Surfactant Enhanced Aquifer Remediation of a Low Permeability Unit Containing Light Non-Aqueous Phase Liquid

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remediation technologies symposium

Terracon

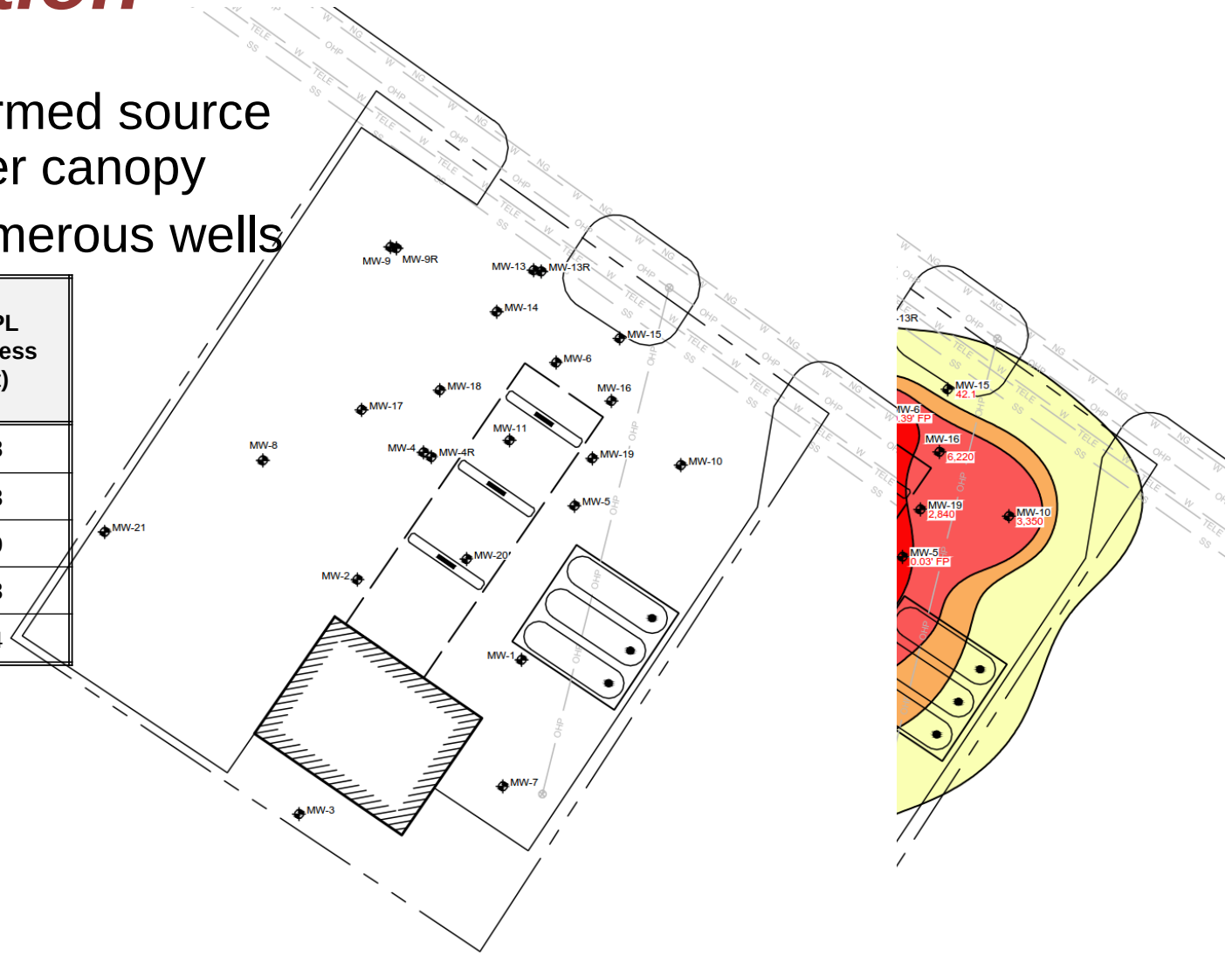
Site Background

- Gas station/convenience store in Richmond Hill, Georgia (near Savannah, Georgia)
- Release of gasoline discovered in 1991 during Phase II ESA – characterized as ‘suspected release’
- Three USTs removed and replaced in 1994
- No UST Closure report filed with the Georgia EPD
- Release confirmed by Georgia EPD in 2009

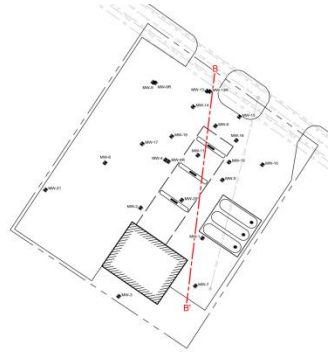
Plume Delineation

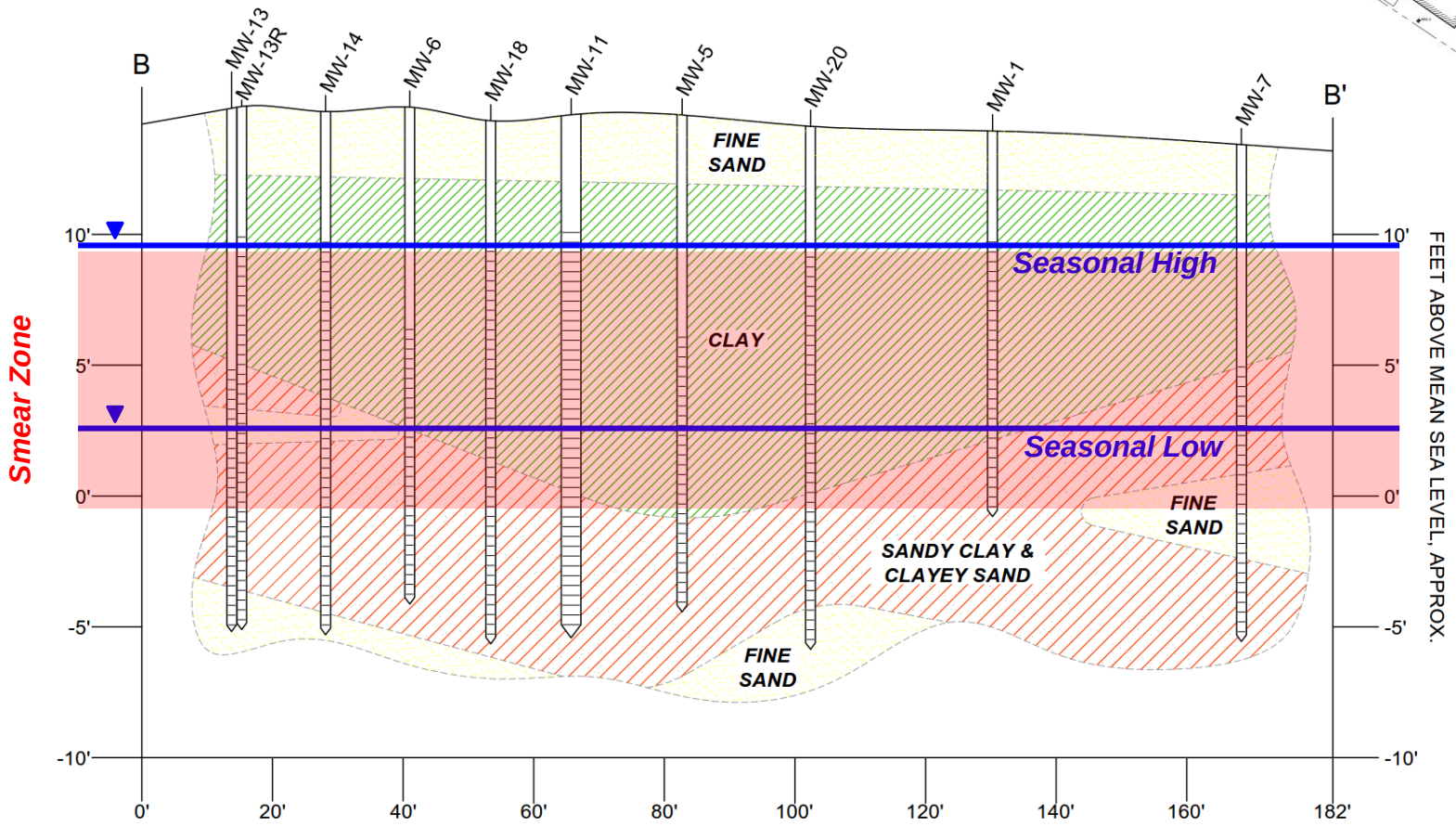
- March 2014 data confirmed source zone beneath dispenser canopy
- LNAPL identified in numerous wells

Well ID	Depth to Water (feet below TOC)	LNAPL Thickness (feet)
MW-4	6.75	0.08
MW-5	6.87	0.03
MW-6	7.52	0.39
MW-11	7.46	0.53
MW-20	7.27	0.24



Hydrogeology





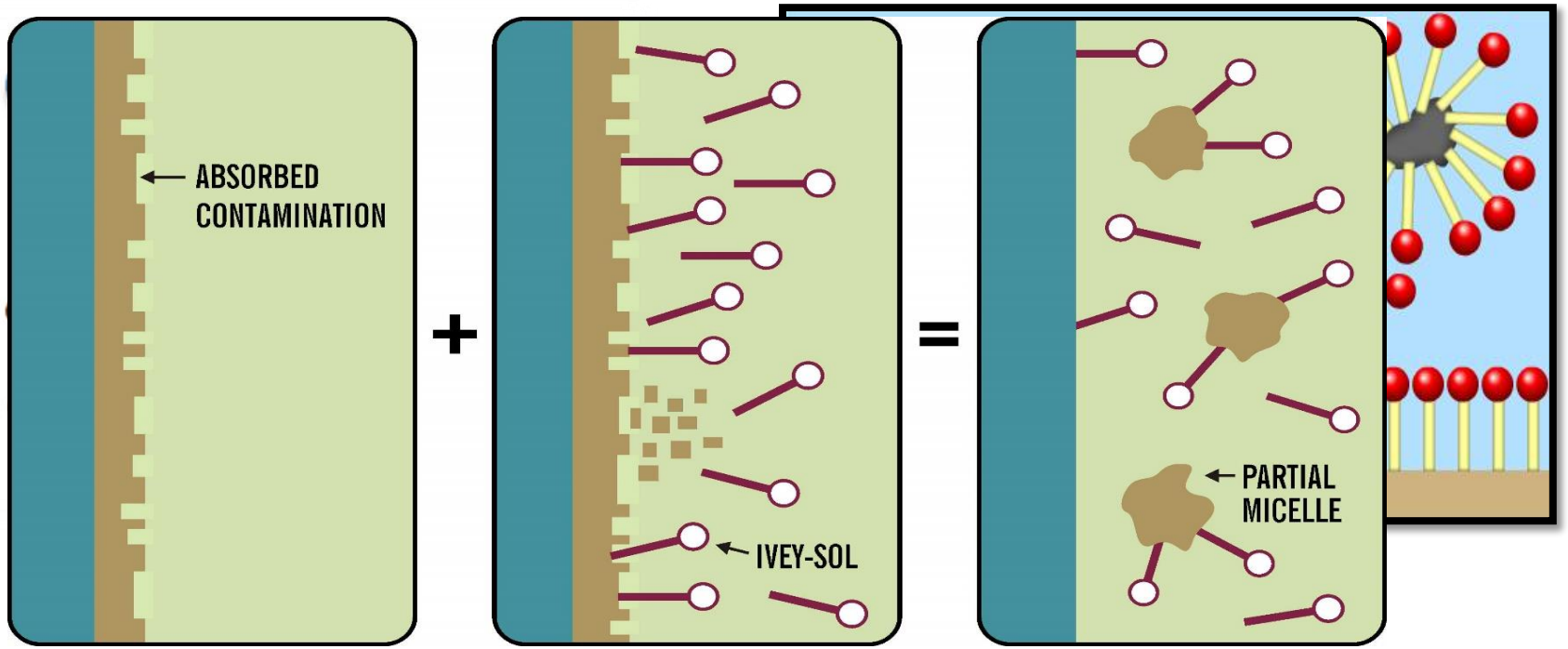
Remedy Selection

- Surfactant Enhanced Aquifer Remediation (SEAR)
- Regulatory Objectives
  - Remove LNAPL that exceeds 1/8th inch (Georgia EPD, 1995)
  - Liberate and mobilize sorbed LNAPL for subsequent removal
- Client Objectives
  - No disturbance to active site operations
  - Prefer no permanent system
  - Quick remediation time frame
- Remedial Action Objectives
  - Reduce LNAPL to residual saturation
  - ≤20 equivalent gallons of gasoline recovered
  - Demonstrate dissolved phase plume is stable
  - Low groundwater recovery and/or decreasing
  - No long term impact on in-well LNAPL thickness
- Previous interim HVR events had little success
  - Encourage dissolution of LNAPL for subsequent natural attenuation processes

Surfactant Selection

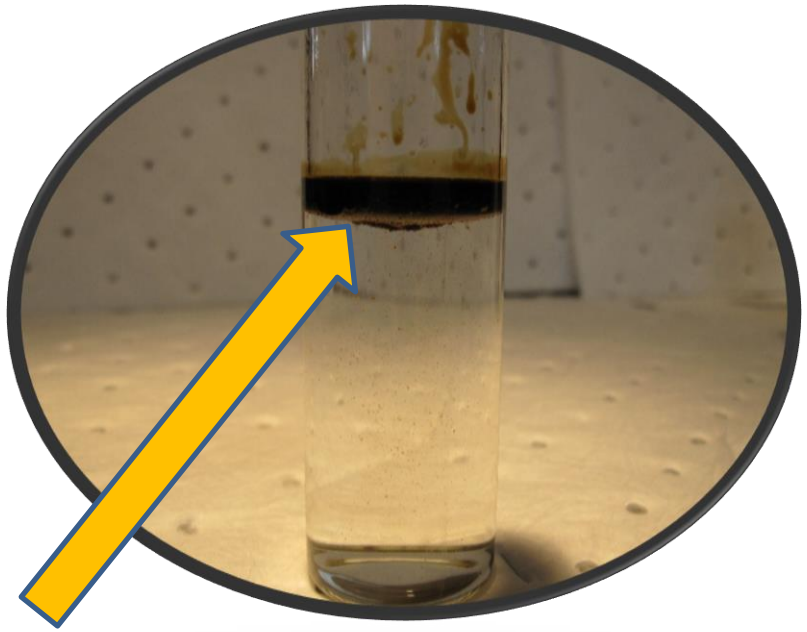
- Ivey-sol® nonionic surfactants form encapsulations at the critical micelle concentration
- Mechanism is selective and works below the critical micelle concentration

Conventional surfactants form
encapsulations at the critical
micelle concentration

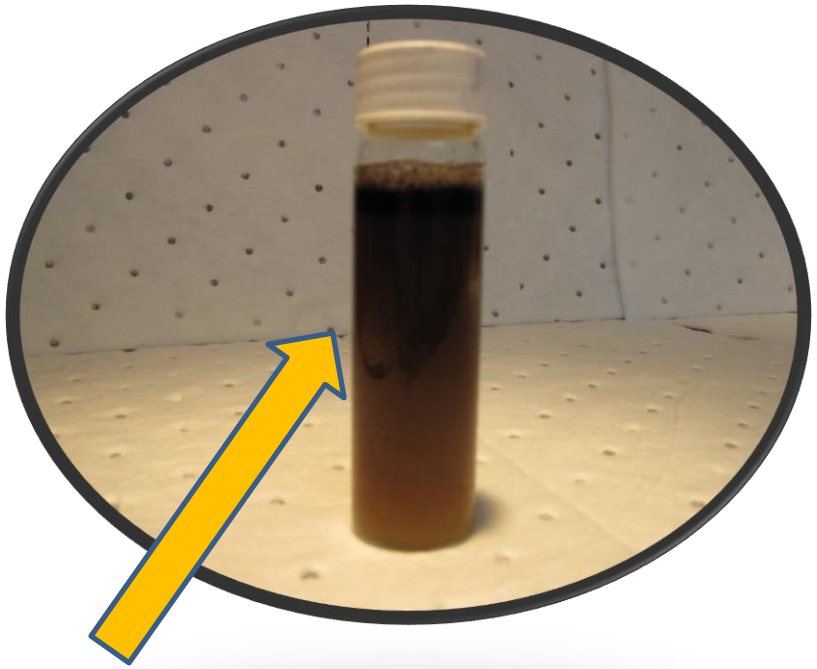


Surfactant Selection

- Ivey-sol® interaction with LNAPL



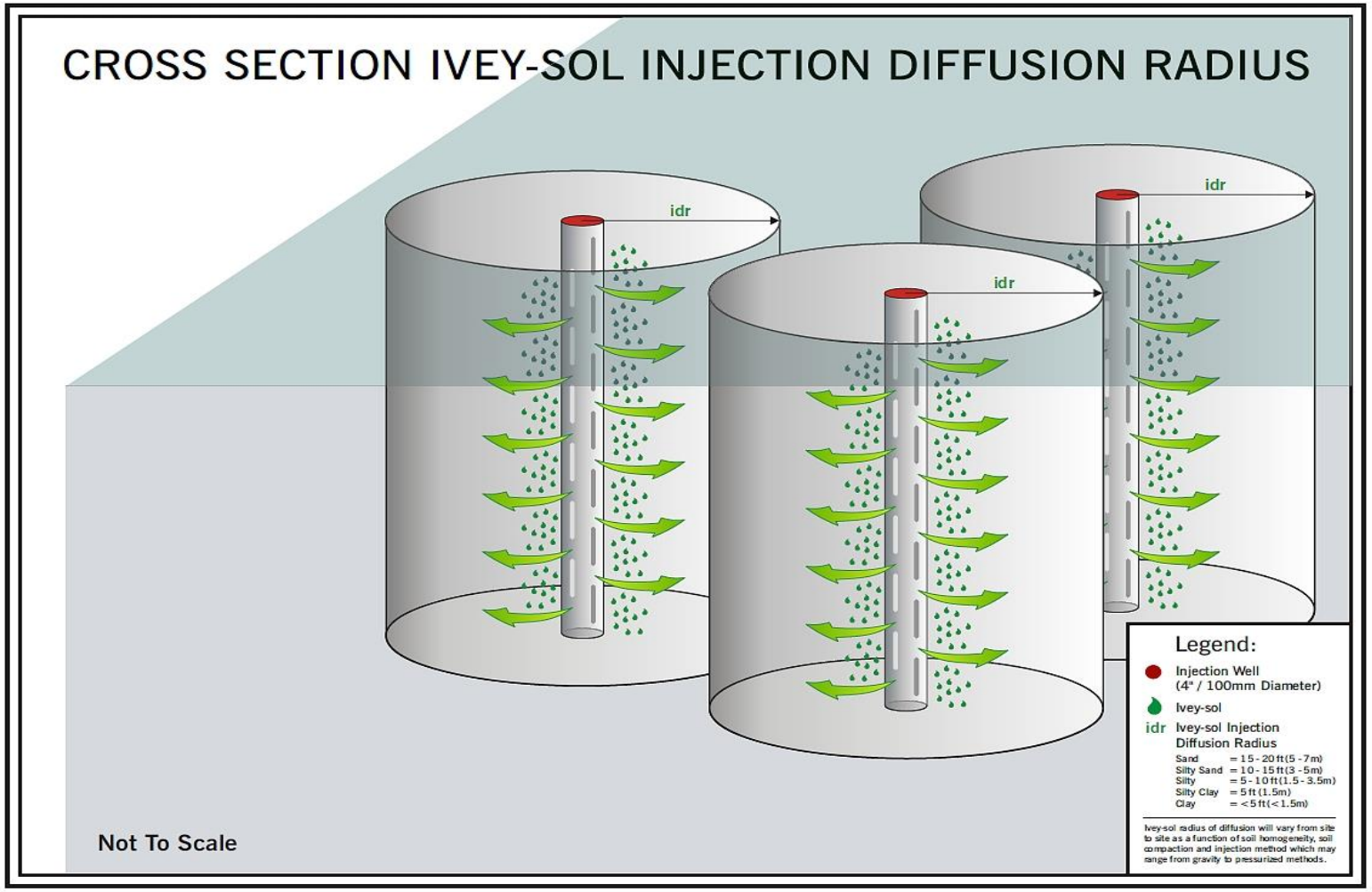
LNAPL



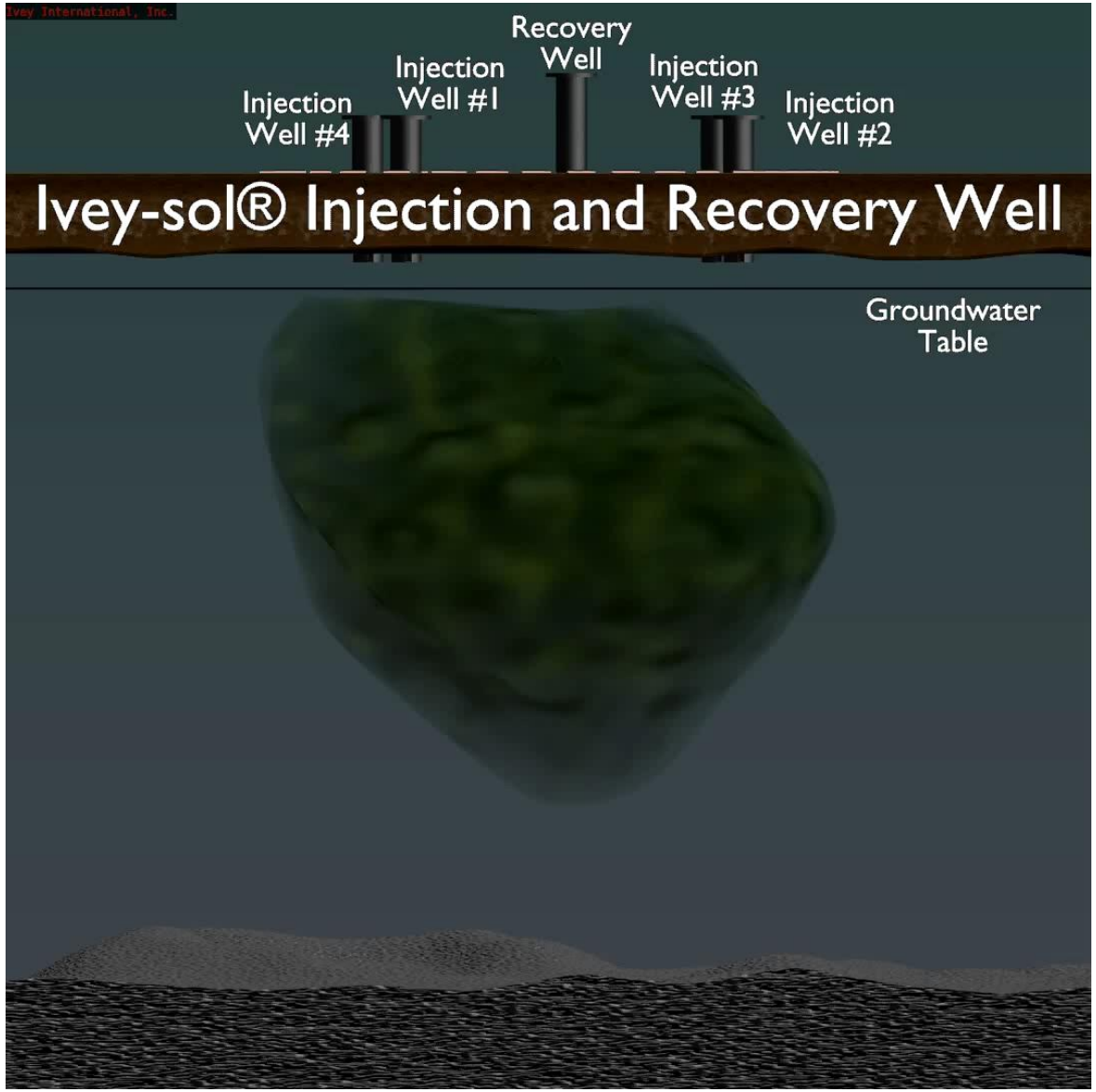
Made Miscible In
Water With Ivey-sol®

Surfactant Delivery Method

- Injection of Ivey-sol® surfactant at injection wells, making contact with target LNAPL, sorbed phase, and smear zone impacts.

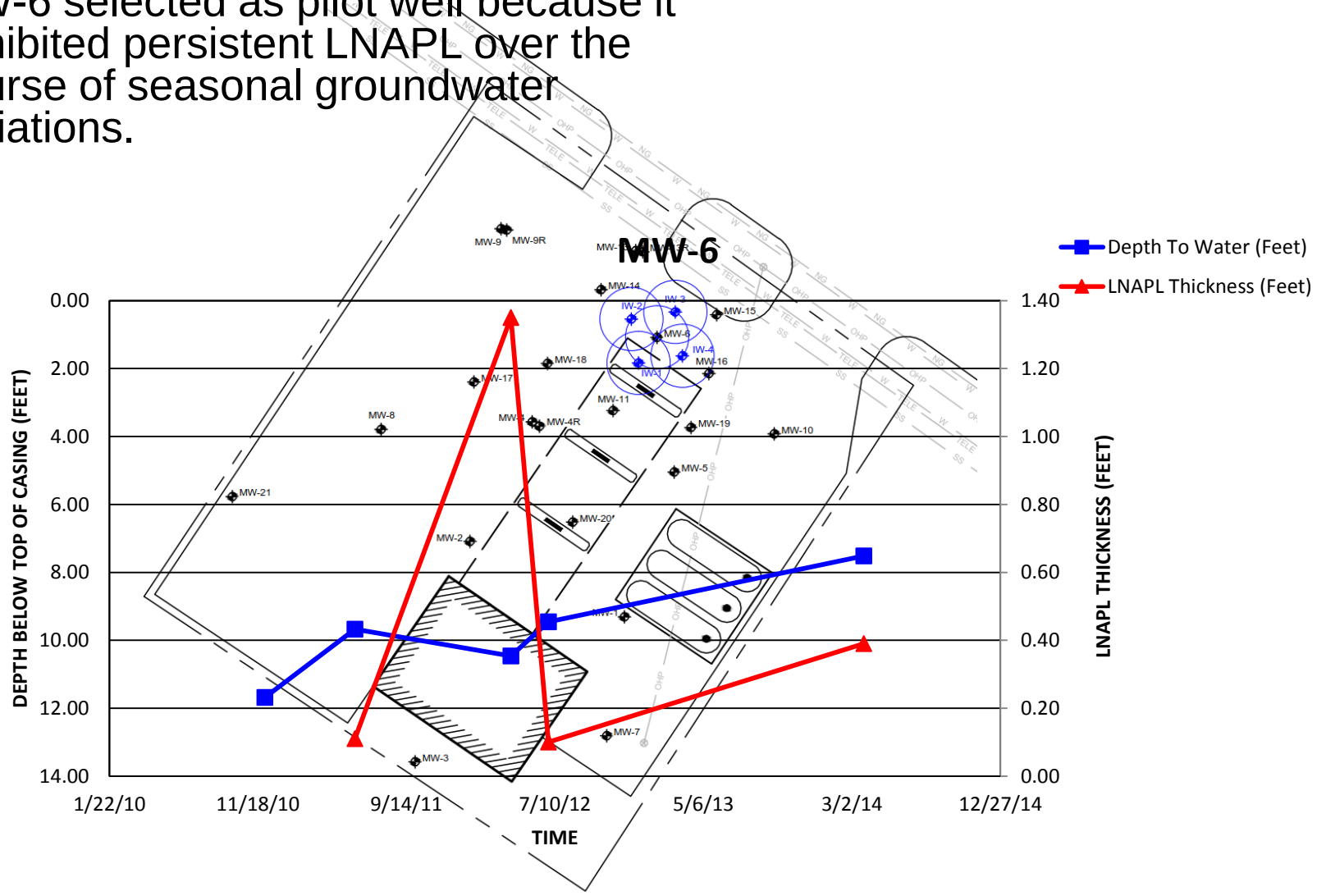


Surfactant Delivery Method



Pilot Testing

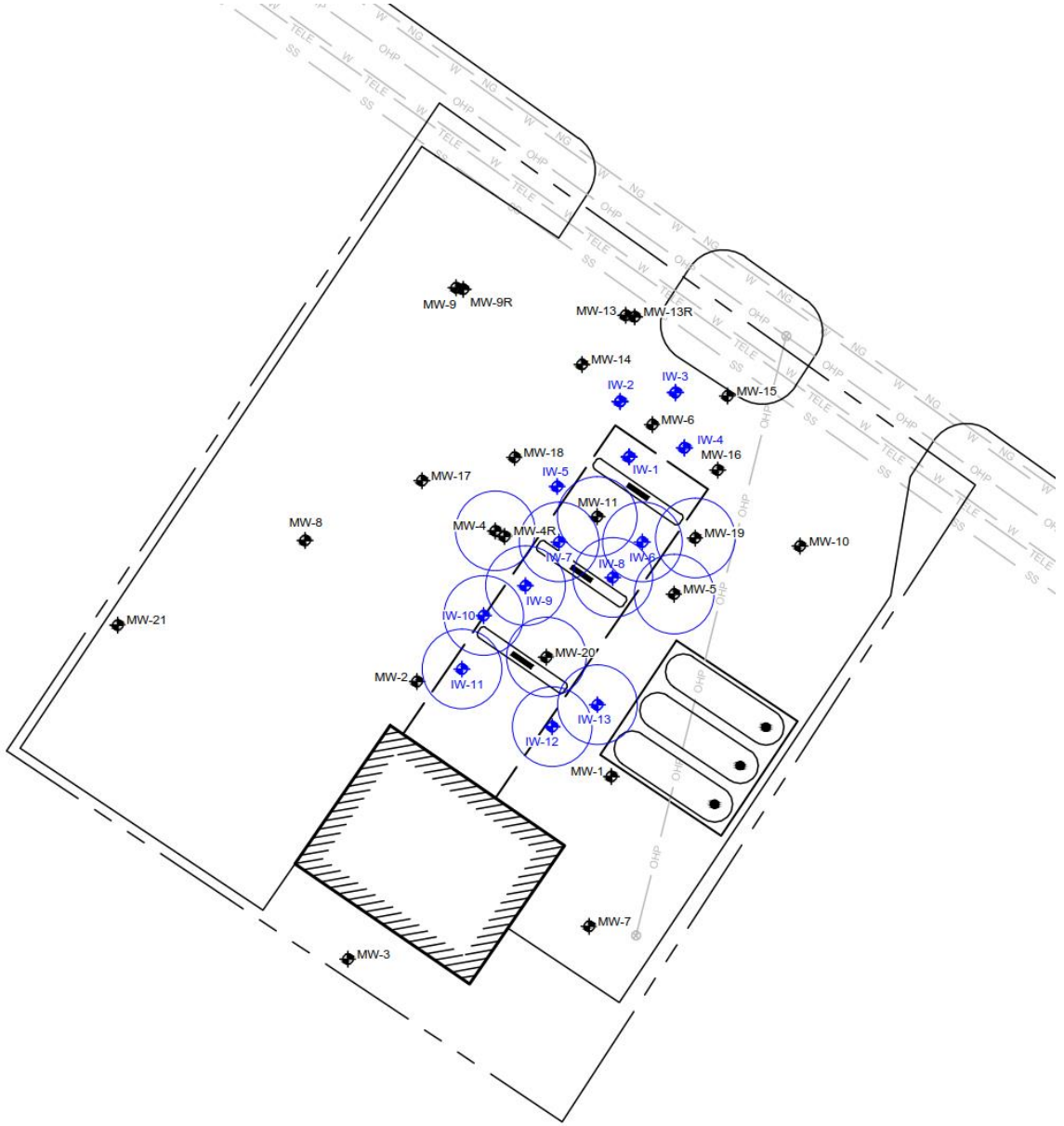
- MW-6 selected as pilot well because it exhibited persistent LNAPL over the course of seasonal groundwater variations.



Remedial Design

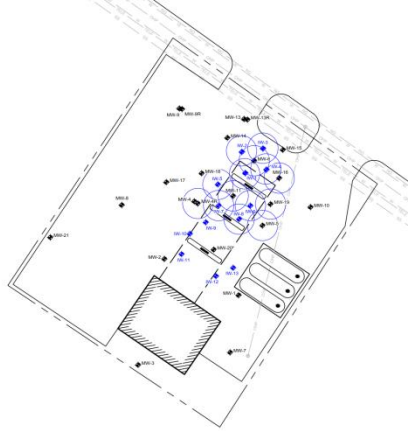
Phase II SEAR

- Pre-Injection 16-hour HVR - 5 wells
- Injection Event – 13 wells
- Post-Injection 24-hour HVR
  - 5 wells initially
  - Alternated 2 of the wells after 12 hours and added 5th well



SEAR Phase I Results

June 16-19, 2015



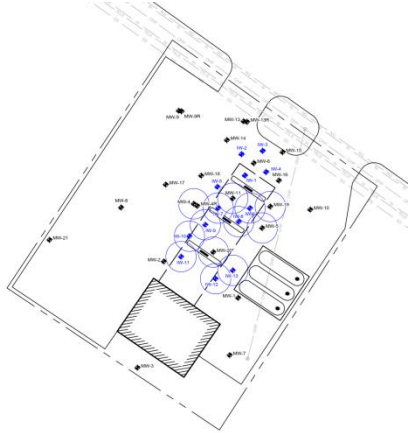
	Pre 16-hour HVR Event		16-hour HVR Event Results	Post 16-hour HVR Event	
Well ID	**LNAPL Thickness** (feet)	**Depth to Water** (feet below TOC)	**2,000 gallons PCW 4.17 equivalent gallons of gasoline**	**LNAPL Thickness** (feet)	**Depth to Water** (feet below TOC)
MW-5	0.36	8.63		0.00	12.15
MW-10	0.07	8.37		0.06	14.81
MW-11	0.39	8.83		0.00	13.21

2,415 gallons of 4% nonionic surfactant solution injected

	Pre 24-hour HVR Event		24-hour HVR Event Results	Post 24-hour HVR Event	
Well ID	**LNAPL Thickness** (feet)	**Depth to Water** (feet below TOC)	**3,235 gallons PCW 4.59 equivalent gallons of gasoline**	**LNAPL Thickness** (feet)	**Depth to Water** (feet below TOC)
MW-5	0.00	7.86		0.00	14.81
MW-10	0.01	8.93		0.00	14.87
MW-11	0.05	8.43		0.00	14.23

SEAR Phase II Results

June 23-26, 2015



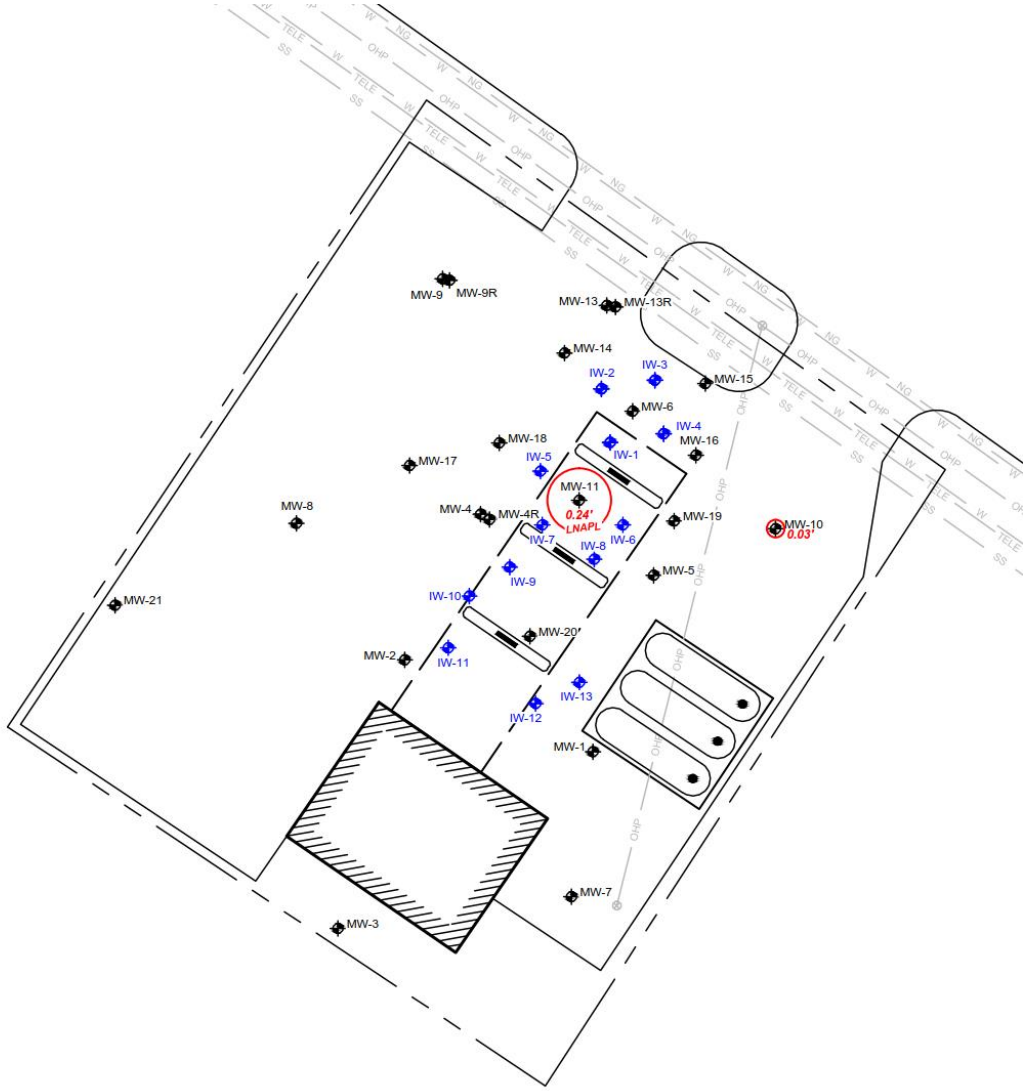
	Pre 16-hour HVR Event		16-hour HVR Event Results	Post 16-hour HVR Event	
Well ID	**LNAPL Thickness** (feet)	**Depth to Water** (feet below TOC)	**1,725 gallons PCW** **2.96 equivalent gallons of gasoline**	**LNAPL Thickness** (feet)	**Depth to Water** (feet below TOC)
MW-11	0.07	9.45		0.06	13.02
MW-20	0.10	9.13		0.00	15.37

2,449 gallons of 4% nonionic surfactant solution injected

	Pre 24-hour HVR Event		24-hour HVR Event Results	Post 24-hour HVR Event	
Well ID	**LNAPL Thickness** (feet)	**Depth to Water** (feet below TOC)	**3,148 gallons PCW** **9.07 equivalent gallons of gasoline**	**LNAPL Thickness** (feet)	**Depth to Water** (feet below TOC)
MW-11	0.01	8.75		0.00	15.14
MW-20	0.00	9.46		0.00	15.26

SEAR Phase I & II – Monitoring Results

August 5, 2015



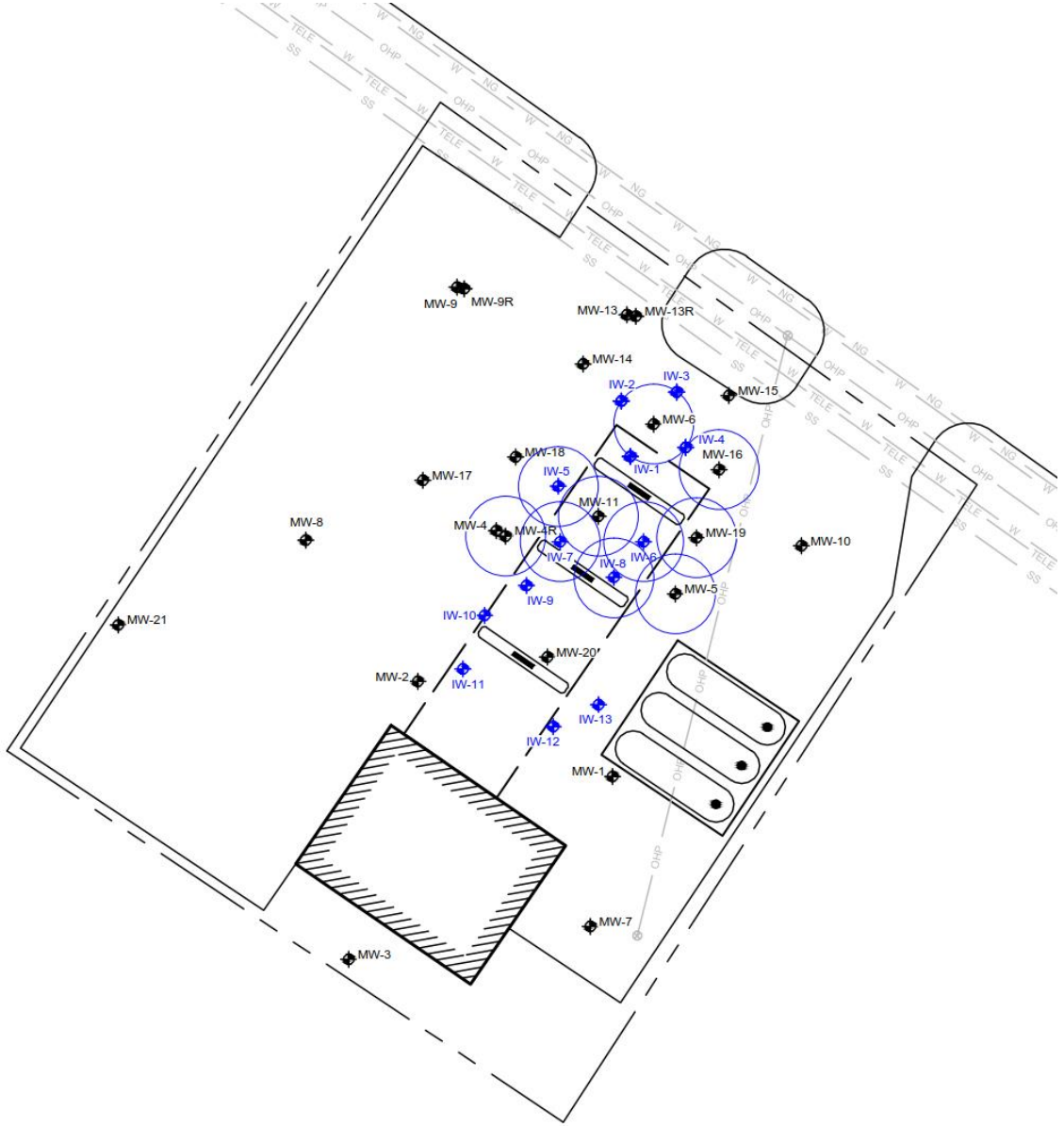
SEAR Phase I & II – Conclusions

- LNAPL footprint reduced
- Elevated dissolved phase concentrations remain within source area
  - Entrained LNAPL remains
  - Some desorption/dissolution of LNAPL evident
  - Concentrations stable and/or decreasing
- Additional SEAR event recommended in vicinity of MW-11

SEAR Phase III

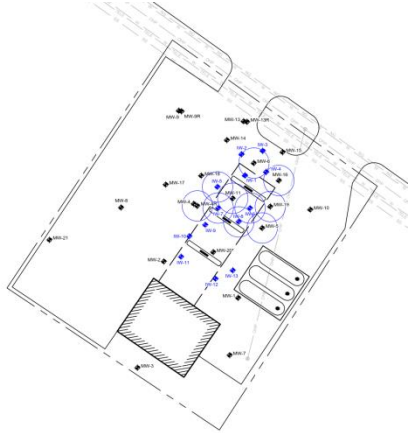
Phase III SEAR

- Pre-Injection 16-hour HVR - 5 wells
- Injection Event – 11 wells
- Post-Injection 24-hour HVR – 5 wells



SEAR Phase III Results

October 27-30, 2015



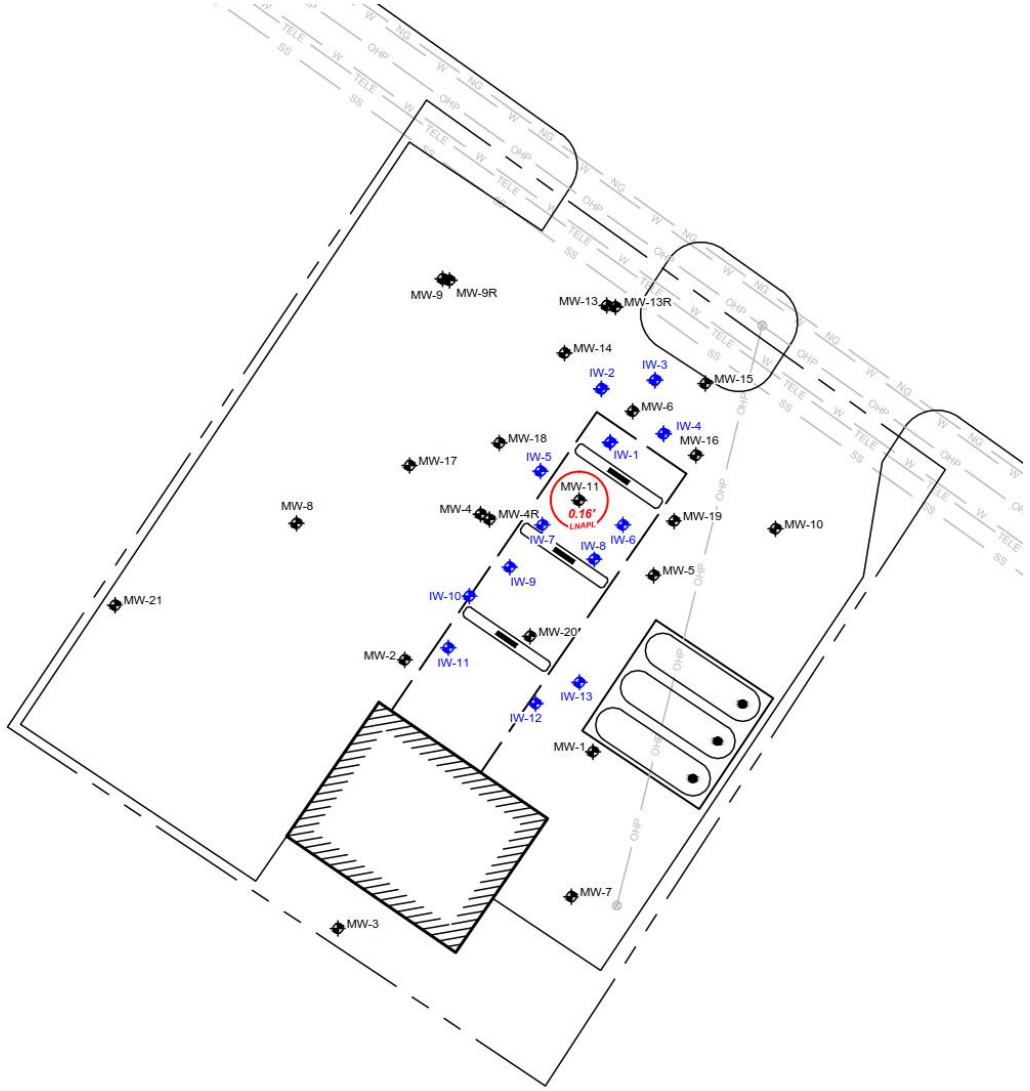
	Pre 16-hour HVR Event		16-hour HVR Event Results	Post 16-hour HVR Event	
Well ID	**LNAPL Thickness** (feet)	**Depth to Water** (feet below TOC)	**1,425 gallons PCW 7.89 equivalent gallons of gasoline**	**LNAPL Thickness** (feet)	**Depth to Water** (feet below TOC)
MW-10	0.01	8.61		0.00	12.00
MW-11	0.20	8.82		0.00	15.66

2,800 gallons of 4% nonionic surfactant solution injected

	Pre 24-hour HVR Event		24-hour HVR Event Results	Post 24-hour HVR Event	
Well ID	**LNAPL Thickness** (feet)	**Depth to Water** (feet below TOC)	**3,500 gallons PCW 7.24 equivalent gallons of gasoline**	**LNAPL Thickness** (feet)	**Depth to Water** (feet below TOC)
MW-10	0.00	9.43		0.00	13.91
MW-11	0.00	8.34		0.00	16.28

SEAR Phase III – Monitoring Results

December 10, 2015



SEAR Phase III – Conclusions

- Further reduced LNAPL footprint
- In-well LNAPL limited to MW-11 only
  - Wells IW-5 through IW-8 within 15 foot radius of MW-11 have not exhibited LNAPL since March 2015 installation
- Stable and/or decreasing dissolved phase concentrations

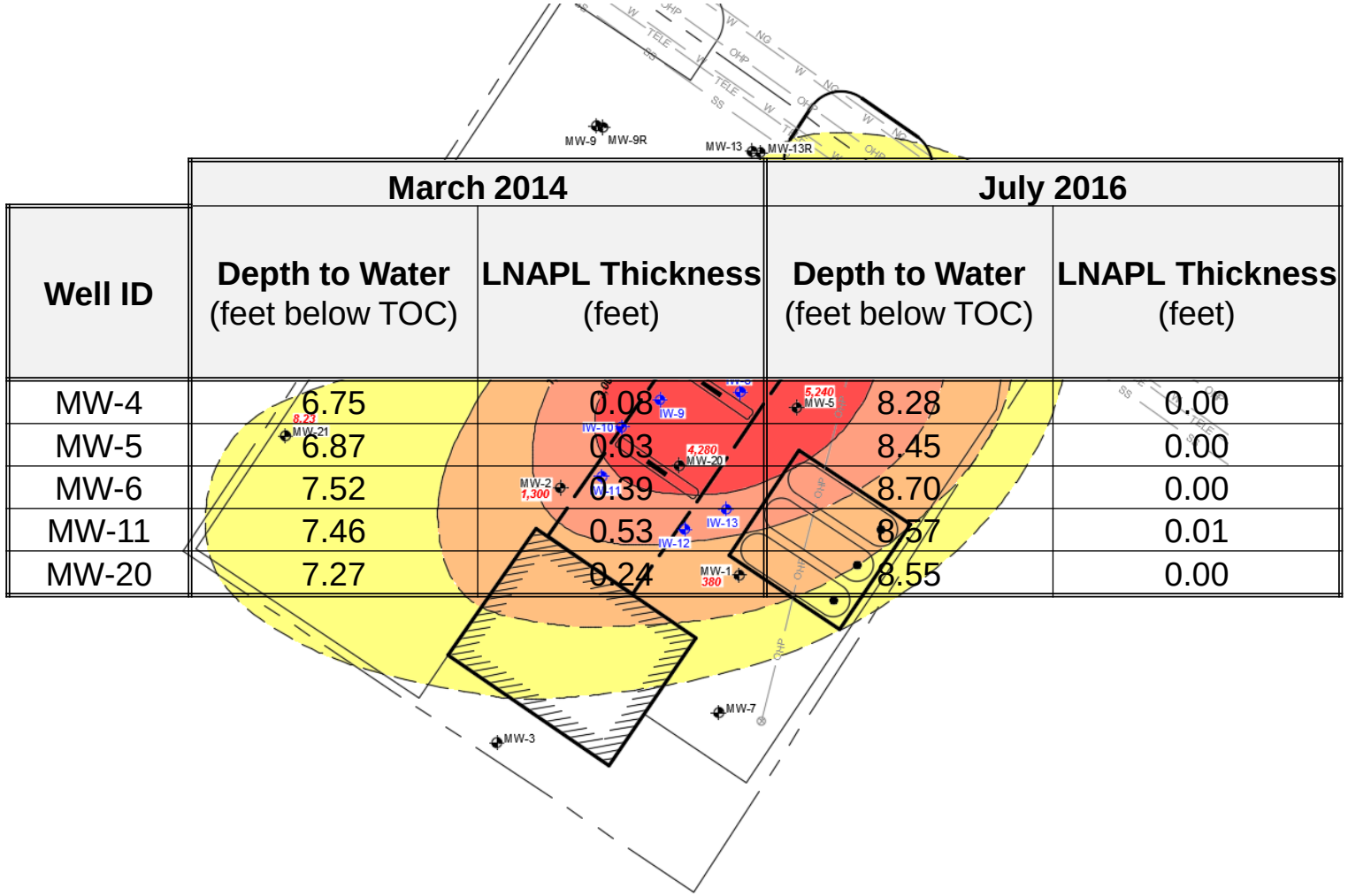
Post Corrective Action Monitoring

- December 2015 monitoring event indicated groundwater elevation approaching seasonal high
  - LNAPL could be submerged
  - Monitor through June 2016
- Interim gauging event conducted in March 2016

	March 2014		March 2016	
Well ID	**Depth to Water** (feet below TOC)	**LNAPL Thickness** (feet)	**Depth to Water** (feet below TOC)	**LNAPL Thickness** (feet)
MW-4	6.75	0.08	6.90	0.00
MW-5	6.87	0.03	7.08	0.00
MW-6	7.52	0.39	7.33	0.00
MW-11	7.46	0.53	8.19	0.00
MW-20	7.27	0.24	7.16	0.00

Post Corrective Action Monitoring

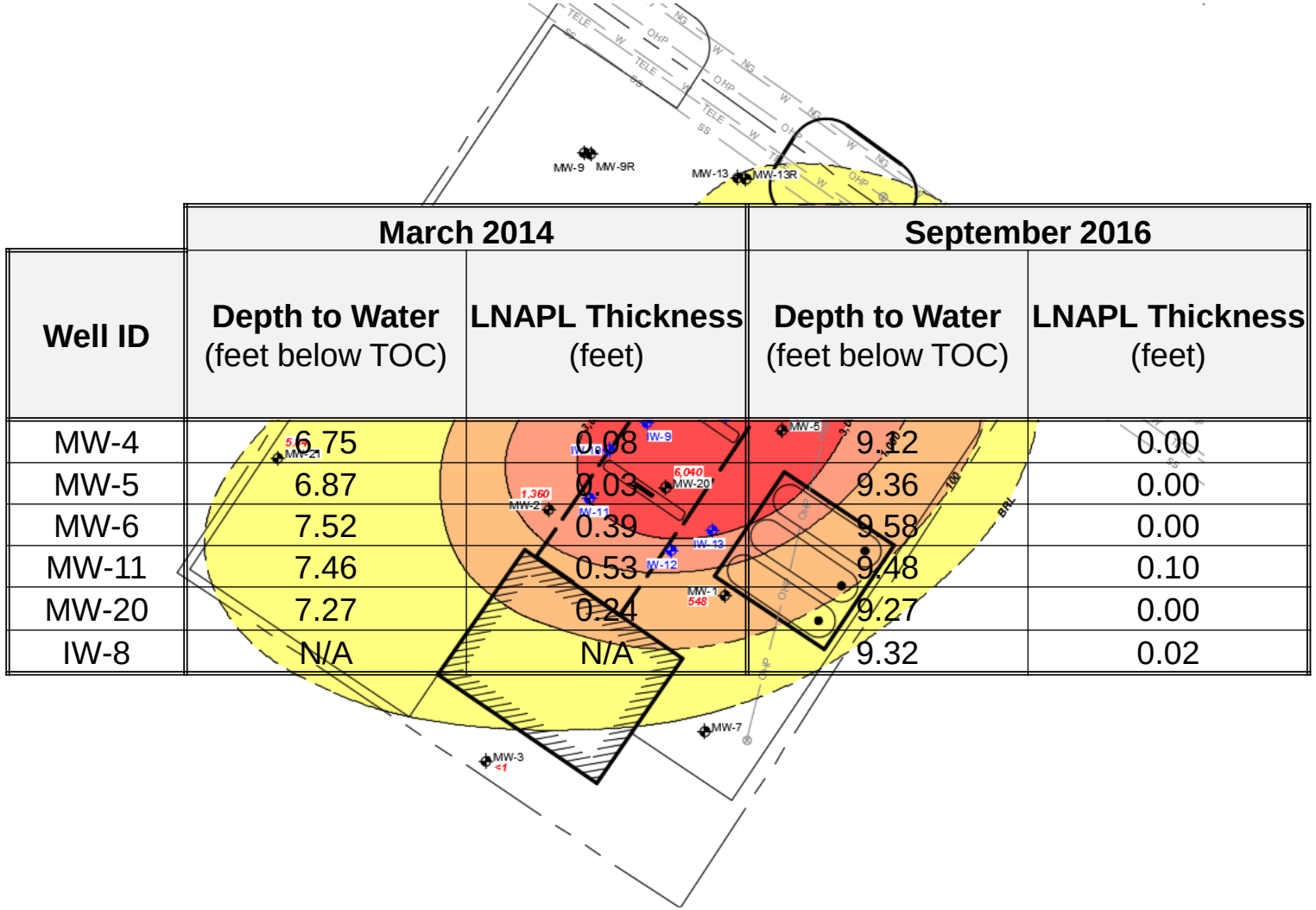
- July 2016 Monitoring Event



Well ID	March 2014		July 2016	
	Depth to Water (feet below TOC)	**LNAPL Thickness** (feet)	**Depth to Water** (feet below TOC)	**LNAPL Thickness** (feet)
MW-4	6.75	0.08	8.28	0.00
MW-5	6.87	0.03	8.45	0.00
MW-6	7.52	0.39	8.70	0.00
MW-11	7.46	0.53	8.57	0.01
MW-20	7.27	0.24	8.55	0.00

Post Corrective Action Monitoring

- September 2016 Monitoring Event



Well ID	March 2014		September 2016	
	Depth to Water (feet below TOC)	LNAPL Thickness (feet)	Depth to Water (feet below TOC)	LNAPL Thickness (feet)
MW-4	6.75	0.08	9.12	0.00
MW-5	6.87	0.03	9.36	0.00
MW-6	7.52	0.39	9.58	0.00
MW-11	7.46	0.53	9.48	0.10
MW-20	7.27	0.24	9.27	0.00
IW-8	N/A	N/A	9.32	0.02

Conclusions

- Previous HVR-only events results in <20 equivalent gallons of gasoline total with no long term impact on the in-well LNAPL
- SEAR methodology reduced the occurrence and thickness of in-well LNAPL
- While many wells show trends of decreasing concentrations, it is likely that some LNAPL remains entrained within the source zone clay formation
- With low rate of mass flux from the source area, it is likely that elevated dissolved phase contamination could remain

Future Plans

Phase IV SEAR

- Pre-Injection 24-hour HVR - 5 wells
- Injection Event – 13 wells
  - 4% Ivey-sol® solution
  - Target of 200-300 gallons per well
- Post-Injection 48-hour HVR – 5 wells