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In-Situ Chemical Treatment for Reduction of Dissolved Arsenic Concentration near an Active Spur Line in Burnaby, BC

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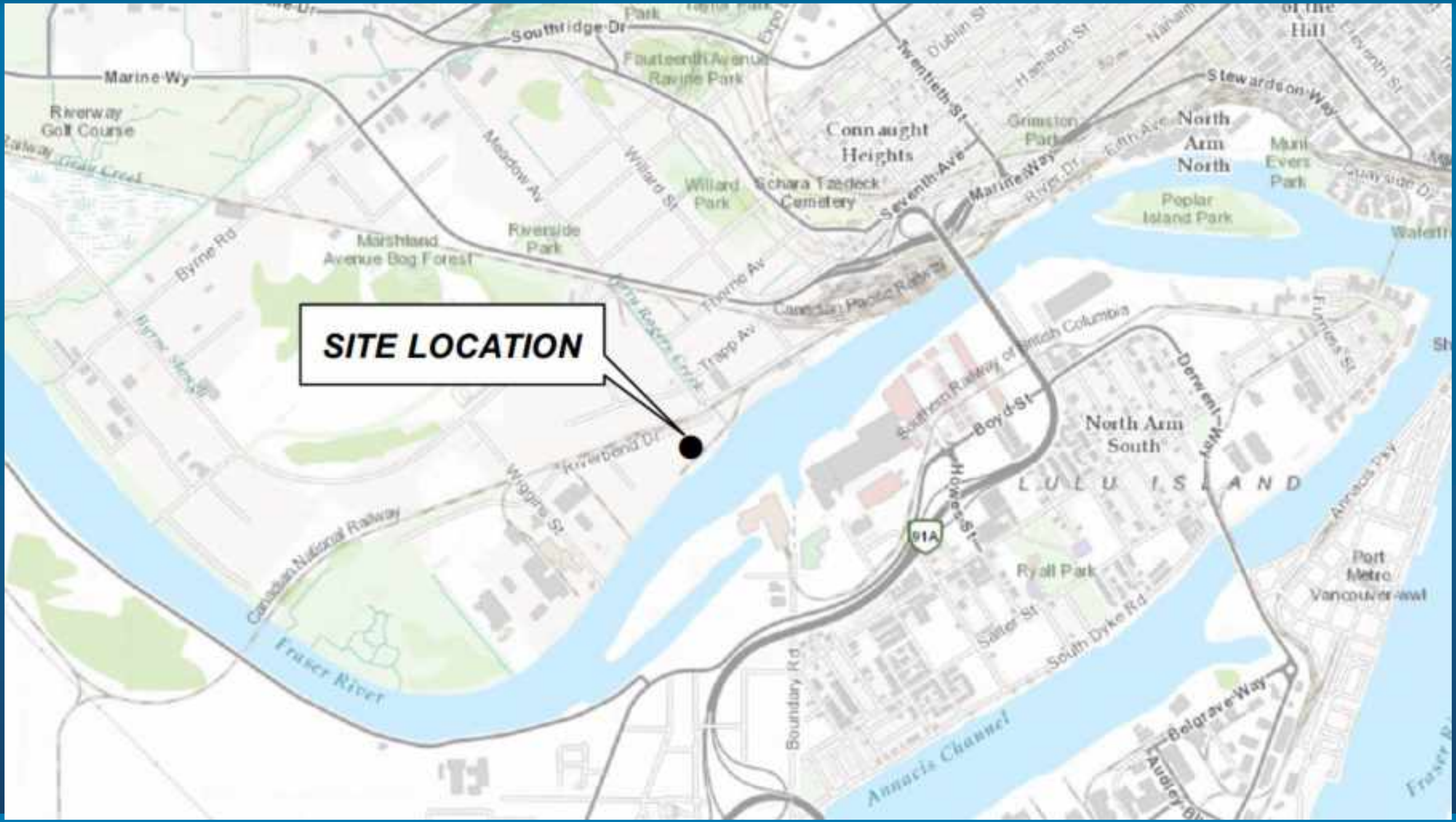
BACKGROUND: SITE LOCATION

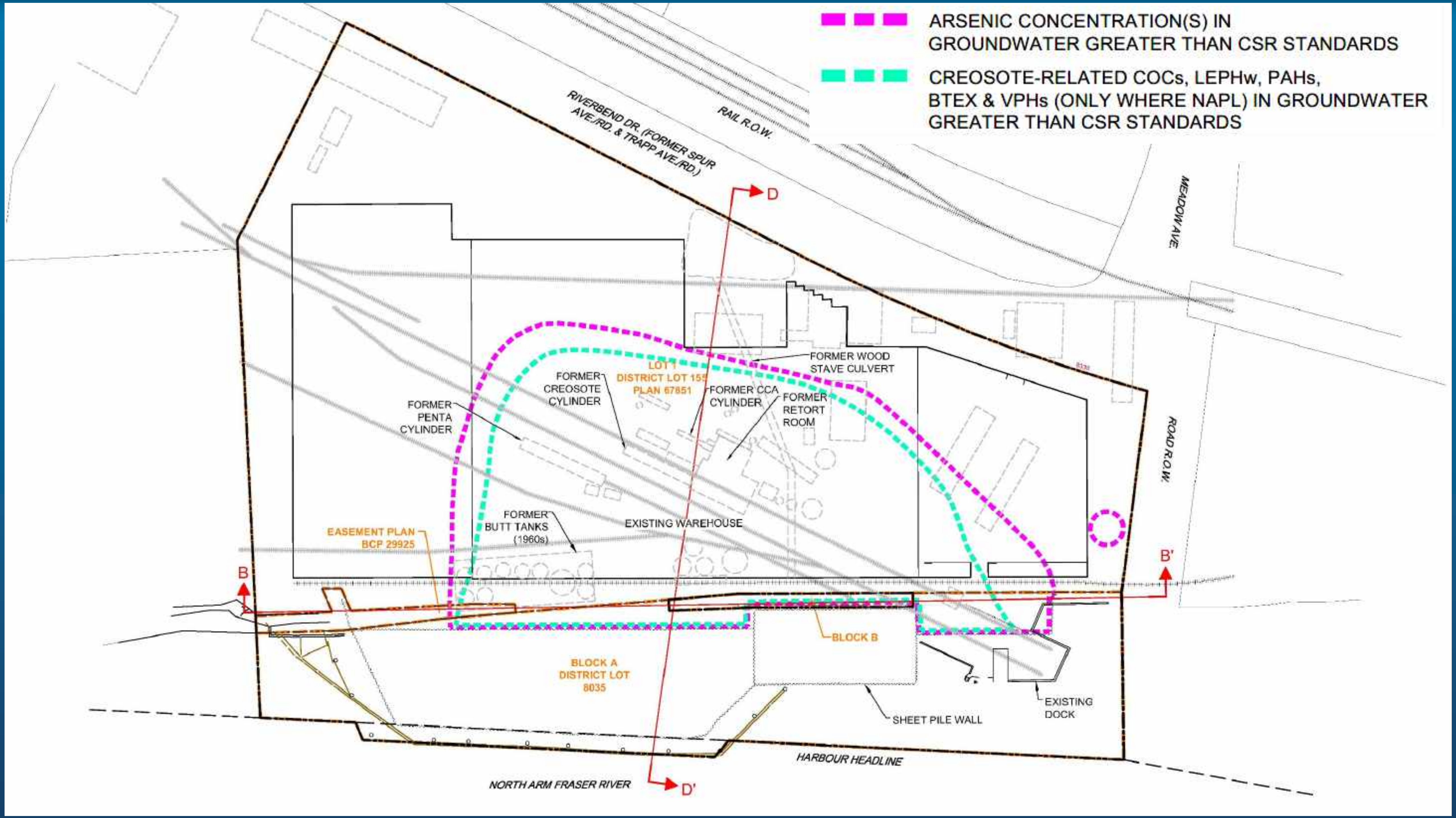


BACKGROUND: SITE HISTORY

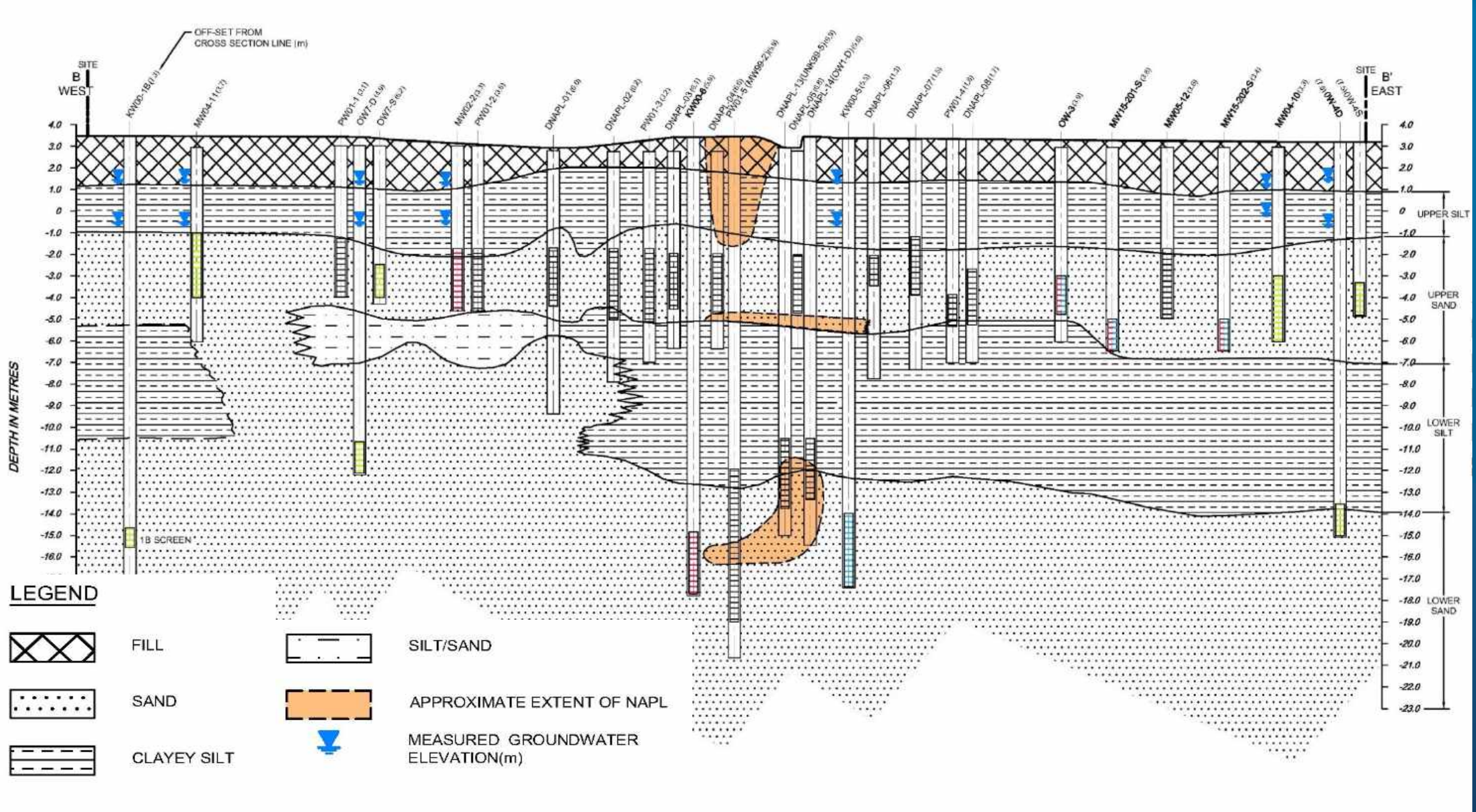
Wood Preservation Activities

- Creosote
  DNAPL and dissolved phase constituents (PAHs)
- Copper-chromium-arsenate (CCA) Dissolved arsenic
- Pentachlorophenol (PCP)

BACKGROUND: SITE HISTORY



CONCEPTUAL SITE MODEL
SITE GEOLOGY



CONCEPTUAL SITE MODEL PREVIOUS REMEDIATION WORKS

Remedial works completed in 2004:

- Dredging
- Installation of cap and sheet pile walls
- Construction of new industrial wharf
- Backfilling and construction of a new marsh

Source: APEGBC Innovation Magazine

CONCEPTUAL SITE MODEL PREVIOUS REMEDIATION WORKS

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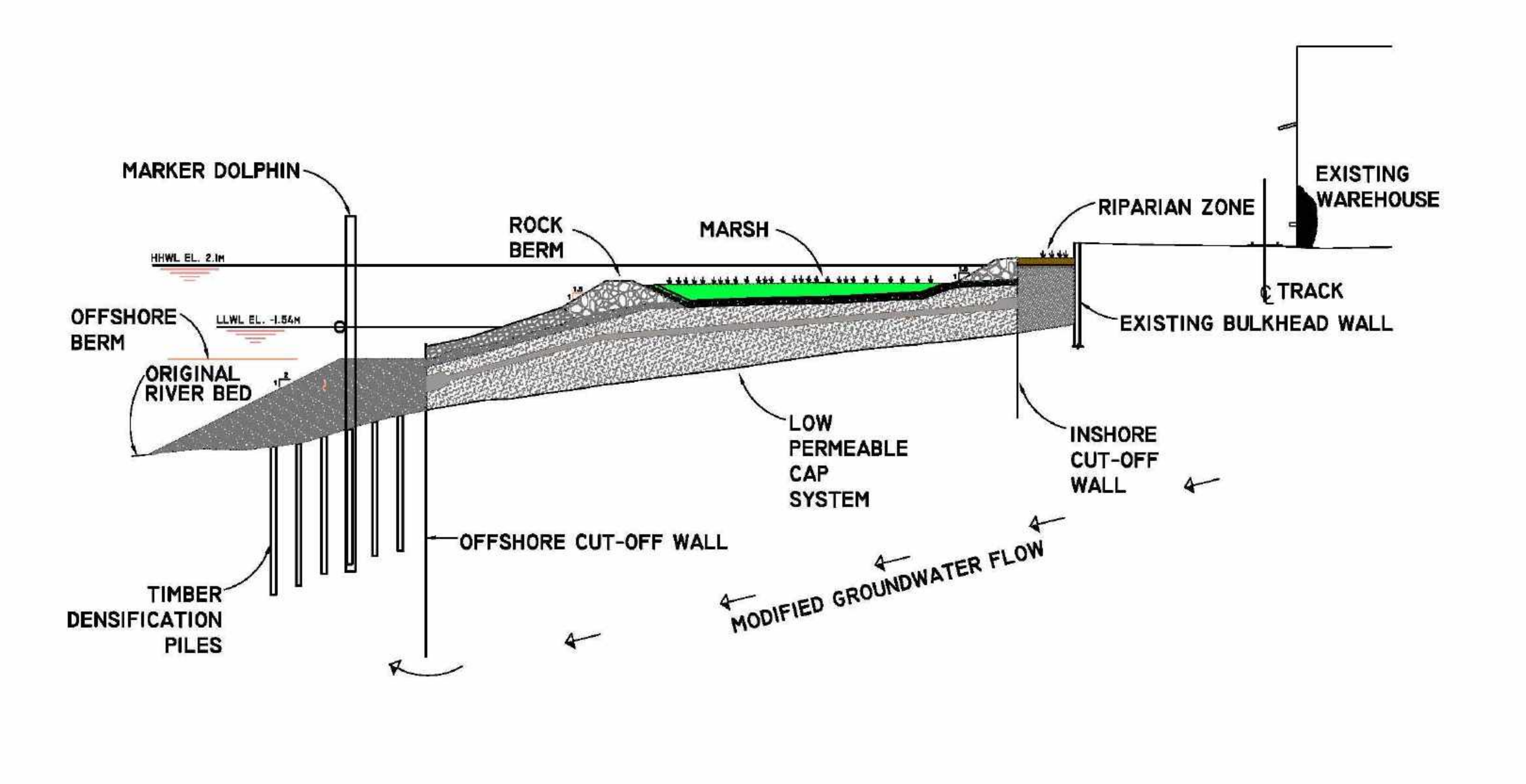
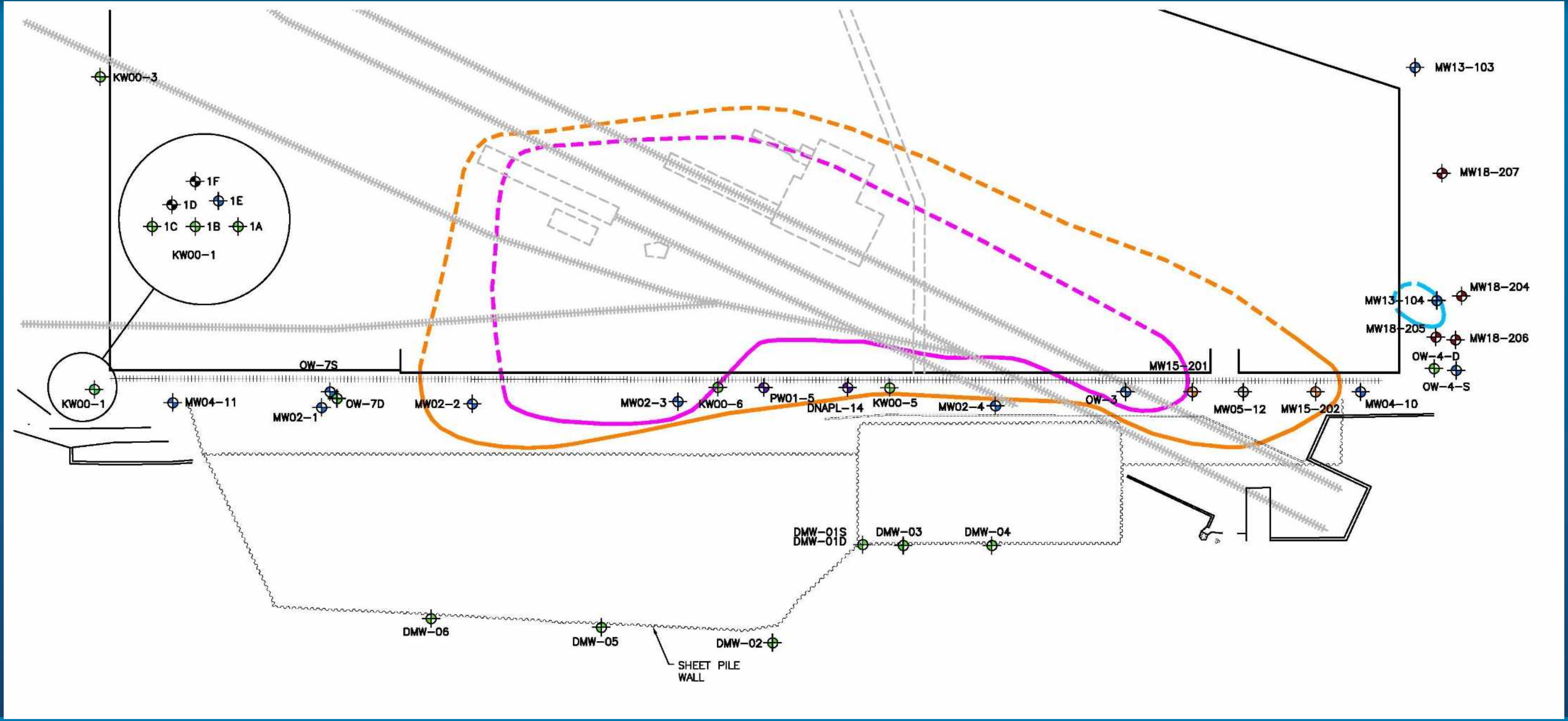


REGULATORY ENVIRONMENT

Performance Monitoring Plan (PMP)

- Defines ongoing sampling, monitoring, and inspections
- Used BC CSR framework as basis to establish site-specific toxicity reference values (TRVs)
- Establishes trigger criteria to increase or reduce frequency of sampling
- Initiates further actions if thresholds are exceeded

DISSOLVED ARSENIC



SITE CONDITIONS

- Warehouse occupies more than 90% of the upland footprint.
- Spur line runs between warehouse and river.
- Active warehouse operations 24/7.

SITE GEOCHEMISTRY

- The site fluvial sediments at the site contain organics which contribute to reducing conditions at the site
- PAH contamination and active anaerobes consuming electron acceptors at the site influences the site geochemistry to have strong reducing conditions

ARSENIC GEOCHEMISTRY

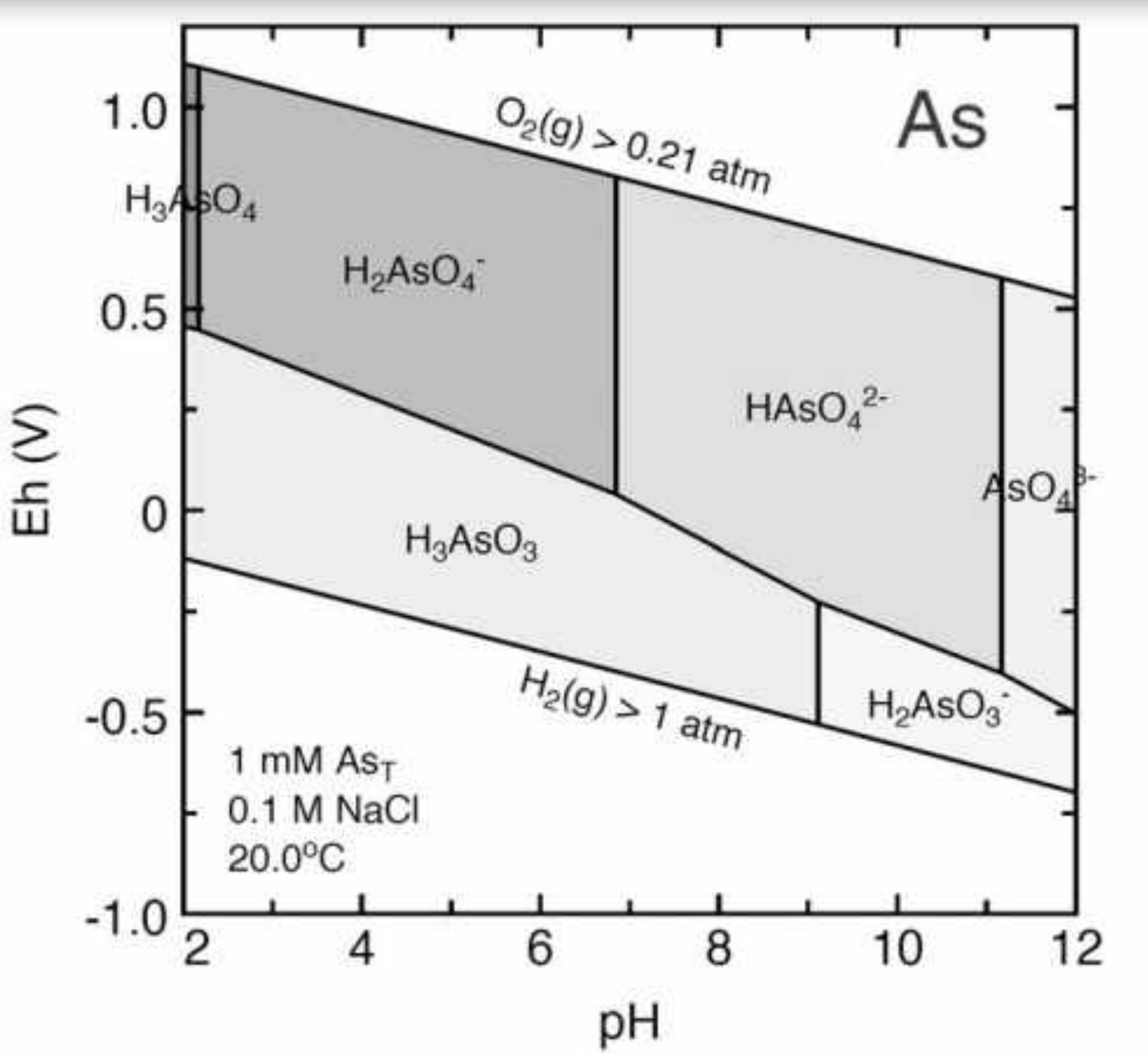
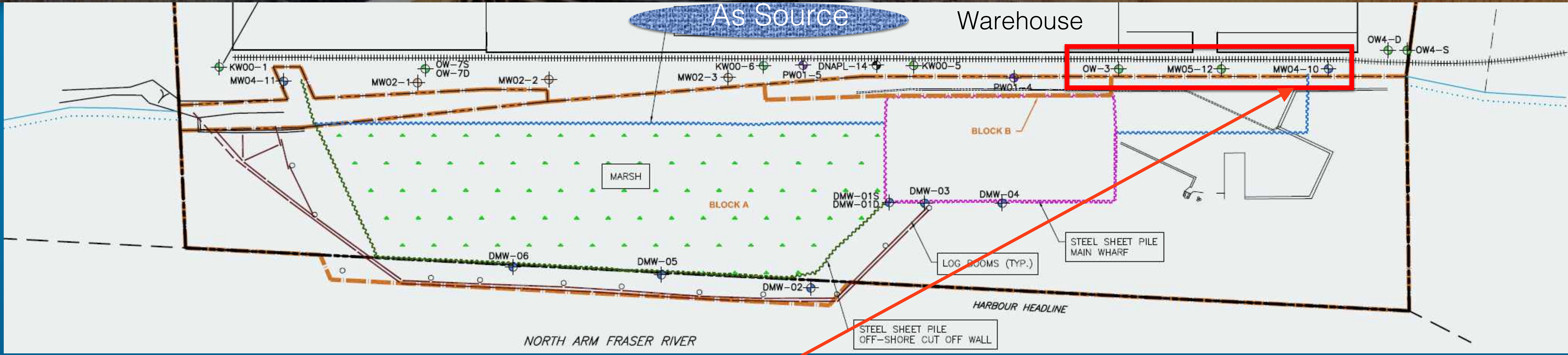


Figure 1. Eh-pH diagram of arsenic species (Petrusevski et al., 2007)

- Arsenic mobility is greatly affected by its speciation.
- In groundwater, inorganic Arsenic predominantly exists as As (V) arsenate, and As (III) arsenite.
- Arsenic in groundwater is predominantly in the form of arsenite at the site due to the reducing conditions present
- Arsenite is more mobile than arsenate, and typically remediation of arsenic in groundwater focusses on oxidizing arsenic to arsenate.

DISSOLVED ARSENIC EXCEEDANCES

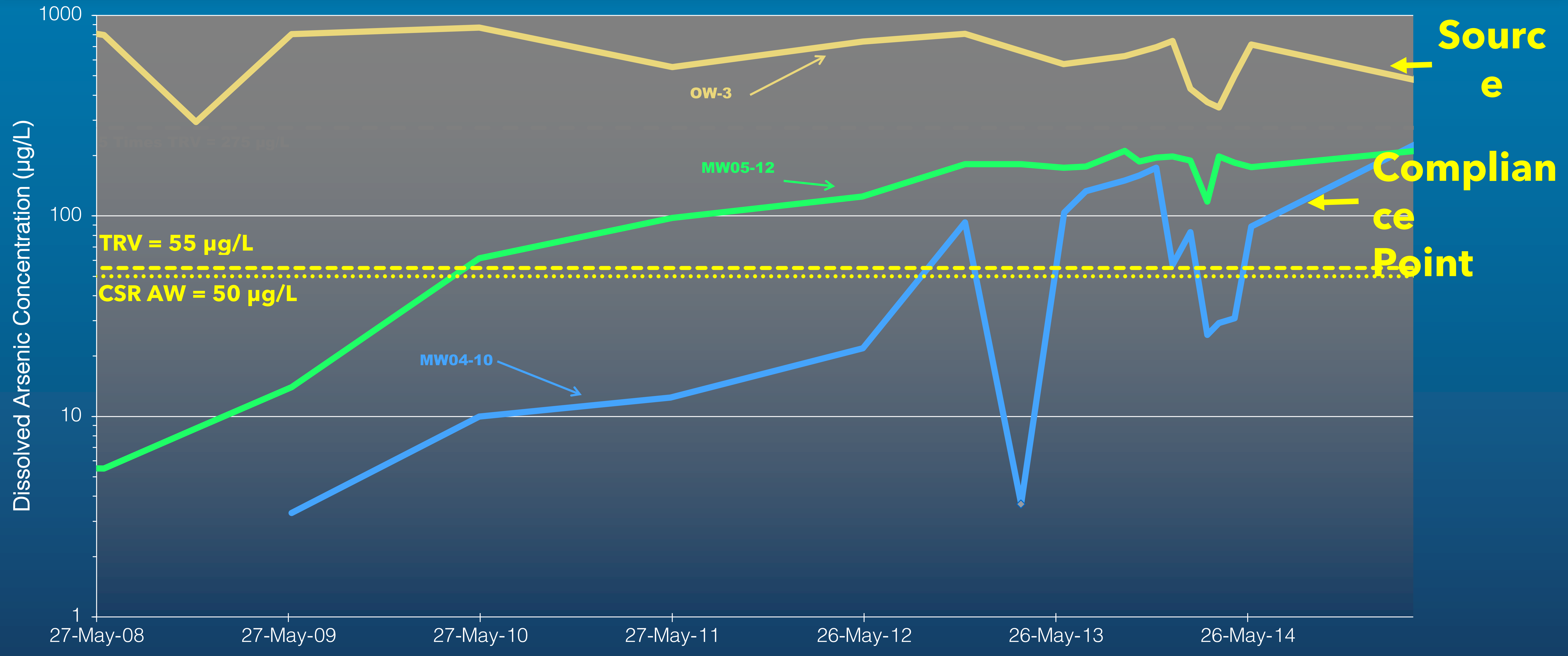


Sample ID / Date Sampled	RDL	MW04-10							TRV	CSR (AW_{FW})
		02-Jun-09	25-May-10	24-May-11	24-May-12	04-Dec-12	11-Jun-13	02-Jun-14		
Arsenic	0.1	3.3	10	12.4	21.9	**93**	**104**	**88.5**	55	50

Target [ ]

Dissolved As concentration increasing over time

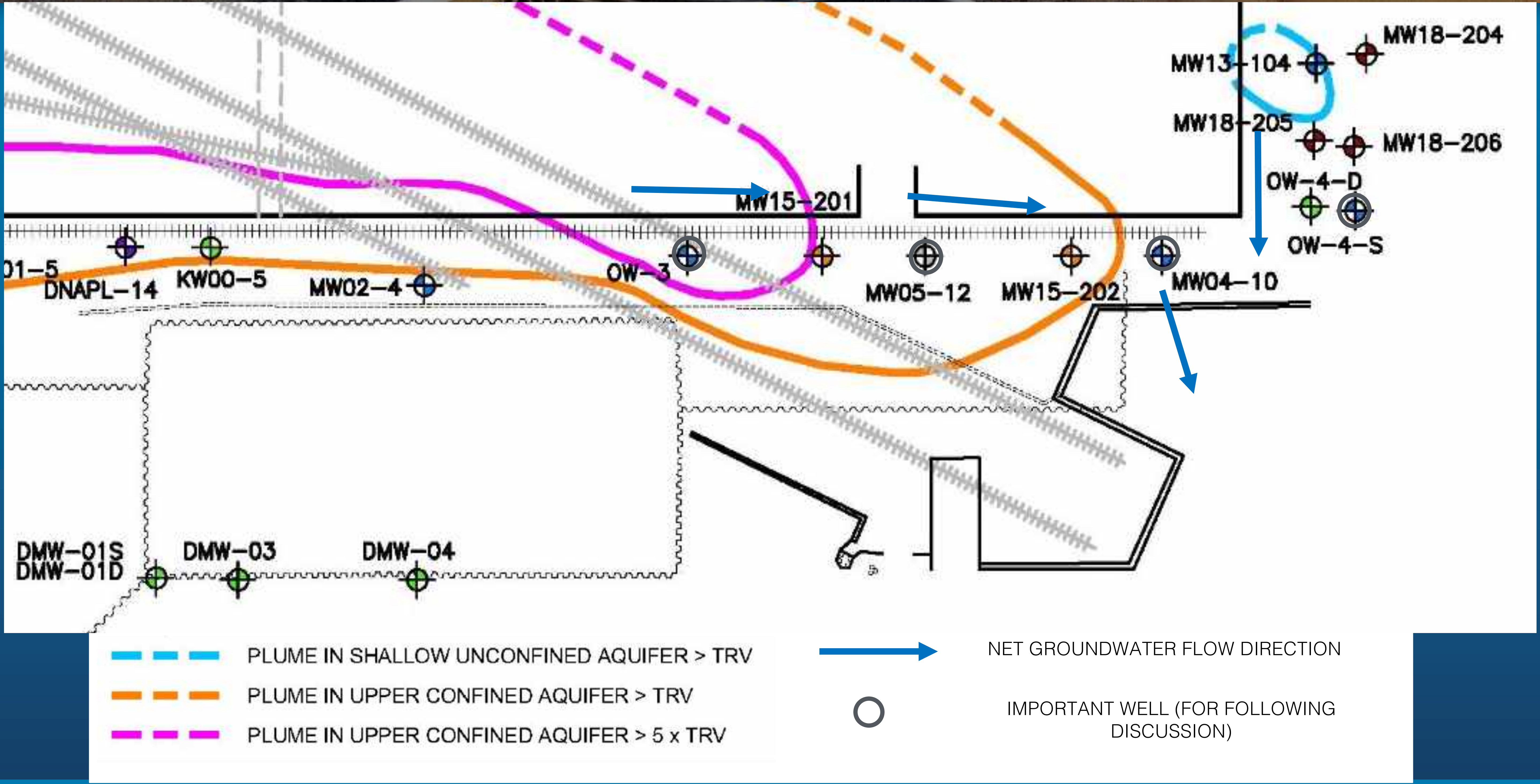
Pre-Treatment Dissolved Arsenic Concentrations 2008-2015 OW-3 (near the source) and MW04-10 (near the discharge zone)



INJECTION PROGRAM OBJECTIVES

- Investigate the rate of arsenic immobilization, the injection radius of influence, and the effects, benefits and limitations of different injection methods on the site geochemistry
- Reduce dissolved arsenic concentrations in groundwater below applicable standards (CSR and TRV)
- Reach stable / decreasing concentrations

ARSENIC REMEDIAL STRATEGY



CHEMICAL INJECTION AREA

PILOT CHEMICAL INJECTION PROGRAM CHEMICAL SELECTION

Arsenic reacts with iron and sulphide from reduced sulphate to form arsenopyrite (FeAsS) precipitate

- Organic amendment
- Zero-valent iron
- Sulphate source

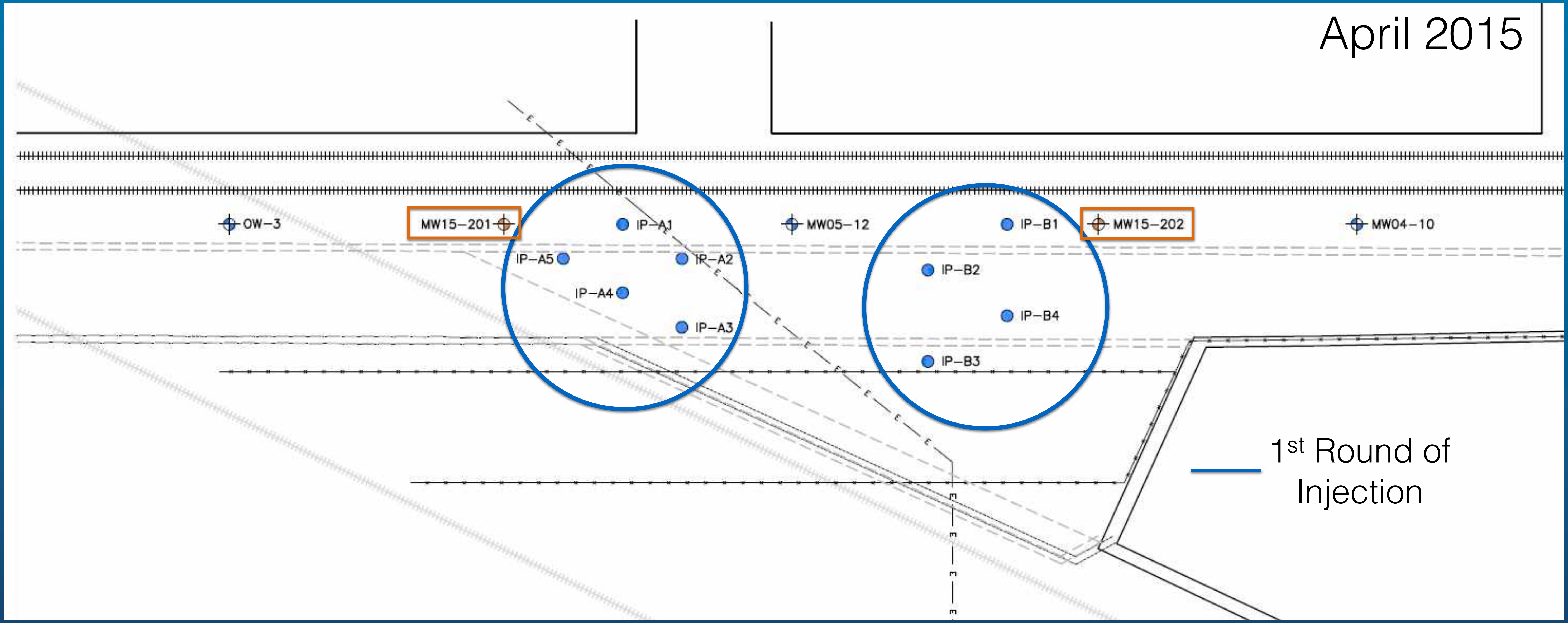
FORMATION OF STABLE ARSENIC PRECIPITATE

$$2\ Fe^{0} + O_2 + 2H_2O = 2\ Fe^{2+} + 4\ OH^{-}$$

$$CH_4 + SO_4^{2-} = HCO_3^{-} + HS^{-} + H_2O$$

$$2\ Fe(OH)_3 + HS^{-} + 2\ H_3AsO_3 = 2\ FeAsS + 7\ O_2 + 8\ H_2O$$

PILOT CHEMICAL INJECTION PROGRAM

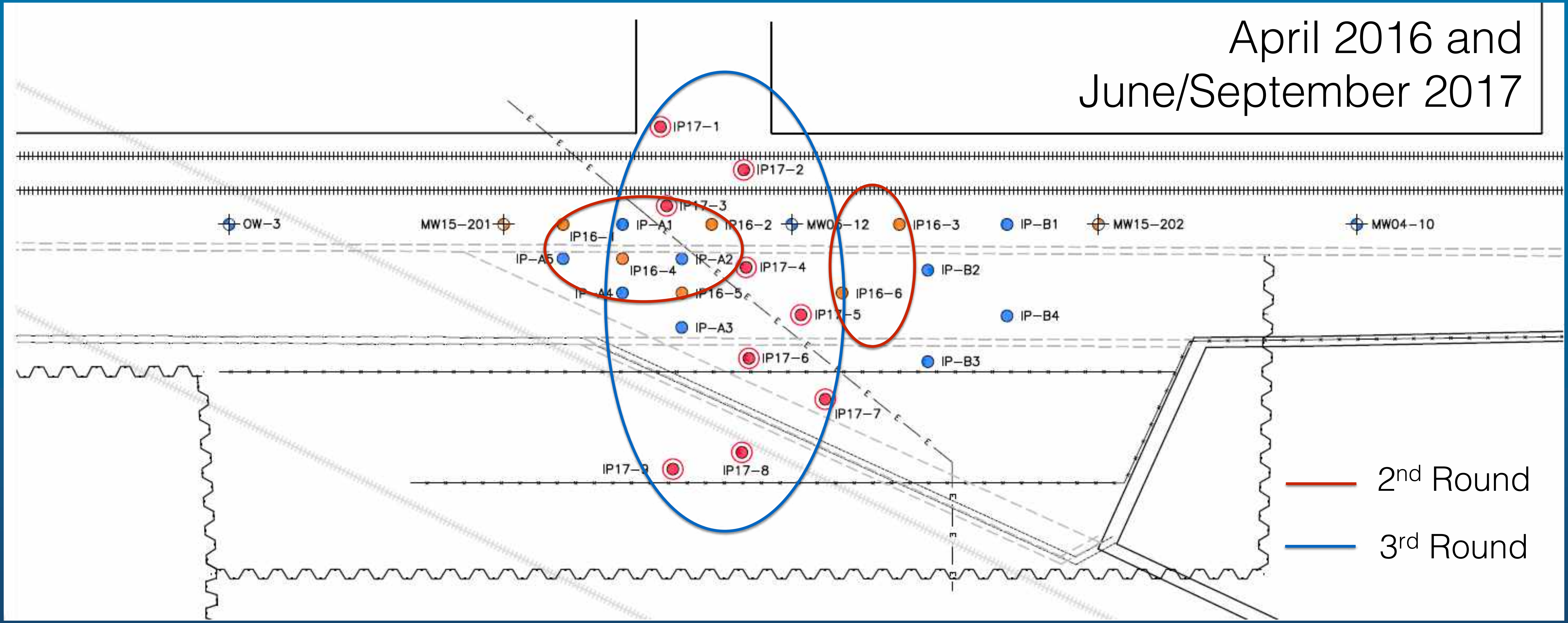


FIRST ROUND OF CHEMICAL INJECTION

- Direct push injection selected
- Targeted slurry mixture of 25%-35% solids content
- Delivered chemical through soil fracture to 3 m radius, at depth from 10 mbg to 5 mbg
- Delivered half of the calculated chemical through this method
- Problem = short-circuiting from soil fracture into adjacent MW

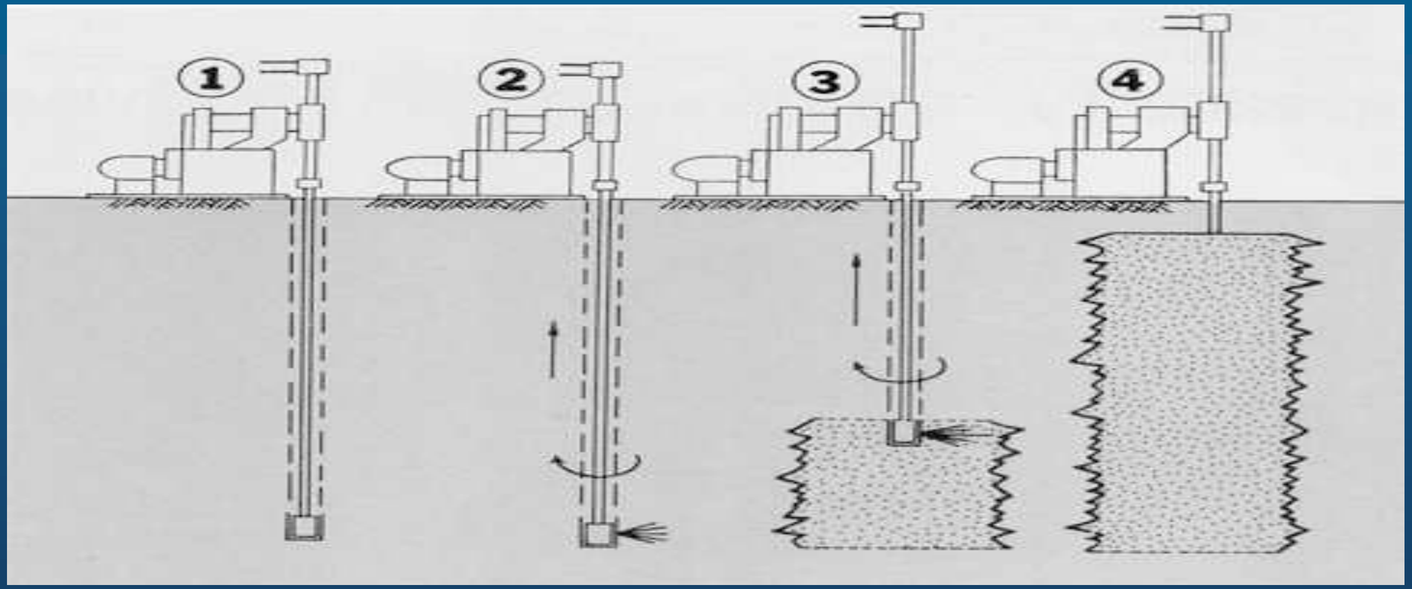
FIRST ROUND OF CHEMICAL INJECTION

SECOND & THIRD ROUND OF CHEMICAL INJECTION



SECOND & THIRD ROUND OF CHEMICAL INJECTION INJECTION METHODOLOGY

- Chemical injected at 16 locations
- Pressure grout method selected
- Delivered chemical through high-pressure rotating tip to form chemical / soil mix columns
- Displaced media is released to surface through the drill pipe to reduce potential for short-circuiting to other release points



CHEMICAL SELECTION AMENDMENT

Slurry matrix Round 2:

- EHC-M®
- Calcium Lactate – carbon source
- Epsom salt (MgSO4) – fast Rx SO_4

Slurry matrix Round 3/4:

- EHC-M®
- Calcium Lactate Gluconate – carbon source
- Epsom salt (MgSO4) – fast Rx SO_4
- Gypsum – slow Rx SO_4
- Ferrous Sulphate – additional iron source and medium Rx SO_4

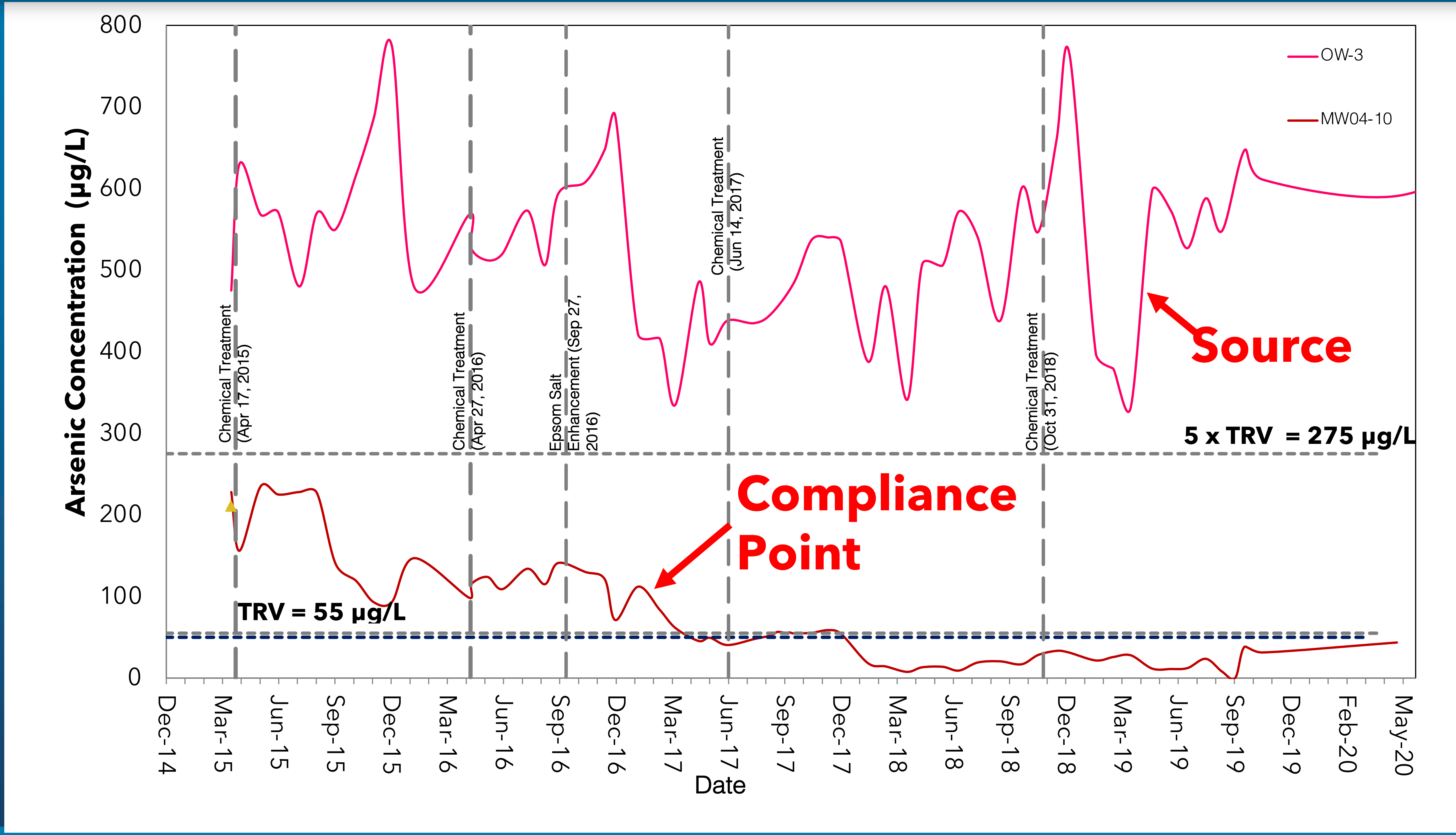
CHEMICAL INJECTION EQUIPMENT

CHEMICAL INJECTION EQUIPMENT

AMENDMENTS USED FOR CHEMICAL INJECTION

	2015	2016	2017	2018
EHC-M®	✓	✓	✓	✓
Magnesium Sulphate	-	✓	✓	✓
Calcium Lactate	-	✓	-	-
Calcium Lactate Gluconate	-	-	✓	✓
Ferrous Sulphate	-	-	✓	✓
Calcium Sulphate	-	-	✓	✓
Water	✓	✓	✓	✓

ARSENIC RESULTS



SUMMARY OF INITIAL PILOT PROGRAM

- Reduced concentrations below standard
- Preference to achieve lower ORP following injection
- Sulphate was moving past the injection area soon after the injection event
- Post-treatment monitoring shows slow increasing concentration trend due to ongoing source which requires further monitoring and treatment

INJECTION CHEMISTRY CHANGE

Injection was modified to include:

- Ferric Sulphide
- Zero Valent Iron
- Iron oxides
- Carbonates

INJECTION UPDATE

THANK YOU

Questions?

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