Bugs and Bubbles:
A Bioremediation Learning Experience

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Presentation Outline

A. The Challenge and Outcome

B. Lessons Learned
   - Filling Data Gaps => the Lever
   - Establish Efficient Flows
   - Persistence Pays Off

C. Closing Remarks
   - Collaboration Always Key

The Challenge

- Tree farm/residential property along a protected stream
- Historic releases from:
  - 1,000-gallon heating oil UST
  - 290-gallon gasoline UST
- USTs/source reportedly removed
- Dissolved GW Contamination Persists
  - MTBE: ~500 µg/L to ~1,000 µg/L
  - Benzene: ~100 µg/L to ~300 µg/L

Project Drivers

- Buyer and Seller both ready
- Both want contamination eliminated
- As quickly and 'sustainably' as possible

Effectively, eliminate the last 10% of the problem instead of MNA

The Outcome

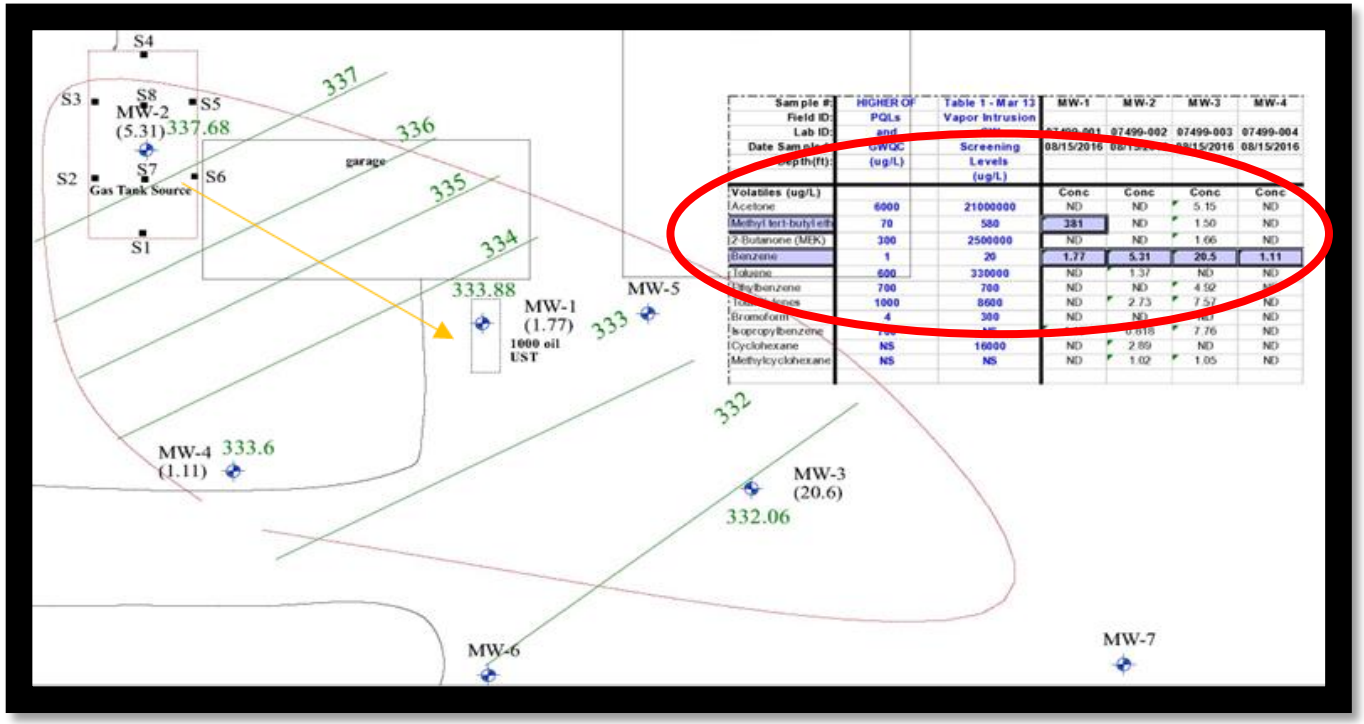
- Groundwater ‘good enough to drink’
- Remedy: Aerobic Bioremediation
  - Groundwater Re-Circulation
  - Dissolved Oxygen ‘Bubbler’
  - Bio-stimulation + Bio-augmentation

<u>Treatment Summary</u>

- 3 Years of Continuous Operation (99% run time)
- ~ 2.5 Million Gallons Treated
- ~24 O&M Visits
- 11 Sampling Events
- 11 vertical injection/extraction wells
- 2 horizonal injection wells

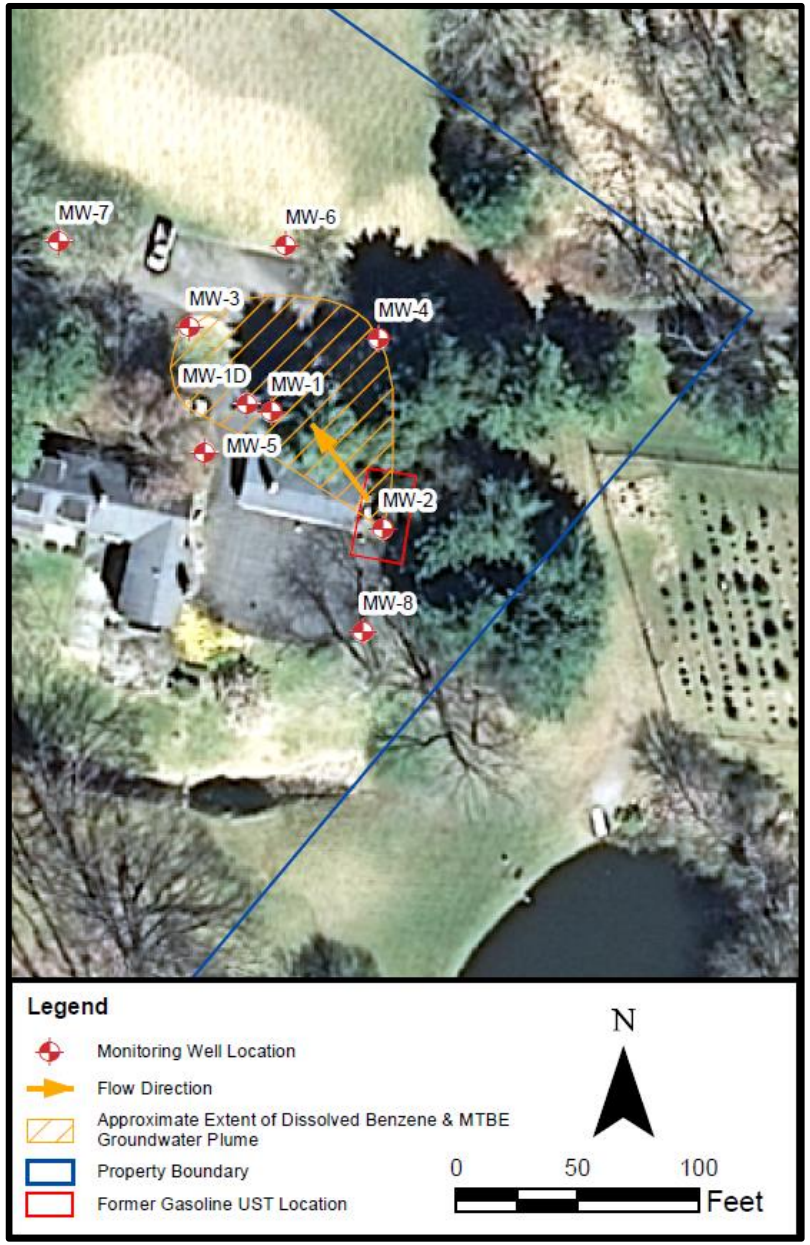
Total remediation cost = ~$750,000

Leveraging Filled Data Gaps



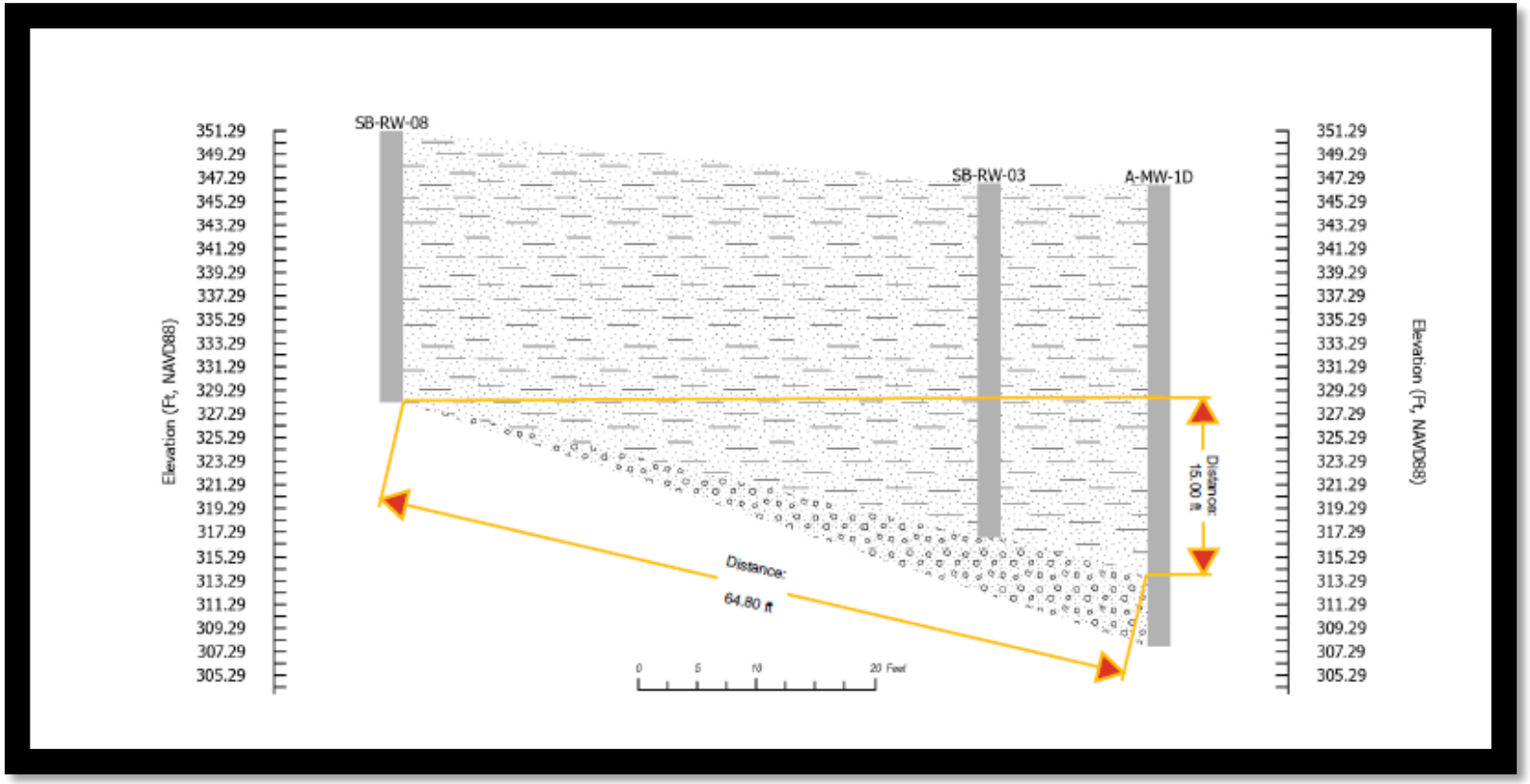
Sample #:	HIGHER OF	Table 1 - Mar 12	MW-1	MW-2	MW-3	MW-4
Field ID:	PQLs	Vapor Intrusion				
Lab ID:	and			07499-002	07499-003	07499-004
Date Sampled:	GWQC	Screening	08/15/2016		08/15/2016	08/15/2016
Depth(ft):	(ug/L)	Levels (ug/L)				
Volatiles (ug/L)			Conc	Conc	Conc	Conc
Acetone	6000	21000000	ND	ND	5.15	ND
Methyl tert-butyl ether	70	580	381	ND	1.50	ND
2-Butanone (MEK)	300	2500000	ND	ND	1.66	ND
Benzene	1	20	1.77	5.31	20.5	1.11
Toluene	600	330000	ND	1.37	ND	ND
Ethylbenzene	700	700	ND	ND	4.92	ND
[illegible]	1000	8600	ND	2.73	7.57	ND
Bromoform	4	300	ND	ND	ND	ND
Isopropylbenzene	[illegible]	[illegible]	[illegible]	[illegible]	0.818	7.76
Cyclohexane	NS	16000	ND	2.89	ND	ND
Methylcyclohexane	NS	NS	ND	1.02	1.05	ND

- Contaminant Source Removal Status?
- Source Beneath Building?
- Conductivity/Recharge?
- Geochemistry?
- Any Bugs? Any Bubbles?



Leveraging Data

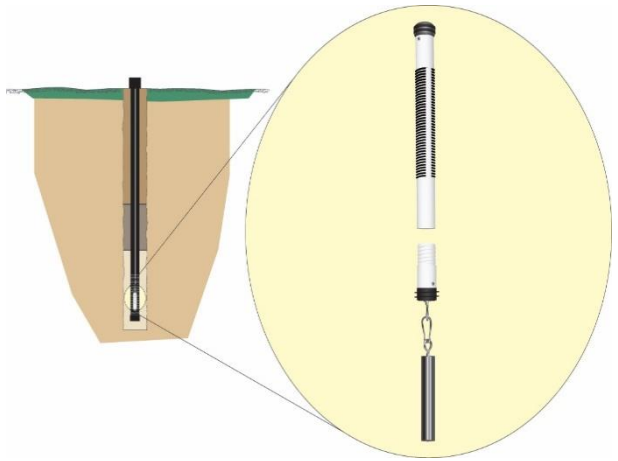
Riding the Diabase Slide



Leveraging Data

Biologic Site Data

In Situ Microcosm



microbialinsights

Unit

Samplers

Supplier

COC

MICRO
(Bio-Trap)

GEO

Supplier

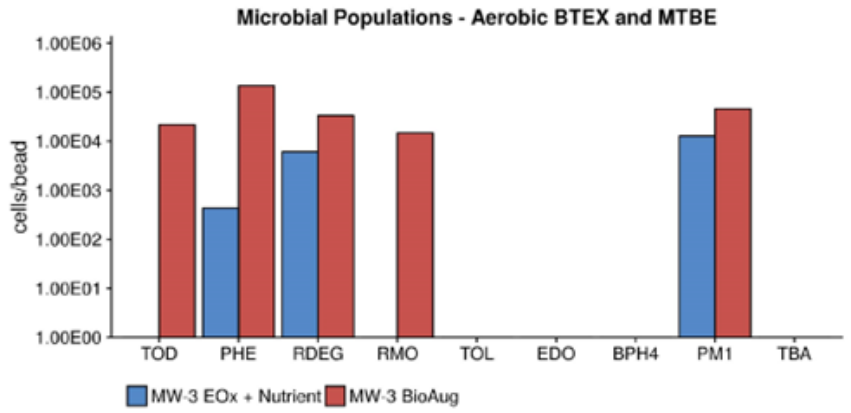
Leveraging Data

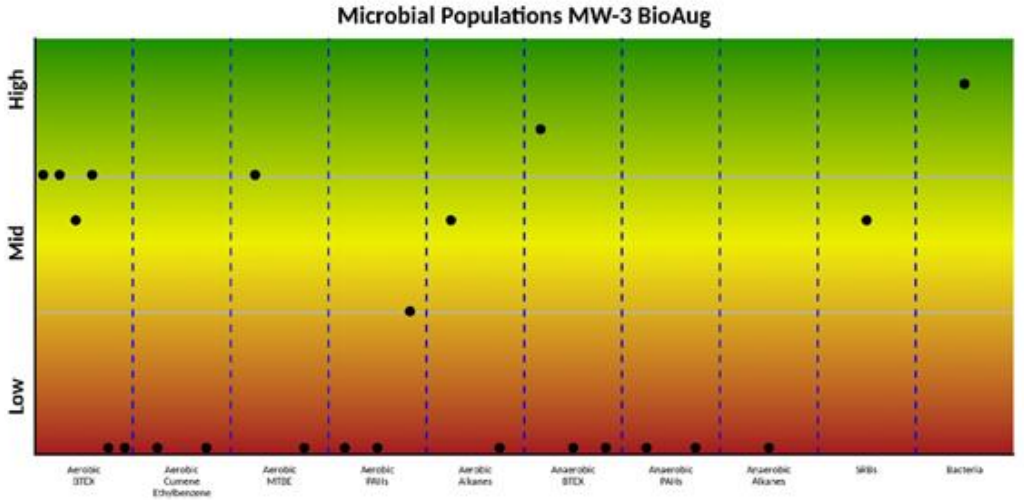
Biotrap Data

Key Findings:

- The methylibium petroleiphilum strain (PM1) appeared to be pre-existing at the site, and thrived during the pilot study period
- The BioAug unit indicated eubacteria (EBAC) biomass increased by two orders of magnitude (10^7 cells/bead), indicating the in-situ survival of the ENV404 bacterial culture.
- Populations of sulfate-reducing bacteria also showed a substantial increase in the BioAug unit.

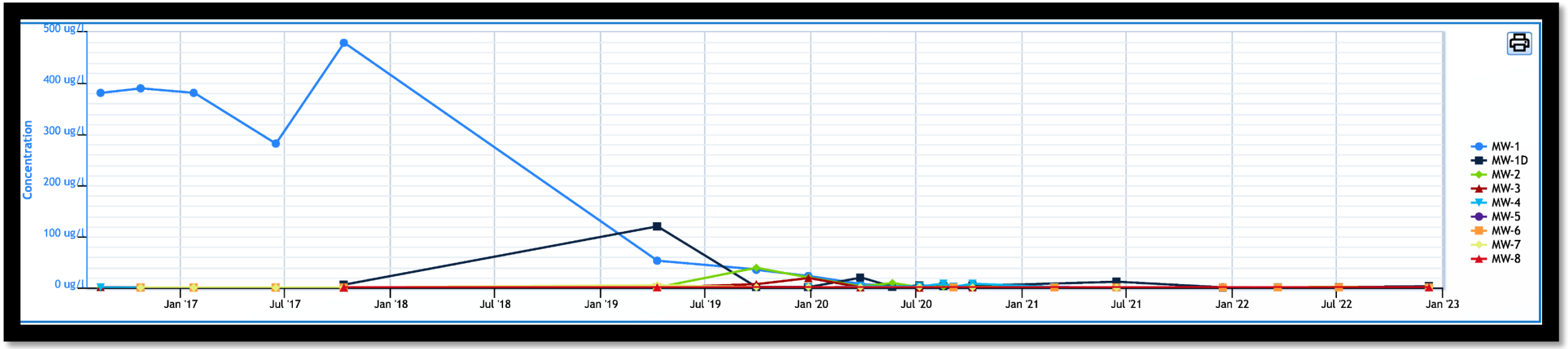
Sample Name	MW-3 EOx + Nutrient	MW-3 BioAug
Sample Date	01/24/2018	01/24/2018
Aerobic BTEX and MTBE	cells/bead	cells/bead
Toluene/Benzene Dioxygenase (TOD)	<2.50E+02	**2.16E+04**
Phenol Hydroxylase (PHE)	**4.34E+02**	**1.35E+05**
Toluene 2 Monooxygenase/Phenol Hydroxylase (RDEG)	**6.10E+03**	**3.33E+04**
Toluene Ring Hydroxylating Monooxygenases (RMO)	<2.50E+02	**1.47E+04**
Xylene/Toluene Monooxygenase (TOL)	<2.50E+02	<2.50E+02
Ethylbenzene/Isopropylbenzene Dioxygenase (EDO)	<2.50E+02	<2.50E+02
Biphenyl/Isopropylbenzene Dioxygenase (BPH4)	<2.50E+02	<2.50E+02
Methylibium petroleiphilum PM1 (PM1)	**1.28E+04**	**4.55E+04**
TBA Monooxygenase (TBA)	<2.50E+02	<2.50E+02





Establish Efficient Flow(s)

Successful Data Management Plan Design => Successful Remedial Design



MTBE

- Reliable, organized data -> Confident Decision Making
- Unlocks the door to remedial system optimization

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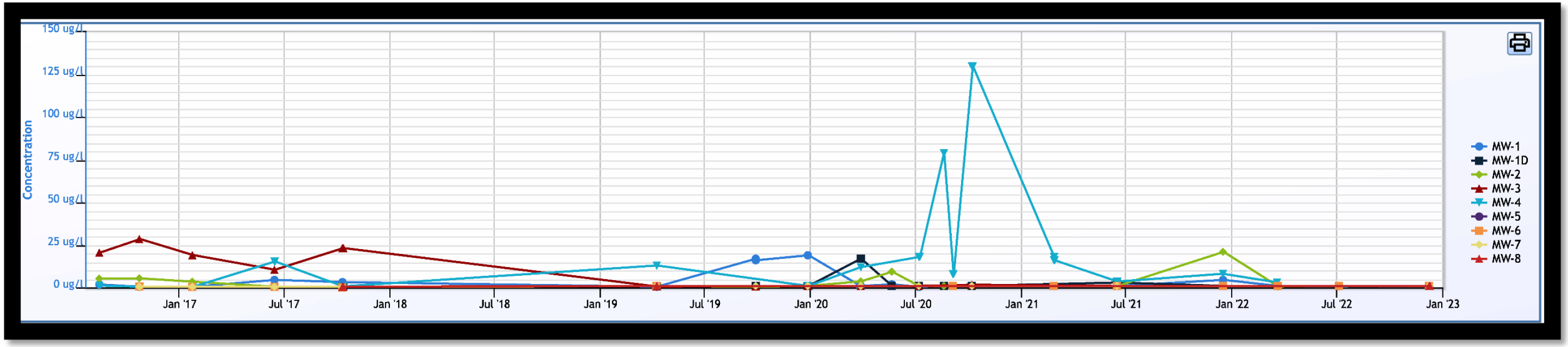


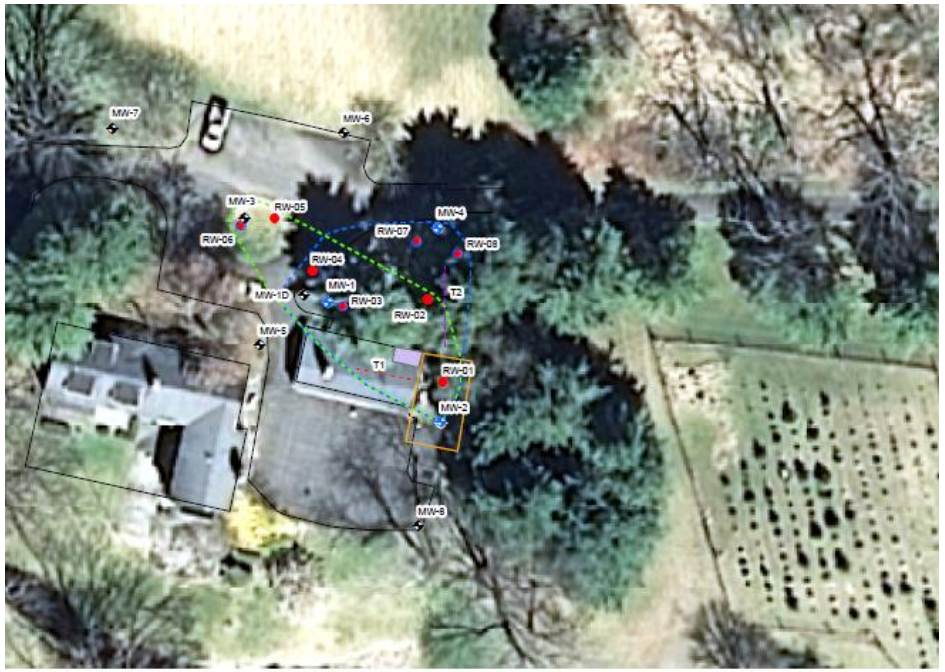
BENZENE

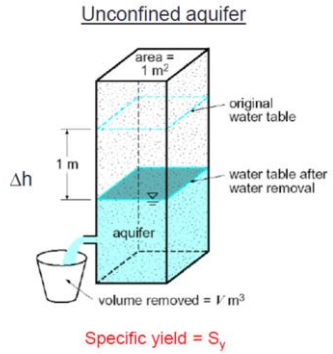
- Less time communicating results = more time to optimize treatment approach

Mechanically Efficient Flow(s)

Recharged Flow > uses DO, requires less amendments

Minimizes problems





Figures from Hornberger et al. (1998)

Optimal Flow, Bugs Grow

System Flows – Phase 1 Operations

4 vertical injection wells, 1 horizontal injection trench

4/5 vertical extraction wells (1 deep)

Approx. Operation Period (Days)	Total Gallons Recirculated/Delivered	Average Gallons Per Day	Average Gallons Per Minute
851	1,531,635	1,800	1.25

System Flows – Phase 2 Operations

3 vertical injection wells, 2 horizontal injection trenches

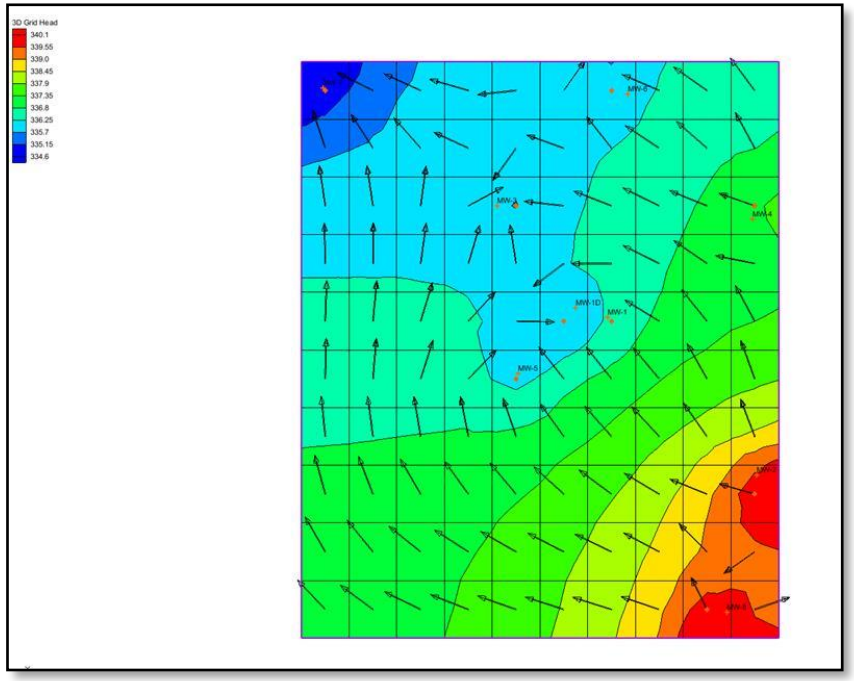
6 vertical extraction wells (1 deep)

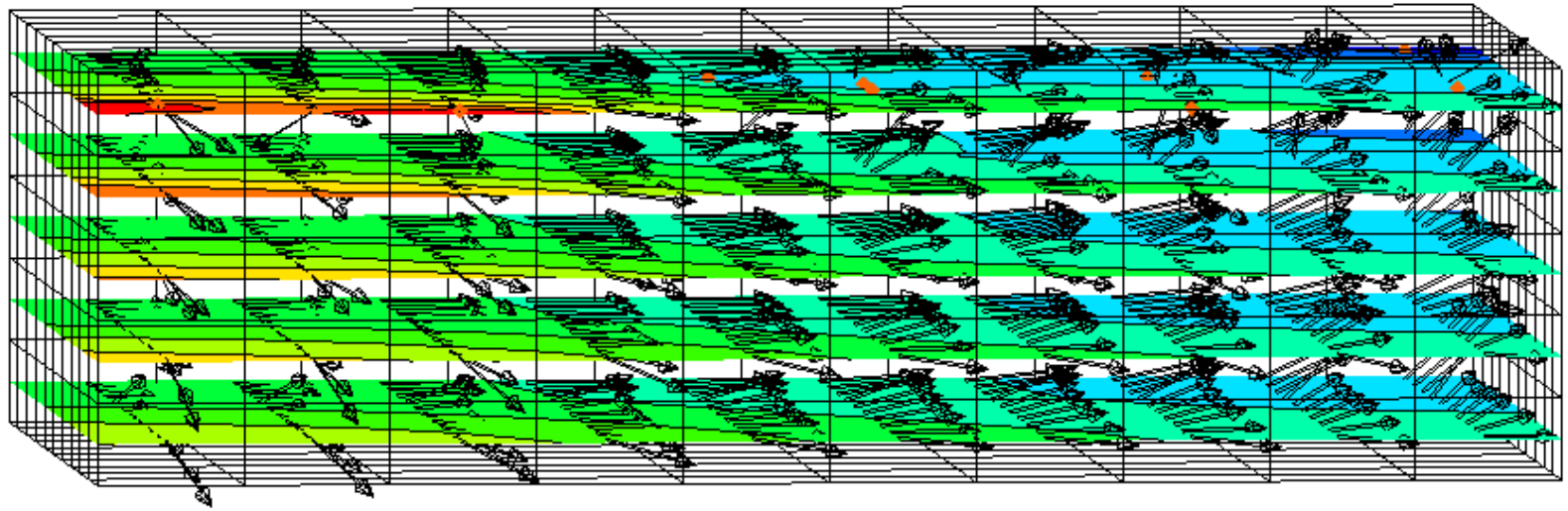
Approx. Operation Period (Days)	Total Gallons Recirculated/Delivered	Average Gallons Per Day	Average Gallons Per Minute
232	835,294	3,600	2.50

- POINTS OF EMPHASIS:
  - SYSTEM DELIVERY CLOSER TO PLANE OF FLOW MADE A DIFFERENCE
  - HORIZONTAL > VERTICAL (DELIVERY) IF GW FLOW IS PREDOMINANTLY HORIZONTAL
  - MORE BUBBLES, MORE BUGS, MORE DEGRADATION

Persistent Optimization

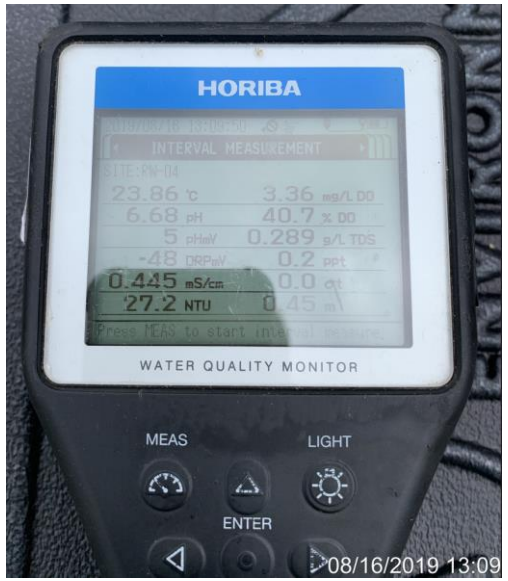
Analytical / Modeling Tools Used to Understand and Adjust System Operations

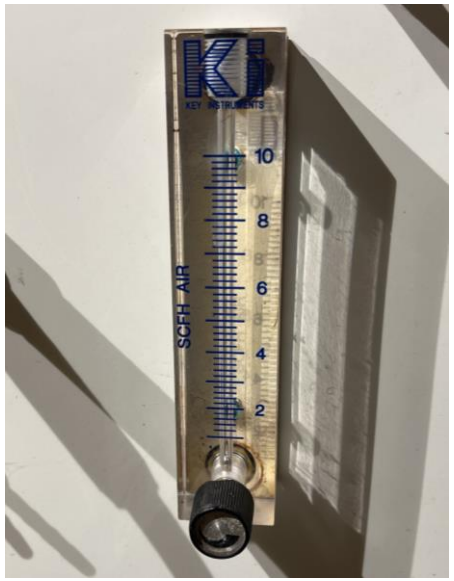




Persistent Optimization

- Continuous field experience/involvement was invaluable
- Group discussions respecting input from everyone





Closing Remarks

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If you want to do great work, surround yourself with great people.