Tidal Implications for Contaminant Delineation in a Foreshore Environment

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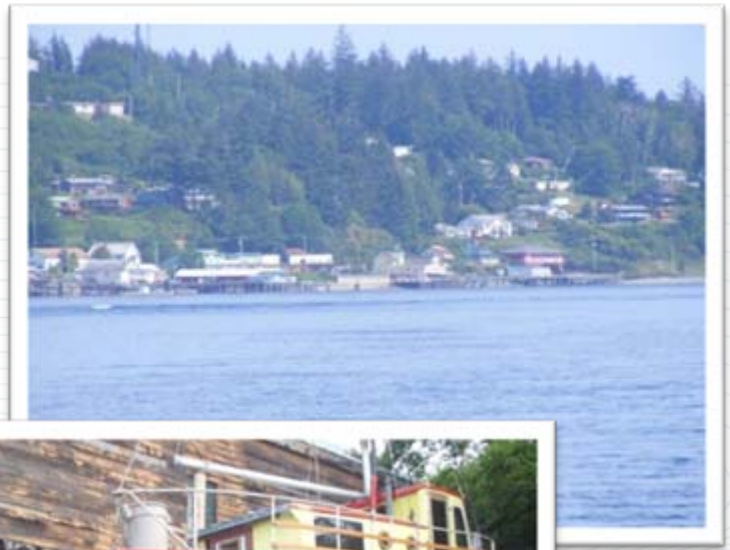

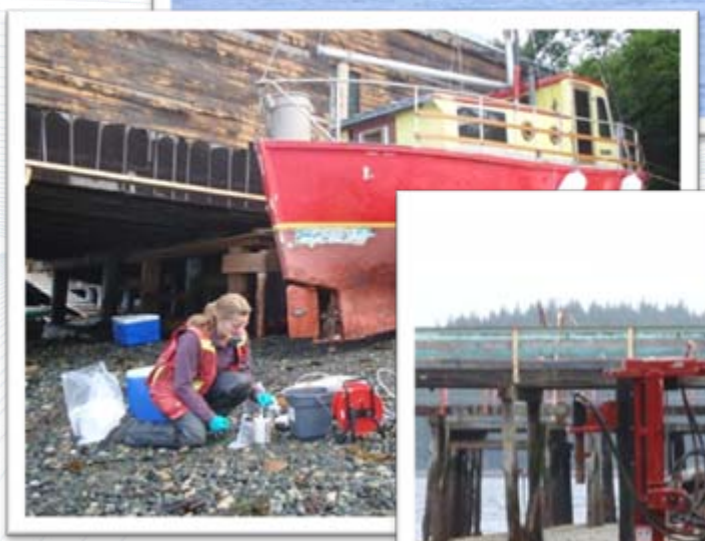

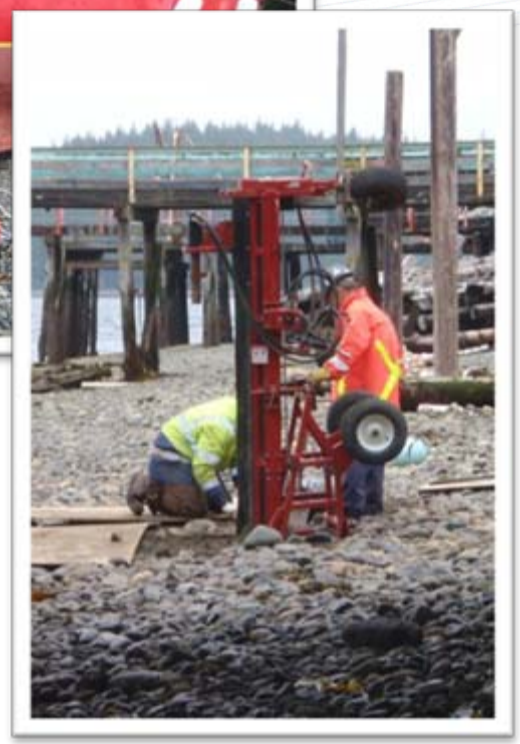

Outline

- Site Description and History
- Previous Environmental Investigations
- Regulatory Framework and Literature Review
- Scope of Assessment
- Challenges
- Results of Hydrogeological Investigation
- Conclusions

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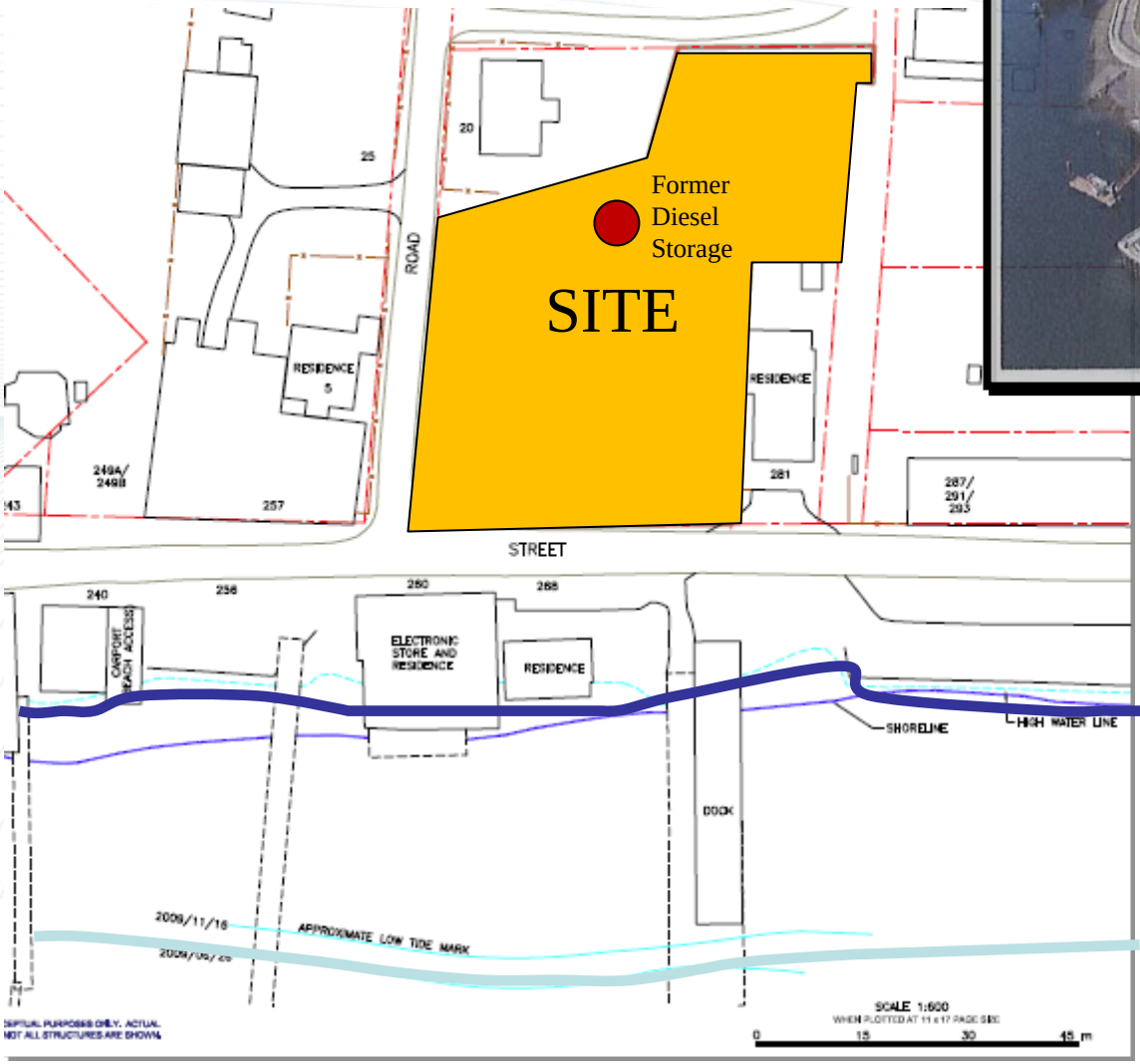
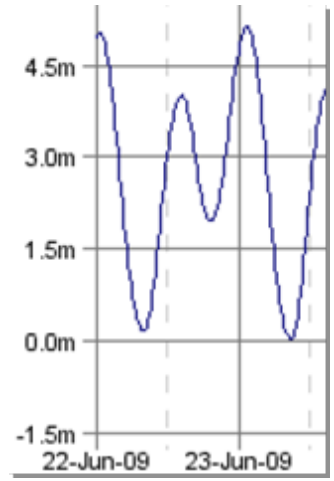
Site Layout



HIGH TIDE MARK

LOW TIDE MARK



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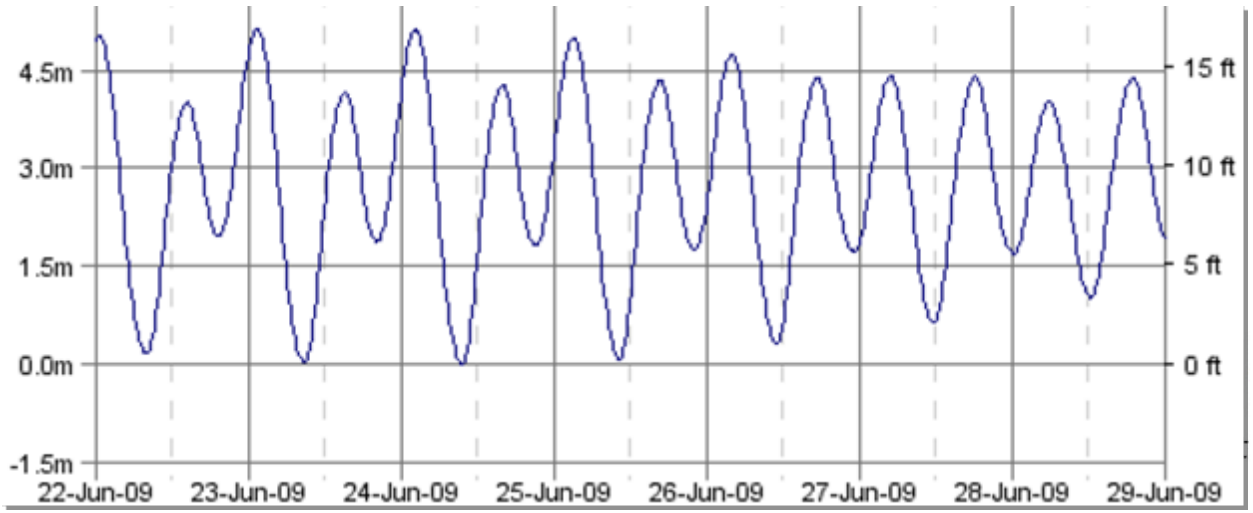
Tide cycle - definitions

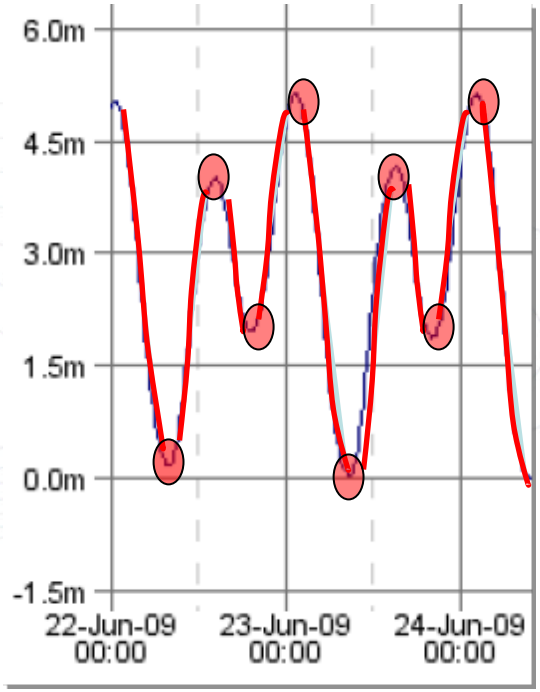
- **Intertidal Zone –** the foreshore area between the low-tide and high-tide lines
- **Mixing Zone –** the zone in which seawater and fresh land-based groundwater mix within the foreshore sediments of the intertidal zone
- **Salinity –** refers to the measured specific conductivity of groundwater samples converted to salinity, in grams per litre, using the Practical Salinity Scale

Tide cycle - definitions

- **Sea Water Interface –** the location of the interface between saline ocean water and the mixing 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

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Previous Investigations

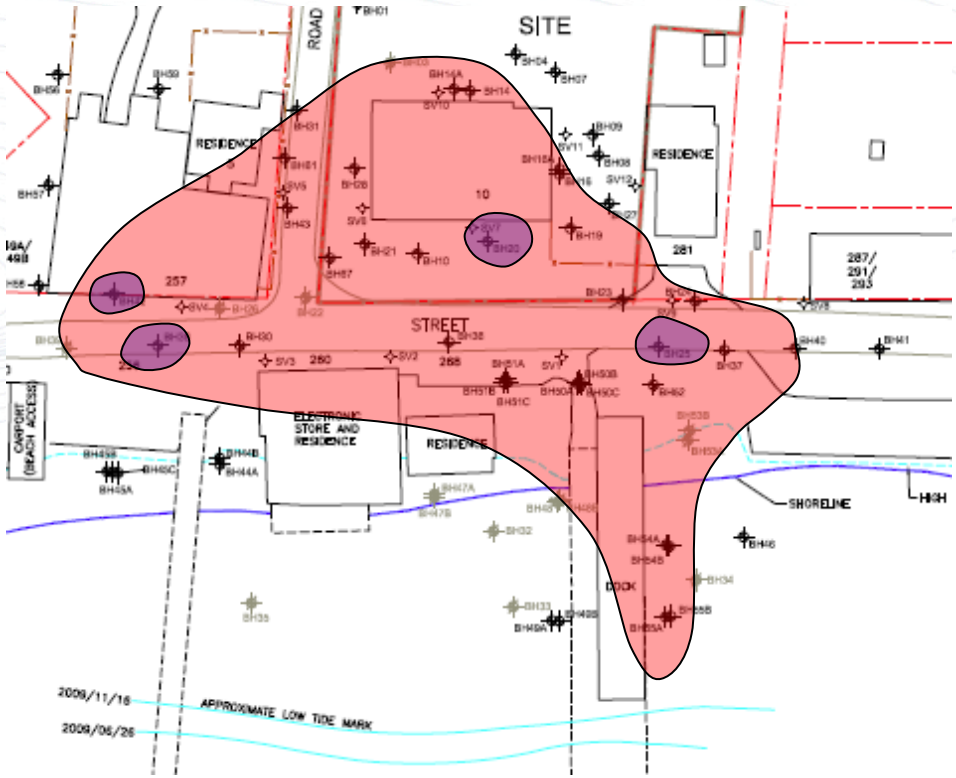
-Investigated in stages since mid-1990's

-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



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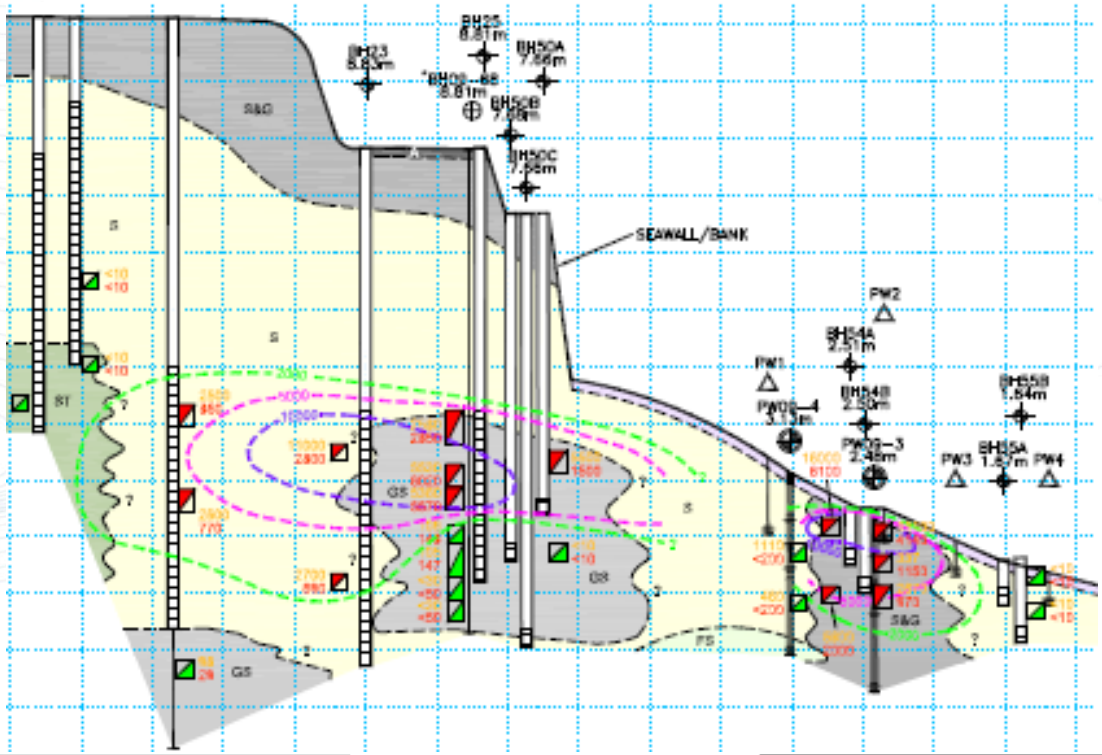
Objectives

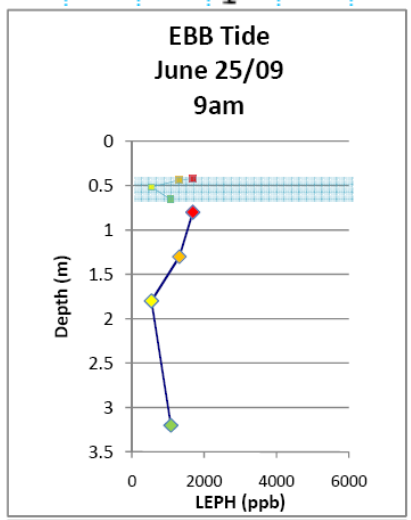
Long term: Validate exposure concentrations for Risk Assessment and Risk Management and move towards site closure

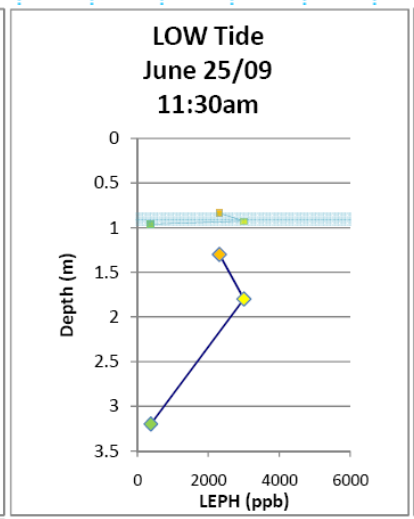
Short term:

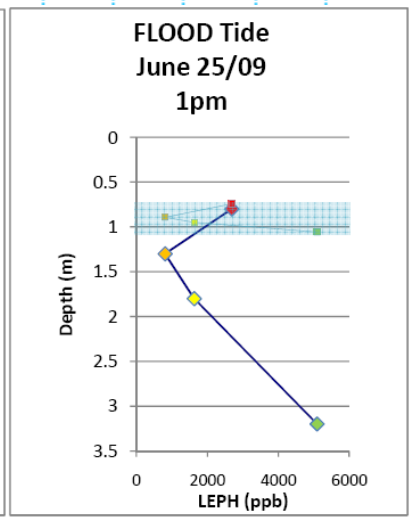
-Evaluate and predict how groundwater chemistry changes under varying tidal conditions

-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 is present over an inferred area of at least $10m^2$; 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

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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 recirculated 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

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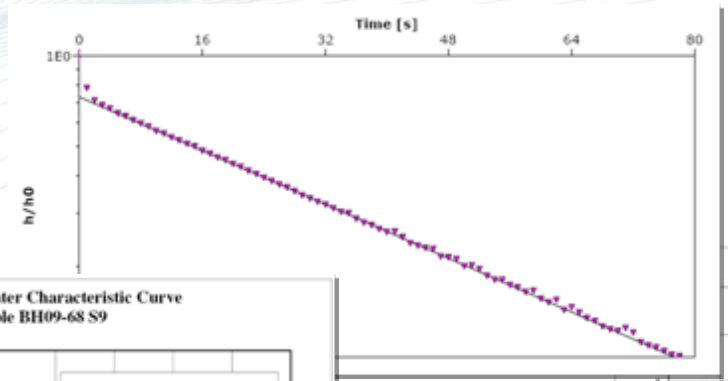
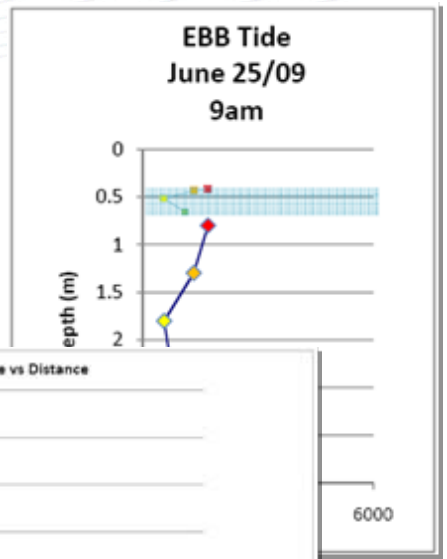
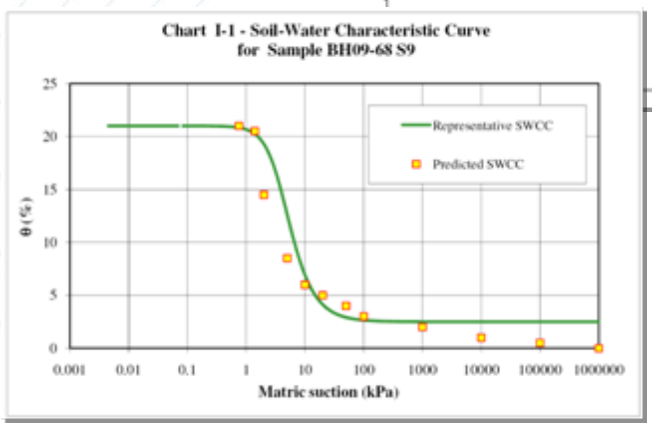
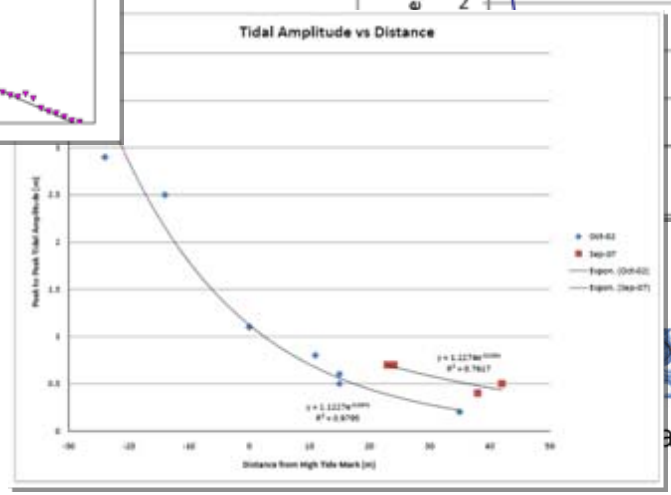
Hydrogeological Assessment

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









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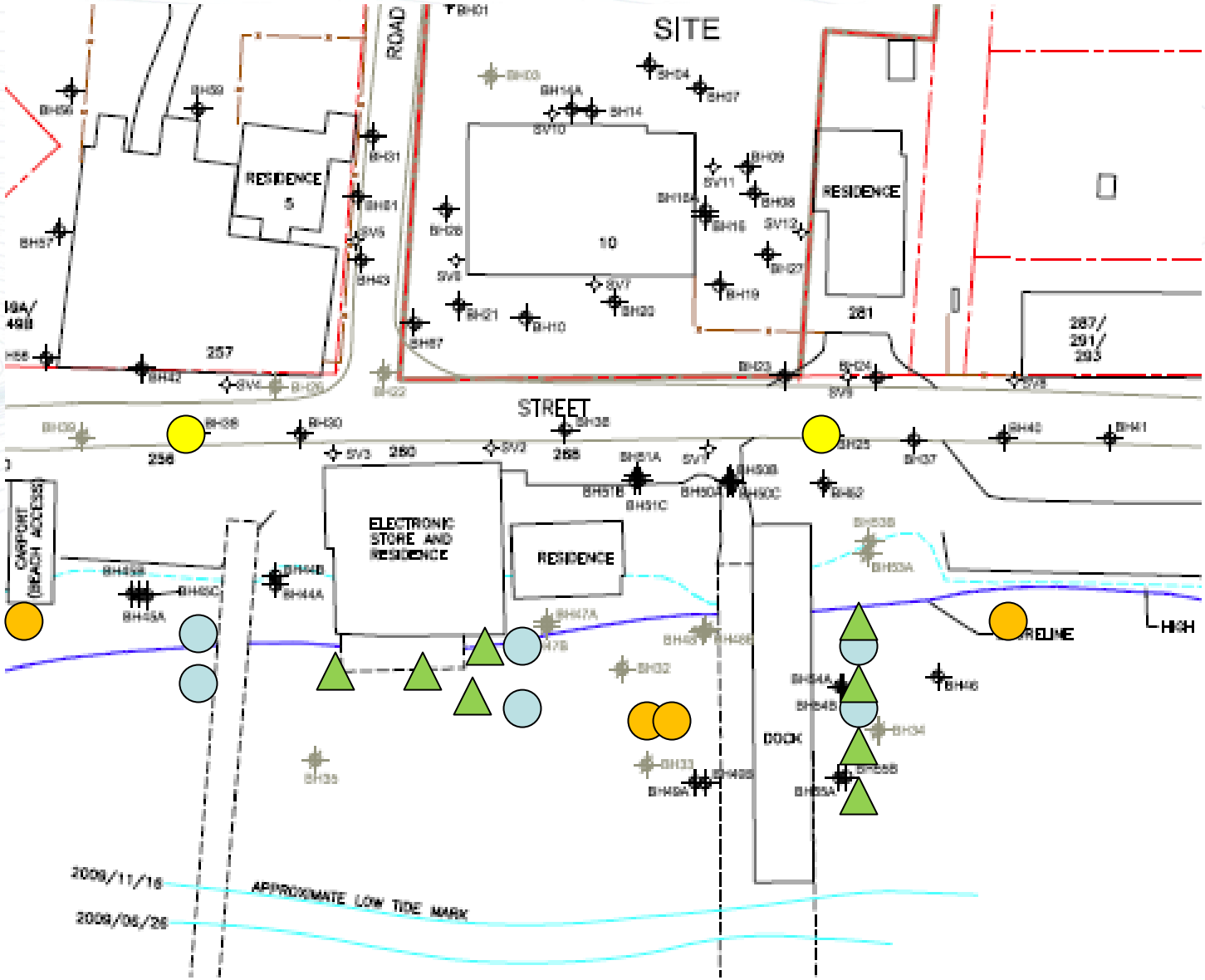
Scope of Intrusive Investigation

- Hand Dug Pore water Sampling Pit
- Monitoring Well
- Multilevel Sampler
- LNAPL Assessment Borehole



Challenges

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

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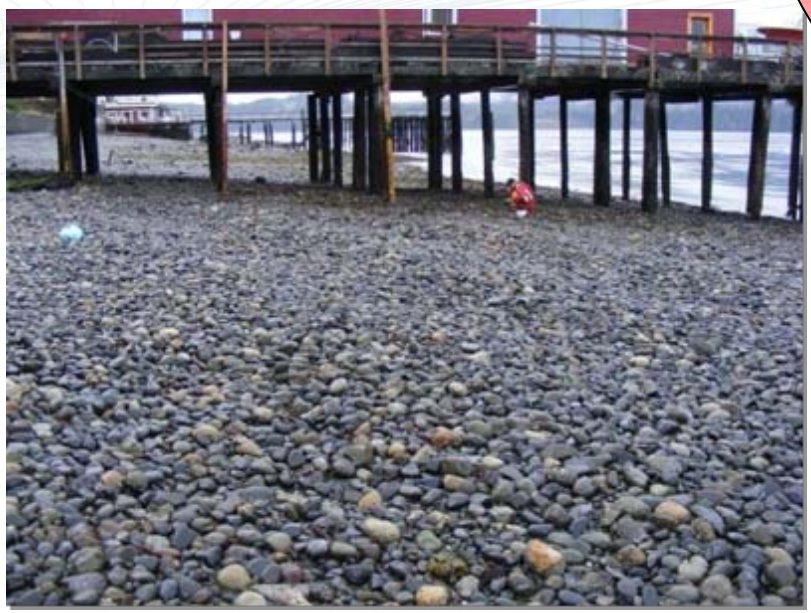
Challenges

- Coarse sediments - traditional hand-driven porewater profilers would not work!



- Drill rig would be required

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Challenges

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

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Multilevel groundwater samplers designed

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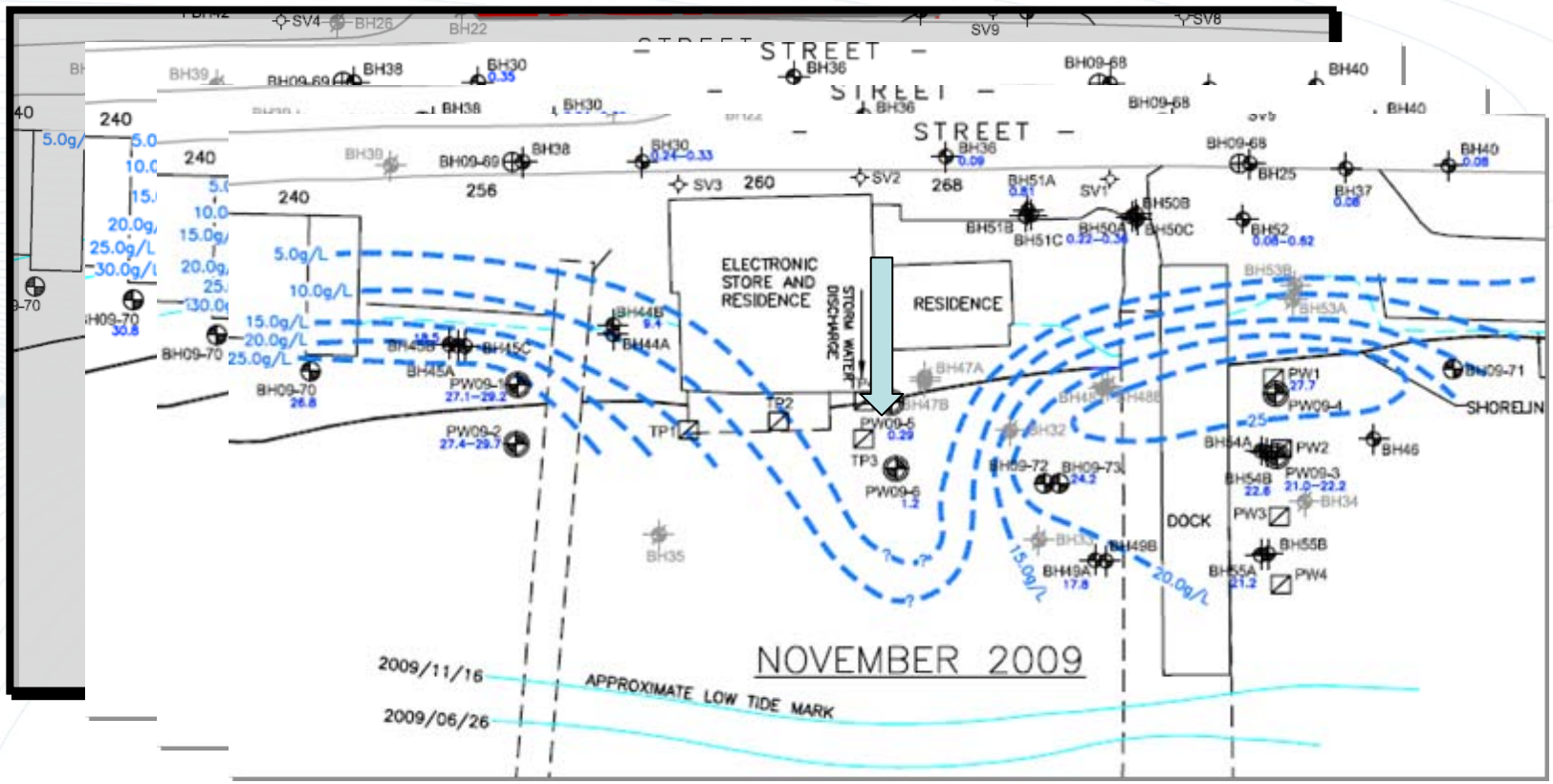
Extent of tidal influence inland



Salinity Contours
(Seawater ~ 32 g/L)

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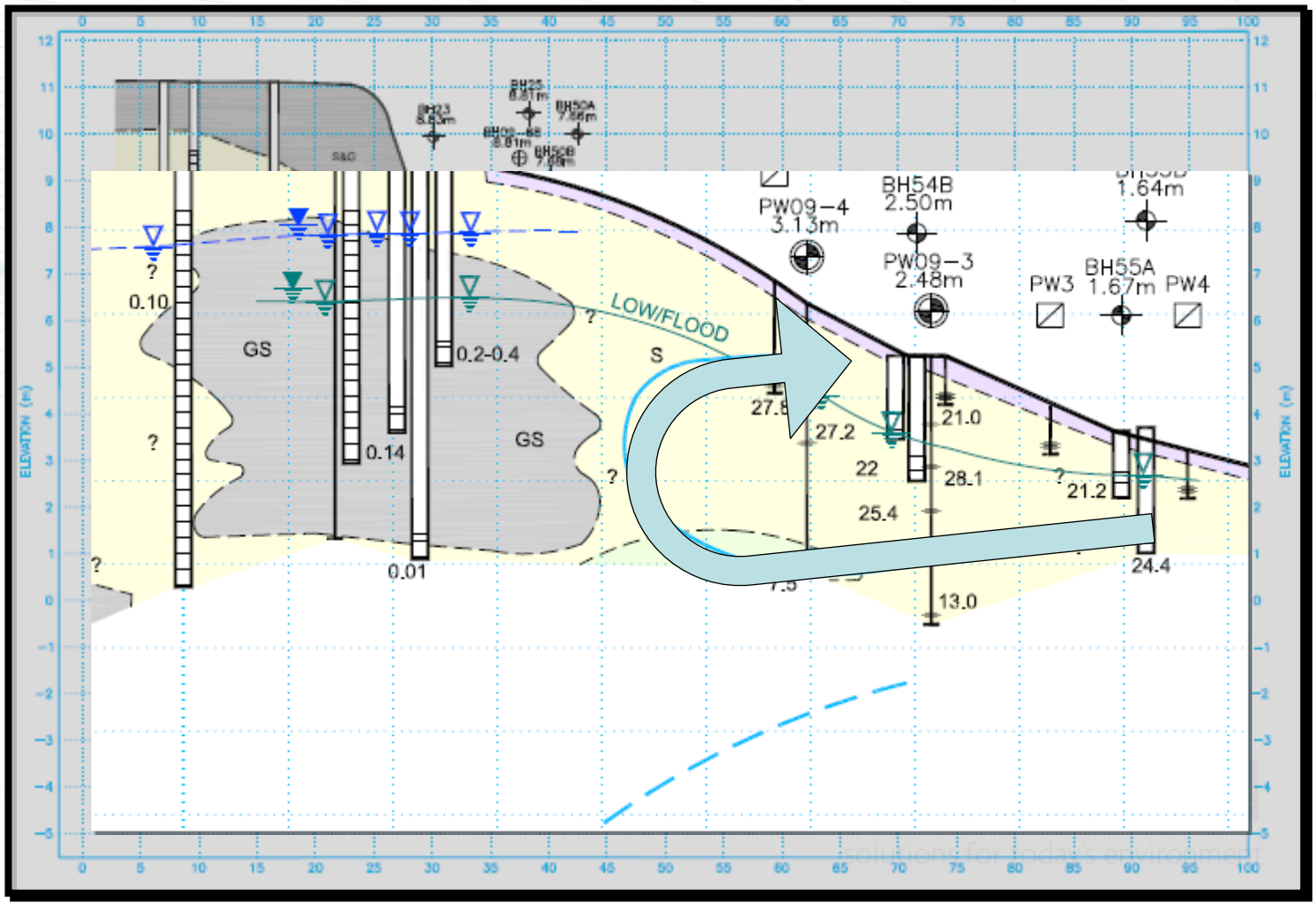
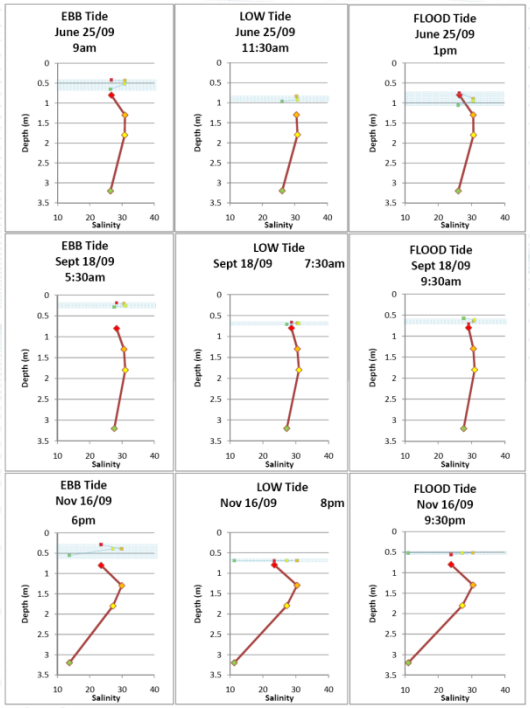
Saltwater/Groundwater mixing zone

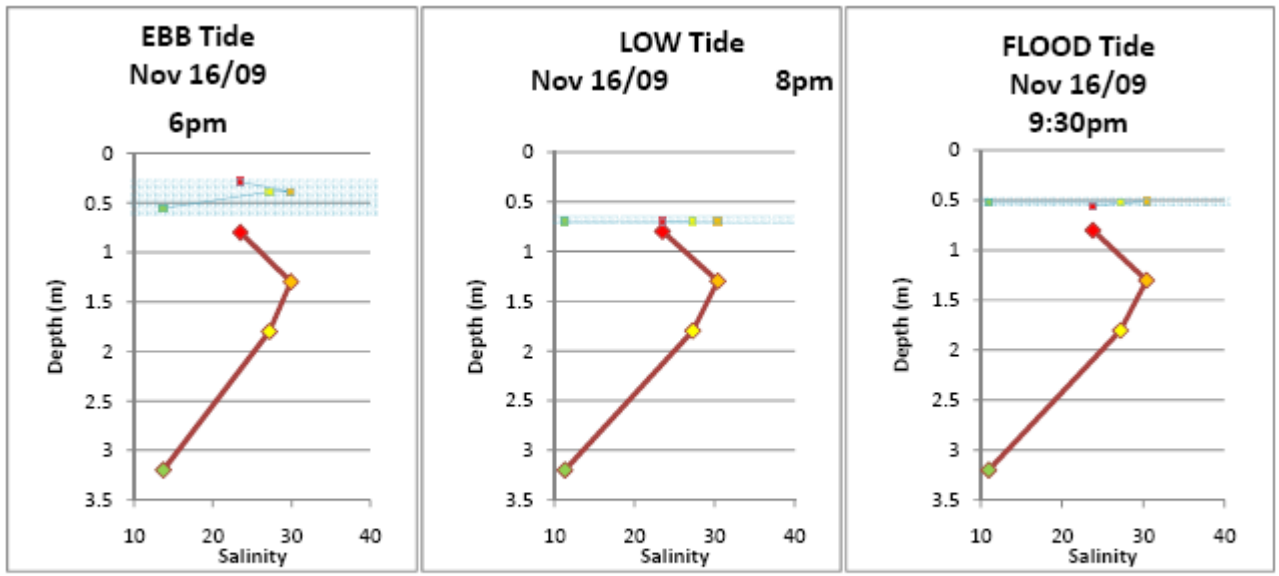


Multi-level groundwater sampler results

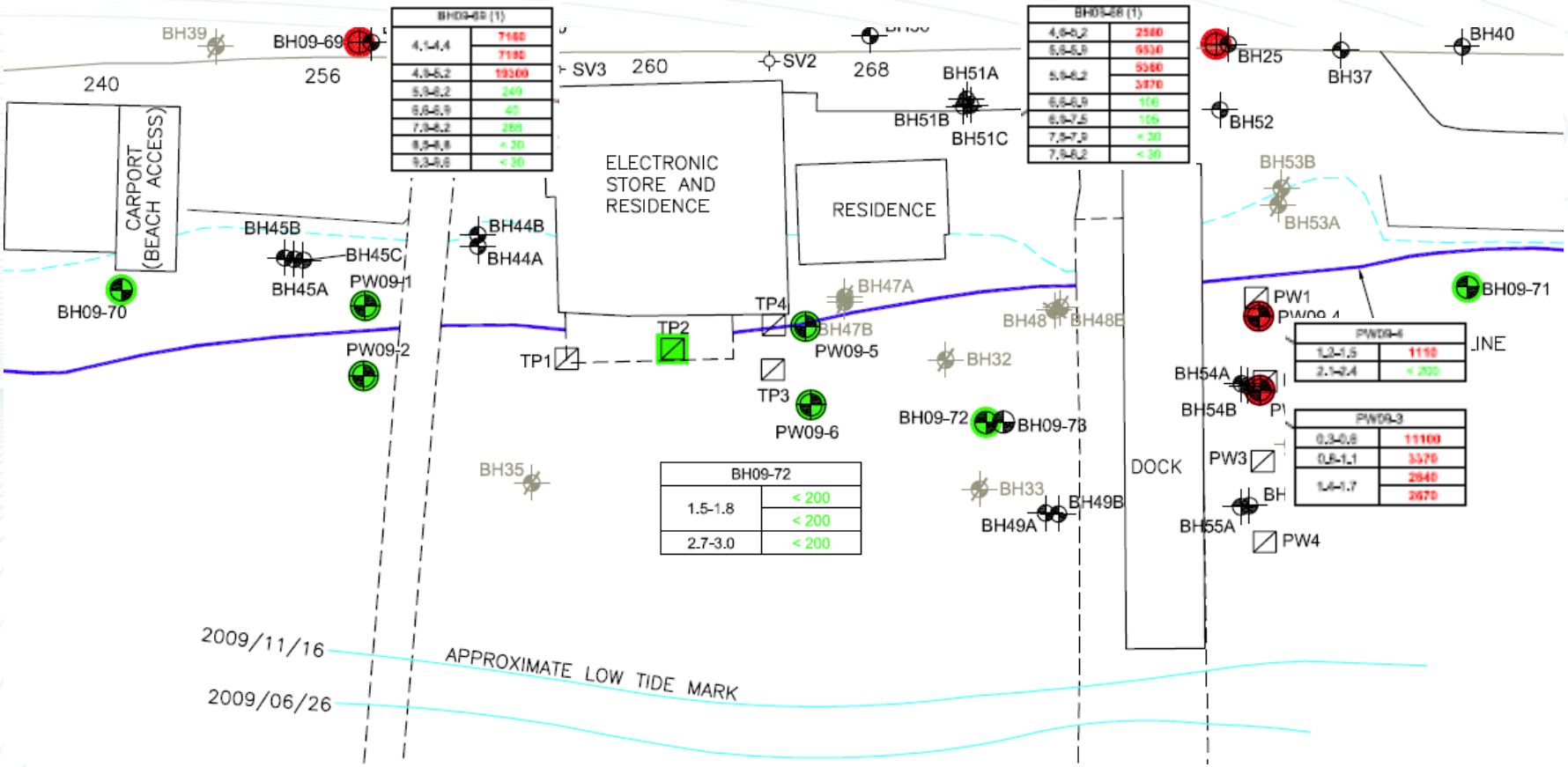
Salinity Profiles



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



Plume Delineation in Intertidal - Soil



BH09-72	
1.5-1.8	< 200
	< 200
2.7-3.0	< 200

Results consistent with previous investigations

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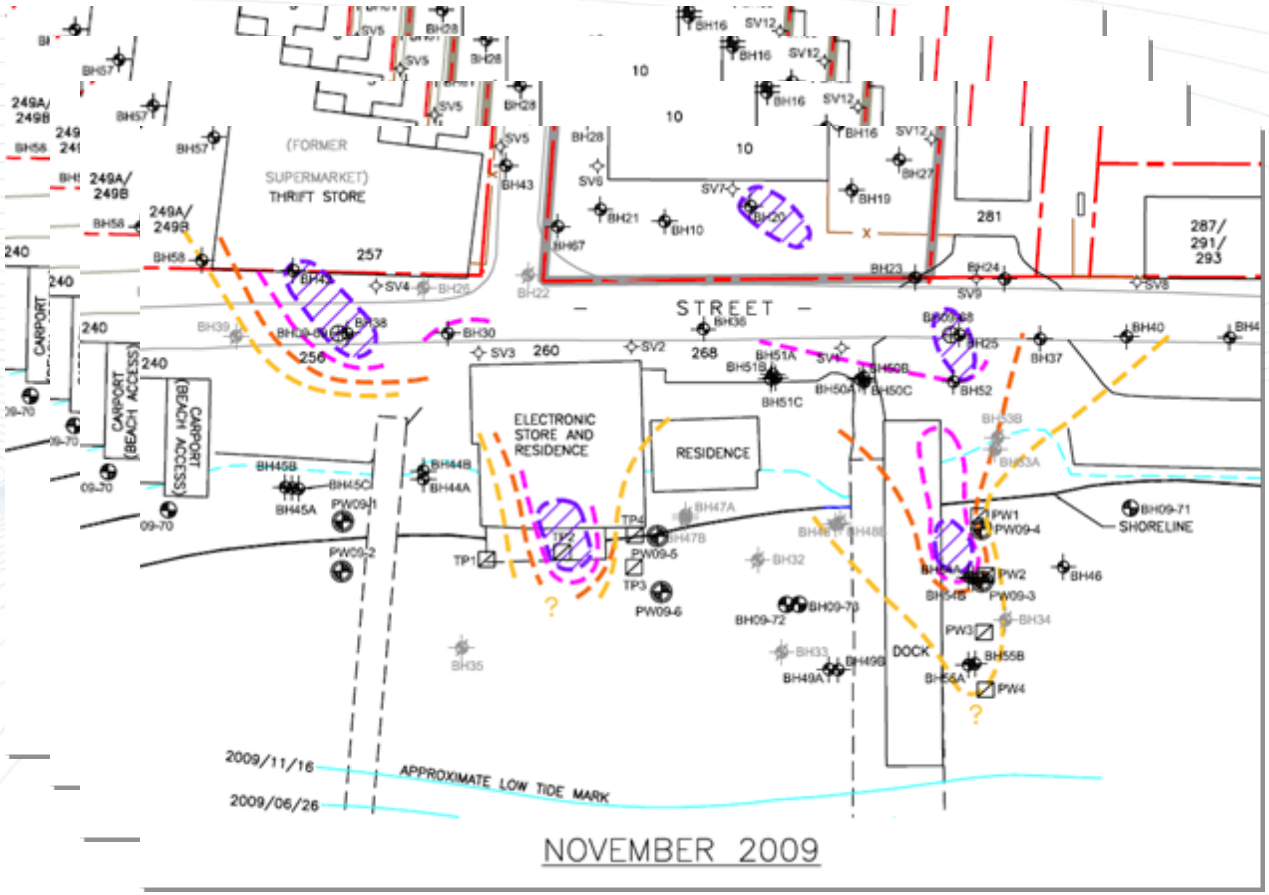
Seasonal LNAPL Distribution



500 ---------- 500 ug/L LEPHw

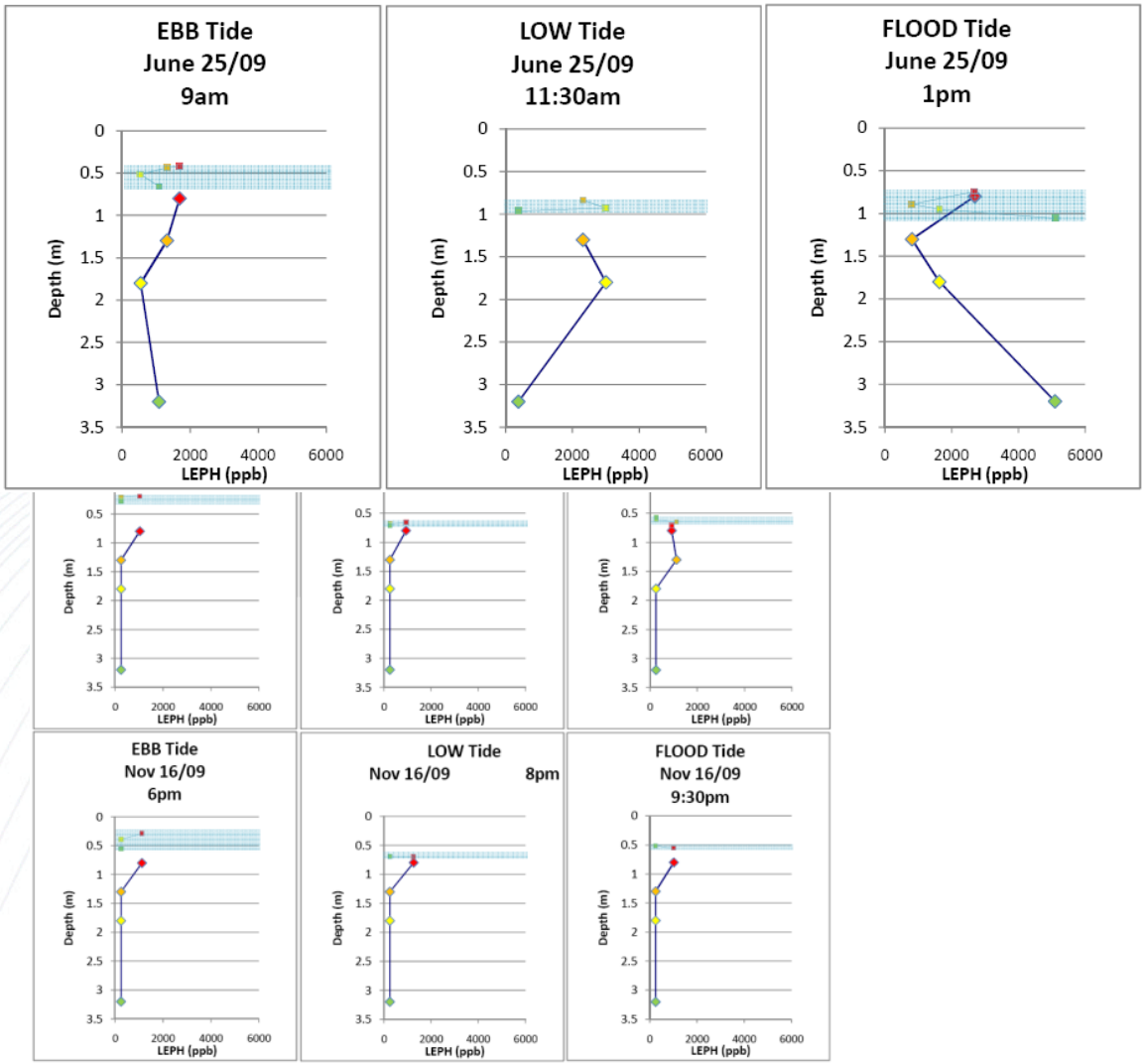
2000 ---------- 2000 ug/L LEPHw

5000 ---------- 5000 ug/L LEPHw

LNAPL OR CONCENTRATIONS OF LEPH INDICATIVE OF LNAPL

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

Multi-level groundwater sampler results



LEPHw Profiles

- Consistent over tide cycle during Sept and Nov events
- Significant variability at depth during June event
- Concentrations not as high as adjacent hand dug pits or shallow monitoring wells

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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
- Additional zone of dissolved contamination in central area
- Free-phase LNAPL (or concentrations indicative of) only observed in hand dug pits or monitoring wells which intercepted the water table – results from multi-level profiling points were lower

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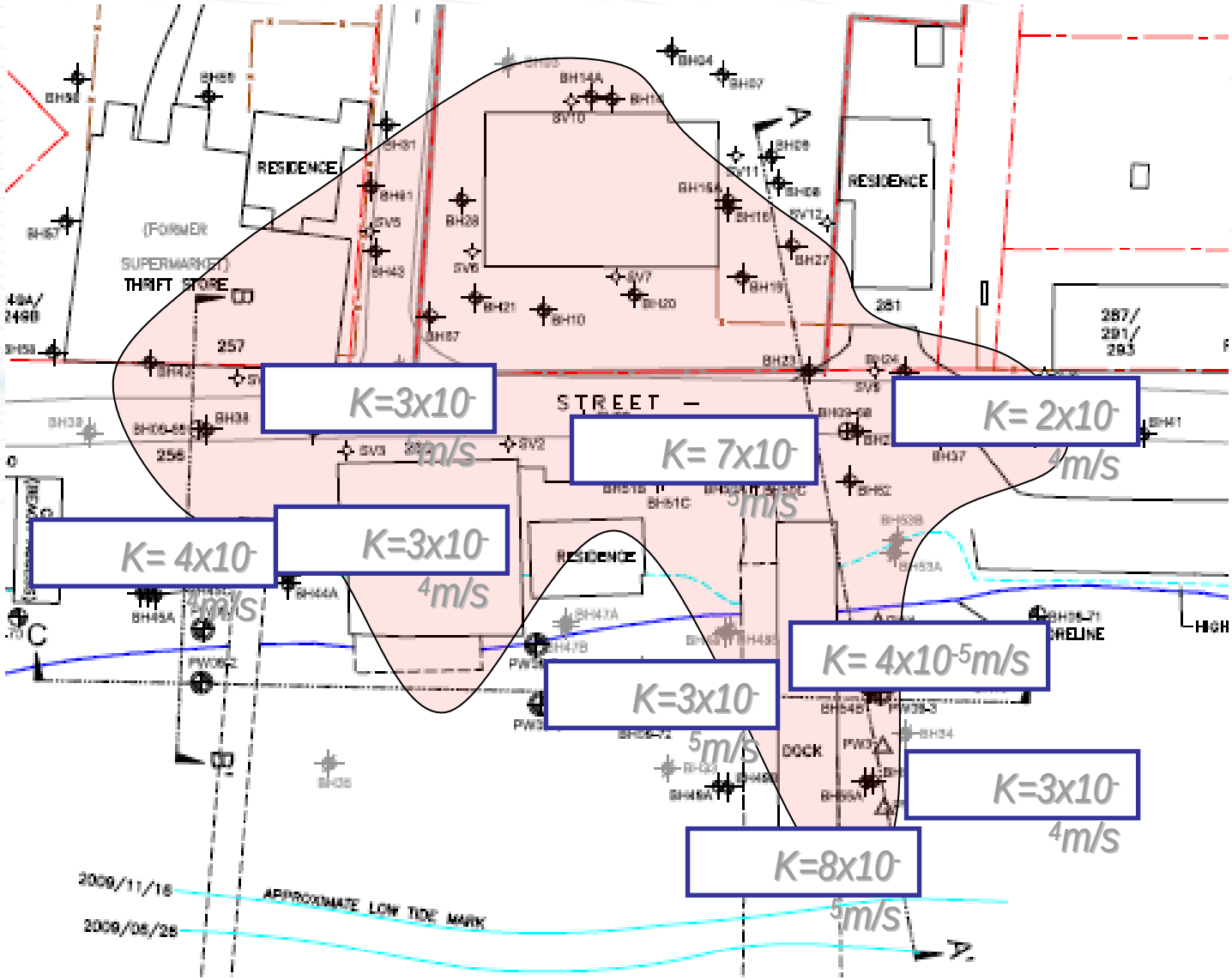
Permeability vs Contaminant distribution



Permeability vs. Grain size

TABLE E-1: HYDRAULIC CONDUCTIVITY VALUES

Test	Screen Interval (m)	Saturated Screen Length Stratigraphy	Hydraulic Conductivity (m/s)		
			Individual Tests	Well Averages	Geometric Mean
Upland Wells					
BH30	4.6 - 7.6	SAND	3.2×10^{-5}	3.2×10^{-5}	
BH37	4.6 - 7.6	SAND, some gravel	2.2×10^{-4}	2.2×10^{-4}	
BH50B Test 1	5.8 - 6.1	SAND, some gravel	7.1×10^{-5}	7.0×10^{-5}	
BH50B Test 2			6.9×10^{-5}		
BH50B Test 3			6.9×10^{-5}		
Shallow Foreshore Wells					
BH55A	0.5 - 0.8	SAND, some gravel	8.3×10^{-5}	8.3×10^{-5}	1.1×10^{-4}
Intermediate Foreshore Wells					
BH54B	1.2 - 1.5	SAND, some gravel	3.7×10^{-5}	3.7×10^{-5}	
BH55B Test 1	1.2 - 1.5	SAND, some gravel	2.7×10^{-4}	2.7×10^{-4}	
BH55B Test 2			2.7×10^{-4}		
Deep Foreshore Wells					
BH09-72	2.7 - 3.0	SAND and GRAVEL	3.0×10^{-5}	3.0×10^{-5}	
BH44B	2.7 - 3.0	SAND	3.1×10^{-4}	3.1×10^{-4}	
BH45C	4.2 - 4.5	SAND, some gravel	4.3×10^{-4}	4.3×10^{-4}	

Notes:
m/s - metres per second

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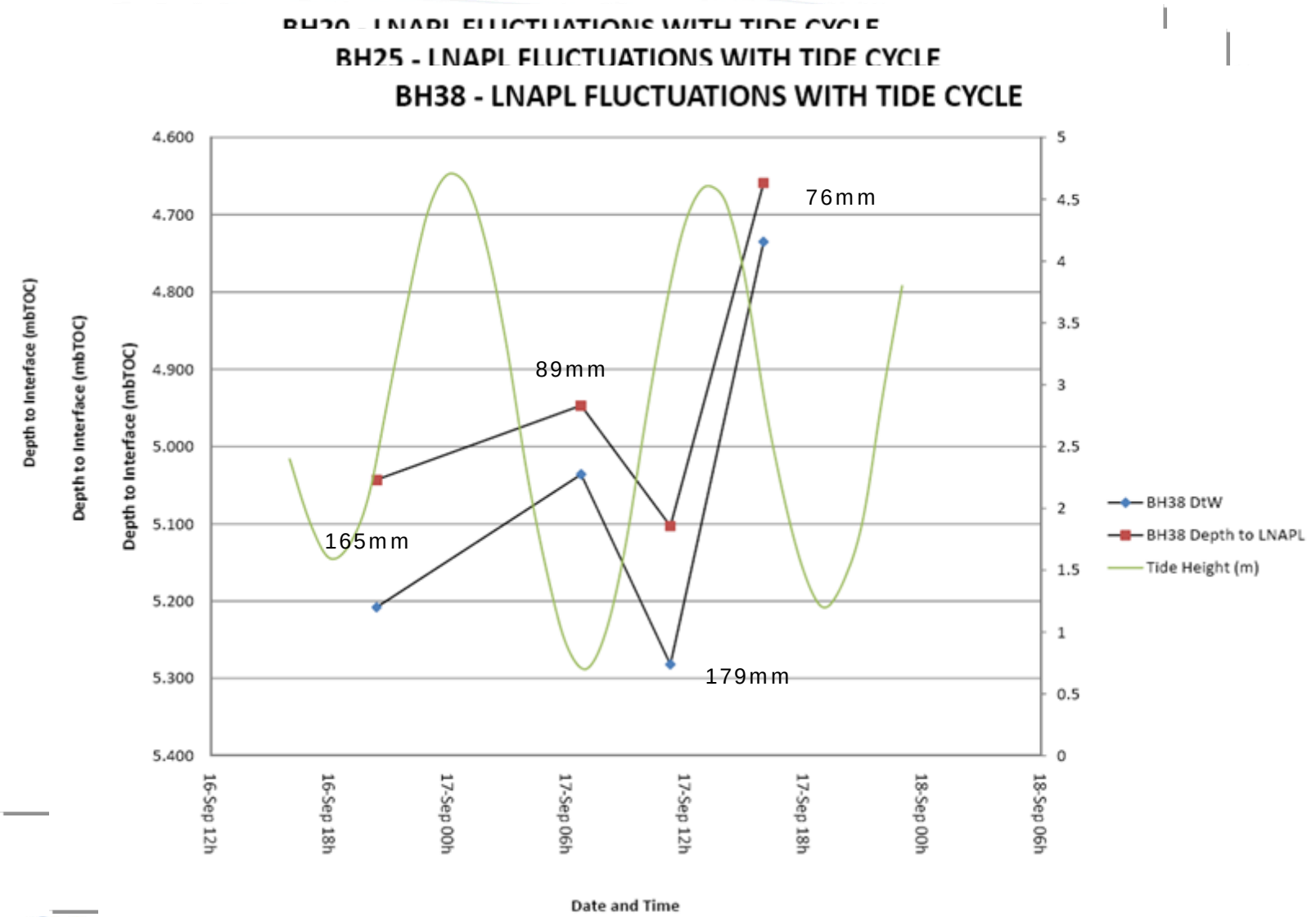
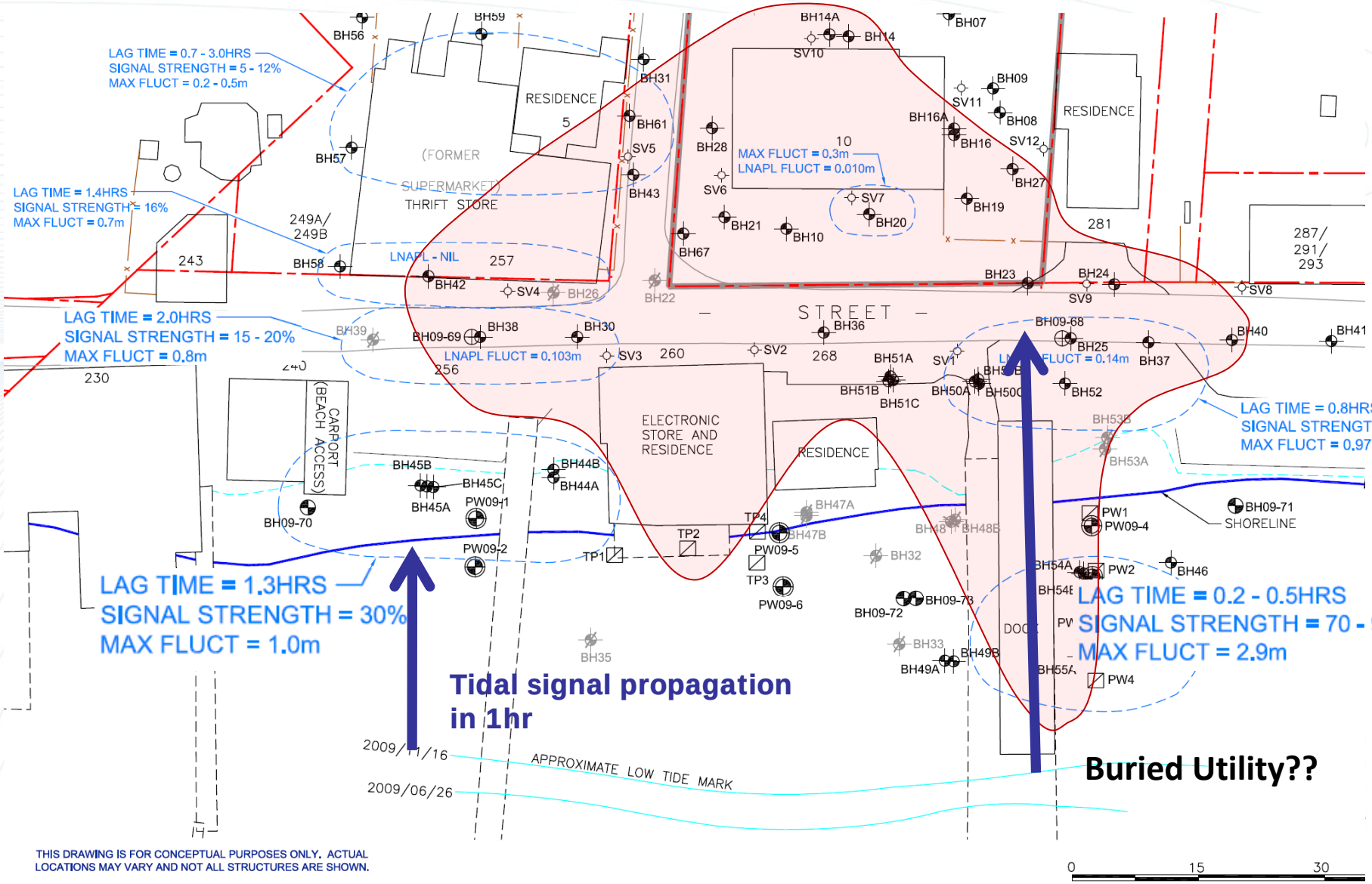
Effect of Tides on LNAPL Thicknesses



WESTERN LNAPL WELL

Inland Tidal Signal Strength and Lag Times



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

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Reading between the tides…

- Separate-phase LNAPL present on the east side of the intertidal zone
- Dissolved LEPHw indicative of LNAPL identified in the mid to western portion of the intertidal zone
- Peak LNAPL thicknesses following low tide
- Propagation of tidal signal and salinity gradient support potential preferential flow on the east side of the intertidal zone

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Conclusions

- LNAPL mobility is low
- 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

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