Environmental Risk Reduction through *In-Situ* Remediation and Monitored Natural Attenuation:

Results from Conventional Monitoring and Passive Flux Meter

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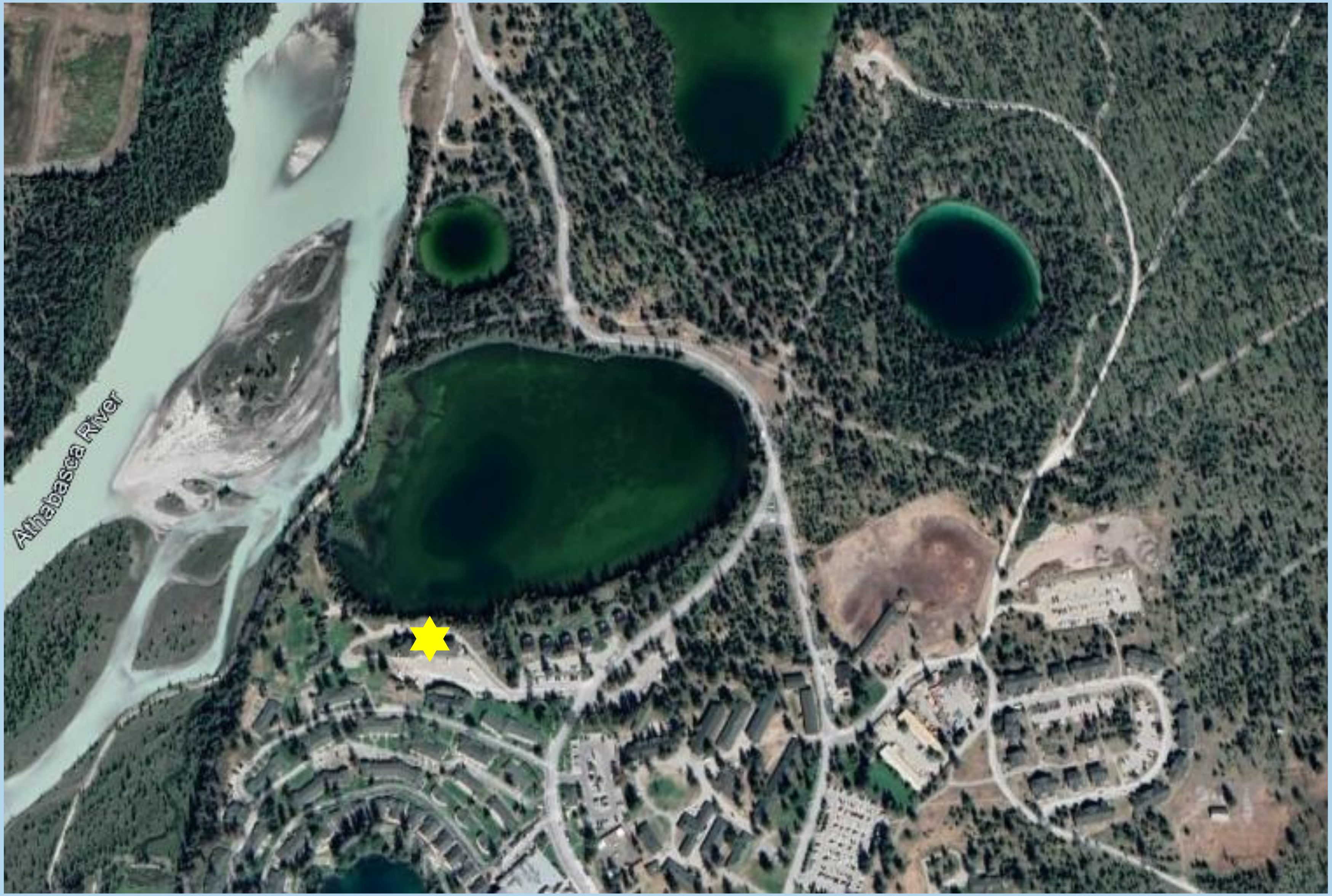
Outline

1. Objectives of ERRP
2. Site Characteristics
3. Contaminant Characteristics
4. Remedial Measures
5. Monitoring Methods
6. Summary of Results

Objectives

1. Demonstrate effective protection of a receptor downgradient of the source area
2. Monitor source area contaminant concentration for regulatory compliance and site closure through MNA and complementary *in-situ* remediation
3. Improve the CSM by collecting previously unavailable water and contaminant transport parameters

The Site



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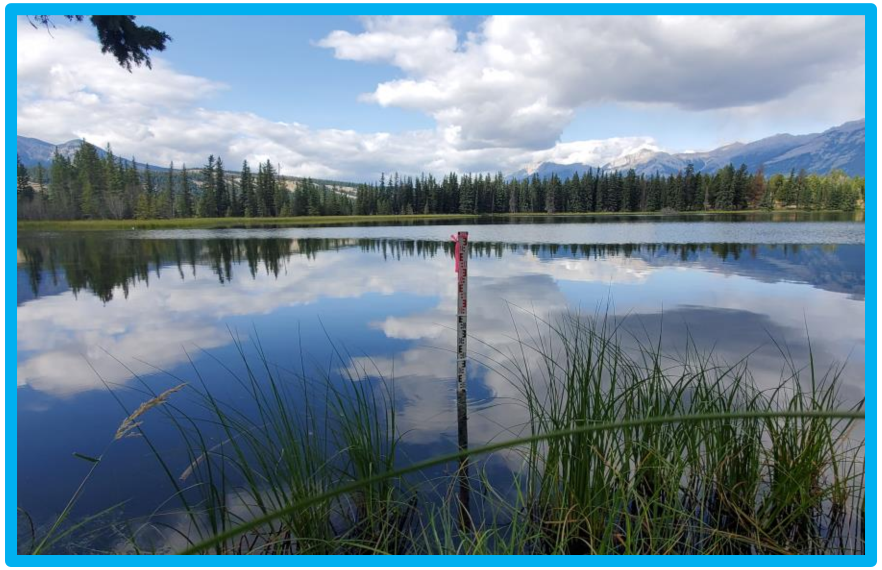

The Site

- The surficial materials consist of glaciofluvial sands and gravels.
- Borehole logs show granular materials, overlying cobbles, and then the bedrock.
- Static water level ranges from 5.8 to 6.0 m on the south, and 0.3 to 1.8 m on the north close to the Lake.

Contaminant Characteristics

- The Site has been operating since 1922 as a lodge (Residential and Parkland).
- Petroleum Hydrocarbons (gasoline, diesel, and fuel oils such as Bunker C)
  - In 1995, four diesel USTs were removed
  - In 2017 and 2021, three USTs were removed
- The impacted soils from the UST areas were removed

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The Site

Contaminant Characteristics

The plan for the ERR was conceived after reviewing the 2020 data

- Hydrocarbons within the vicinity of the Lake
- June 2020: **benzene** at three locations and some **PAHs** at four locations
- Trace levels of PHCs and PAHs

Contaminant Characteristics

Remedial Measures

A review of the 2020 groundwater monitoring indicated that the timeframe for natural attenuation was an unacceptable risk for the client.

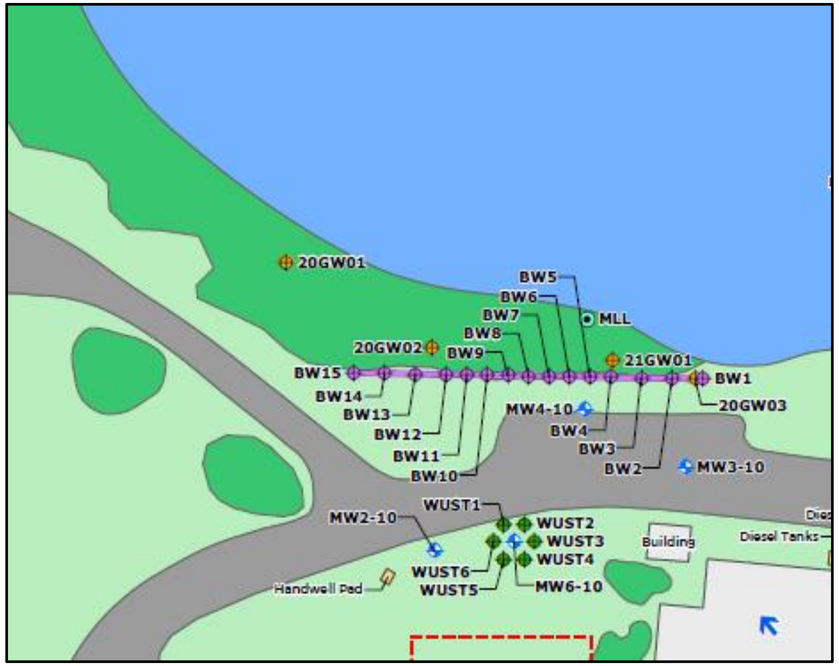
In January 2021, two remedial measures were applied

- A groundwater interceptor (reactive barrier) between the source and the Lake.
- Oxygen release compounds within the 'hotspots' and the former UST areas.

Remedial Measures

Groundwater **interceptor / ‘barrier wall’**

- An activated carbon coated with electron acceptors was injected at 15 points along a 36 m transect to intercept the plume
- The product we used is marketed under the tradename ‘**PetroFix™**’ from REGENESIS Bioremediation Products
- Formed transverse line configured across the plume direction



PetroFix™ Specification Sheet

PetroFix Technical Description

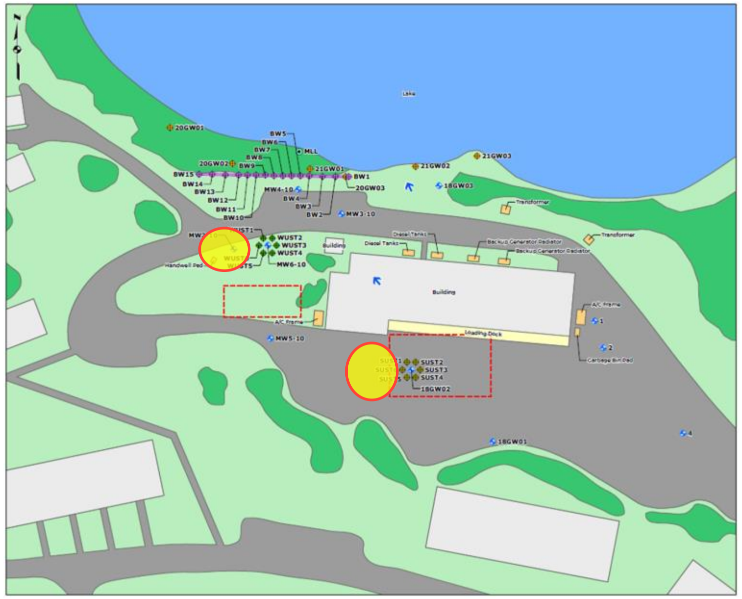
PetroFix is a new remedial technology designed to treat petroleum fuel spills in soil and groundwater. A simple-to-use fluid that can be applied under low pressure into the subsurface or simply poured into open excavations, PetroFix offers a cost-effective solution for environmental practitioners and responsible parties to address petroleum hydrocarbon contaminants quickly and effectively.

PetroFix has a dual function; quickly removing hydrocarbons from the dissolved phase, by absorbing them onto the activated carbon particles, while added electron acceptors stimulate hydrocarbon biodegradation in-place. PetroFix does not require high pressure "fracking" for application and can be applied with ease using readily available equipment associated with direct push technology.

Remedial Measures

Maintaining oxygenated groundwater within the ‘hotspots’

- Injected oxygen-release compound around hot spot wells (six injections at each location, and to the maximum depth or to the bedrock)
- The product used is marketed under the tradename **ORC Advanced®** is also from REGENESIS and is a calcium hydroxide derivative



OXYGEN RELEASE COMPOUND

ORC Advanced® Technical Description

ORC Advanced® is an engineered, oxygen release compound designed specifically for enhanced, *in situ* aerobic bioremediation of petroleum hydrocarbons in groundwater and saturated soils. Upon contact with groundwater, this calcium oxyhydroxide-based material becomes hydrated producing a controlled release of molecular oxygen (17% by weight) for periods of up to 12 months on a single application.

ORC Advanced decreases time to site closure and accelerates degradation rates up to 100 times faster than natural degradation rates. A single ORC Advanced application can support aerobic biodegradation for up to 12 months with minimal site disturbance, no permanent or emplaced above ground equipment, piping, tanks, power sources, etc are needed. There is no operation or maintenance required. ORC Advanced provides lower costs, greater efficiency and reliability compared to engineered mechanical systems, oxygen emitters and bubblers.

Example of ORC Advanced

N
Lake
20GW01
BW5
BW6
BW7
MLL
BW8
20GW02
BW9
21GW01
21GW02
21GW03
BW15
BW1
BW14
20GW03
18GW03
BW13
MW4-10
BW12
BW4
BW11
BW3
BW10
BW2
MW3-10
Transformer
Transformer
WUST1
WUST2
WUST3
WUST4
MW2-10
WUST6
WUST5
MW6-10
Handwell Pad
Building
Diesel Tanks
Diesel Tanks
Backup Generator Radiator
Backup Generator Radiator
Building
A/C Frame
A/C Frame
1
2
Loading Dock
Garbage Bin Pad
MW5-10
SUST1
SUST2
SUST6
SUST3
SUST5
SUST4
18GW02
18GW01
4

Monitoring Methods

- Drive-point wells for nearshore monitoring
- Level loggers for nearshore and Lake level monitoring
- Passive Flux Meters – water and contaminant mass discharge measurements
- Well networks: background, source wells, interceptor performance wells, and Lake sentinel wells

Monitoring Methods

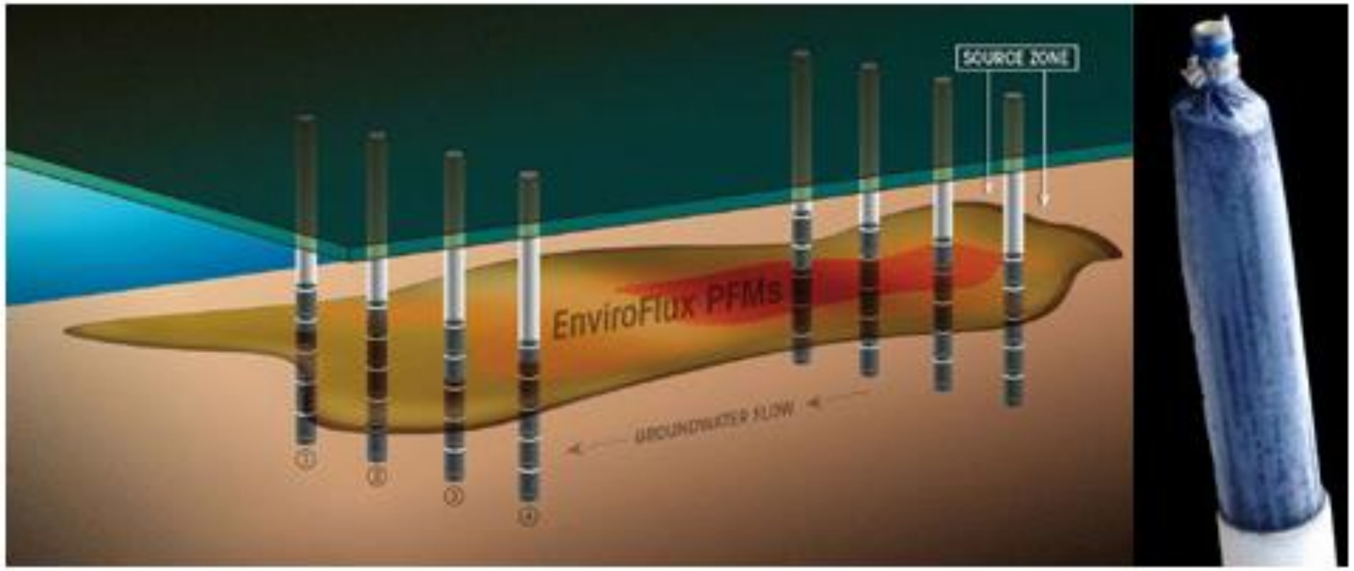
Groundwater Passive Flux Meters (PFMs)

- Conventional K testing of those wells was problematic due to the sandy gravel-boulder fill underlying the Site.
- The K at the Site >10^{-4} m/s; cannot be measured by the in-well ('slug') testing method.
- Prior to 2022, groundwater velocity and the mass of groundwater-transported contaminants were documented at a screening-level of reliably.
- In July 2022, we installed three PFMs.

Monitoring Methods

Monitoring Methods

- The PFM is a nylon mesh tube filled with a sorbent and tracer mixture.
- They are inserted into groundwater MWs where they passively intercept the flow.
- The tracer provides cumulative groundwater flux which can be used to calculate the linear velocity, and then the K.
- The sorbent provides time-averaged concentration of contaminants as opposed to the bailer method (or grab-samples).



Monitoring Methods

Discussion of Results

1. The interceptor's performance
2. Contaminant concentration
3. Concentration–time correlations versus groundwater elevations
4. Results from the PFMs

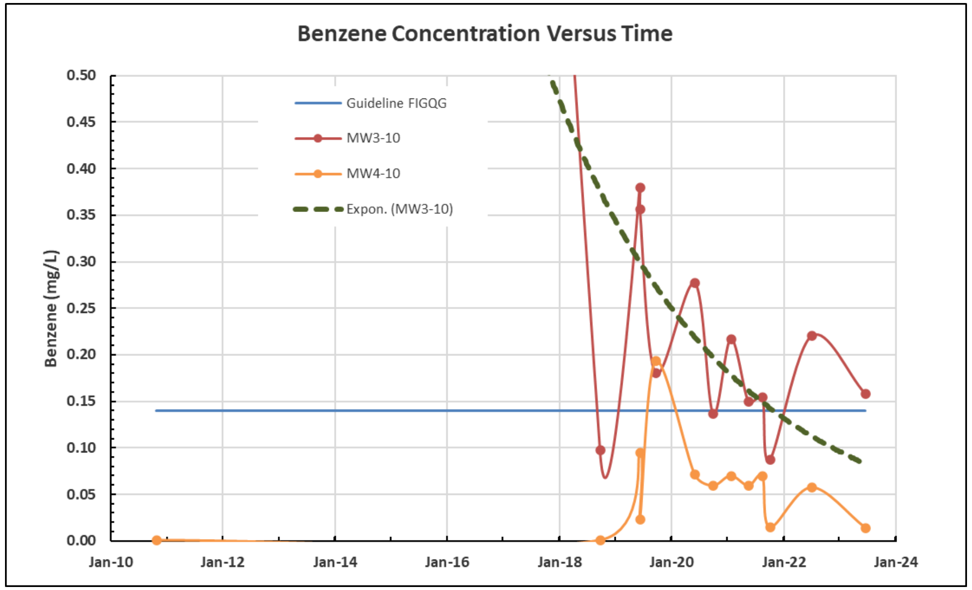
Interceptor Performance

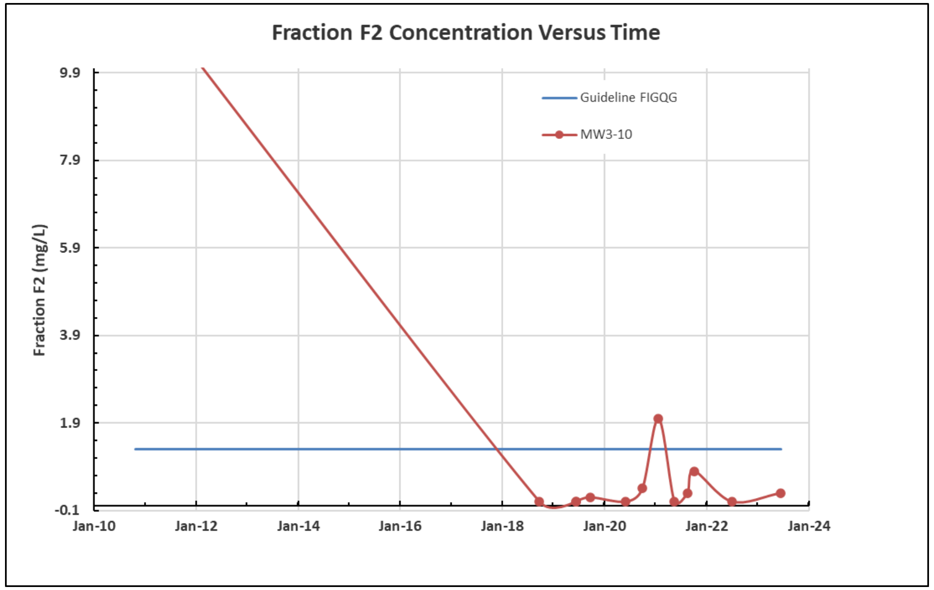
- The groundwater quality at the interceptor wells demonstrated the interceptor was effectively halting hydrocarbon migration

Monitoring Well	Sample Date	Benzene (mg/L)	Toluene (mg/L)	Ethylbenzene (mg/L)	Xylenes (mg/L)	F1-BTEX (mg/L)	F2 (mg/L)	F3 (mg/L)	F4 (mg/L)	Styrene (mg/L)
FIGQG		**0.14**	0.083	11	**3.9**	**0.81**	**1.3**	NS	NS	**0.072**
CWQG		0.37	**0.002**	**0.09**	NS	NS	NS	NS	NS	**0.072**
20GW01 Interceptor Performance Well	01-Feb-21	<0.0005	<0.0003	<0.0005	<0.0005	<0.1	<0.1	-	-	-
	24-Mar-21	<0.0005	<0.0003	<0.0005	<0.0005	<0.1	<0.1	-	-	-
	19-May-21	<0.0005	<0.0003	<0.0005	<0.0005	<0.1	<0.1	-	-	-
	20-Aug-21	<0.0005	<0.0003	<0.0005	<0.0005	<0.1	<0.1	-	-	-
	06-Oct-21	<0.0005	<0.0003	<0.0005	<0.0005	<0.1	<0.1	-	-	-
	06-Jul-22	<0.0005	<0.0003	<0.0005	<0.0005	<0.1	<0.1	-	-	-
20GW02 Interceptor Performance Well	01-Feb-21	<0.0005	<0.0003	<0.0005	<0.0005	<0.1	<0.1	-	-	-
	24-Mar-21	<0.0005	<0.0003	<0.0005	<0.0005	<0.1	<0.1	-	-	-
	19-May-21	<0.0005	<0.0003	<0.0005	<0.0005	<0.1	<0.1	-	-	-
	20-Aug-21	<0.0005	<0.0003	<0.0005	<0.0005	<0.1	<0.1	-	-	-
	06-Oct-21	<0.0005	<0.0003	<0.0005	<0.0005	<0.1	<0.1	-	-	-
	06-Jul-22	<0.0005	<0.0003	<0.0005	<0.0005	<0.1	<0.1	-	-	-
21GW02 Lake Sentinel Well	20-Aug-21	0.0036	<0.0003	<0.0005	<0.0005	<0.1	<0.1	-	-	-
	06-Oct-21	<0.0005	<0.0003	<0.0005	<0.0005	<0.1	<0.1	-	-	-
	05-Jul-22	0.081	<0.0003	<0.0005	<0.0005	<0.1	<0.1	-	-	-

Contaminant concentration

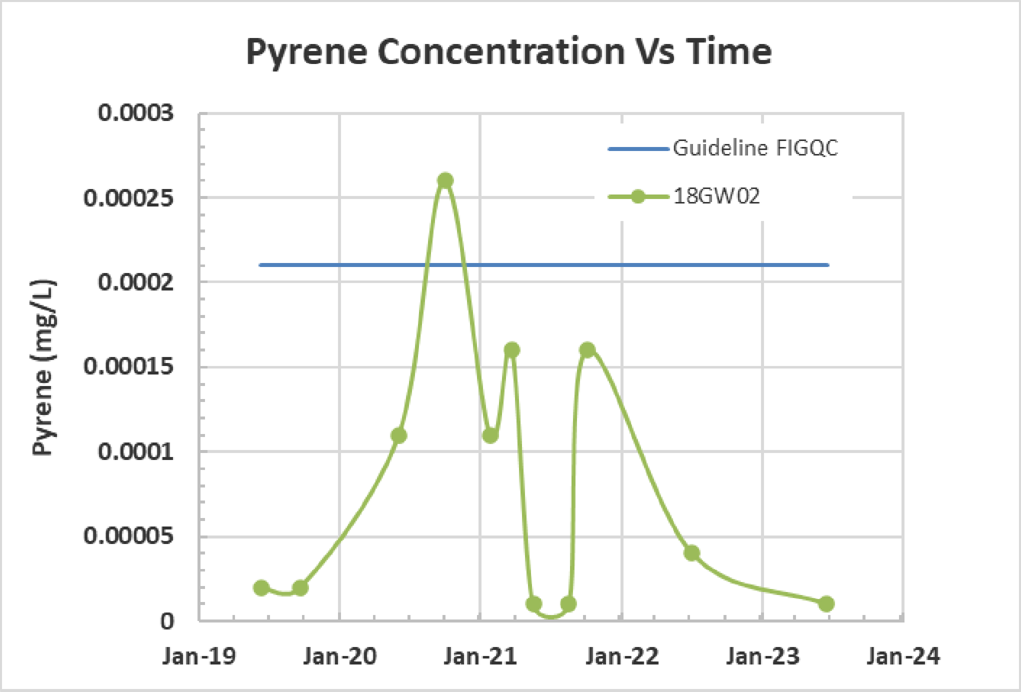
➢ The groundwater quality at upgradient wells indicated a reduction of some hydrocarbon parameters mainly due to passive natural attenuation and some biodegradation

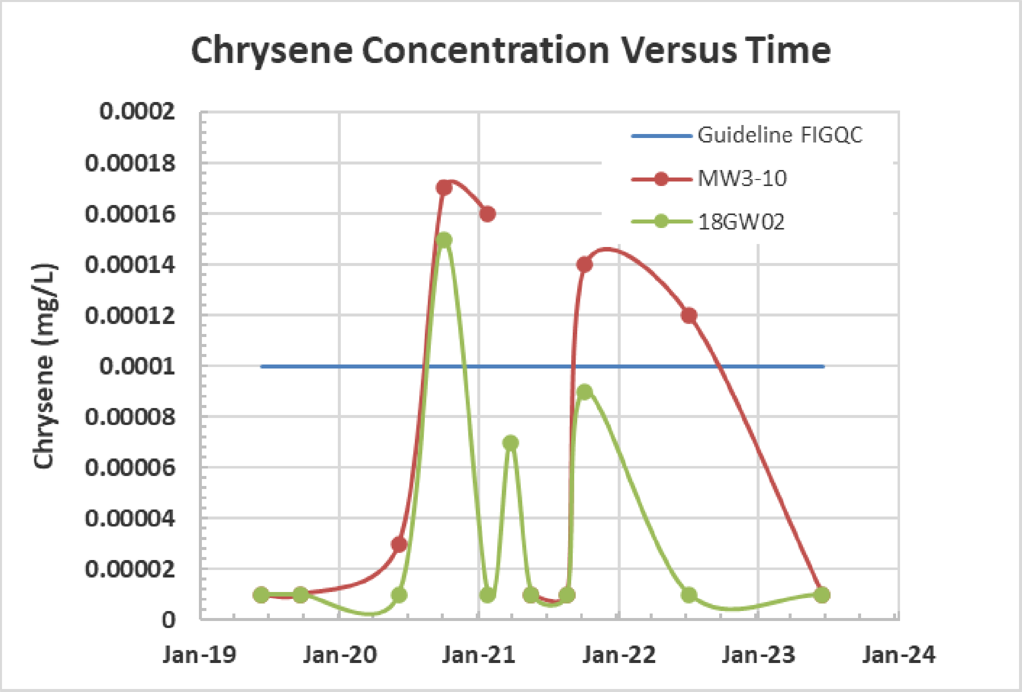




Contaminant concentration

- The groundwater quality at upgradient wells indicated a reduction of some hydrocarbon parameters due to passive natural attenuation and limited biodegradation





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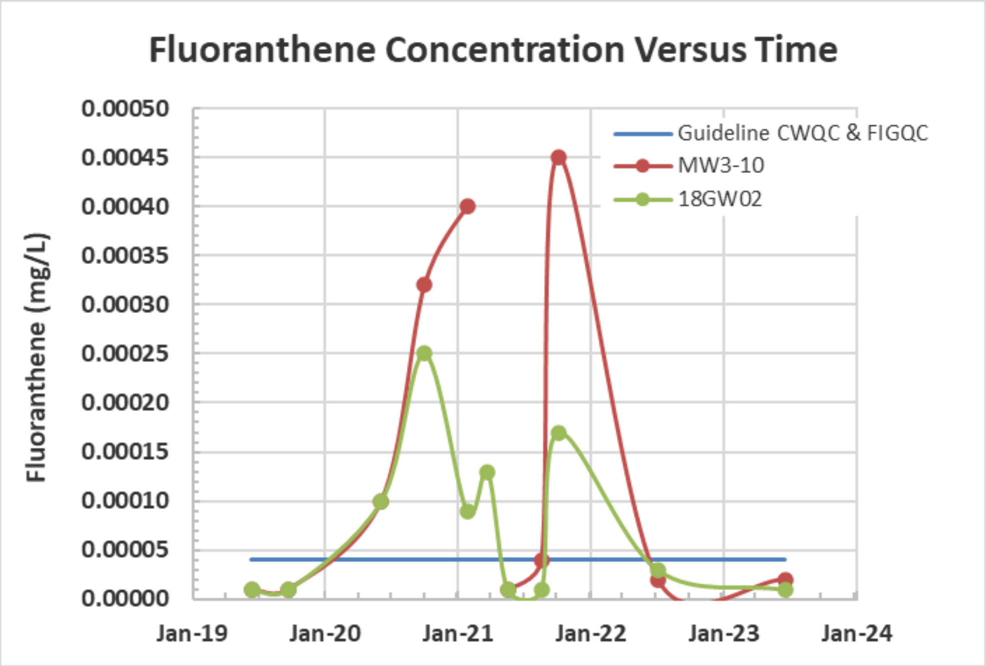
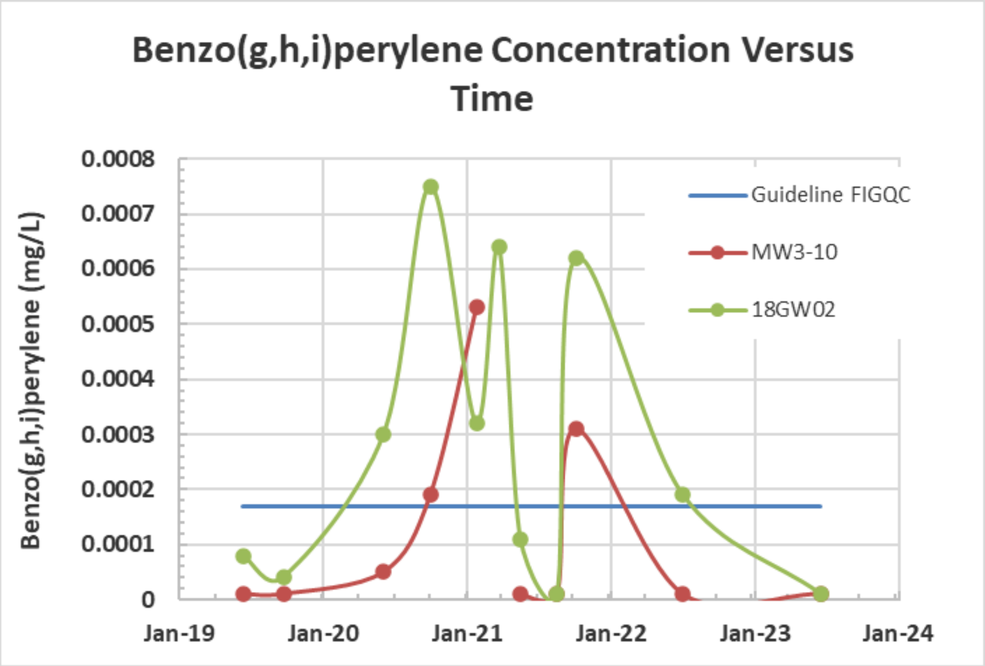




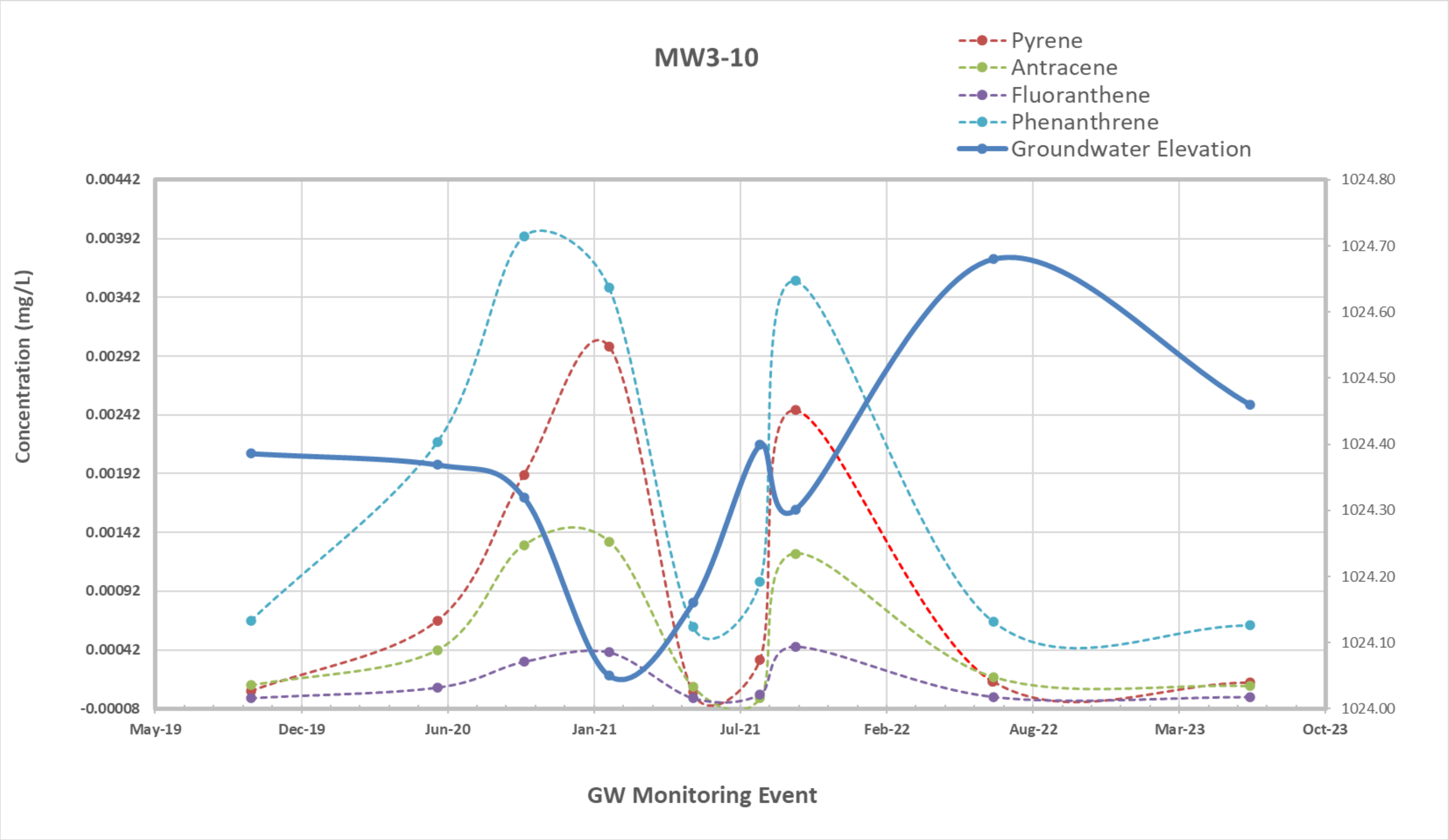
Concentration–time correlations

- Concentration–time correlations were hindered by cyclical concentration changes in PAHs in which higher concentrations correlate to lower groundwater elevations

Concentration–time correlations

Cyclical concentration changes in PAH

- ➢ Higher PAH concentrations correlate to lower groundwater elevations (R^2 = -0.56 to -0.60)



Concentration–time correlations

Cyclical concentration changes in PAH

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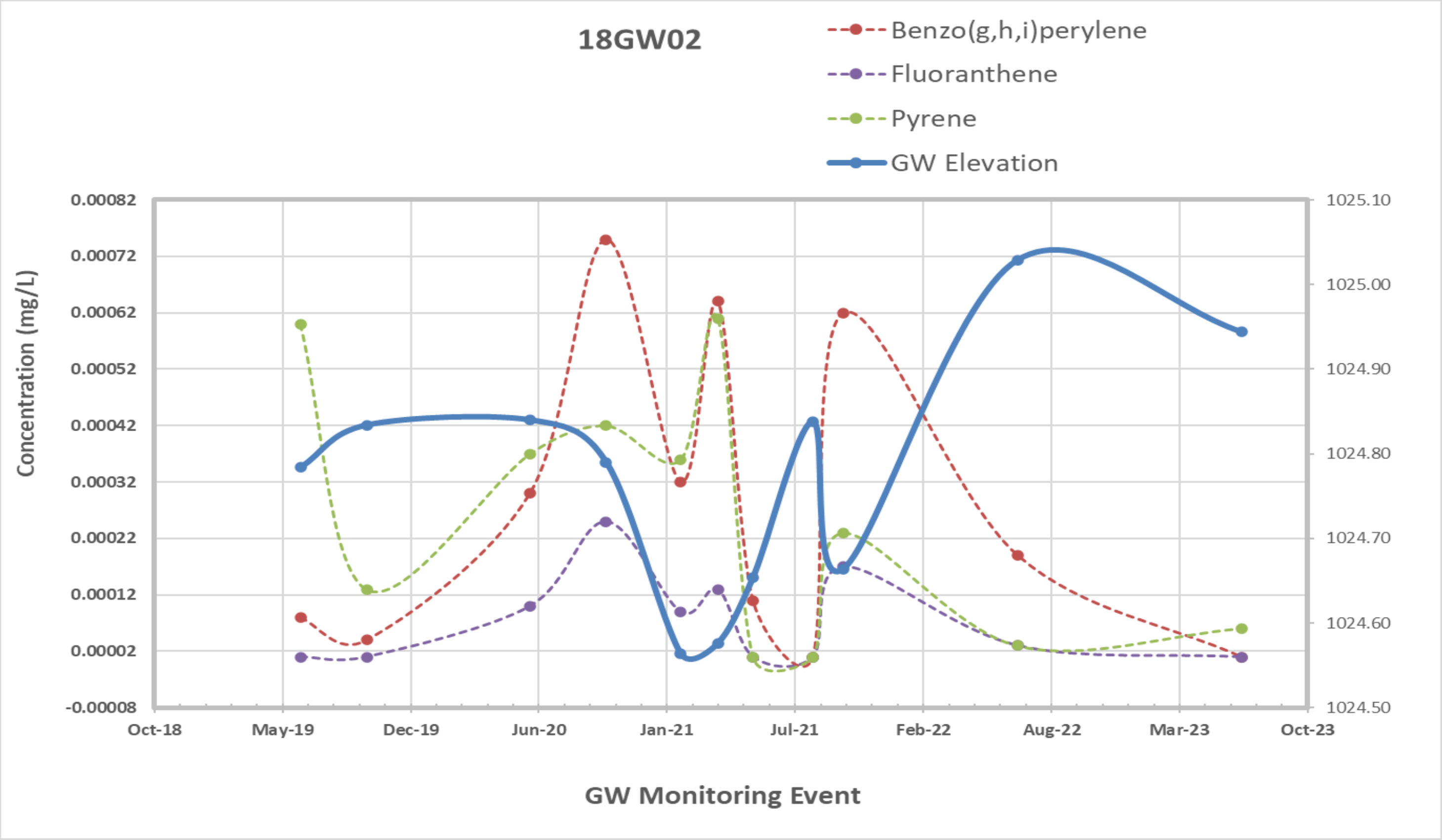
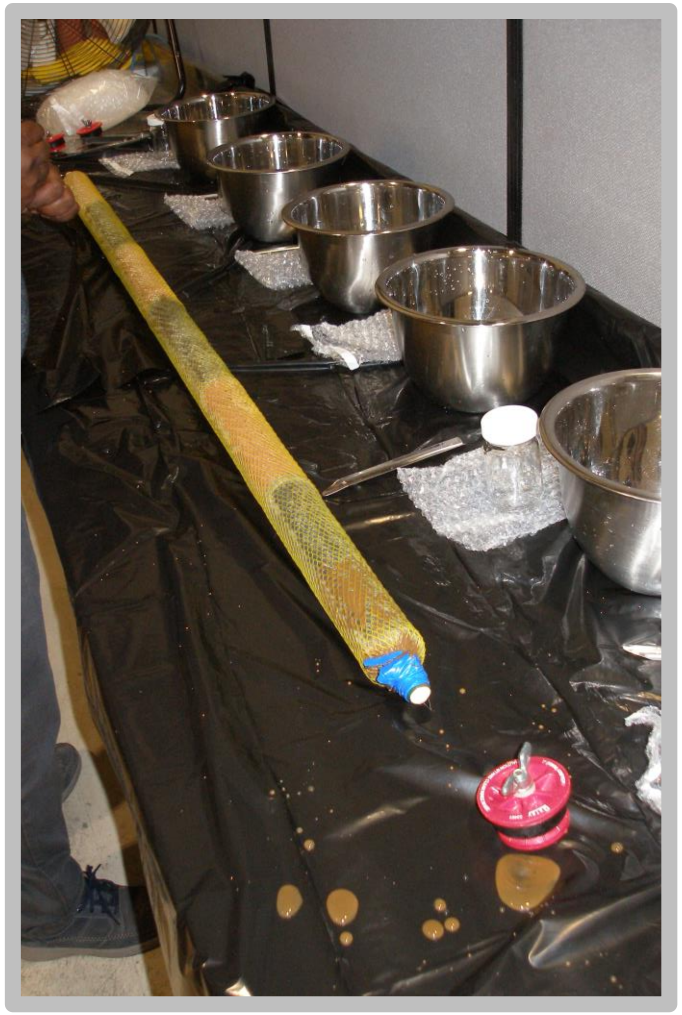


Results from the PFMs

Passive Flux Metre (PFMs) Monitoring Results



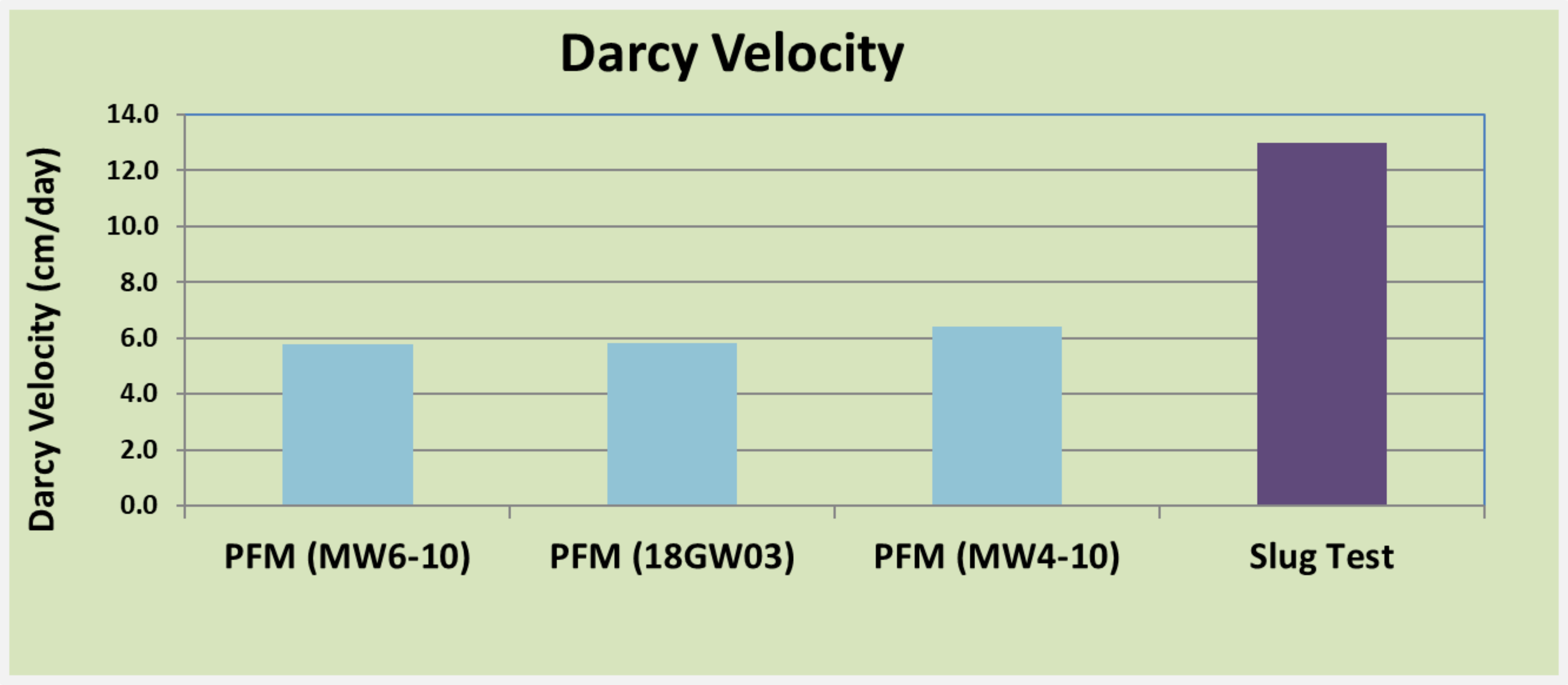
Results from the PFMs

Measured groundwater velocities with PFMs were only one-third of that previously documented

- previously measured linear velocity was **17 cm/day**
- PFM measured linear velocity is 6 cm/day

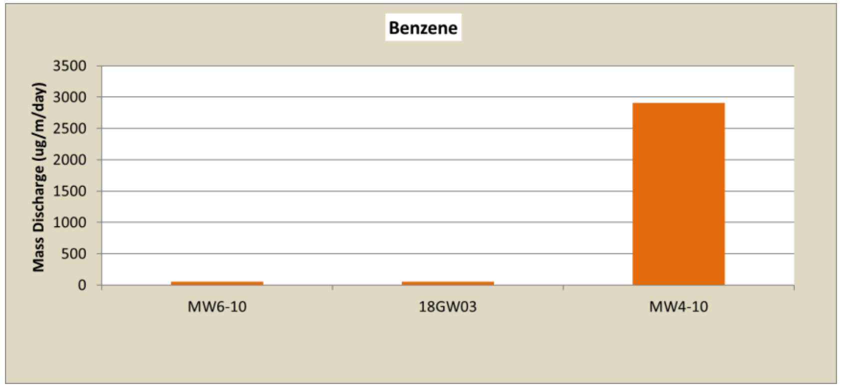
Well ID	Depth Interval (mbgl)	Darcy Velocity (cm/day)	Average Darcy Velocity (cm/day)
MW6-10	3.60 - 4.10	6.2	5.8
	4.10 - 4.60	7.9	
	4.60 - 5.10	3.2	
MW4-10	2.38 - 2.88	7.3	6.4
	2.88-3.38	5.1	
	3.38 - 3.88	6.8	
18GW03	2.86 - 3.36	7.9	5.8
	3.36 - 3.86	7.9	
	3.86 - 4.36	1.6	
Overall Average			**6.0**

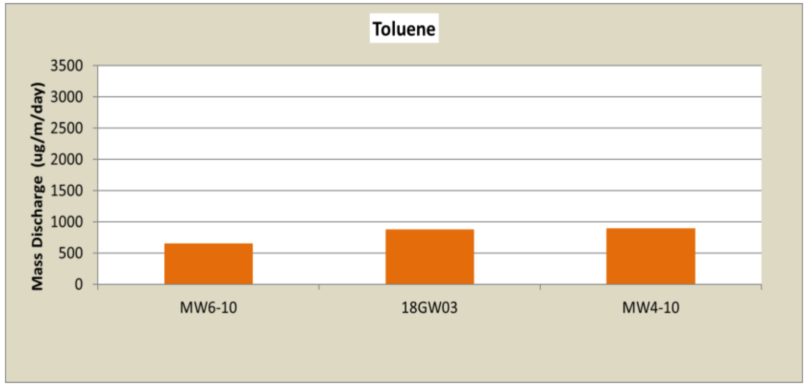
Results from the PFMs

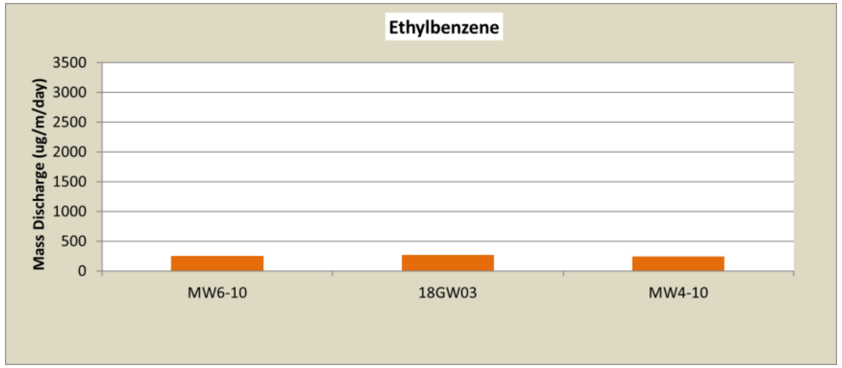


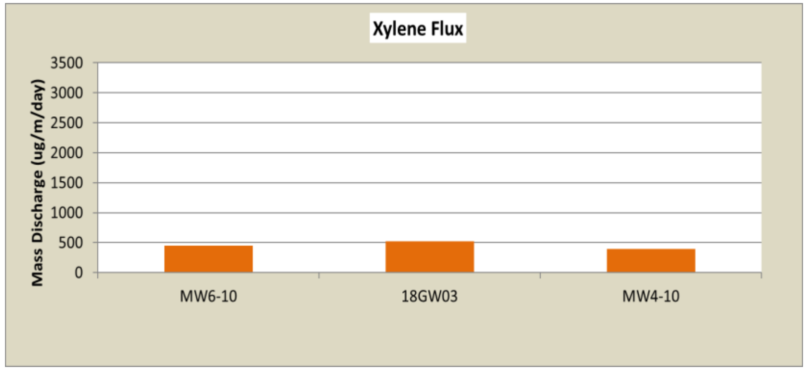
Results from the PFMs

- **Mass discharge** at each PFMs well - **PHCs**
  - i.e., total mass, moving per unit width of the local flow path



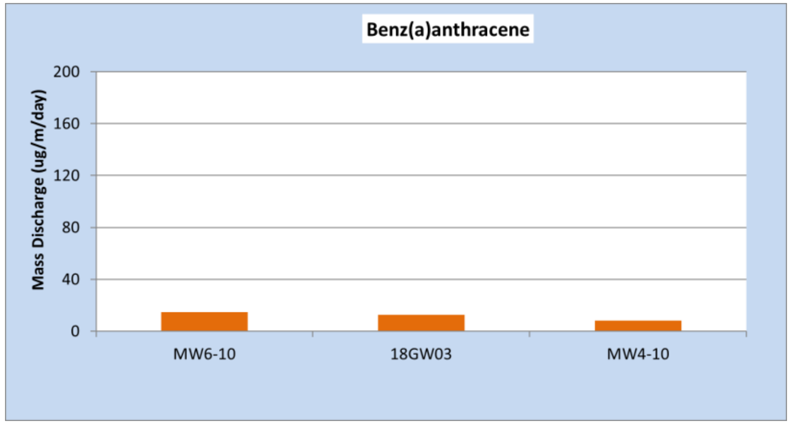


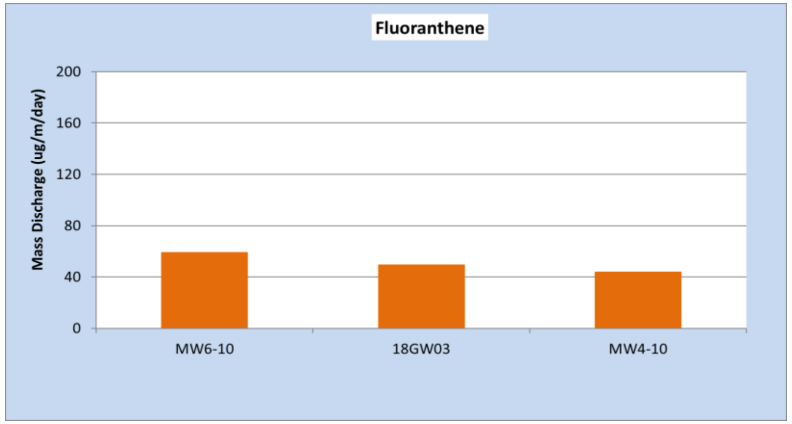


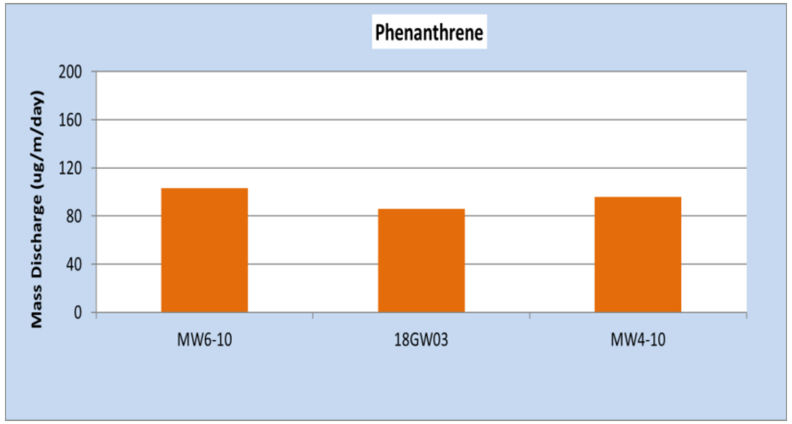


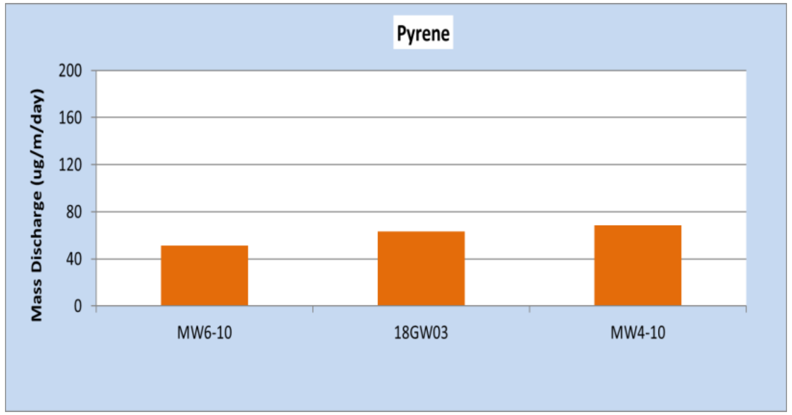
Results from the PFMs

➢ **Mass discharge** at each PFM wells - **PAHs**
   - i.e., total mass, moving per unit width of the local flow path









Results from the PFMs

- **Mass Discharge** at each PFM wells
  - i.e., total mass, moving per unit width of the local flow path
  - presented as a summation of BTEX and PAHs flowing within a metre width of the local flow path

Well ID	BTEX Flux (mg/m/day)	PAHs Flux (mg/m/day)
MW6-10	1.41	0.30
MW4-10	4.45	0.26
18GW03	1.72	0.26

Summary

1. The interceptor is effectively protecting the Lake.
2. In general, a decrease in some contaminants of concern at the source wells was observed meeting the GW quality objectives of the ERRP.
3. Concentration–time correlations were hindered by cyclical concentration changes in PAHs.
4. The PFMs enabled groundwater Darcy velocity to be measured more accurately and showed that the measured groundwater-transported hydrocarbons masses are proportionally lower, i.e., by about a third, than documented prior to the PFM's results.
5. Previously non-detect groundwater-transported hydrocarbons were detected by the PFM method's lower detection limit, refining the CSM with respect to mobile PAHs, i.e., dissolved- and colloidally-transported PAHs.

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Questions?