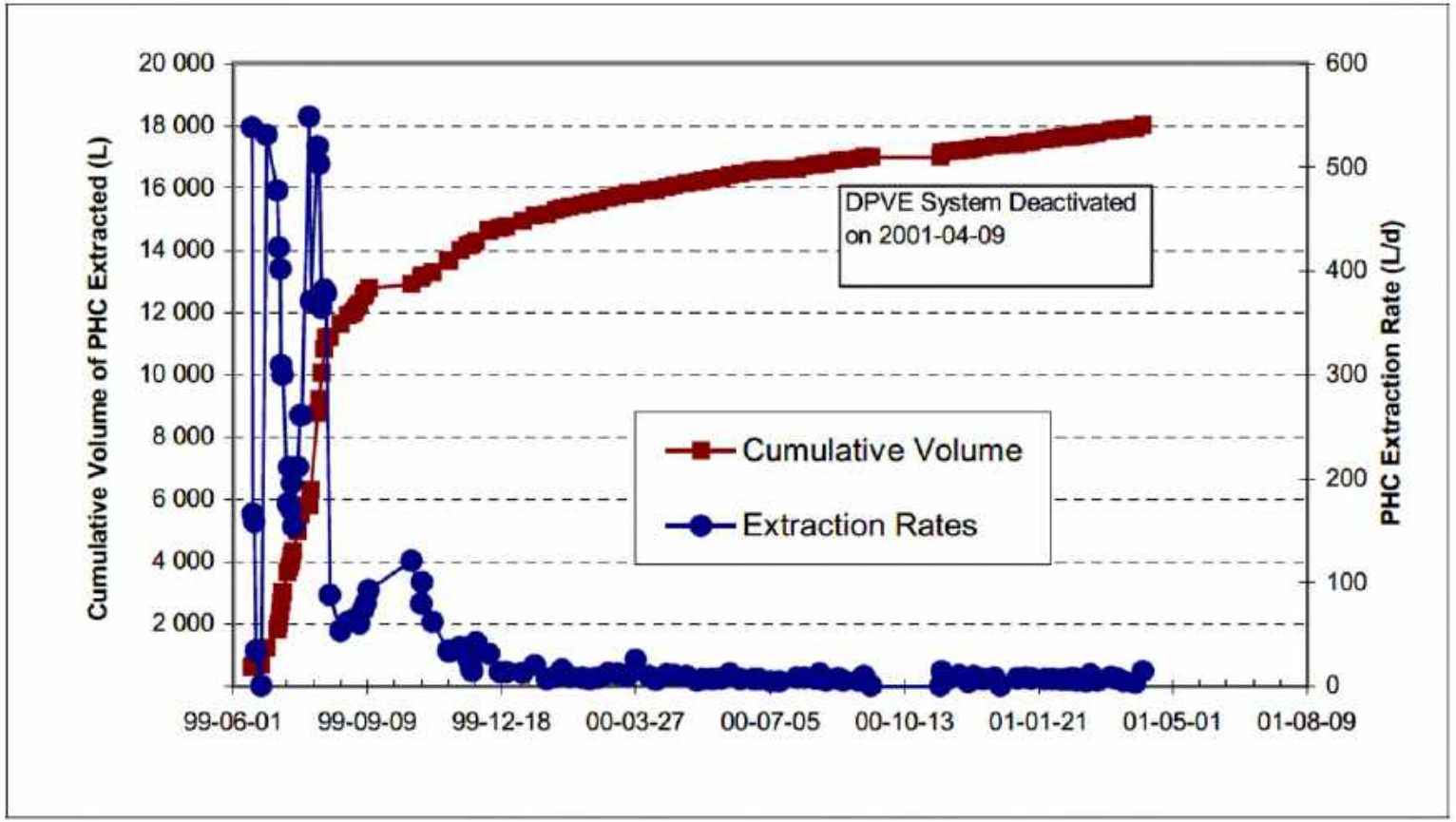


Figure 3. Petroleum Hydrocarbon Extraction History

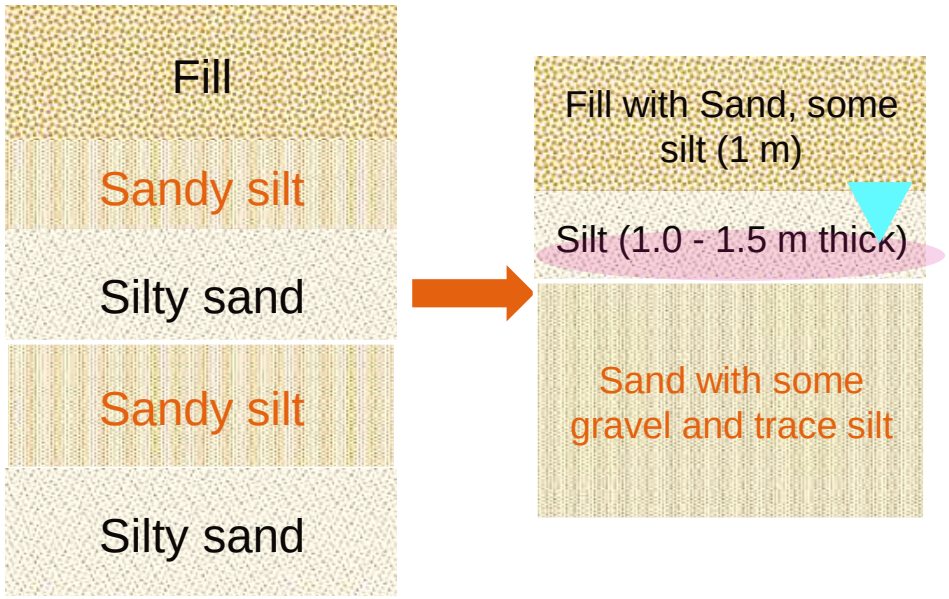
CASE STUDY 2

Site Conditions

- Site formerly occupied by a fuelling facility (gas station) in urban area of City in interior BC
- Onsite and offsite contamination into a paved parking lot;
- Light and heavier end hydrocarbons – Gasoline and diesel in silt layer
- Minor thickness of LNAPL, sheen at the groundwater table ▽ ~ 2 m bgs
- Client's agreement with 3rd parties – Insitu Remediation to Numerical Standards in 3 years

Challenges

- Stratigraphy unclear (drilling over 5 year period)
- Conceptual Site Model not developed
- Remedial Options Review to be completed
- Remediation Plan to align with client commitment
- Low remedial standards in soil VPH = 200 mg/Kg

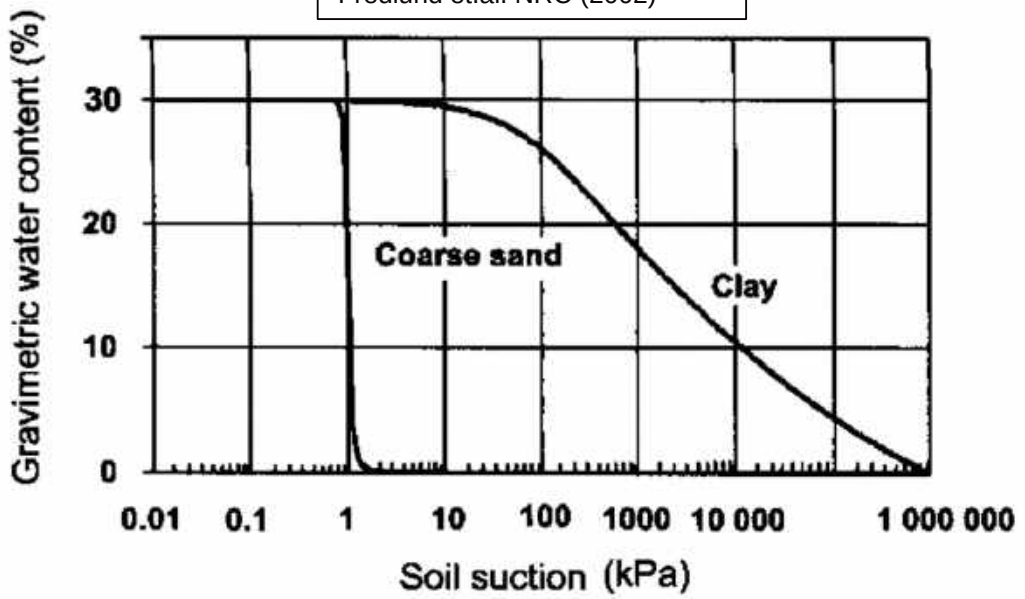


CASE STUDY 2

Process Adopted / Solutions

- Data and information gap analyses completed, K tests
- Utilized onsite drilling opportunities for low cost data collection – Grain Size Analyses Profile
- Decision to obtain a Shelby tube sample during field call
- Carried out test to develop soil moisture characteristic curve (Residual W/C = 30% to 40%)

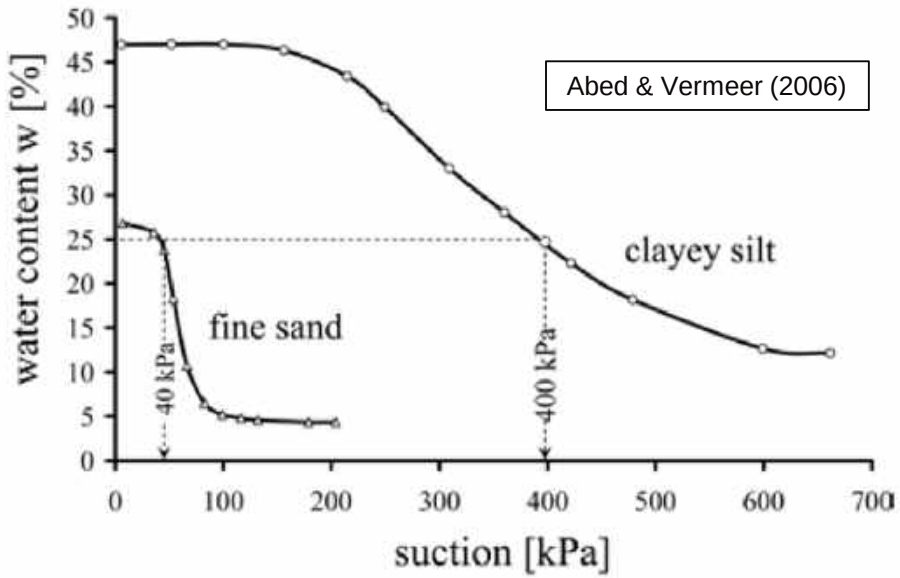
Fredlund et.al. NRC (2002)



Results

- Decision - Site was not suitable for insitu technologies to achieve remedial objectives
- Client revised legal agreement
- Saved $ 1.5 to 2 Million by data collection that cost $3000

Abed & Vermeer (2006)



CASE STUDY 3

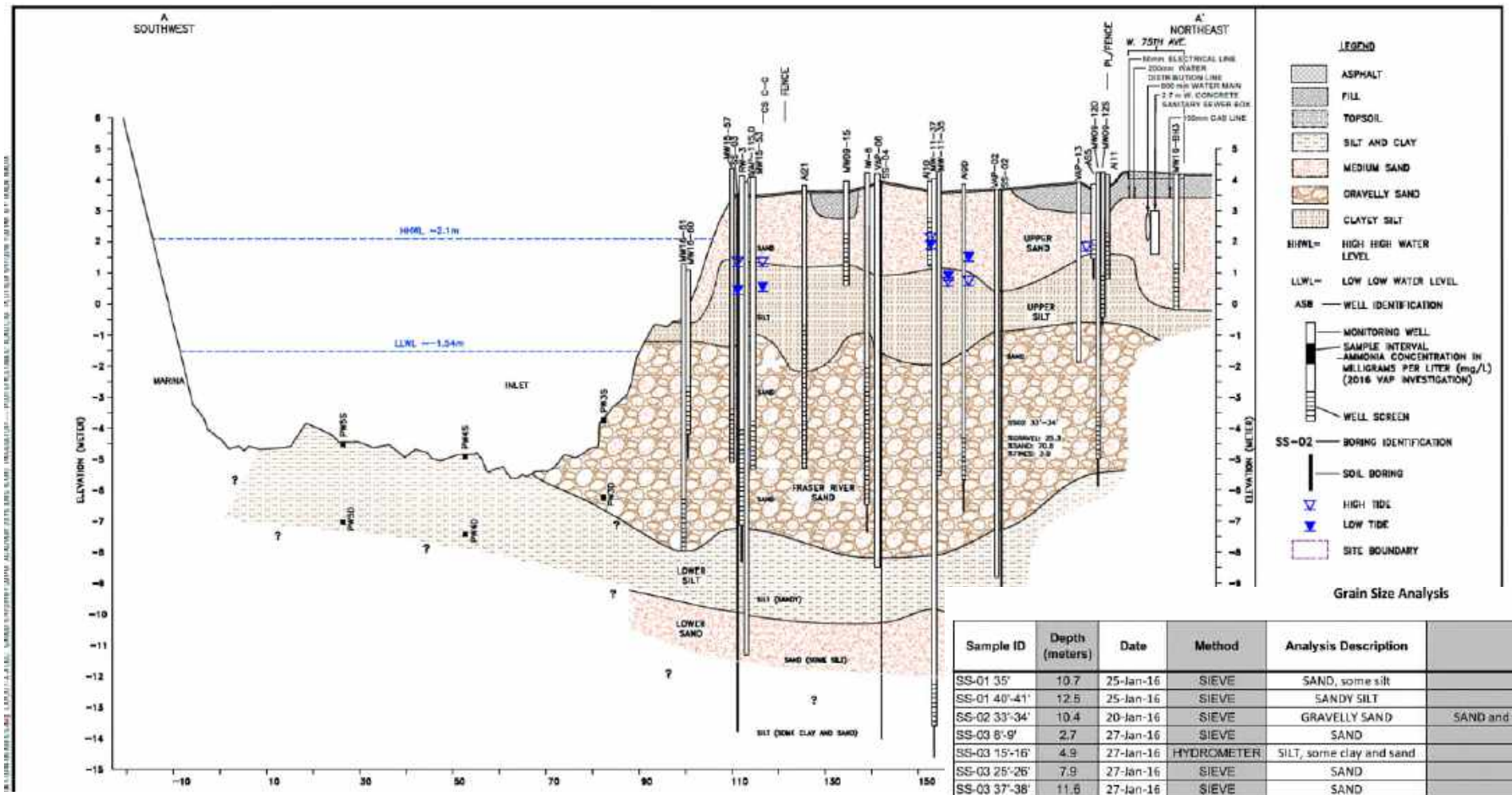
Site Conditions

- Former chemical industrial site along shoreline
- Contaminants of concern included hydrocarbons, metals, inorganics (ammonia and nitrates), phenols
- Historically infilled site above river bed (heterogenous)
- Tidal influence

Development of CSM leading to Remediation

- Vertical Aquifer Profiling – Physical and Chemical
- Data collection using loggers for tidal influence
- Modelling
- Innovative remedial approach to enhance bioremediation for source reduction

CASE STUDY 3



Grain Size Analysis

Sample ID	Depth (meters)	Date	Method	Analysis Description	Borehole Description
SS-01 35'	10.7	25-Jan-16	SIEVE	SAND, some silt	SAND, trace silt and clay
SS-01 40'-41'	12.5	25-Jan-16	SIEVE	SANDY SILT	SILT and CLAY, some sand, some clay
SS-02 33'-34'	10.4	20-Jan-16	SIEVE	GRAVELLY SAND	SAND and GRAVEL, some gravel and cobbles, little silt and clay
SS-03 8'-9'	2.7	27-Jan-16	SIEVE	SAND	SAND, trace pebbles
SS-03 15'-16'	4.9	27-Jan-16	HYDROMETER	SILT, some clay and sand	SILT, some very fine sand, some clay
SS-03 25'-26'	7.9	27-Jan-16	SIEVE	SAND	SAND, trace pebbles
SS-03 37'-38'	11.6	27-Jan-16	SIEVE	SAND	SAND
SS-03 47'-48'	14.6	27-Jan-16	SIEVE	SAND, some silt	SAND and GRAVEL
SS-03 51'-52'	15.9	27-Jan-16	HYDROMETER	SILT, some clay and sand	SILT and CLAY, some fine sand

CASE STUDY 3

Vertical Aquifer Profiling

CONCLUSIONS

- CSM is a critical step in the investigation and remediation process that can influence the outcome:
  - Extent of risk mitigation
  - Schedule
  - Costs
  - Development Plans
  - Environmental Liability.

- Low cost data collection methods are available that can provide critical information for a more accurate CSM and successful Risk Mitigation

Credits:

Clients, Colleagues, Staff, Contractors, Stakeholders and Regulators.