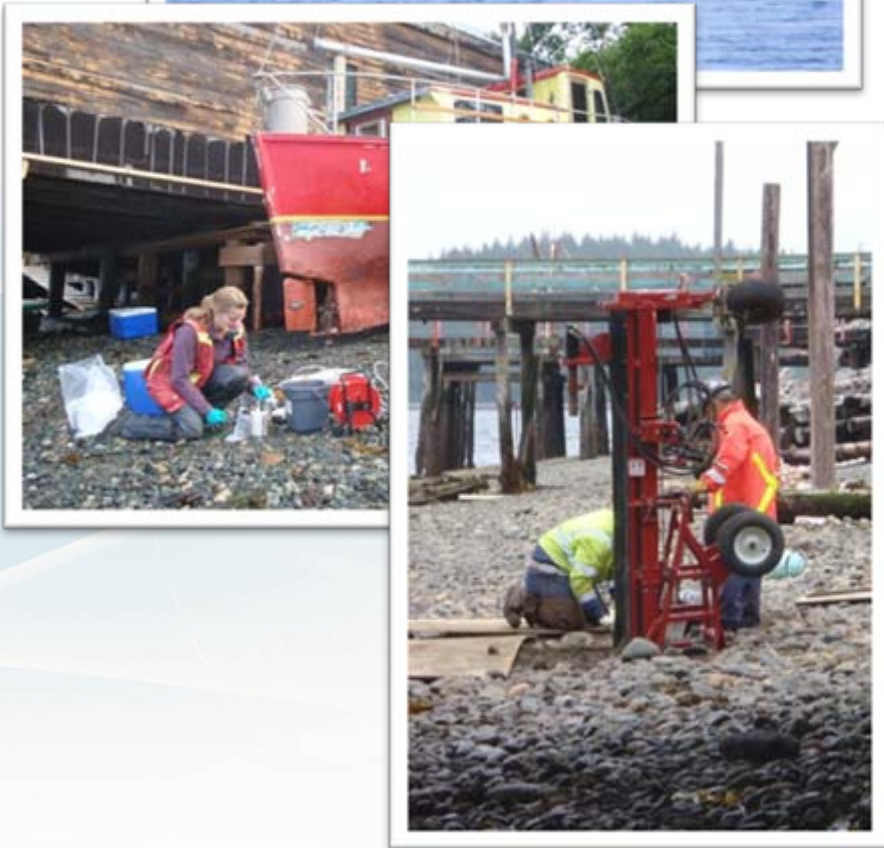


# **Tidal Implications For Development of a Risk Management Program in a Coastal Environment**

Erin Robson, M.Eng., P.Eng. and Ian Mitchell, M.Sc., P.Geo.

21/10/2010



# Outline

- Goals / Objectives
- Site Description
- Previous Environmental Investigations
- Regulatory Framework and Literature Review
- Scope of Assessment
- Results of Investigation
- Results of Ongoing Risk Assessment
- Conclusions – path forward

# Goals of the Risk Management Program

- Obtain a solid understanding of existing contamination
- Ensure that human health and ecological risks are acceptable
- Identify options for remediation and/or risk management of contaminants
- Develop and Implement Remediation Action Plan and Risk Management Plan

# Risk Assessment - Approach

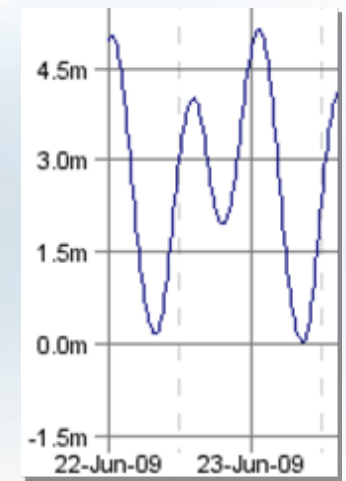
- Primarily following BC MOE guidance; CCME, Health Canada, and US EPA guidance also consulted
- Using site-specific information and weight of evidence approach
- Current site conditions, pathways to receptors and effects characterized using information obtained as part of 2009 and 2010 investigations, including:
  - Additional delineation of contaminant plume
  - Vapour assessment
  - Characterization of tidal influence
  - Characterization of permeability
  - Evaluation of LNAPL mobility
  - Collection of concurrent sediment samples for chemistry, toxicity and benthic community structure assessment
  - Assessment of intertidal macro-invertebrate community, and
  - Assessment of direct human exposure pathways

# Site Layout



HIGH TIDE MARK

LOW TIDE MARK



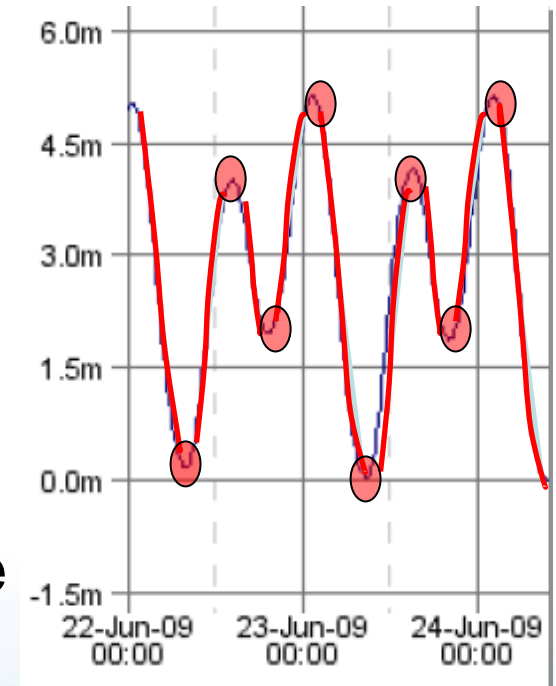
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# Tide cycle - definitions

- **Intertidal Zone** – the foreshore area between the low-tide and high-tide lines
- **Mixing Zone** – the zone in which seawater and fresh land-based groundwater mix within the foreshore sediments of the intertidal zone
- **Tide Cycle** – the rise and fall of sea levels due to the rotation of the Earth and the gravitational forces exerted by the Moon and the Sun. The tides occur with a period of approximately 12.5 hours.

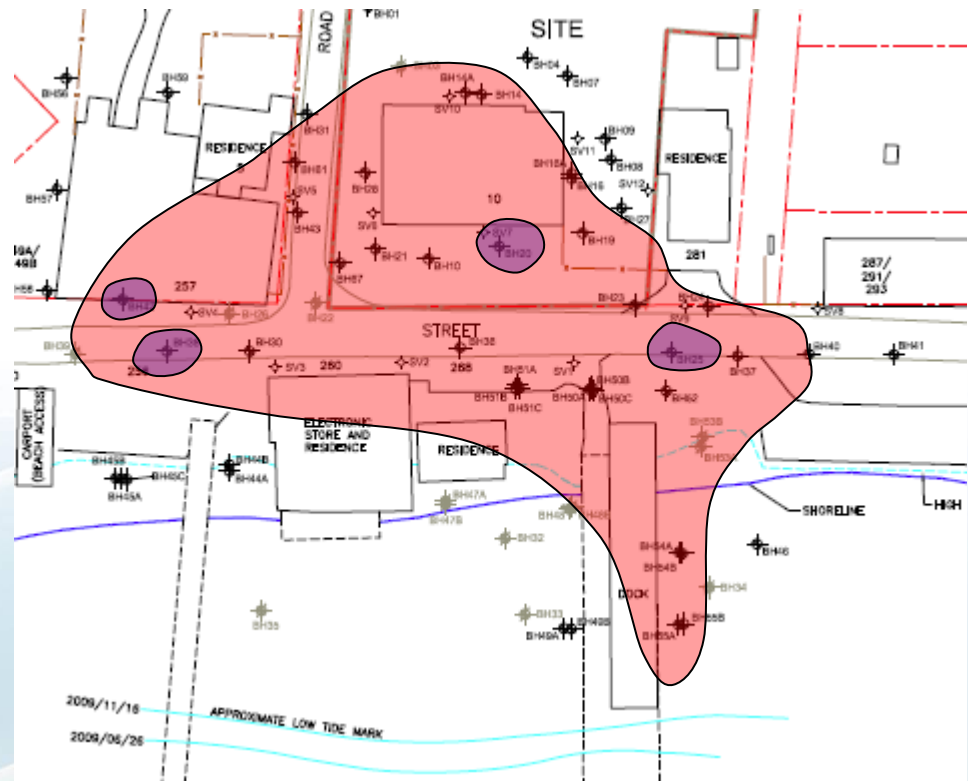
# Tide cycle – 4 stages

- **Ebb Tide** – time within the tide cycle when the sea level is falling, exposing the intertidal zone (also called falling tide)
- **Flood Tide** – time within the tide cycle when the sea level is rising, covering the intertidal zone (also called rising tide)
- **Low Tide** – the point when the tide water has fallen to its lowest level within the tide cycle
- **High Tide** – the point when the tide water has risen to its highest level within the tide cycle



# Previous Investigations

- Investigated in stages since mid-1990's
- Irregular shaped dissolved diesel contaminant plume with "finger" into foreshore
- Intermittent Light Non-Aqueous Phase Liquid (LNAPL), free-phase diesel (none on foreshore)
- Uniform soils but potential preferential pathways and potential tidal influence not fully understood
- Limited data on the foreshore





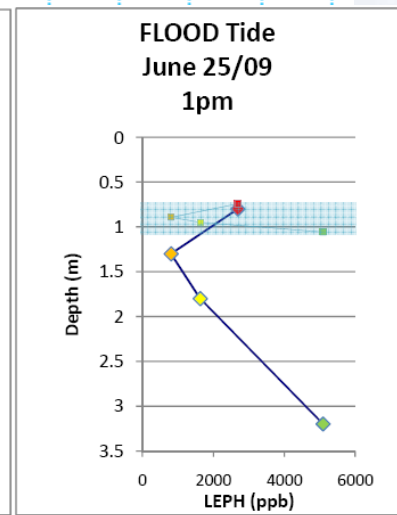
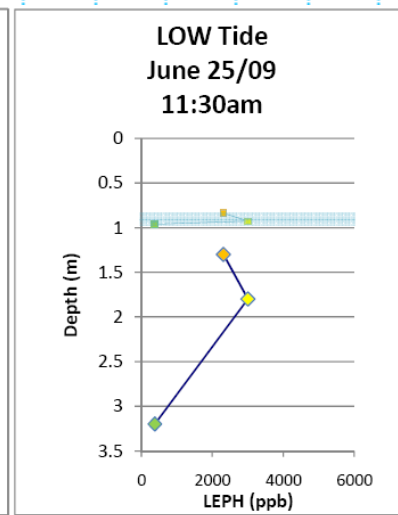
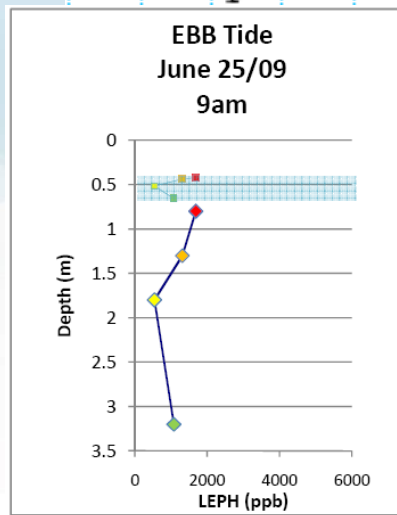
# 2009 Site Investigation Objectives

## Long term:

- Validate exposure concentrations for Risk Assessment and Risk Management

## Short term:

- Evaluate and predict how groundwater chemistry changes under varying tidal conditions
- Assess if contaminant loadings to the foreshore are greater during specific seasons and tides



# British Columbia Regulatory Changes

- BC Ministry of Environment (MoE) has developed 3 new protocols relating to LNAPL and risk classification
- Under these new protocols the site would be classified as “high risk” based on two defined conditions under which LNAPL is considered to be mobile:
  - Measureable LNAPL >2mm is present over an area of at least 50m<sup>2</sup>; and
  - Seasonal water table fluctuations exceed 1 metre
- Observational data can be collected to obtain an exemption from these conditions and thus lower the risk classification
- Lower risk classification = More flexible site management and less cost to client
- Theoretical LNAPL mobility assessment provides an additional line of evidence of LNAPL stability

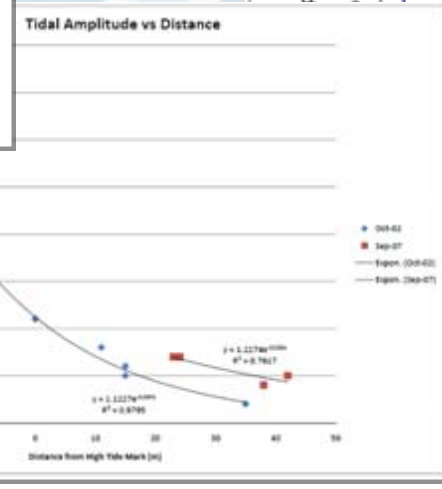
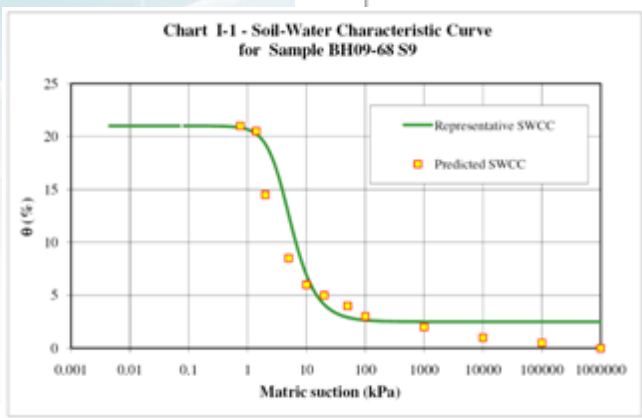
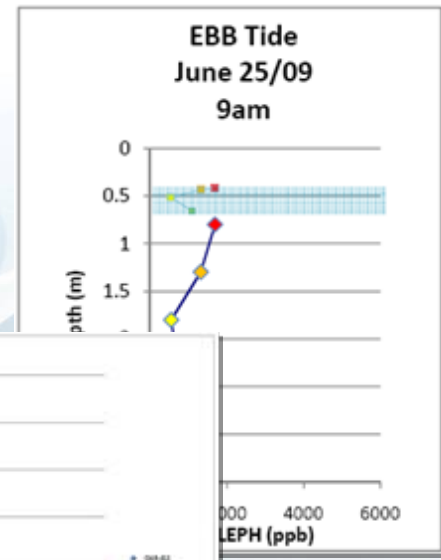
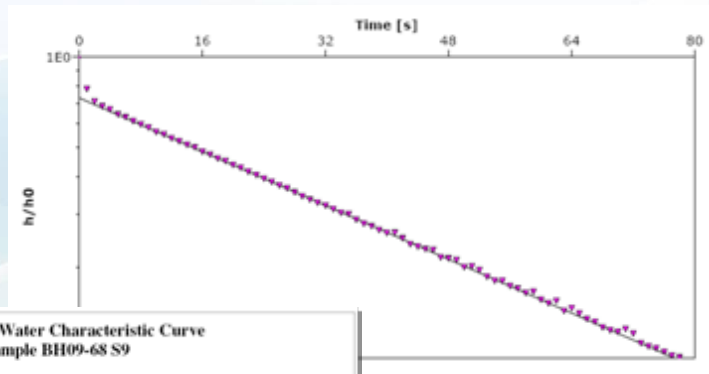
# Literature Review – Numerical Tidal Model

Quantitative analysis of seabed mixing and intertidal zone discharge in coastal aquifers, Roudrajit Maji and Leslie Smith

- Key concepts allowed understanding of tidal effects at our site
  - Groundwater discharge in intertidal >> submarine discharge
  - Majority of intertidal discharge is re-circulated seawater
  - Localized and transient recharge and discharge sites due to density-driven convective circulation in the sediments
  - Spatial and temporal variation in contaminant loading rates can be significant
  - Contaminants discharge via a seepage face above the tide
  - Peak loading rates tend to occur mid tide on the falling tide

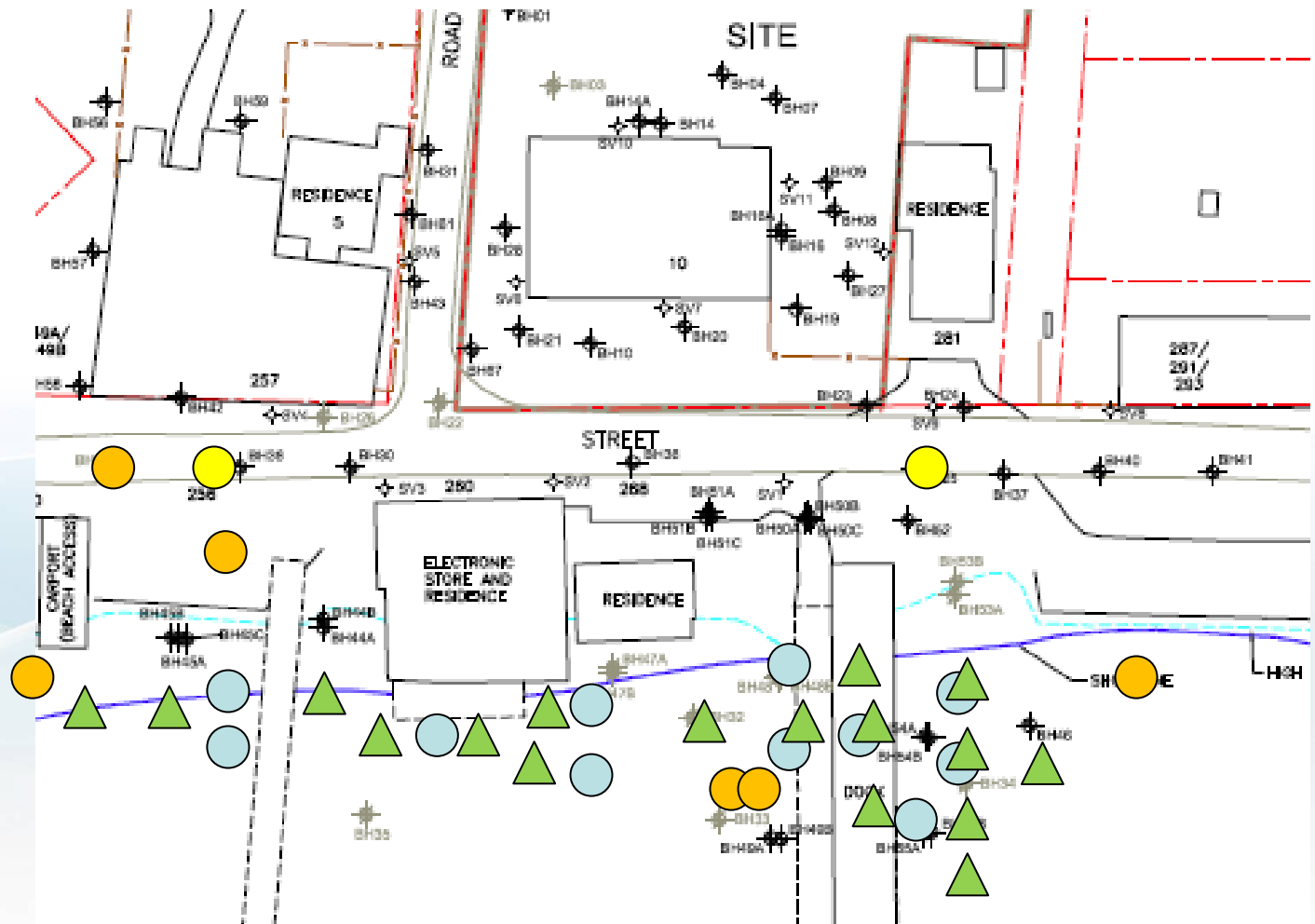
# Hydrogeological Assessment

- Sediment porewater profiling
- Correlation of groundwater chemistry to tide cycles
- Permeability / preferential pathway assessment
- LNAPL mobility assessment



# Scope of Intrusive Investigation

- Monitoring Well (6)
- Multilevel Sampler (11)
- LNAPL Assessment Borehole (2)
- Hand Dug Pore water Sampling Pit (17)



# Challenges

- Time is of the essence when working in the intertidal zone!

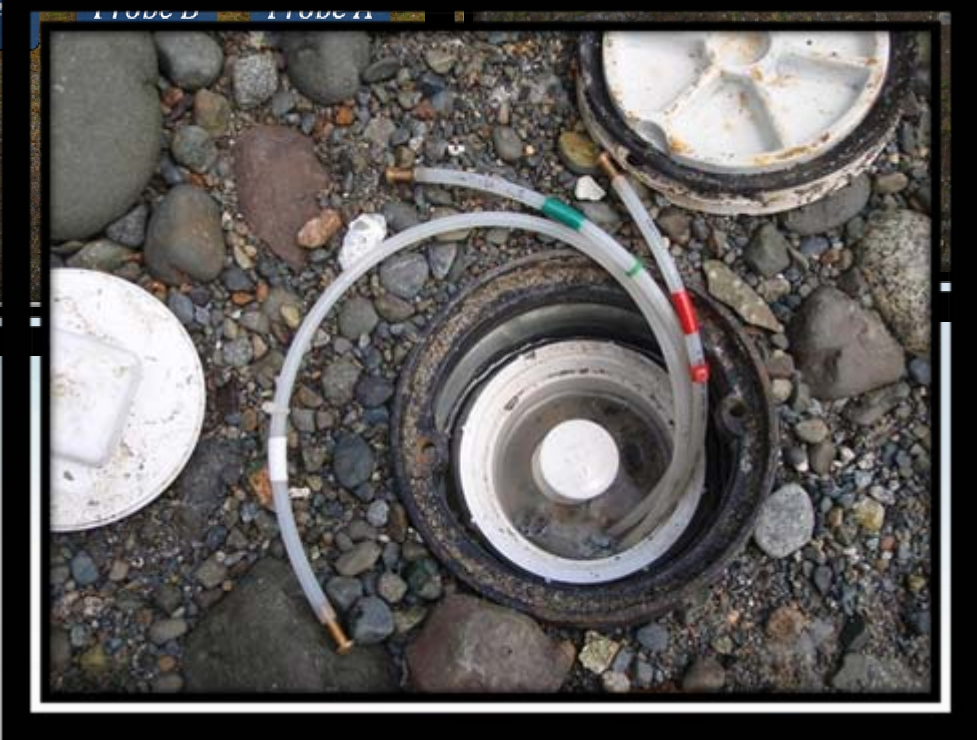


# Challenges

- Even with a small rig, limited beach access called for creative solutions

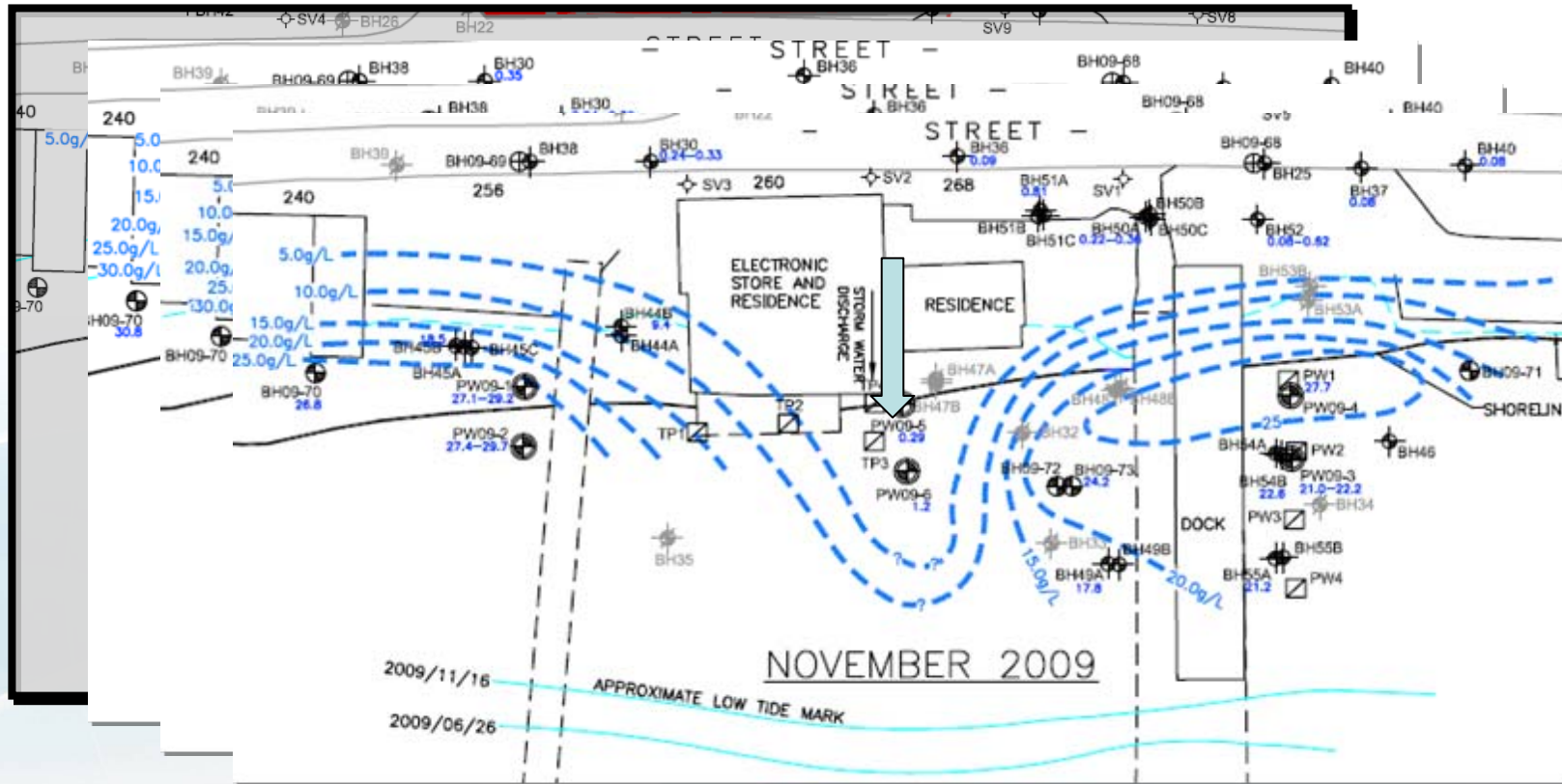


# Multilevel groundwater samplers designed



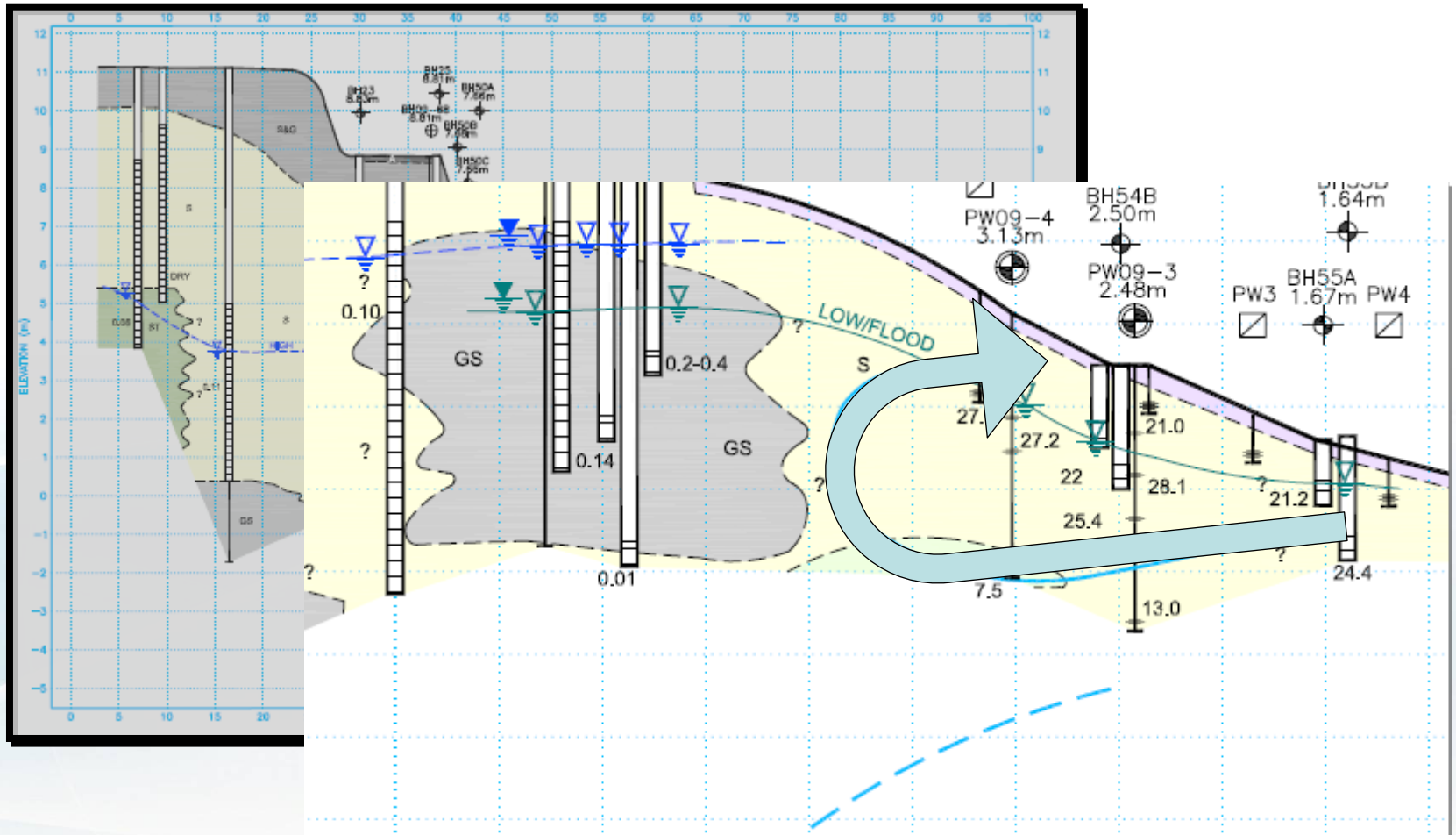


# Extent of tidal influence inland



**Salinity Contours  
(Seawater ~ 32 g/L)**

# Saltwater/Groundwater mixing zone

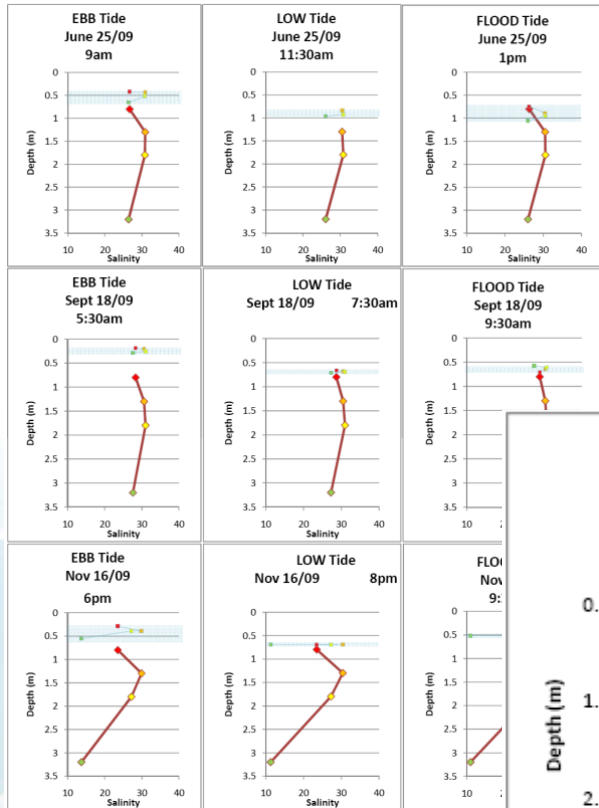


# Multi-level groundwater sampler results

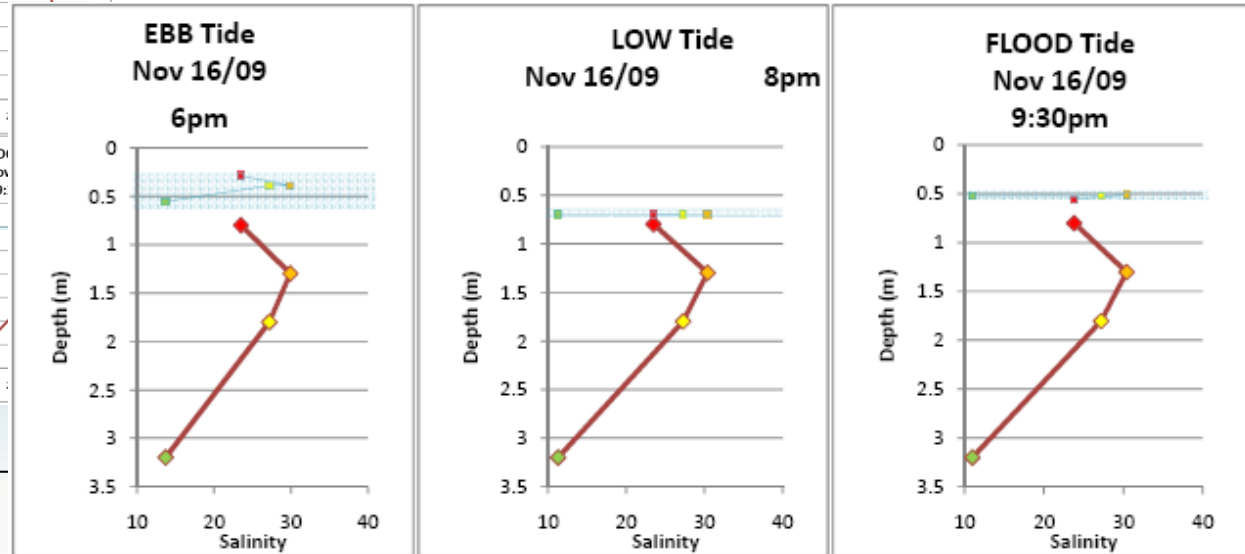
## Salinity Profiles

- Consistent throughout tide cycle
- Not affected by height of water
- Relatively consistent June vs Sept
- Salinity much lower at depth in Nov

Depth

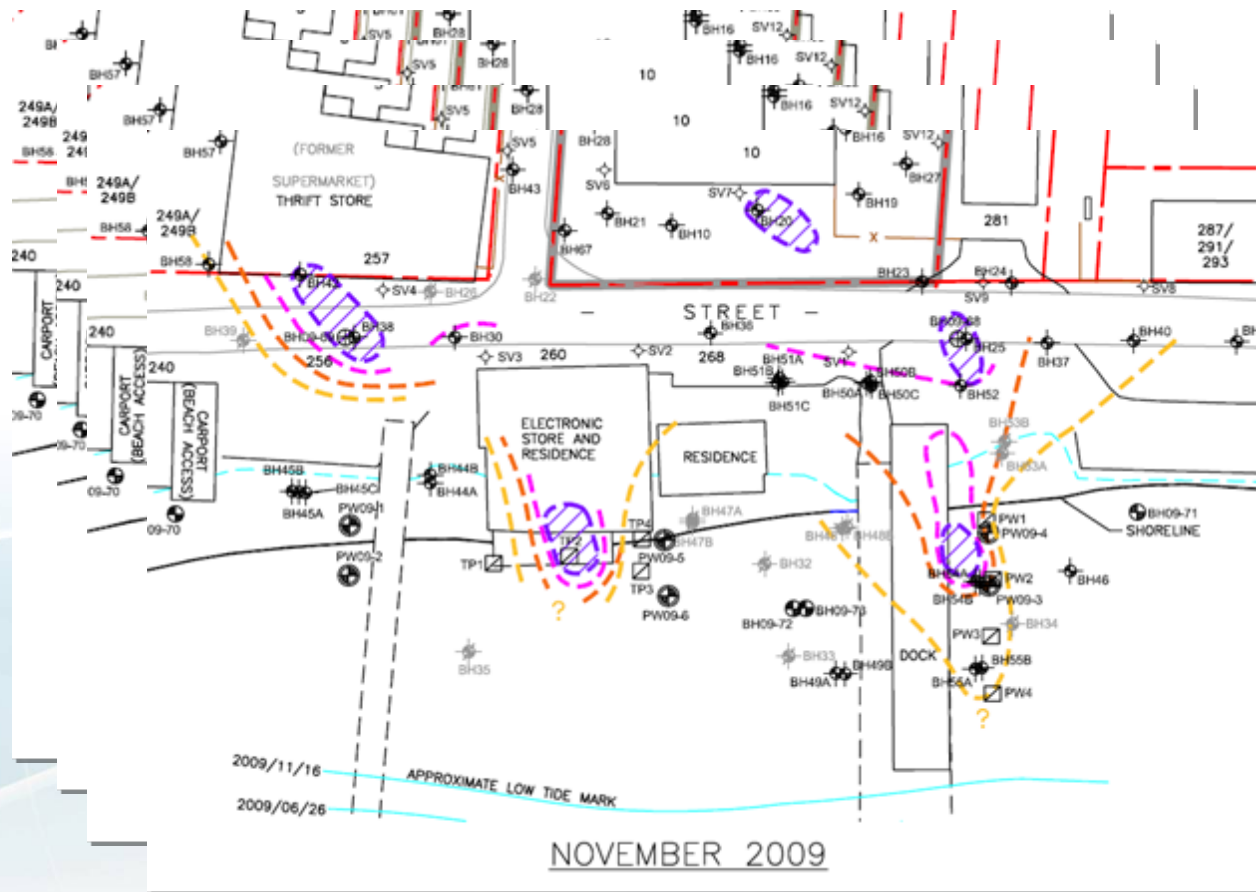


Concentration



—●— Salinity (g/L)      —■— Depth to Water (m)

# Seasonal LNAPL Distribution



- 20mm LNAPL within contaminant finger
- LEPHw indicative of LNAPL in central intertidal

500 - - - - - 500 ug/L LEPHw

2000 - - - - - 2000 ug/L LEPHw

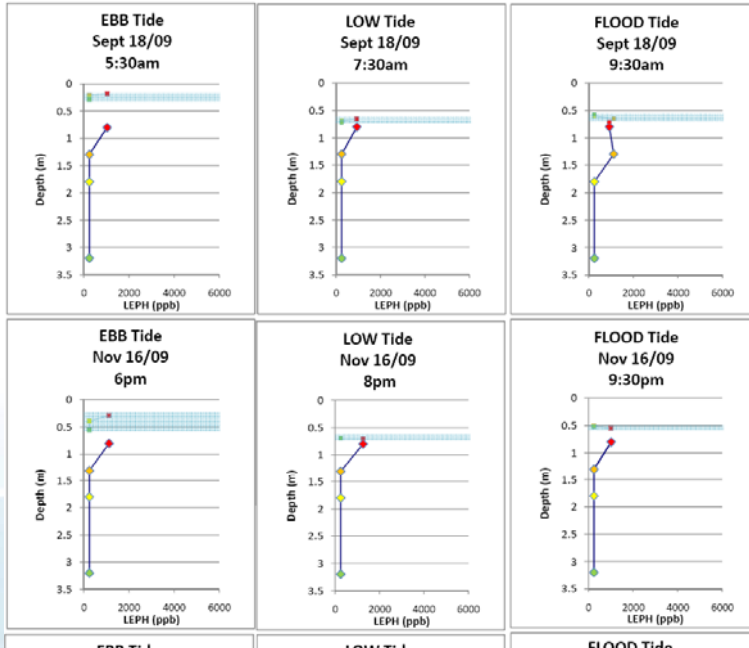
5000 - - - - - 5000 ug/L LEPHw



LNAPL OR CONCENTRATIONS OF LEPH INDICATIVE OF LNAPL

# Multi-level groundwater sampler results

Depth

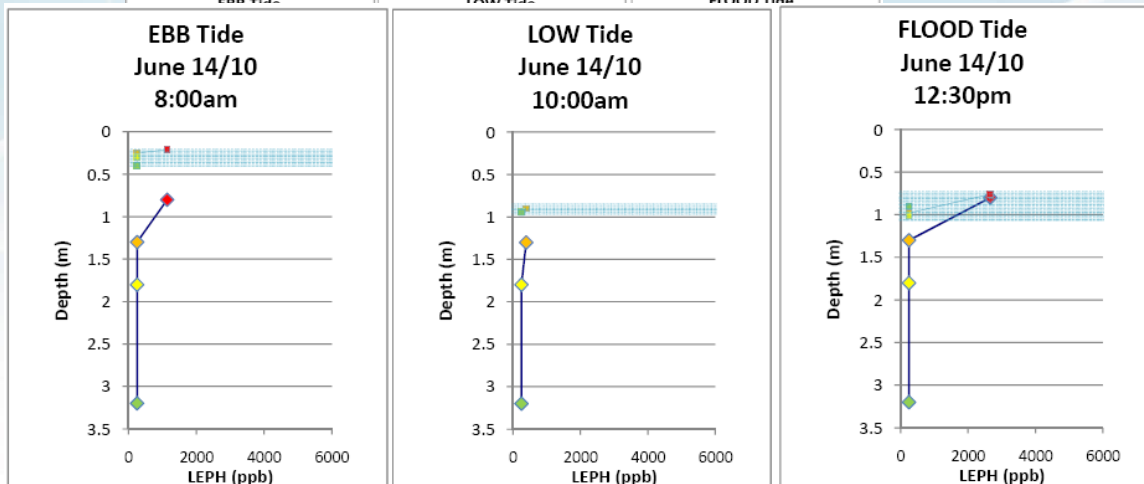


## LEPHw Profiles

- Consistent over tide cycle during Sept and Nov events

- Highest concentrations in June on Flood tide

- Concentrations not as high as adjacent hand dug pits or shallow monitoring wells

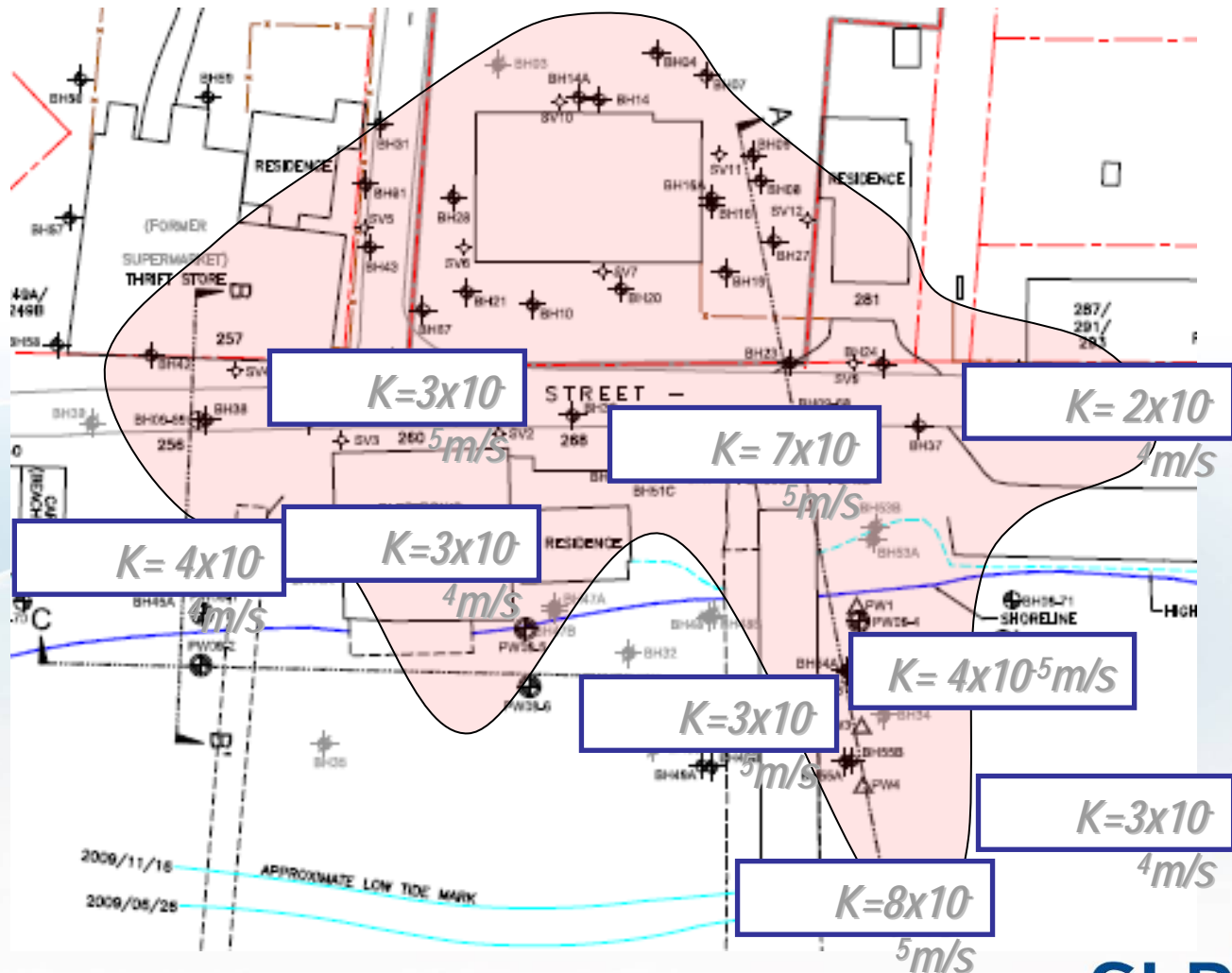


◆ LEPH (ppb)      ◆ Depth to Water (m)

# Groundwater Contaminant Trends

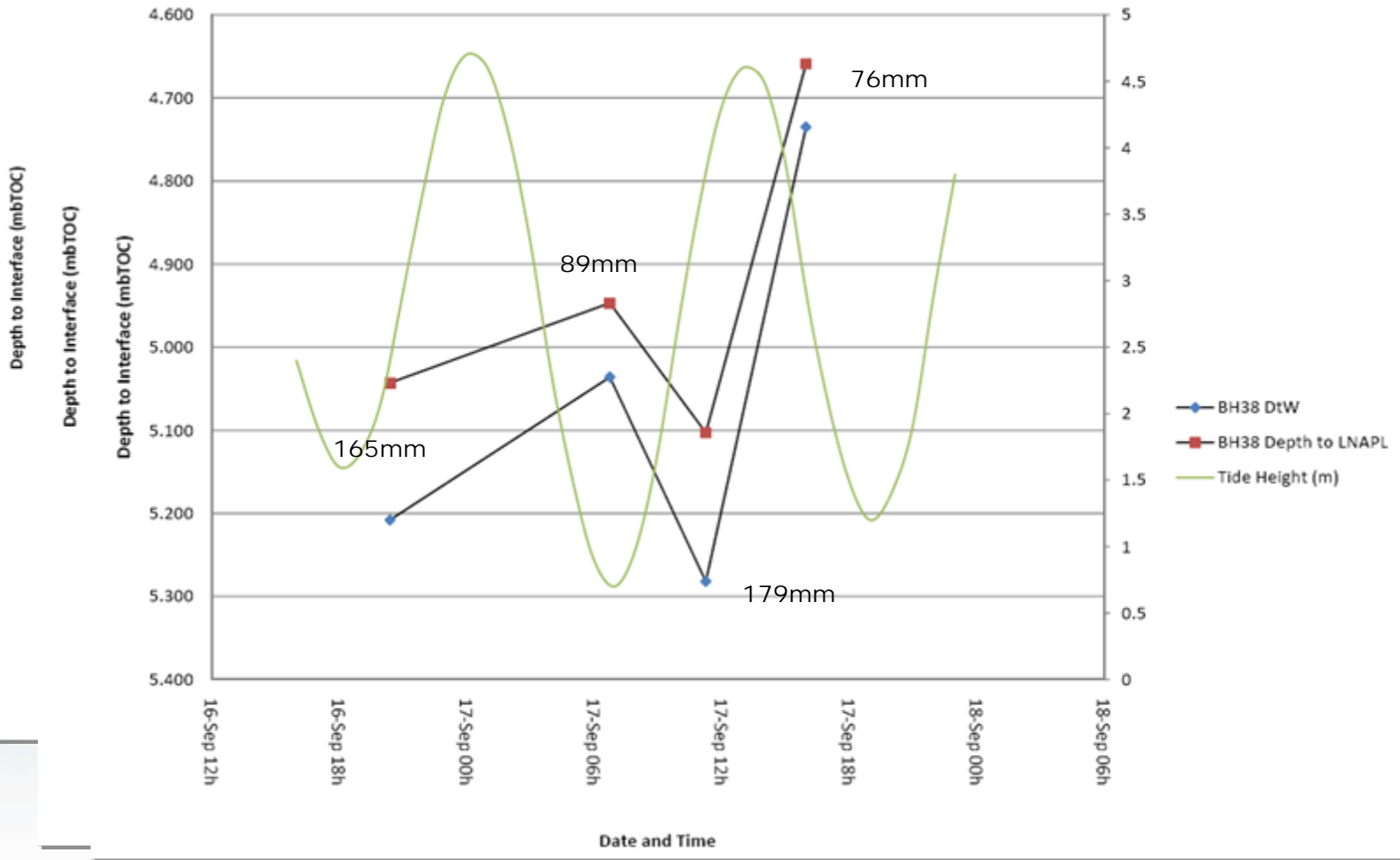
- Highest concentrations in June on the flood tide, in both the intertidal zone and the uplands (dry season and extreme low tides)
- Variability observed over the tide cycle with depth demonstrates the need for tidally correlated data
- Free-phase LNAPL (or concentrations indicative of) only observed in hand dug pits or monitoring wells which intercepted the water table – results from 2009 multi-level profiling points were lower (in 2010 shallow monitoring wells installed as part of multi-levels)

# Permeability vs Contaminant distribution



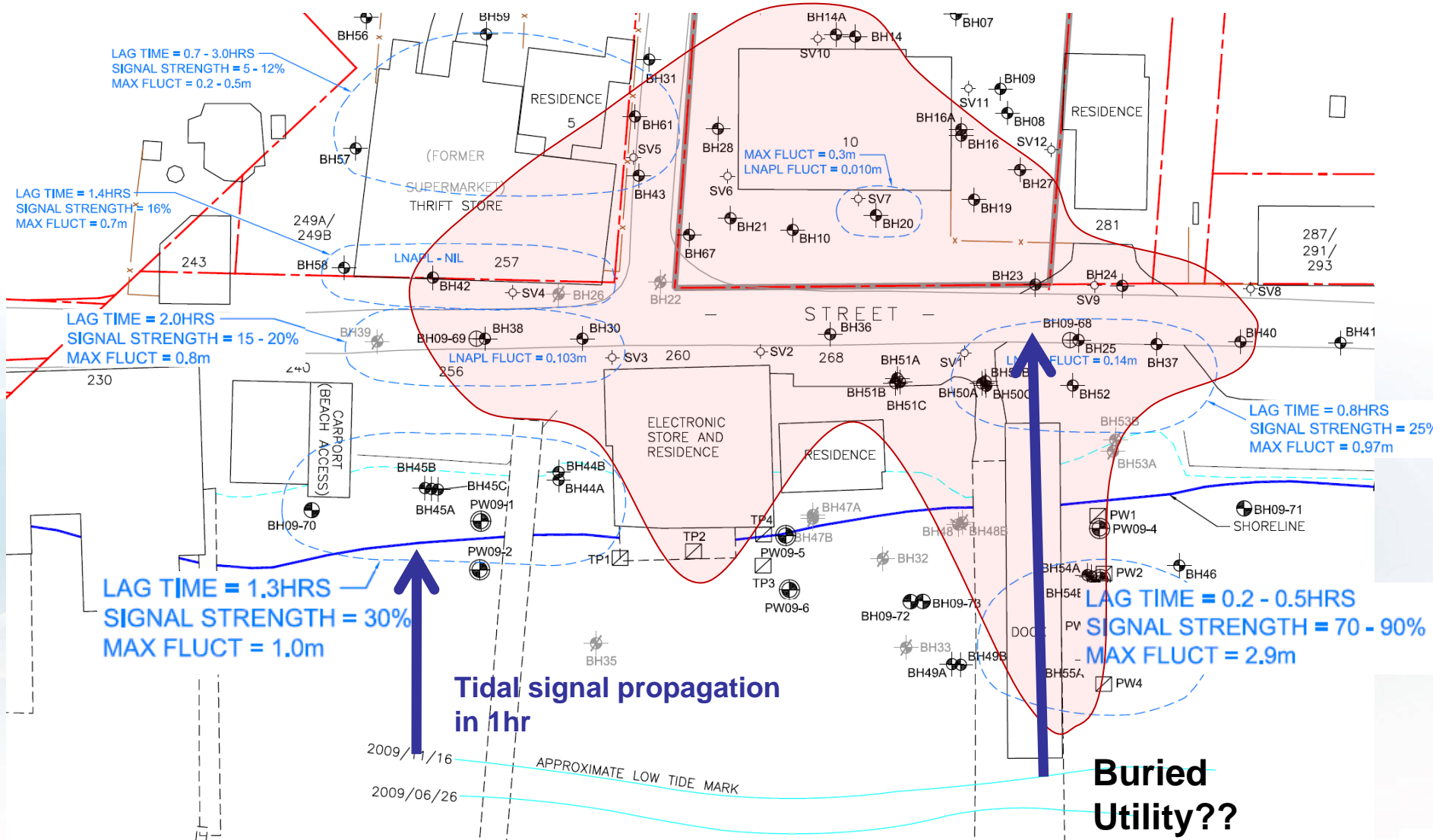
# Effect of Tides on LNAPL Thicknesses

BH20 - LNAPL FLUCTUATIONS WITH TIDE CYCLE  
 BH25 - LNAPL FLUCTUATIONS WITH TIDE CYCLE  
 BH38 - LNAPL FLUCTUATIONS WITH TIDE CYCLE

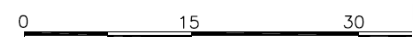




# Inland Tidal Signal Strength and Lag Times



THIS DRAWING IS FOR CONCEPTUAL PURPOSES ONLY. ACTUAL LOCATIONS MAY VARY AND NOT ALL STRUCTURES ARE SHOWN.

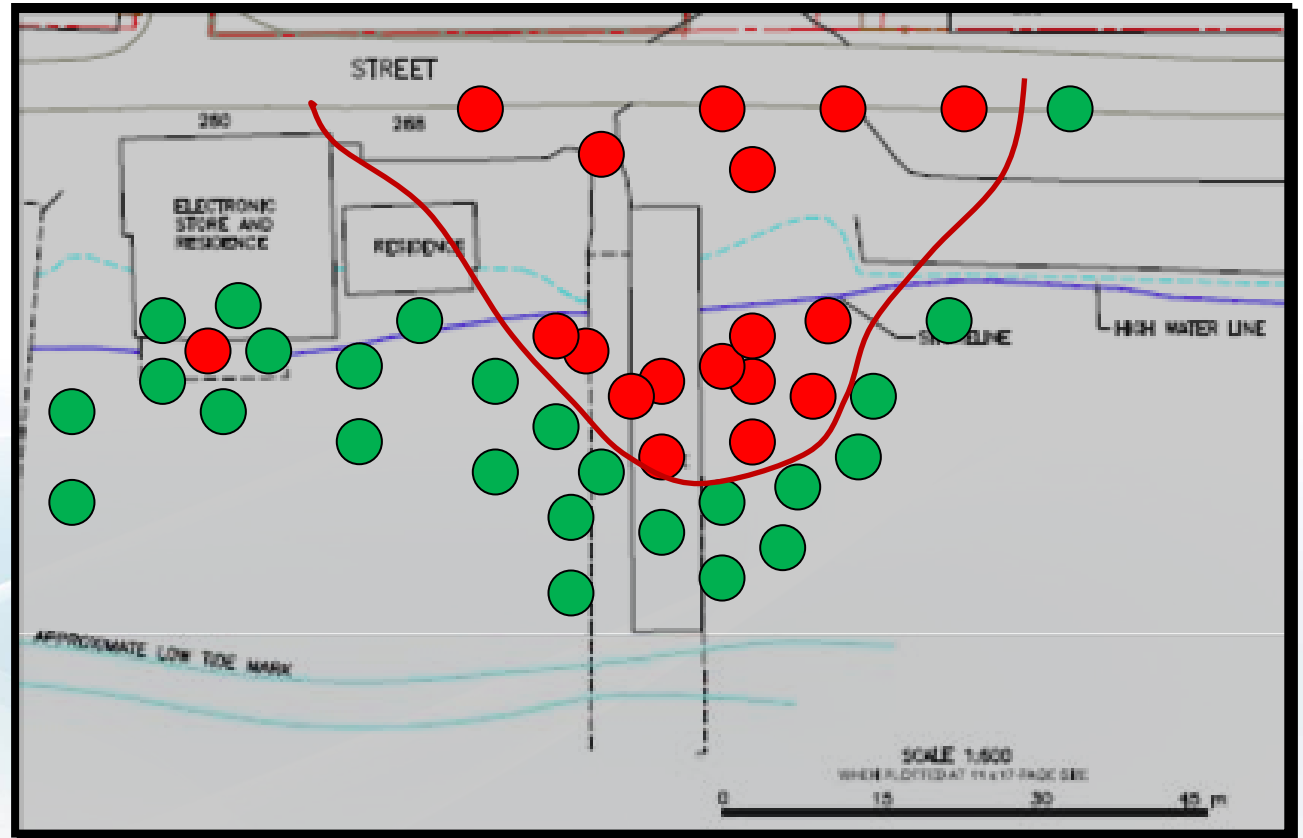


# LNAPL Mobility Assessment

- Mobility was assessed at two locations where maximum LNAPL thickness was 0.32m and 0.21m respectively
- Local-scale mobility should occur only at LNAPL thicknesses exceeding 1.5m and 0.4m respectively, i.e., Local-scale LNAPL mobility is unlikely
- Plume-scale mobility calculated using the API LNAPL mobility assessment tool predicted that the plume is not likely mobile

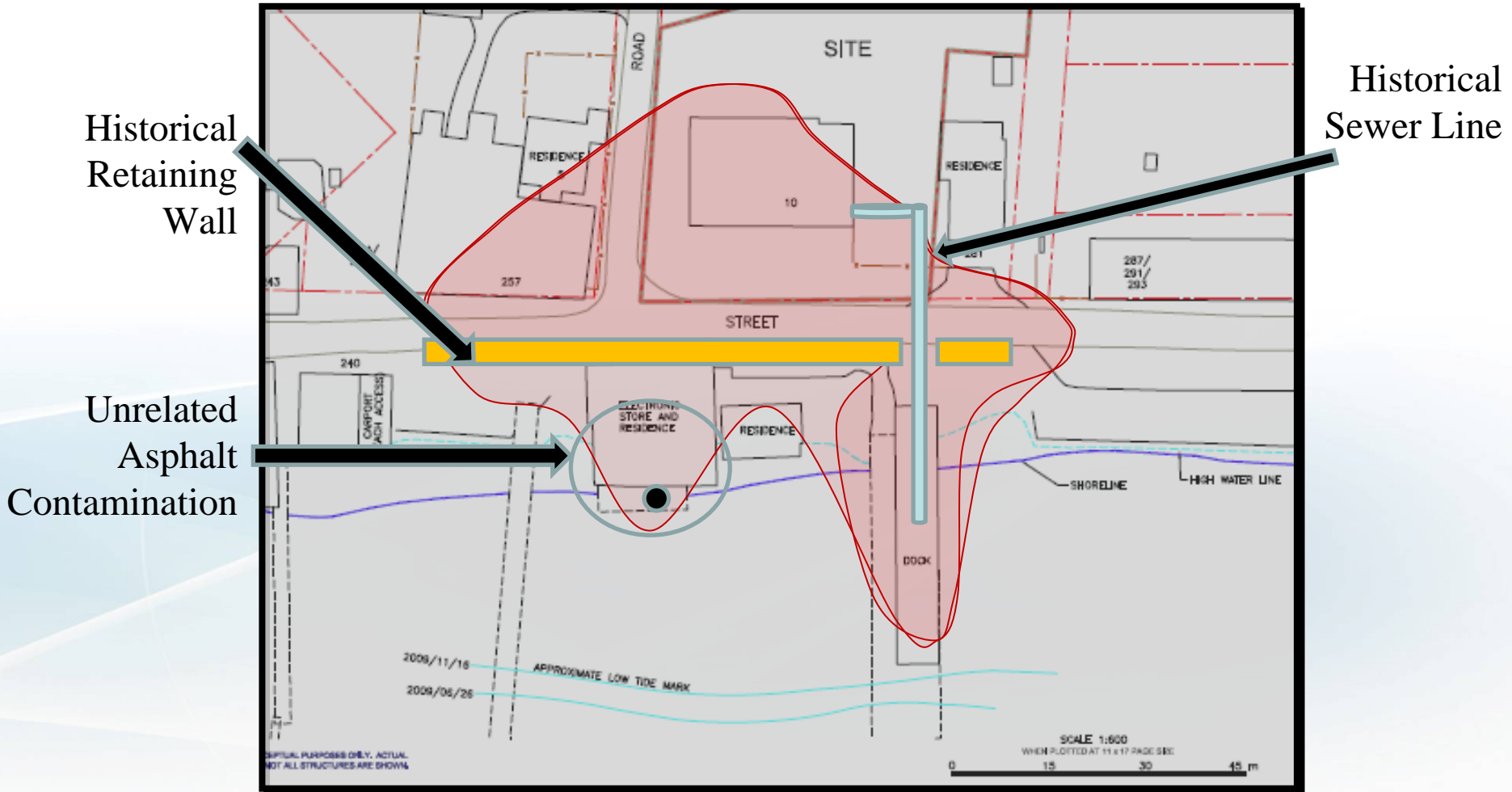
# Plume Delineation in Intertidal – Soil

- Soil Conc'n Exceeds Provincial Standards
- Soil Conc'n Less than Lab detection



**Results consistent with previous investigations but plume resolution improved at the scale required for risk assessment**

# Re-Interpretation of Results



# Reading between the tides...

- Separate-phase LNAPL present on the east side of the intertidal zone
- Peak LNAPL thicknesses following low tide
- Propagation of tidal signal supports potential preferential flow on the east side of the intertidal zone
- Forensic assessment indicated contamination in central area unrelated / disconnected
- Stage 1 updates and forensic assessment indicate likely migration of plume along old sewer line and around edge or break in historical retaining wall
- LNAPL mobility is low

# Measuring Peak Contamination

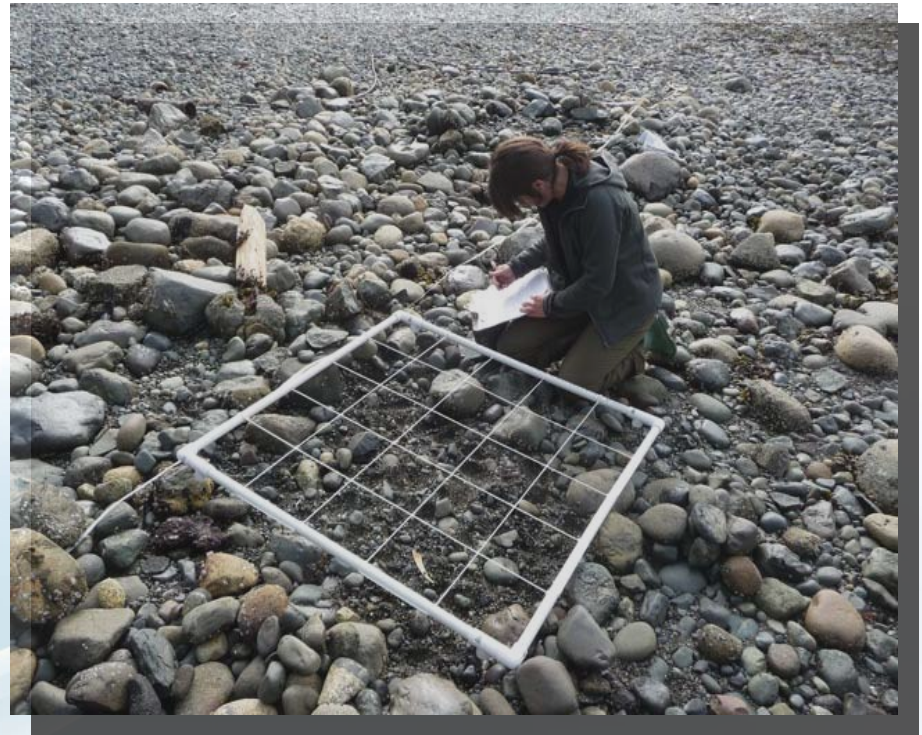
- There are specific tide heights and seasons when monitoring and sampling provides “worst case” conditions for developing risk assessment exposure concentrations:
  - LNAPL and dissolved phase concentration monitoring at low water (low tide + lag time)
  - Contaminant loading rates best measured at mid tide on the falling tide, just after the LNAPL contaminant area is exposed by the receding tide water
  - Dry season is the most important period to collect data

# Risk Assessment Background

- Screening level human health and ecological risk assessments conducted in early 2000 needed to be revised/updated since:
- New regulatory standards and technical guidance were released
- LNAPL was found in the intertidal zone
- Contaminant pathways through the intertidal zone (and to receptors) were not well understood and characterized
- Tidal influence on contaminant concentrations had not been characterized until 2009-2010 investigation

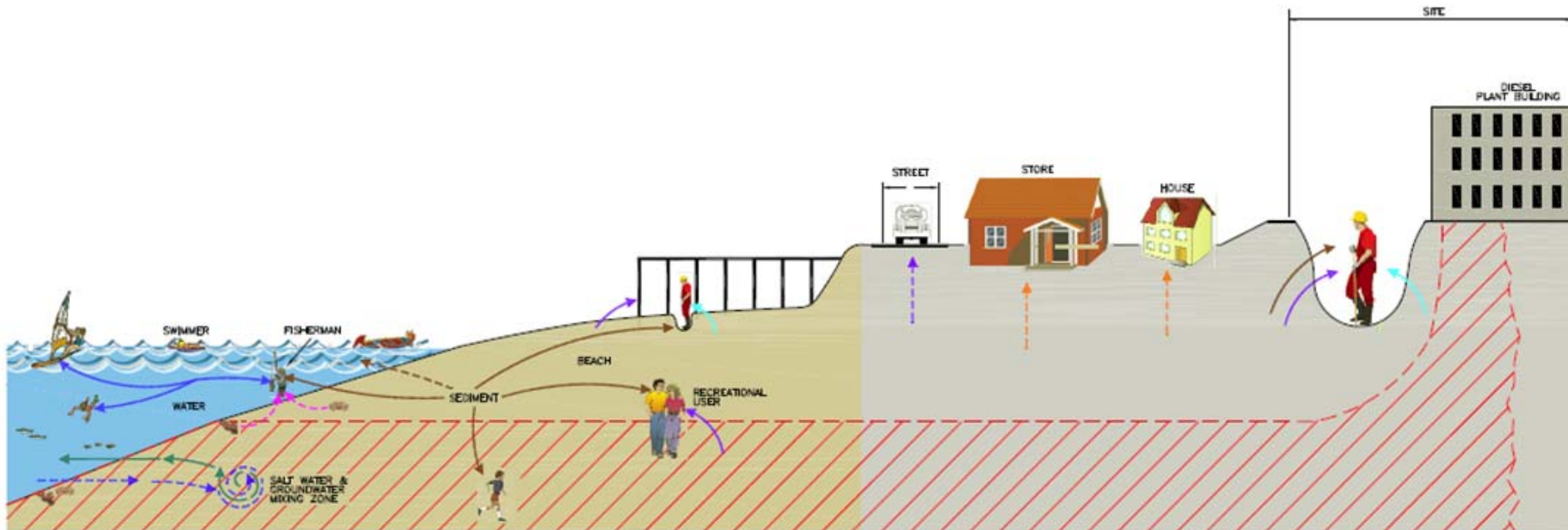
# Risk Assessment - Objectives

- Characterize and refine the environmental liability
- Identify areas requiring active remediation
- Support the selection/design of remedial actions





# Human Health Conceptual Model



## LEGEND

- LIMITS OF CONTAMINATION PLUME
- INGESTION OF SHELLFISH AND FISH
- EXPOSURE TO SEDIMENT OR SOIL (INCIDENTAL INGESTION, DERMAL CONTACT, INHALATION)
- EXPOSURE TO SURFACE WATER (INCIDENTAL INGESTION, DERMAL CONTACT)

- EXPOSURE TO GROUNDWATER (DERMAL ABSORPTION)
- INHALATION OF INDOOR AIR
- INHALATION OF OUTDOOR AIR
- SALT WATER

## NOTES

1. SOLID ARROW MEANS THE PATHWAY IS COMPLETE AND QUANTITATIVE ASSESSMENT OF RISK IS WARRANTED
2. DASHED ARROW MEAN THE PATHWAY COULD THEORETICALLY BE COMPLETE, HOWEVER THERE IS A LOW LIKELYHOOD OF EXPOSURE. EXPOSURE WOULD BE INFREQUENT OR DOSE FROM EXPOSURE WOULD BE VERY LOW. QUALITATIVELY SPEAKING IT LIKELY POSES A LOW LEVEL OF RISK.



# Ecological Risk Assessment – Overview of Findings

## Toxicity:

- Bioassay tests included:
  - 10-d amphipod, *Eohaustorius estuarius* (Endpoint: Survival);
  - 10-d mysid, *Americanmysis bahia* (Endpoint: Survival);
- Sample collected in centre of plume with highest concentration of EPHs, LEPHs and HEPHs was acutely toxic. Samples collected from edge of plume and from local background exhibited marginal toxicity and did not cause any significant adverse effects.

# Ecological Risk Assessment – Overview of Findings

## Benthic macro-invertebrates assessment:

- The community composition encountered at the sampling stations was typical of the upper portion of the mid intertidal zone.
- The overall community within and outside the impacted area was characterized by low species diversity and was dominated by high numbers of periwinkles, limpets and shore crabs.
- There was no significant difference in species diversity in stations located within the contaminated area in comparison to the local background station.
- The location with the highest toxicity and contaminant concentrations in sediment had significantly lower abundance of purple shore crab and periwinkle populations.

# Conclusions - Path Forward

- **Risk Assessment:**

- Human Health impacts focused on evaluation of vapour exposure. Vapour risk to residents acceptable; further evaluation underway for recreational and construction worker scenarios.
- Ecological Impacts still under evaluation: acutely toxic effects appear to be localized and relatively shallow, overall population level effects appear unlikely

- **Risk Management strategy:**

- Results of ecological risk assessment will be used to derive options for addressing shallow sediment contamination
- Remediation measures anticipated to include shallow hot spot excavation of sediments and consideration of upgradient barrier
- Ongoing monitoring required to evaluate/confirm plume stability and potentially obtain release from MoE 'high risk' status.

# References

- Aquiver, Inc., 2004. *“API Interactive LNAPL Guide”*. American Petroleum Institute.
- BC MoE, 2009. BC Ministry of Environment. Draft Protocol 16: Determining the Presence and Mobility of Nonaqueous Phase Liquids and Odorous Substances.
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- Maji, R and L. Smith, 2009. *“Quantitative Analysis of Seabed Mixing and Intertidal Zone Discharge in Coastal Aquifers”*. Water Resour. Res., 45, W11401, doi:10.1029/2008WR007532.



**Thank You**  
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