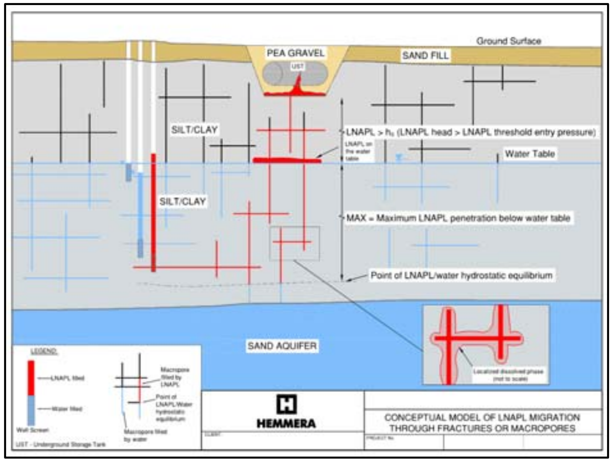
LNAPL Deep Below the Water Table – How Did it Get There? The Importance of Proper Site Characterization and Implications to Remediation

A Case Study



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RemTech 2009, Banff Alberta

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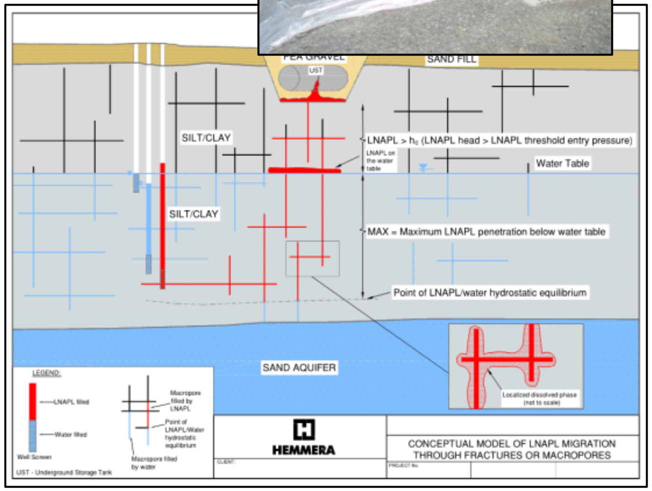
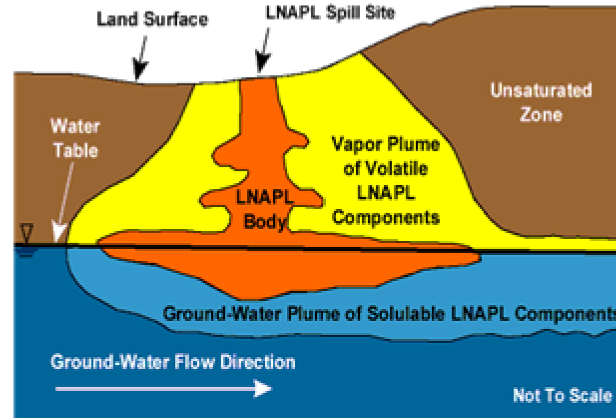
Presentation Outline

- Introduction
- Site Background / History
- Historic Investigation / Remediation Work
- Site Geology
- Physical Hydrogeology
- Contaminant Hydrogeology
- LNAPL Conceptual Model
- Implications to Site Investigation and Remediation

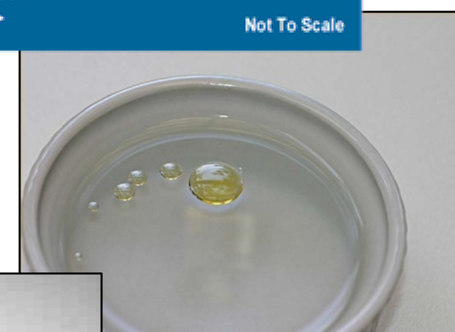


Introduction

- Some definitions:
  - LNAPL – light non-aqueous phase liquid e.g. gasoline, diesel, crude oil
  - USTs – underground storage tank
- Common misconception:
  - Gasoline or LNAPL, expected to ***float*** on water
  - This presentation highlights a case study where this is not the case



From: toxics.usgs.gov



http://www.omccanada.ca/

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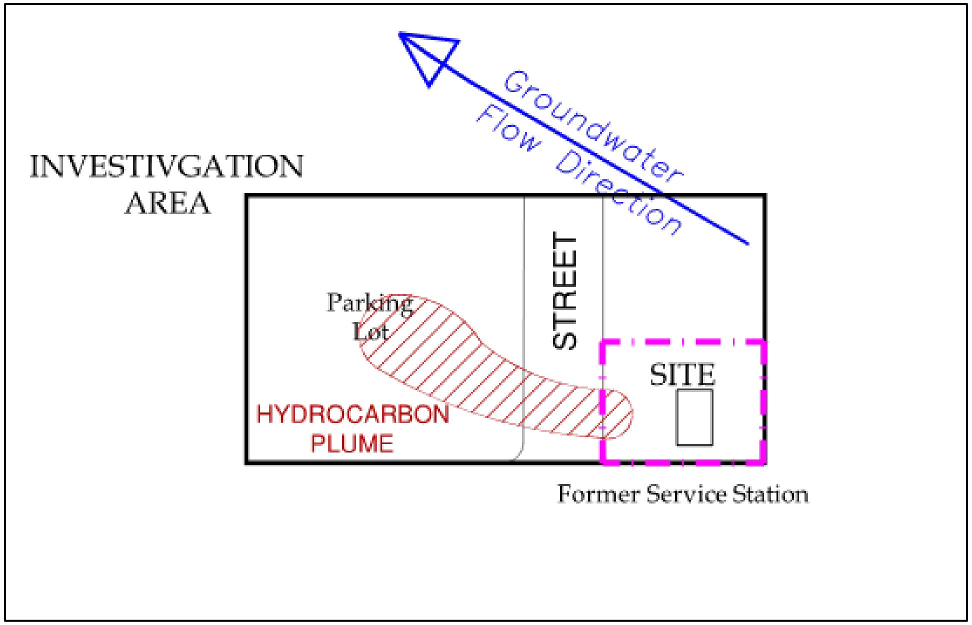
Site Location and Setting

- Located in British Columbia, Canada
- Commercial property “former service station” surrounded by commercial and residential properties
- Situated approx. 300 m east of a large regional lake
- Site elevation approx. 35 m above lake level



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Site Background/History

- Single-family residence from the early 1920s to early 1960s
- Commercial service station from 1962 to 2005
- Decommissioned in 2005 and is currently unpaved and vacant

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Site Background – (Cont'd)

- Facilities included three steel gasoline USTs up to 1996
- In 1996 replacement with three fiberglass USTs – *soil impacts observed*
- Fiberglass USTs removed in 2005 during decommissioning

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Historic Investigation/Remediation Work

- Numerous site investigations completed between 1997 and 1999 – *groundwater considered delineated*
- In 2005, remedial excavation of on-site and partly off-site soils – *deep soil contamination discovered*
- Additional on and off-site investigations 2005 to present
- During lateral assessment of the deep soil contamination - *5 m of LNAPL detected in one well*
    - 2005 to present work has focused on delineation of the deep LNAPL

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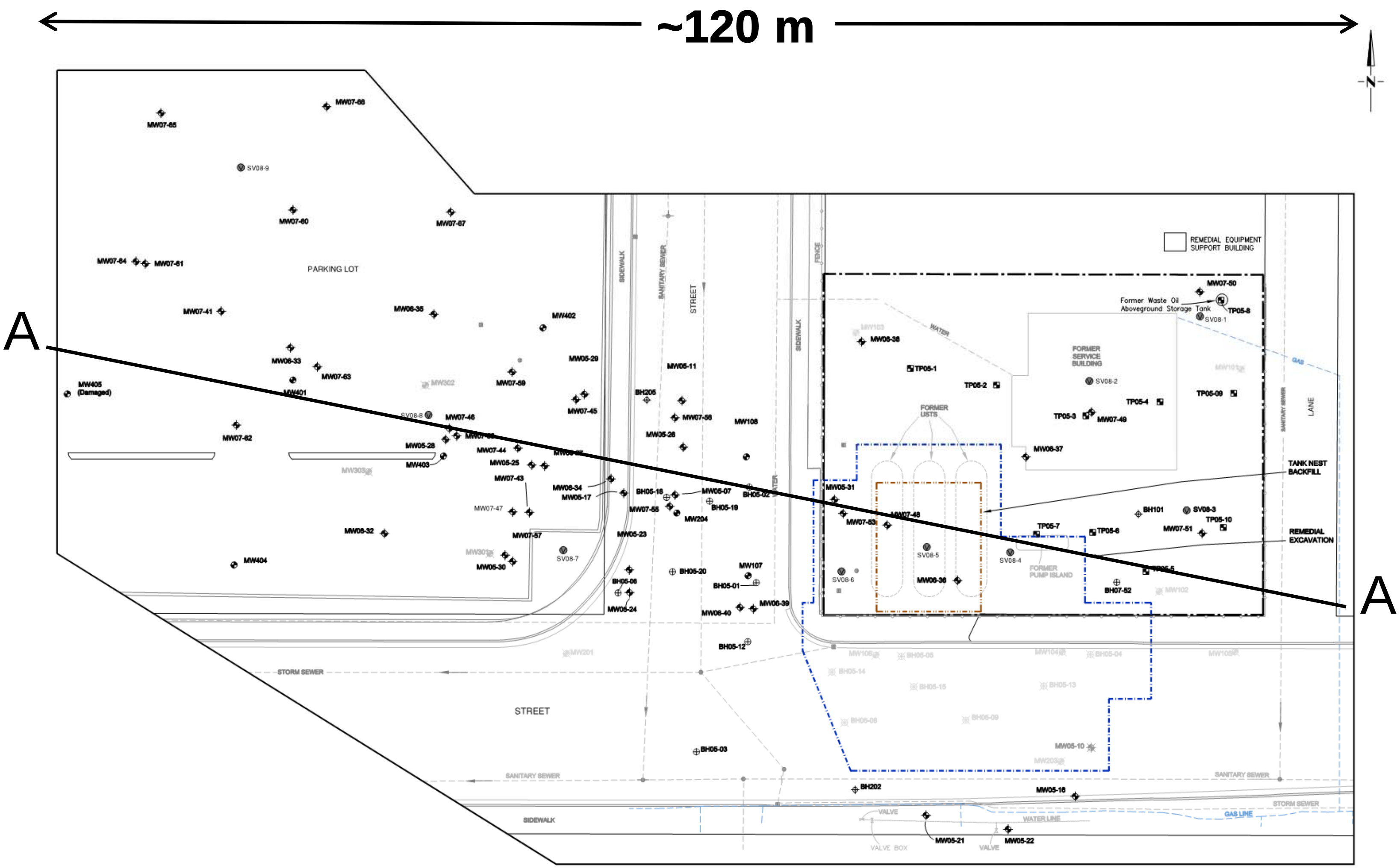
Investigation/Remediation Locations



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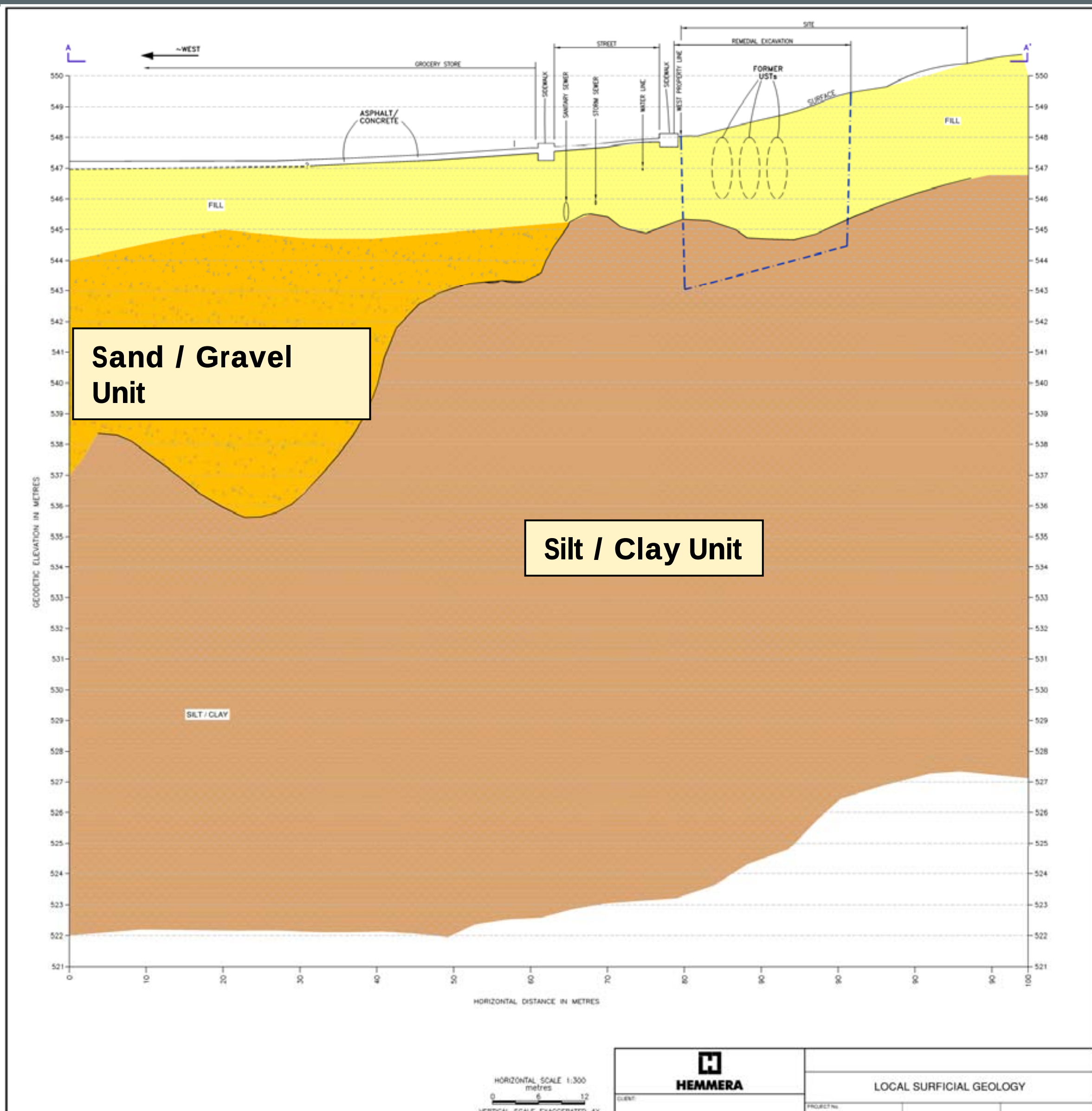
Local Surficial Geology

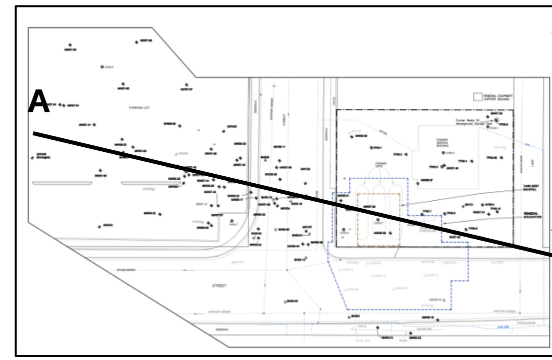
- **Local Surficial Geology** – *2 main units:*

Unit	Approximate Depth (m)	Stratigraphic Unit	Composition/Description
1	From surface up to 12	Sand and Gravel	Medium to coarse sand to sand and gravel, loose, moist to wet.
2	From 2 up to 27	Silt and Clay	Silty sand to sandy silt, silt, or clay, dense/stiff, moist to wet. *Thin sand stringers*

- The sand stringers are defined as ***macropores***

Geologic Cross-Section





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Physical Hydrogeology

- **Hydrostratigraphy** – *Two main units:*

Surficial Geologic Unit	Average depth Interval (metres)	Hydrogeologic Classification
Sand and Gravel (Unit 1)	From surface up to 12	**Perched Sand Aquifer**
Silt and Clay (Unit 2)	≥ 24	**Silt/Clay Aquitard**

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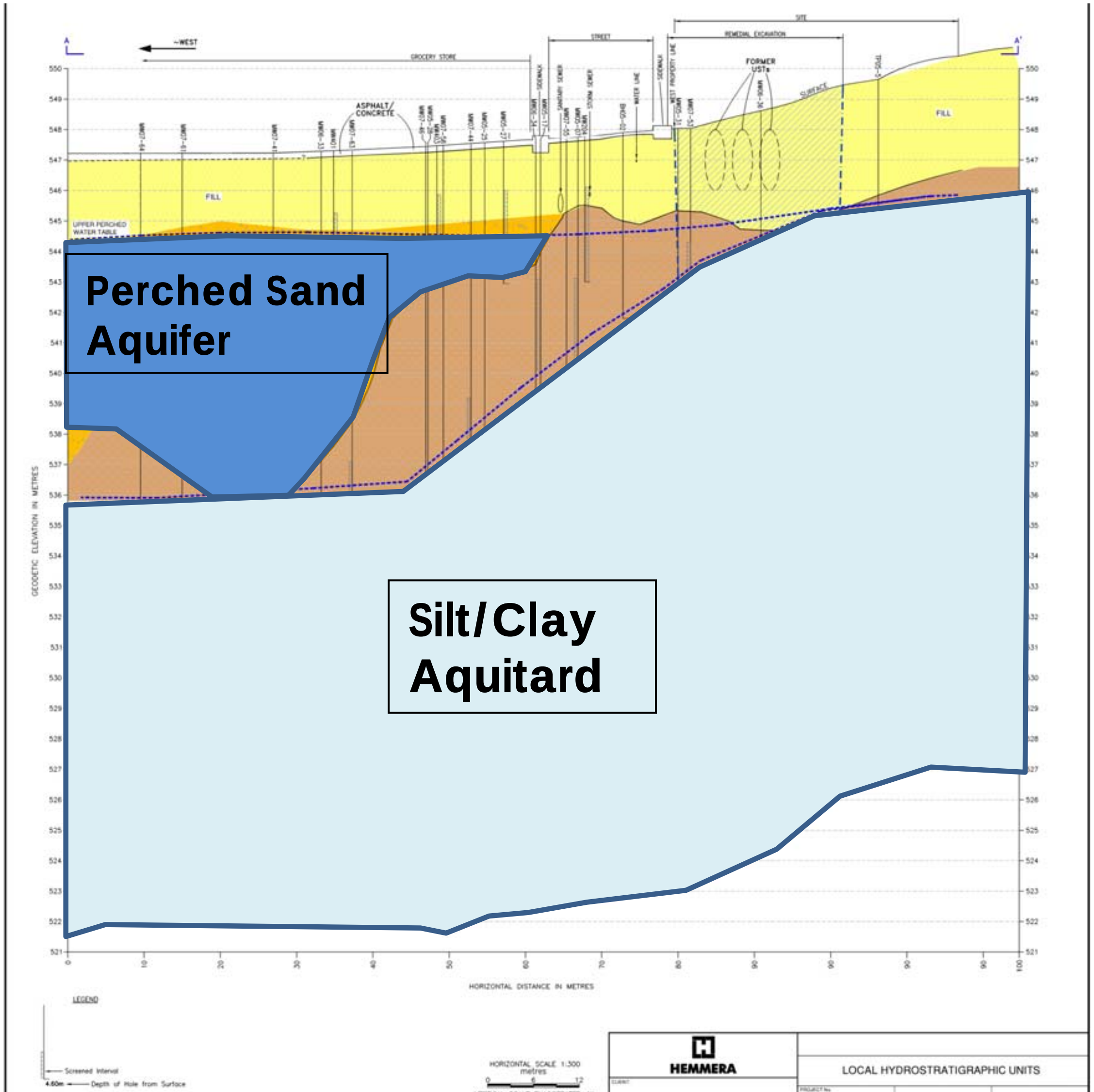
Hydrostratigraphic Units



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Physical Hydrogeology (Cont'd)

- Unit Hydraulic Conductivity – K
  - Aquitard: 8.5×10^{-9} to 6.2×10^{-7} m/sec
  - Perched Aquifer: 1×10^{-4} m/sec

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Physical Hydrogeology (Cont'd)

- Physical Groundwater Flow – *Key Characteristics:*
  - Hydraulic head distributions suggest strong channelized flow within the aquitard
  - Strong vertical hydraulic gradients in aquitard (0.1 to 0.5) much greater than horizontal
  - Vertical gradients generally decrease towards the west
  - Groundwater flows generally towards the west-northwest
  - Groundwater levels in the aquitard fluctuate up to and over 3 m

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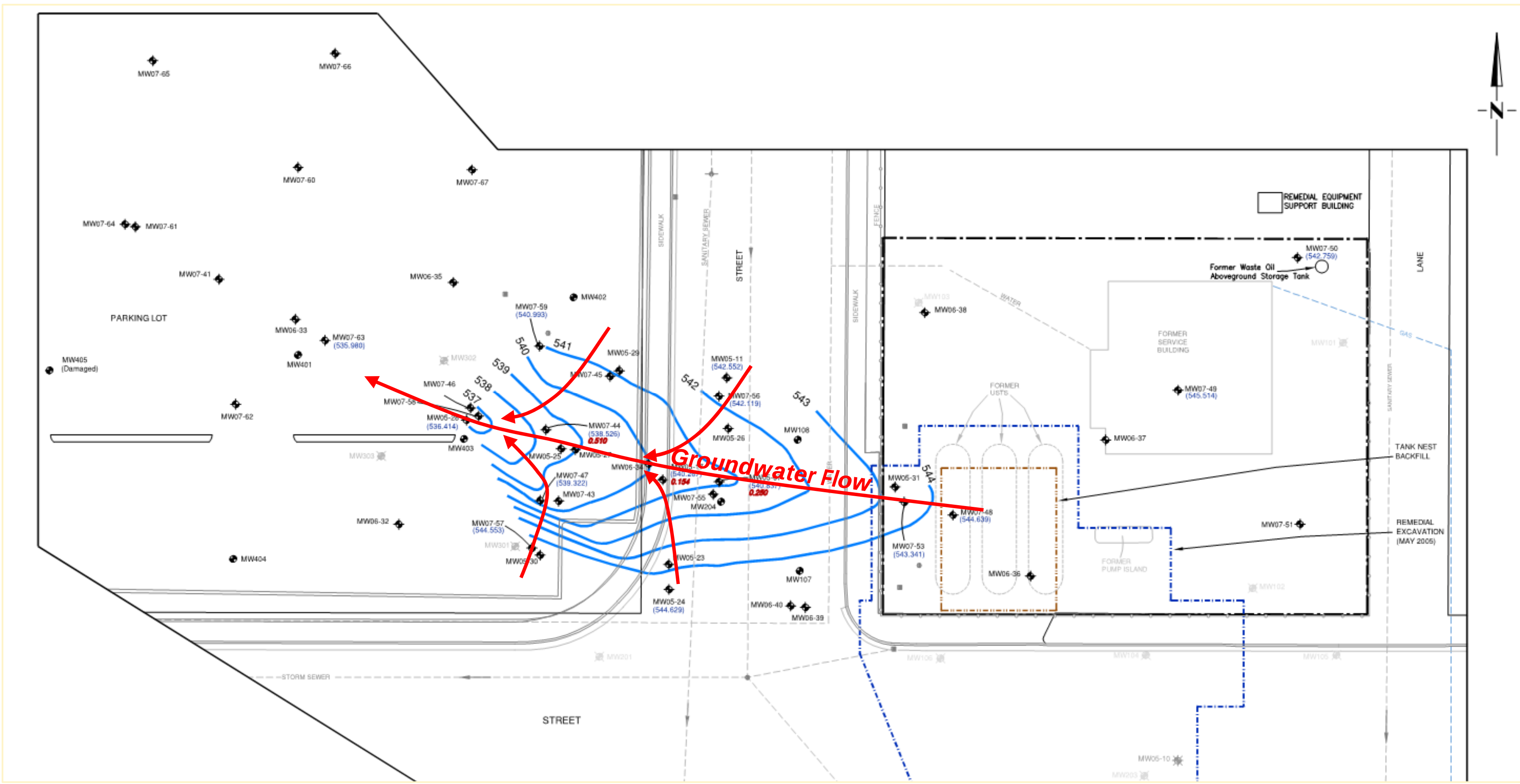
Local Groundwater Flow



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Contaminant Hydrogeology

- Hydrocarbons "gasoline" found in the following phases:

  1. Residual NAPL in soil
  2. LNAPL resting at the water table surface within the aquitard
  3. LNAPL saturating macropores at depths up to 10 metres below the water table within the aquitard
  4. Dissolved phase hydrocarbons associated with the above

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Contaminant Hydrogeology (Cont'd)

- Measured LNAPL thicknesses in wells screened within the aquitard:
  - LNAPL floating on the water table:
    - Measured thicknesses generally <0.3 m
  - LNAPL below the water table:
    - Measured thicknesses up to ***9.8 m***
- No LNAPL measured in wells screened within the perched aquifer

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Contaminant Hydrogeology (Cont'd)

- Key Points:
  - LNAPL measured deep below water table is not an artifact of a LNAPL depressed water table
  - LNAPL below water table is confined within thin macropores
  - Fine grained soil adjacent to the macropores exhibit limited to no residual hydrocarbons i.e. "low concentrations"

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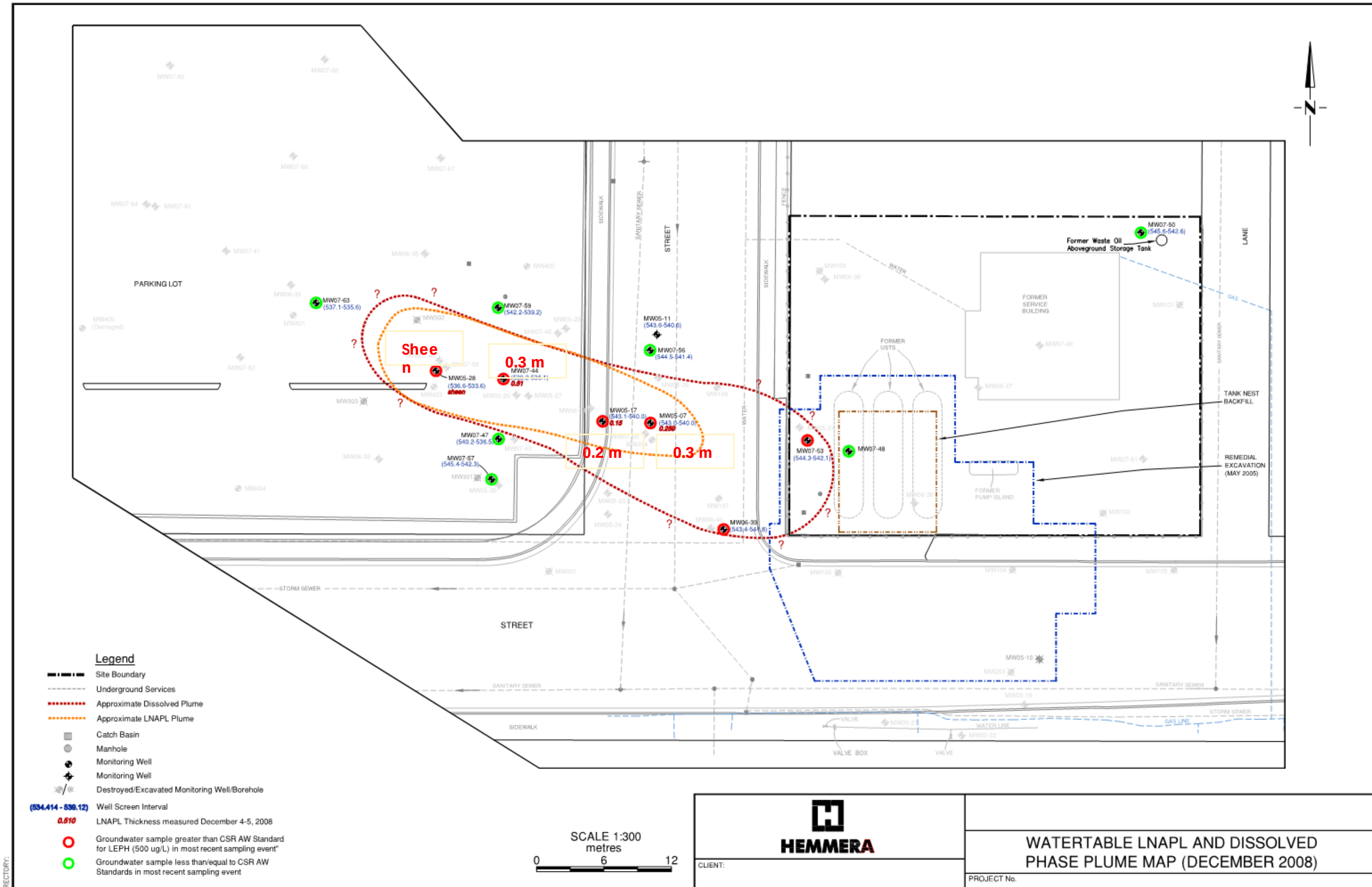
LNAPL/Dissolved Extent on the Aquitard Water Table



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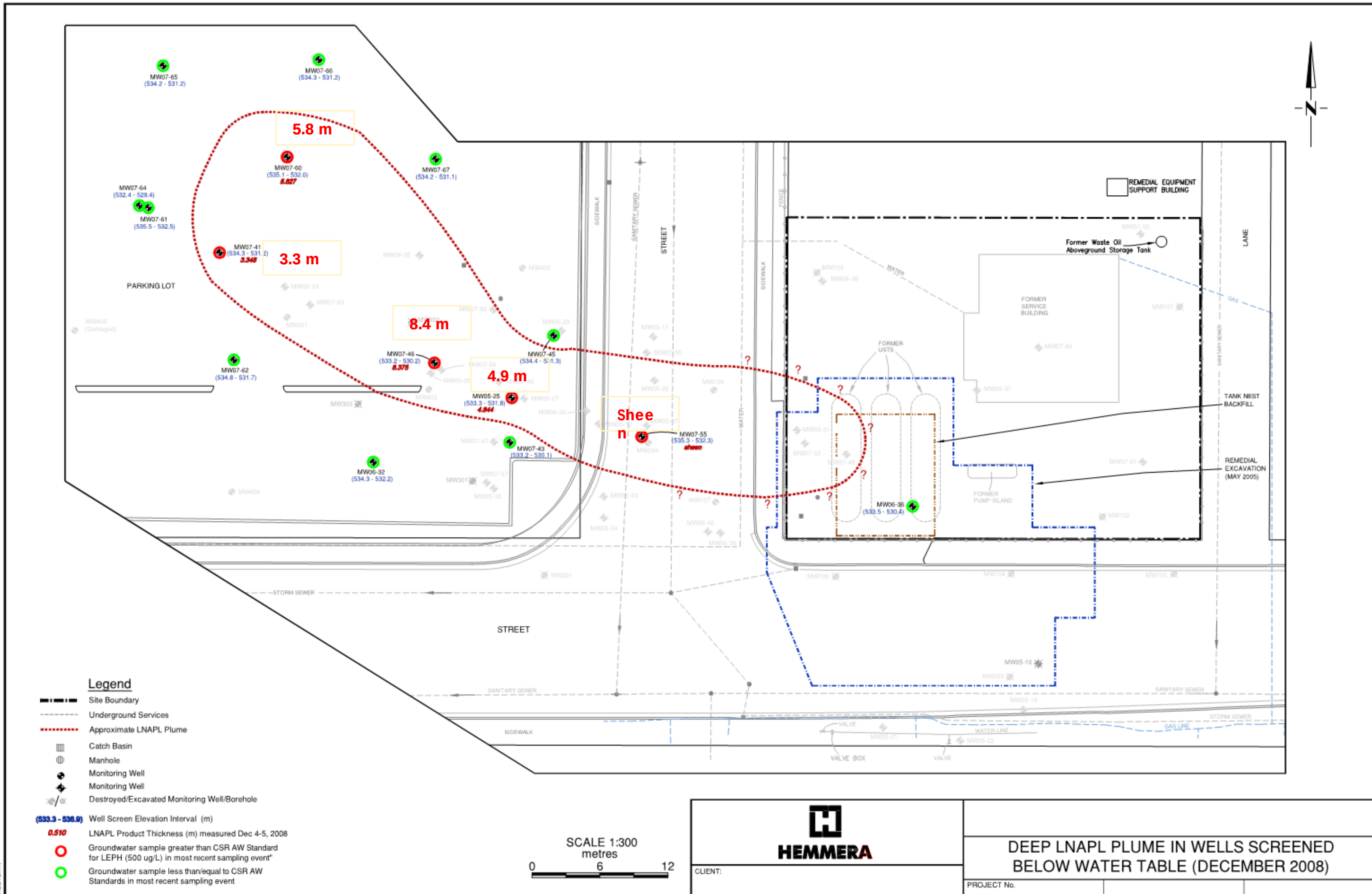
LNAPL below the Aquitard Water Table



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The Big Question

- How did the LNAPL get almost 10 m below the water table?

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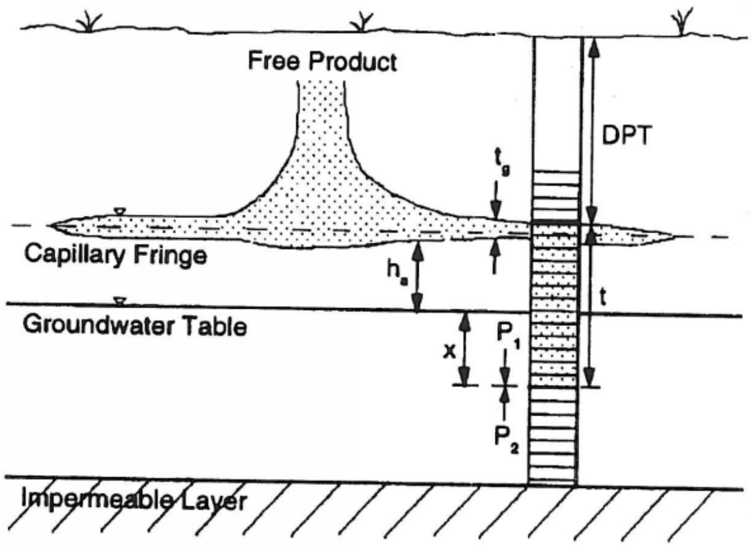
Early LNAPL Conceptual Models



t = apparent (wellbore) product thickness
t_g= actual formation free product thickness
DPT=depth to wellbore product level from ground surface
h_a= free product distance to groundwater table, within formation
x = interface distance below groundwater table, within well
P_1= pressure on product side of interface
P_2= pressure on water side of interface

Source: Ballestero et al. 1994

- Upon reaching the capillary fringe or water table surface, LNAPL spread as a continuous layer in the shape of a pancake "the pancake model"
- Assumed that the LNAPL mass was interconnected and saturation within the pore space was near 100%
- Did not consider capilliarity

This model cannot explain how LNAPL migrated 10 m below the water table !!!

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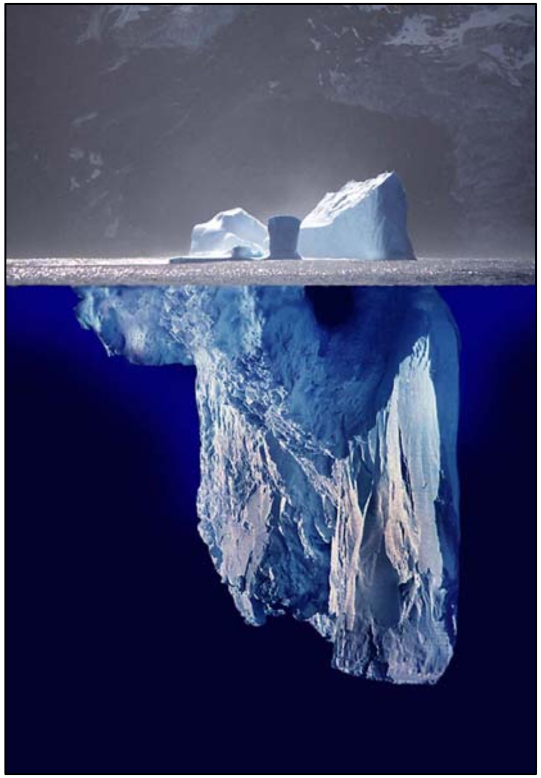
More Recent LNAPL Conceptual Model



- LNAPL rests largely below the water table analogous to an "iceberg" (API, 2003)
- The shape, depth of penetration and margins of the LNAPL mass are dependant on capillary pressure
- LNAPL saturations are much lower than 100% - LNAPL generally occupies the larger pores
- LNAPL can penetrate below the water table depending on thickness of NAPL and capillary pressure
- There are certain circumstances where LNAPL can penetrate several meters below water table:
  - Fractures or macropores in fine grained soils (Adlamski et al. 2005)
  - Fractured bedrock aquifers (Hardisty et al. 2003)

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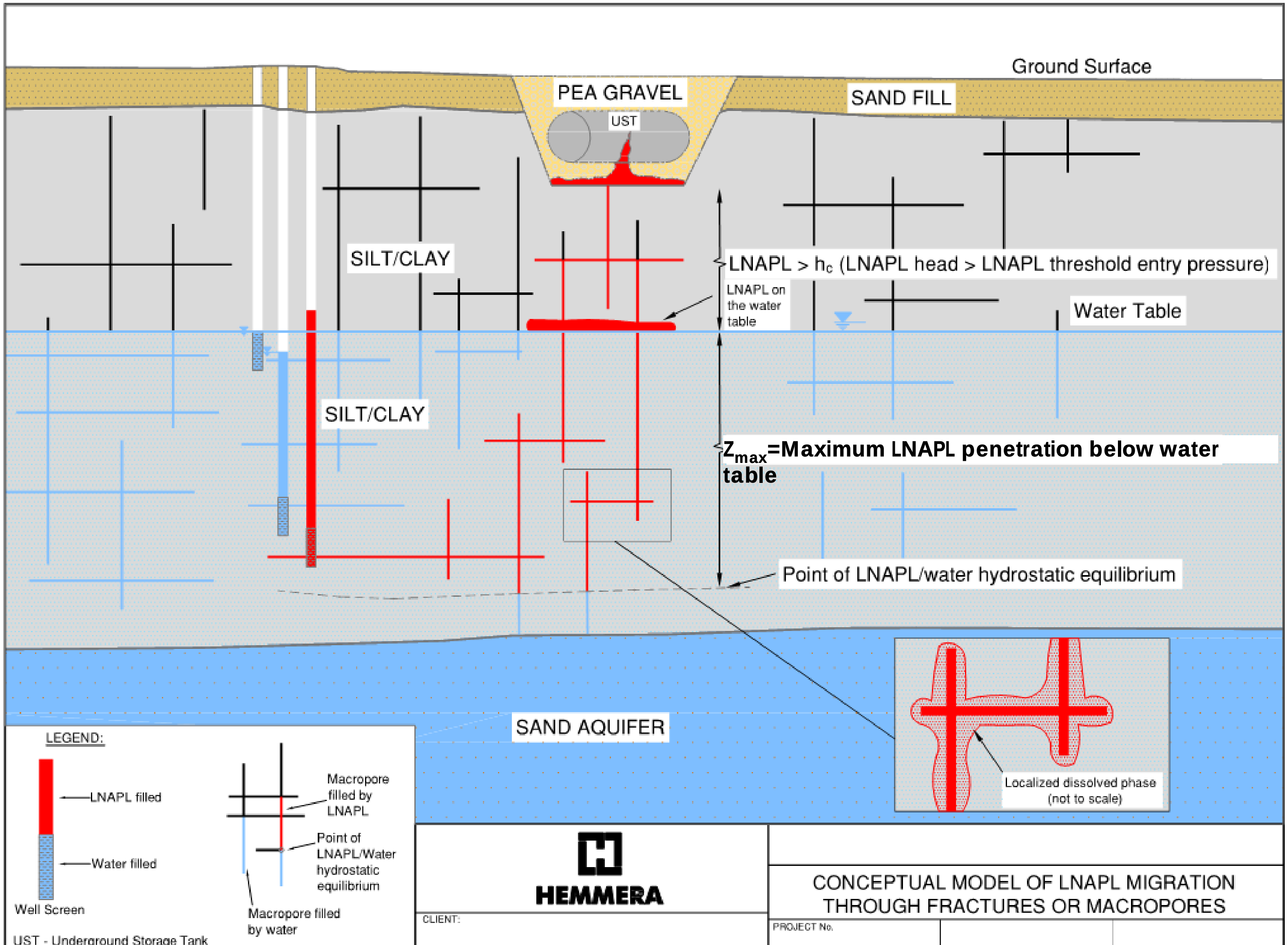
Site Conceptual Model



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Site Conceptual Model - Explained

1. LNAPL accumulated at the base of the UST basin
2. LNAPL drained vertically down through thin macropores into the silt/clay aquitard
3. Low capillary pressures in the macropores allowed LNAPL to penetrate deep through the water table
4. A significant LNAPL head was created since LNAPL was confined to the macropore/fracture walls allowing for greater vertical penetration of the water table

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Site Conceptual Model - Explained

5. Strong downward vertical hydraulic gradients greater than LNAPL buoyancy further acted as a driving force pushing the LNAPL downward

- Minimum downward vertical gradient required according Mercer and Cohen, 1990:

$$\Delta h/\Delta z = (\rho_{NAPL} - \rho_{water})/\rho_{water} = 0.23$$

- Measured vertical gradients in source area $\Delta h/\Delta z = 0.5$

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Site Conceptual Model - Explained

In summary:

- Three main factors contributing to LNAPL penetration:

1. Large LNAPL pressure or LNAPL head;
2. Low capillary pressures in macropores; and
3. Strong downward vertical hydraulic gradients.

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Considerations for Site Investigations

- Targeting the water table surface or fluctuation zone only, may not be sufficient to detect deeper LNAPL bearing zones in macropores
- LNAPL plume may extend greater lateral and vertical distances away from the source
- Vertical delineation becomes critical
- LNAPL in macropores at depth can easily overlooked during investigation work

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Considerations for Site Investigation(cont'd)

- Estimates of LNAPL volume may be underestimated if only the LNAPL at the water table is considered
- Effective porosities may be low
- Developing a sound conceptual model early on is critical

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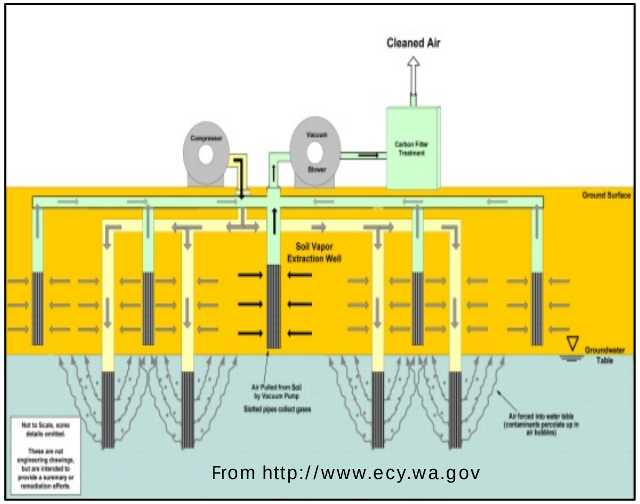
Implications to Site Remediation



From http://www.ecy.wa.gov

Due to the presence of macropores and low effective porosities:

1. LNAPL saturation levels in soils may be very low (few %)
2. LNAPL volumes may be lower than expected and harder to recover
3. LNAPL recovery rates may be significantly slower, therefore target goals may take much longer to achieve
4. LNAPL thicknesses and levels in wells may fluctuate more significantly in comparison to porous media sites – several meters in short time frame

- Without identification of deeper LNAPL, a considerable amount of LNAPL may be overlooked or not remediated

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Questions? Thank You!

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