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Performance of a Large-Scale Reductant Amended Backfill for Groundwater Remediation at a Former Chromate Ore Processing Facility

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Agenda

- Reductant amendment technology
- Amendment design and implementation
- Performance assessment
- Longevity evaluation
- Lessons learned and future actions

Reductant amendment technology

Amendment design and implementation

Performance assessment

Longevity evaluation

Lessons learned and future actions

Reductant amendment technology

The reductant amendment was selected to geochemically fixate chromium and other metals present in groundwater

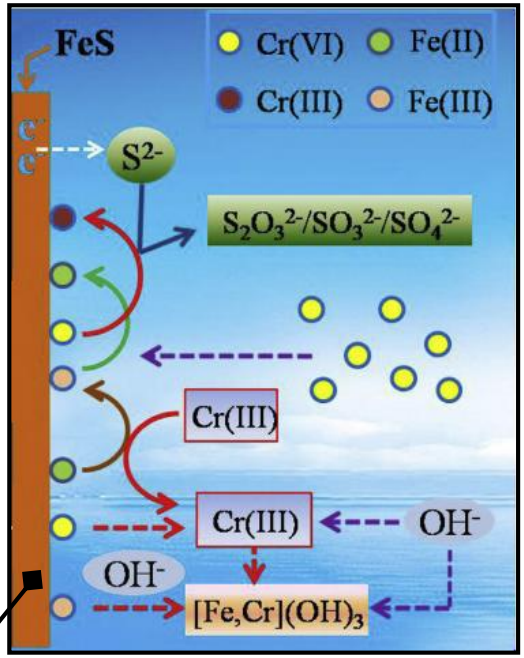
FerroBlack-H reductant
(Redox Solutions, Carmel, IN, USA)

Solid phases
- Iron sulfides 7 – 8%
- Other solids 2 – 4%

Soluble phases
- Sulfides 1 – 2%
- Other diss. salts
- Water

Constituents treated by FerroBlack-H

- Heavy metals (As, Cr, Cd, Cu, Hg, Ni, Pb, Se)
- CCA wood preserving contaminants
- Gas treatment in coal power plants
- Wet scrubber additives
- Chlorinated solvents



Source: Adapted from Du, et al., 2016

Hexavalent chromium is reduced and precipitated out of solution.

Mackinawite (Mullet, et al., 2004)

Reductant amendment technology

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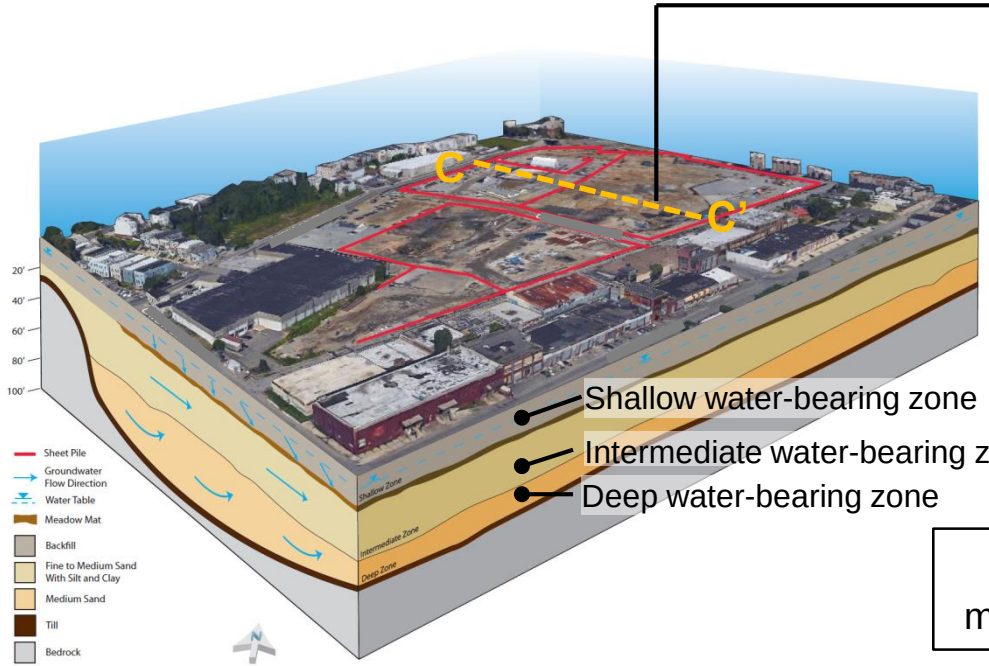
Amendment Design and Implementation

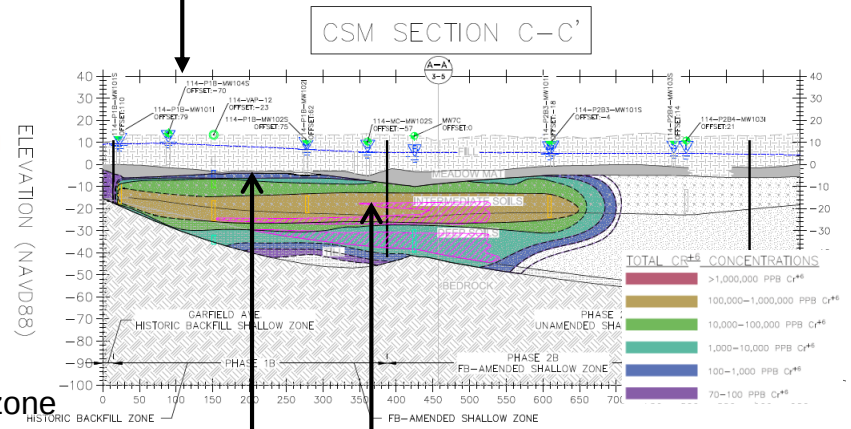
The conceptual site model was used to inform the design of the amended backfill system



Shallow water-bearing zone

Intermediate water-bearing zone

Deep water-bearing zone



Holes in the meadow mat layer

Highly impacted intermediate zone

The top 6 to 10 meters of impacted historic fill over 7 hectares was excavated and replaced with amended backfill to protect the shallow groundwater from becoming re-impacted.

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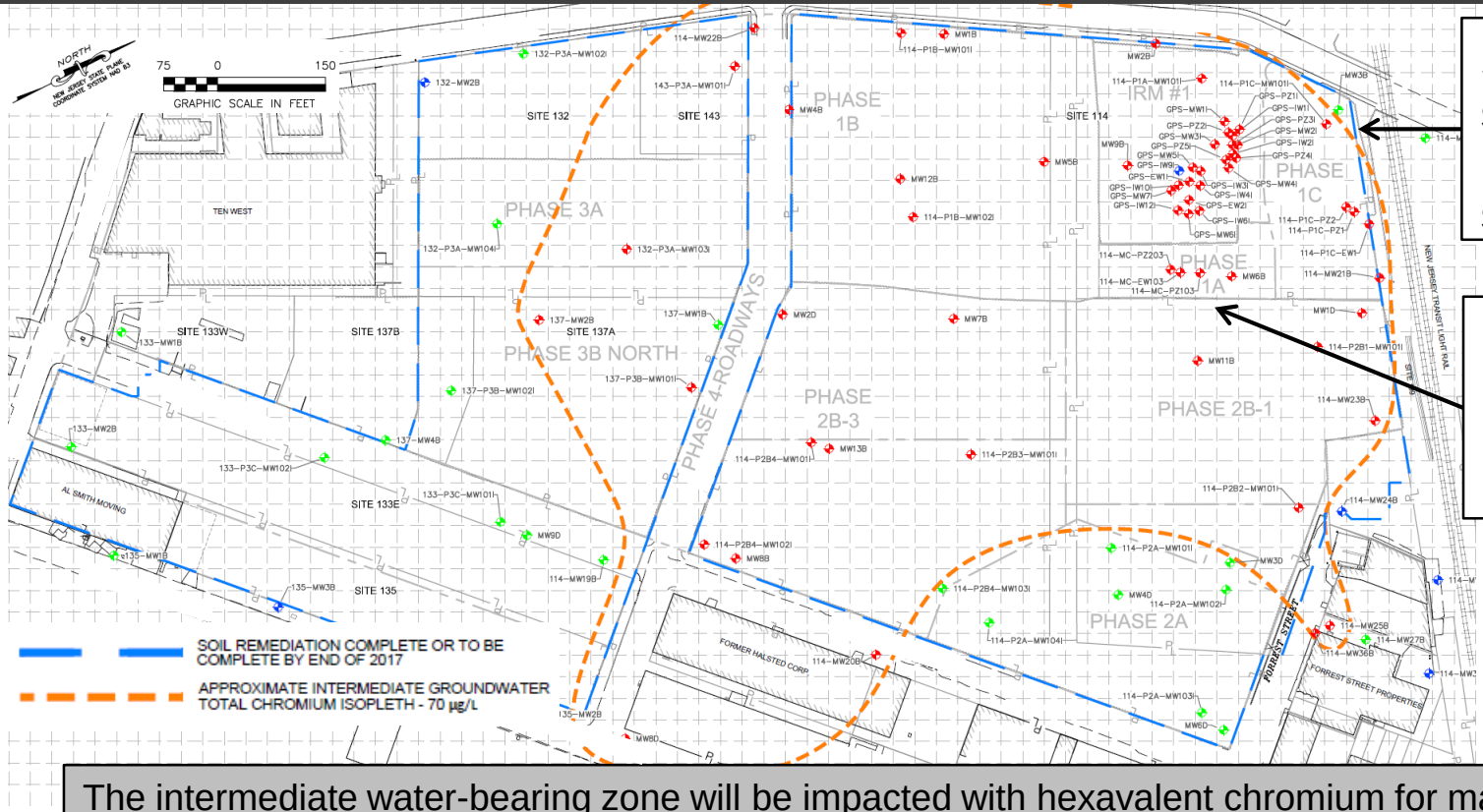
Amendment design and implementation

The intermediate water-bearing zone beneath the amended backfill is impacted with hexavalent chromium



Steel sheetpile surrounds the majority of the site

>1,000 mg/L Cr^{+6} in the center of the plume

The intermediate water-bearing zone will be impacted with hexavalent chromium for many years.

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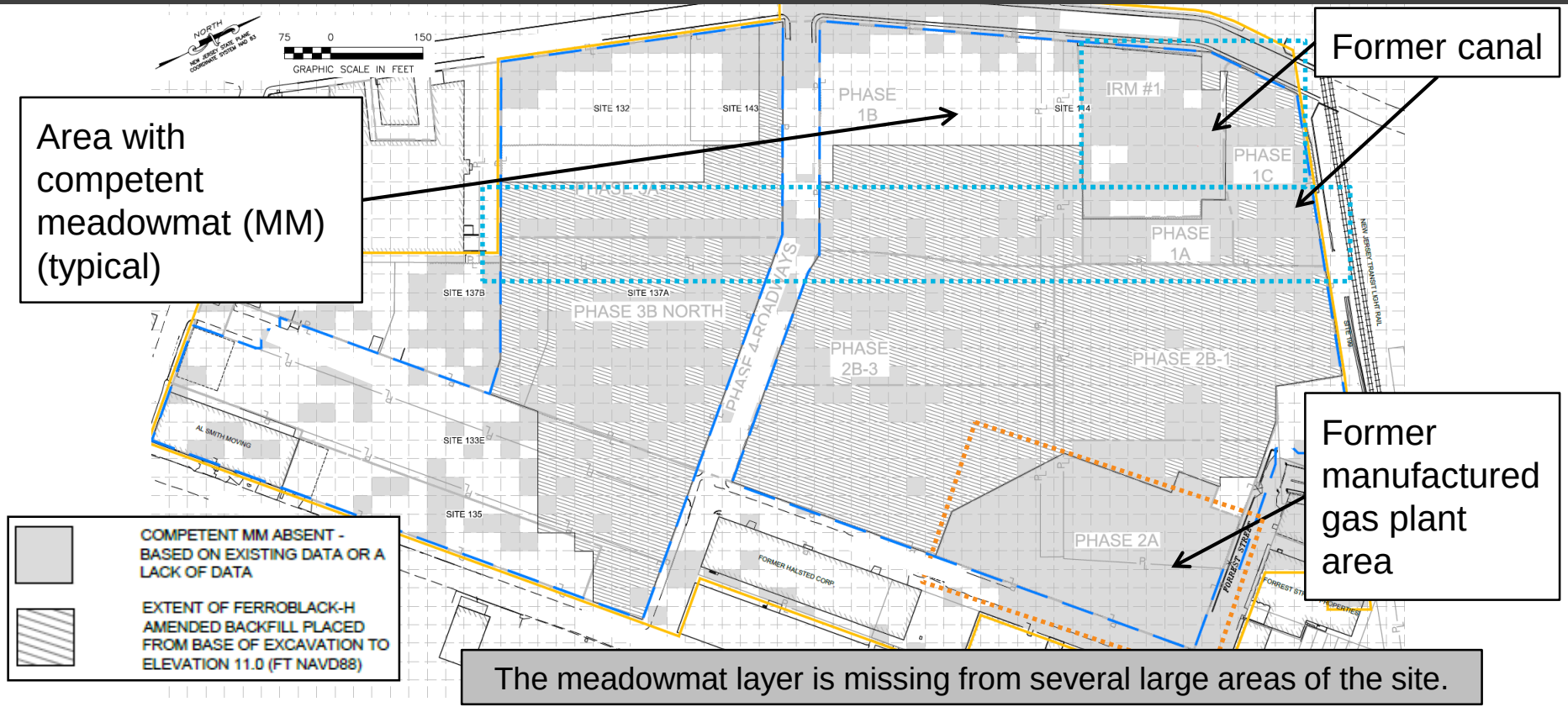
Amendment design and implementation

The reductant amendment is being used as a reactive barrier in lieu of a deeper competent impermeable layer



The meadowmat layer is missing from several large areas of the site.

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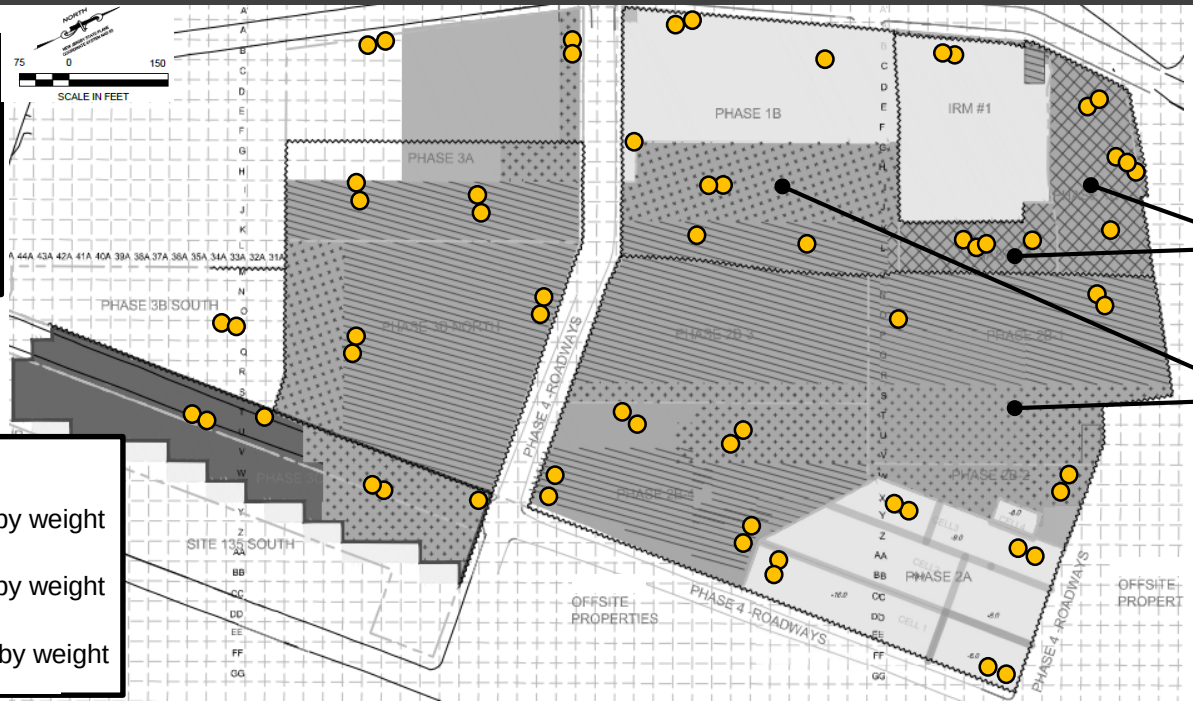
Amendment design and implementation

The FerroBlack-H amendment was placed in varying dosages based on the pre-remediation chromium levels

Shallow/ intermediate groundwater monitoring wells



Highest dosage of reductant

Lowest dosage of reductant

Amended backfill areas

- 0.7% solution by weight
- 2.0% solution by weight
- 2.8% solution by weight

A robust groundwater monitoring network was installed to be able to evaluate the performance of the reductant and was integrated with future redevelopment scenarios.

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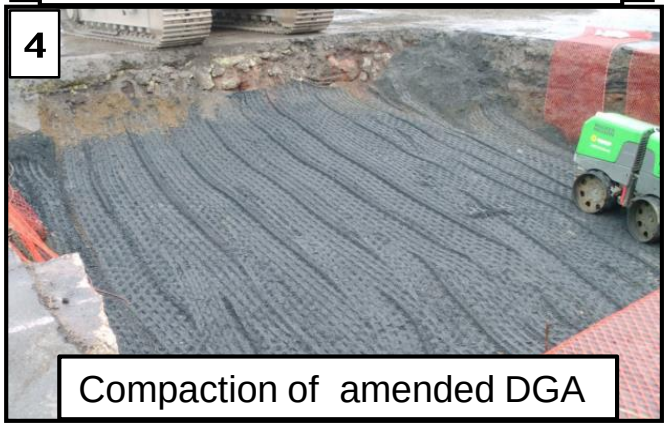
Amendment design and implementation

The reductant amendment was mixed into the clean backfill and placed in grids within the excavation phases



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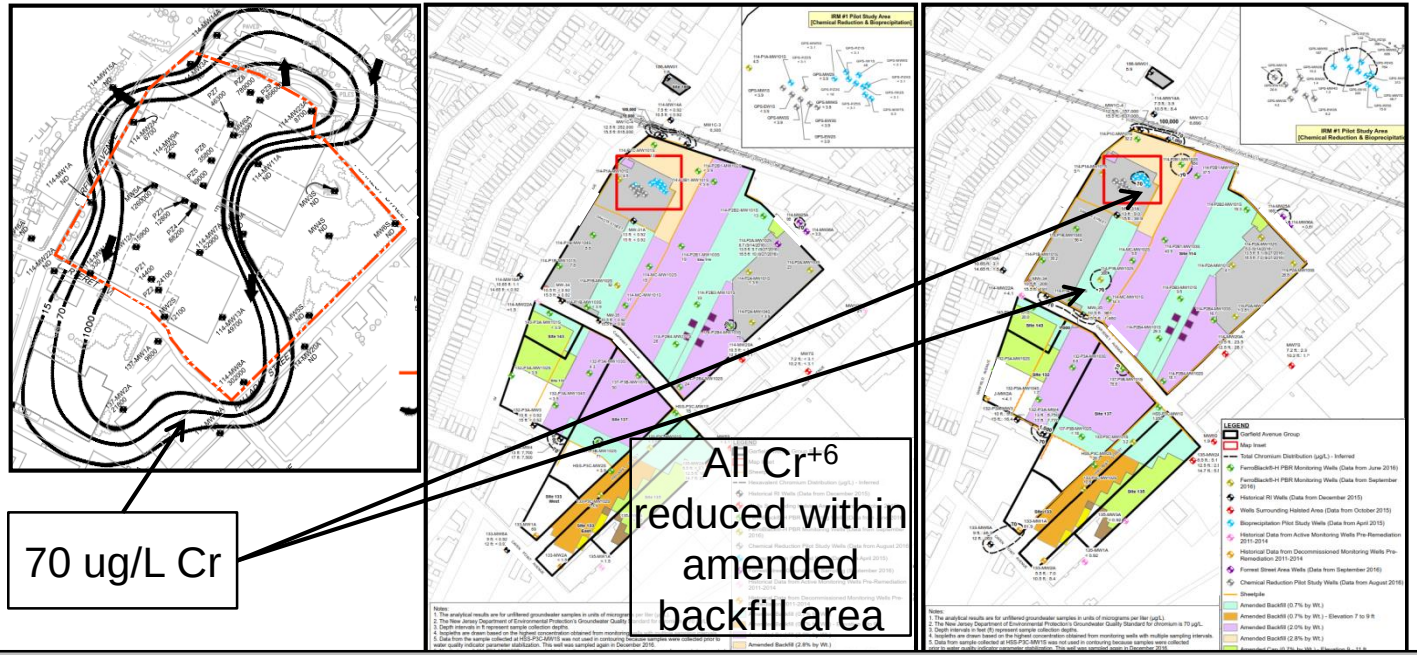
Performance assessment

Shallow groundwater hexavalent and total chromium is being cleaned up

2010 (pre-remediation) - Cr^{+6} in shallow groundwater

2016 - Cr^{+6} in shallow groundwater

2016 - Total Cr in shallow groundwater



Both source removal and the use of FerroBlack-H amended backfill has successfully cleaned up the majority of the shallow groundwater. Concentration trends continue to be downward.

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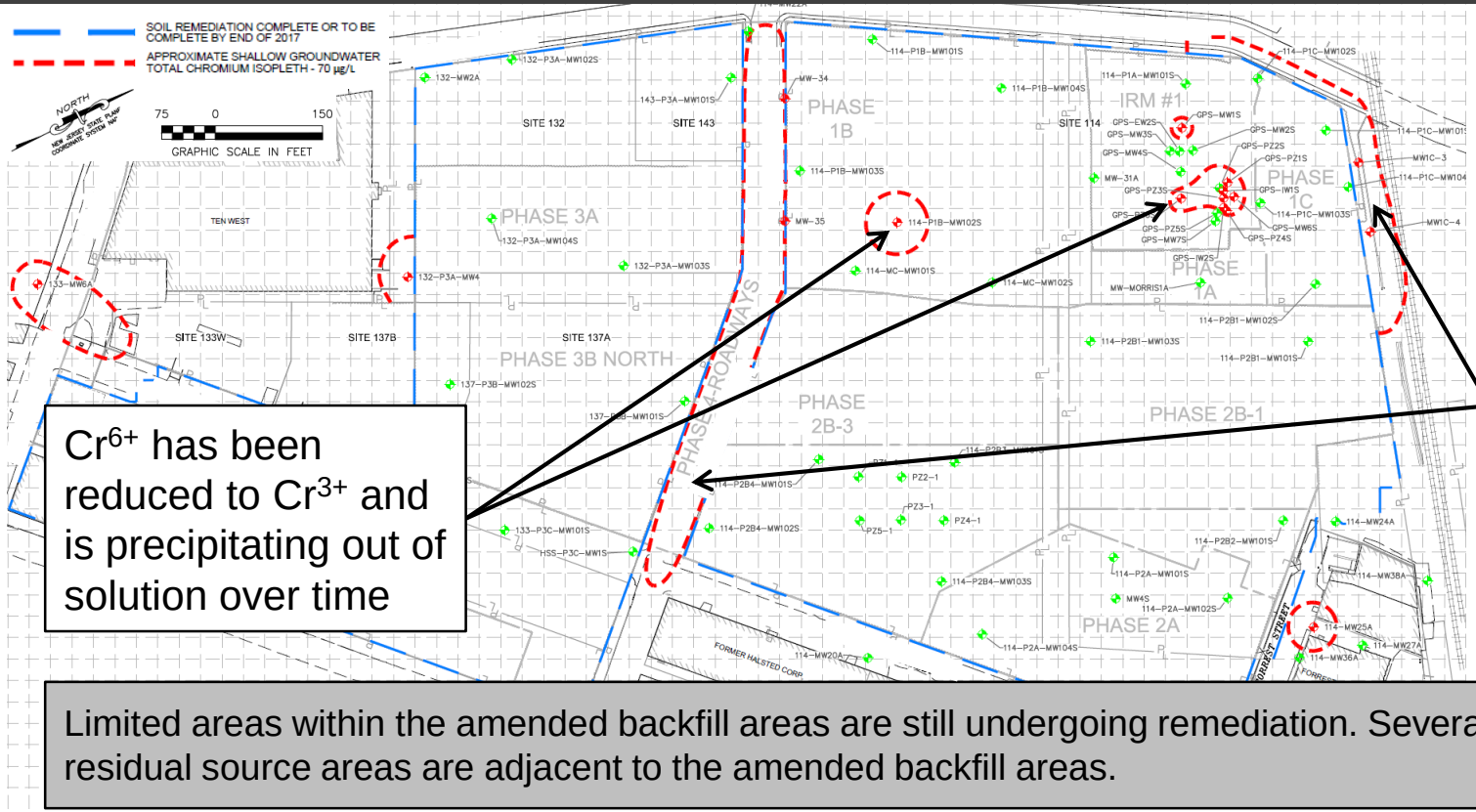
Performance assessment

Chromium in shallow groundwater is primarily remediated within the amended backfill areas



Cr^{6+} has been reduced to Cr^{3+} and is precipitating out of solution over time

Adjacent residual sources of Cr

Limited areas within the amended backfill areas are still undergoing remediation. Several residual source areas are adjacent to the amended backfill areas.

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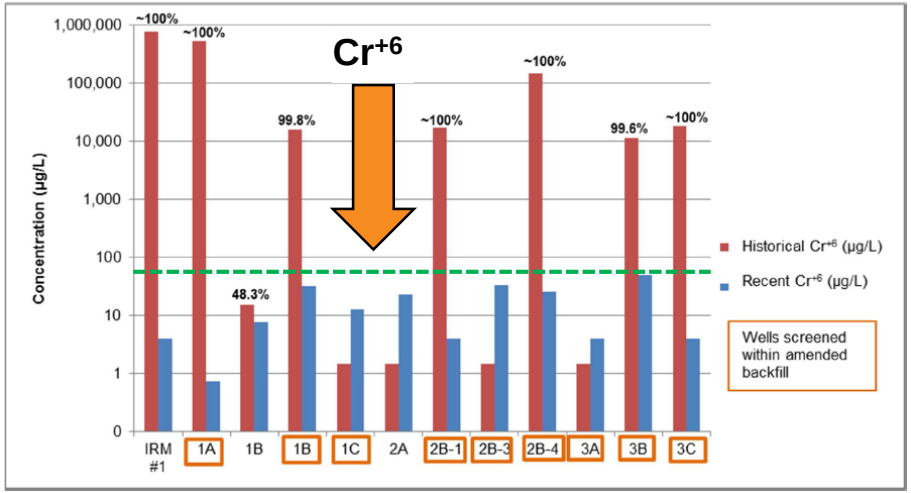
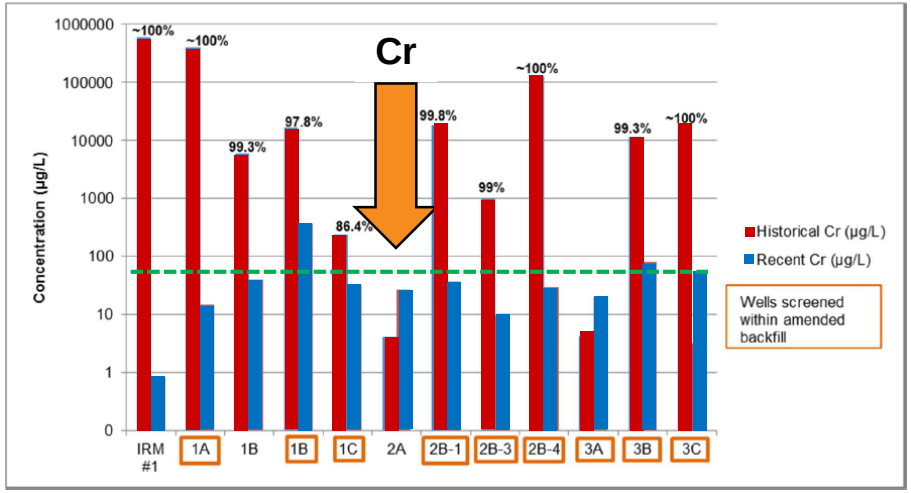
Performance assessment

Groundwater chromium concentrations within the backfill areas now mostly comply with the regulatory criteria

Comparison of pre- and post-remediation Cr^{+6} concentrations in the shallow zone



Comparison of pre- and post-remediation total Cr concentrations in the shallow zone



Amended backfill areas

Regulatory criteria

Hexavalent and total chromium groundwater concentrations have been reduced by between 85 to 100% in amended backfill areas.

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Performance assessment

The amended backfill has resulted in favorable geochemical conditions and results

Parameter	Pre-Remediation	Post-Remediation
pH	10 – 11 s.u.	5.8 – 7.6 s.u.; median = 6.7 s.u.
Oxidation-reduction potential	> 0 mV	Median = -88 mV
Dissolved oxygen	> 1 mg/L	0 – 2.4 mg/L; median = 0.5 mg/L
Sulfate	< 2 mg/L – 5,480 mg/L	166 – 4,050; median = 1,475 mg/L
Sulfide	0 mg/L	ND in 18/22 wells; max = 80 mg/L
Metals	Regulatory exceedances of Al, As, Be, Cr, Pb, Ni, Sb, Tl, V	Al, As, Ba, Cu, Cr, Hg, Mn, Ni, Pb, Sb, Se, Tl, V, Zn decreasing in concentration; Fe increased

Geochemically reducing conditions have been generated, which have resulted in the reduction of metals concentrations. The pH is conducive to the formation of stable precipitates.

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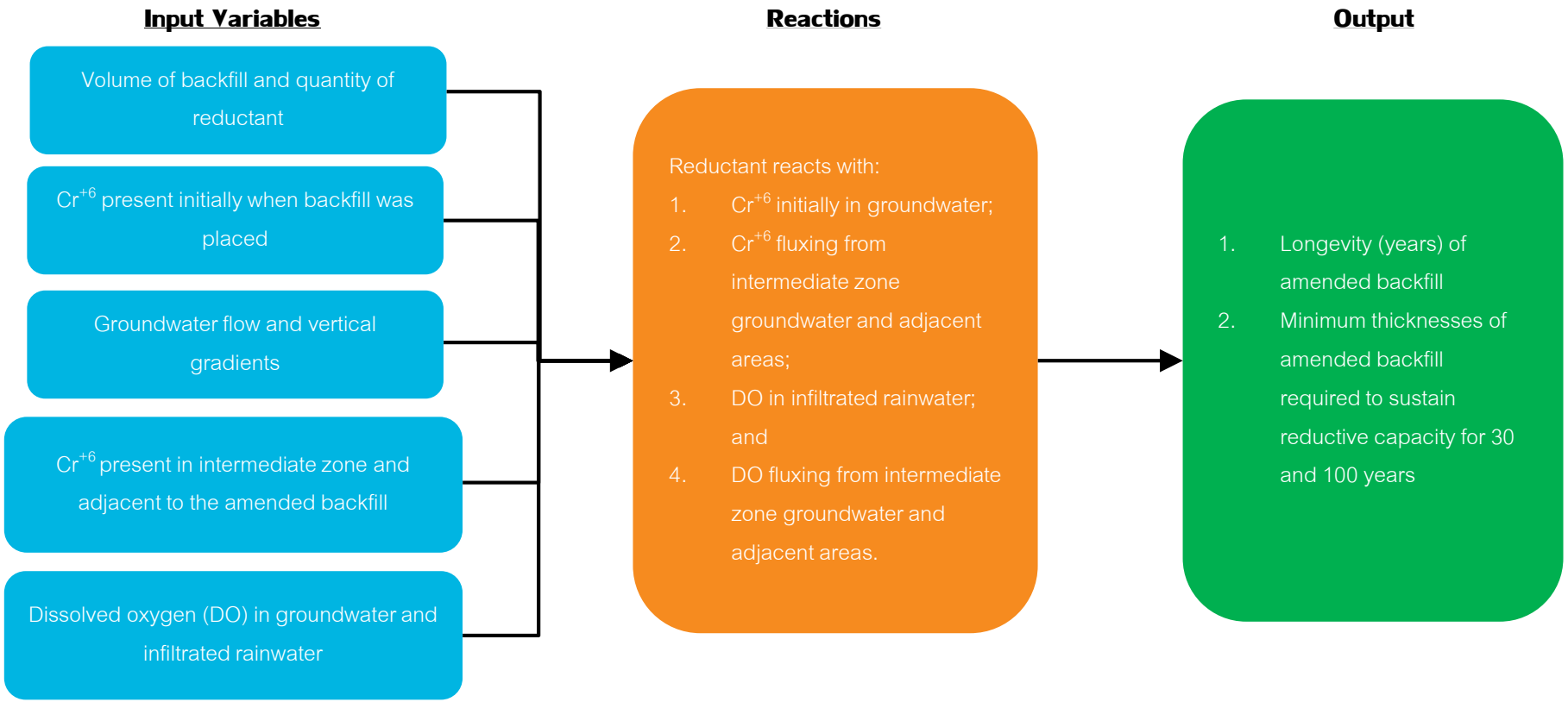
Longevity evaluation

The longevity of the amended backfill is dependent on the amount of reductant and fluxes of oxidizing constituents



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Longevity evaluation

Conditions contributing to the consumption of reductive capacity include fluxes of chromium and oxygen

Red shaded cells indicate a current condition for the reductant to be consumed

Initial Cr in groundwater reacted with the reductant

Cr from intermediate zone

DO from infiltrated rainfall

DO from intermediate zone

Phase and FB-H Dosage (% by wt.)	Average Downward Vertical Gradient	Presence of Cr^{+6} in Shallow Zone	Interaction of FB-H with Total Cr/Cr^{+6} from Intermediate Zone	Infiltration of Oxygen from Shallow Zone	Interaction of Oxygen from Intermediate Zone
IRM #1 (0.7%)[b]	Downward[c]	No	No	Yes	No
Phase 1A (2.8%)	Upward	No	Yes	Yes	Yes
Phase 1B (0.7%)	Upward	No	Yes	Yes	Yes
Phase 1C (2.8%)	Downward	No	No	Yes	No
Phase 2B-1 (2%)	Upward	No	Yes	Yes	Yes
Phase 2B-2 (0.7%)	Upward[c]	No	Yes	Yes	Yes
Phase 2B-3 (0.7%)	Upward	No	Yes	Yes	Yes
Phase 2B-4 (0.7%)	Upward	No	Yes	Yes	Yes
Phase 3A (0.7%)	Downward	No	No	Yes	No
Phase 3B (0.7%)	Downward	No	No	Yes	No
Phase 3C (0.7%)	Upward	No	Yes	Yes	Yes

Hexavalent chromium fluxes from the intermediate zone and adjacent residual source areas, while dissolved oxygen fluxes from infiltrated rainwater and the intermediate zone.

Longevity evaluation

The reactive lifespan and thickness of the amended backfill will be protective for many years

The actual amendment thickness provides a sufficient factor of safety

Phase and FB-H Dosage (% by wt.)	FB-H longevity (Years)[a]	Minimum thickness of amended fill required to sustain reductive capacity for 100 years (ft)	Minimum thickness of amended fill required to sustain reductive capacity for 30 years (ft)	Actual amendment thickness (ft)	FB-H applied (tons)
IRM #1 (0.7%)[b]	1,600	0.5	0.2	10.3	6
Phase 1A (2.8%)	16,000	0.4	0.13	19.0	776
Phase 1B (0.7%)	900	1.1	0.3	12.7	234
Phase 1C (2.8%)	12,000	0.1	0.04	14.5	1,234
Phase 2B-1 (2%)	200	6.7	2.0	12.3	1,365
Phase 2B-2 (0.7%)	400	5.2	1.6	10.9	149
Phase 2B-3 (0.7%)	700	3.4	1.0	13.2	148
Phase 2B-4 (0.7%)	700	2.4	0.7	13.4	326
Phase 3A (0.7%)	3,200	0.5	0.2	5.5	105
Phase 3B (0.7%)	3,200	0.5	0.2	17.0	180
Phase 3C (0.7%)	1,700	1.9	0.6	12.7	370

The amended backfill is expected to be able to continue to reduce chromium for at least 200 years.

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Lessons learned and future actions

The amended backfill system is protective of the remediated shallow groundwater zone

- Chromium concentrations have reduced significantly
  - Continued precipitation of chromium over time is expected
- The concentrations of chromium and other metals continue to decrease
  - Geochemically reducing and circum-neutral pH conditions are conducive to the formation of stable precipitates
- Reductant longevity is a function of the reductant quantities and the fluxes of chromium and dissolved oxygen
  - The intermediate zone and adjacent residual source areas are sources of chromium
  - Dissolved oxygen is contributed from the intermediate zone and infiltrated rainwater
- The reductant amendment will continue to be protective for at least 200 years
- On-going monitoring will be performed to confirm the performance

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Thank You!

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