Optimizing Feasibility Studies & Presumptive Remedies

Presented by:
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Remedial Project Objective

Iterative Process

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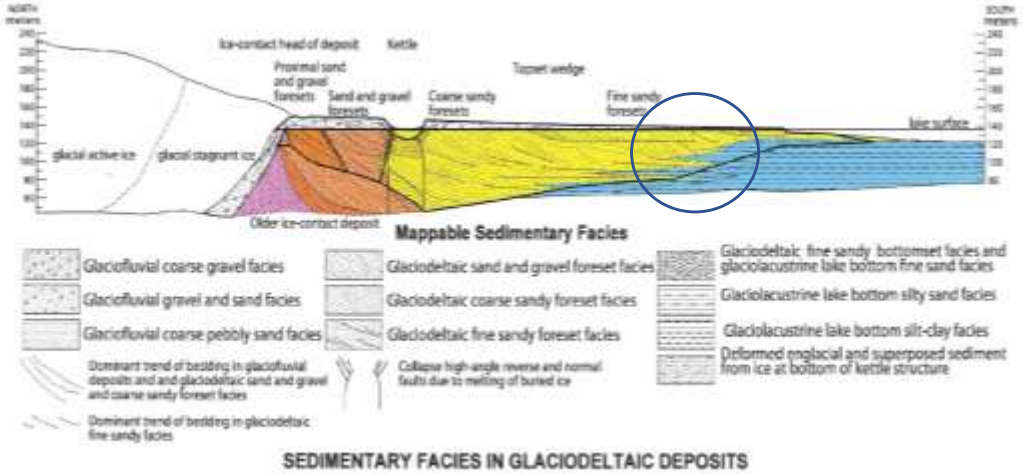
Case Study

- Why Regional Deposition and Groundwater Flow Matters
- Effects of Heterogeneity on the Feasibility of a Remedial Design
- Information Needed to Develop Site Plans
- Factors influencing Remedy
- Benefits of Full-Scale Pilot Studies for Remedy Selection, Design and Implementation
- Impact of Optimized Remedies

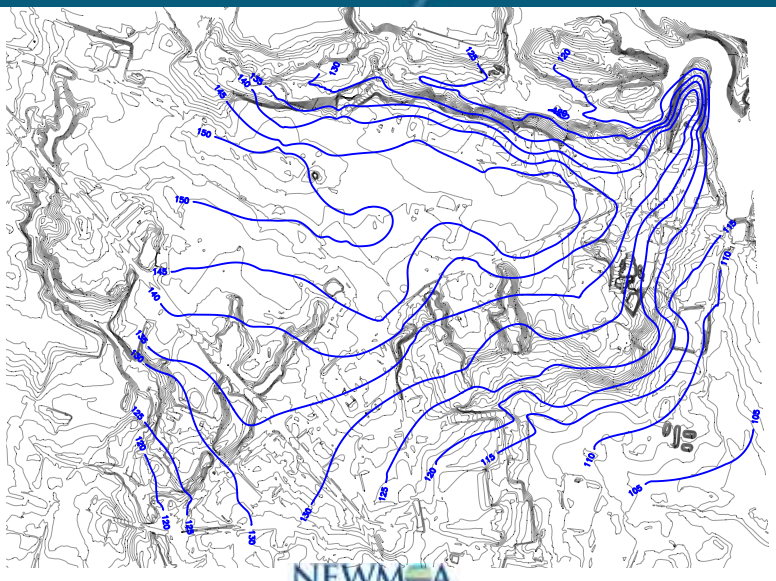
Regional Sedimentary Facies



SEDIMENTARY FACIES IN GLACIODELTAIC DEPOSITS

Conceptual model of mappable sedimentary facies within glaciodeltaic deposits (Stone, 2015), extended at the distal end

Shallow - Water Table Contour



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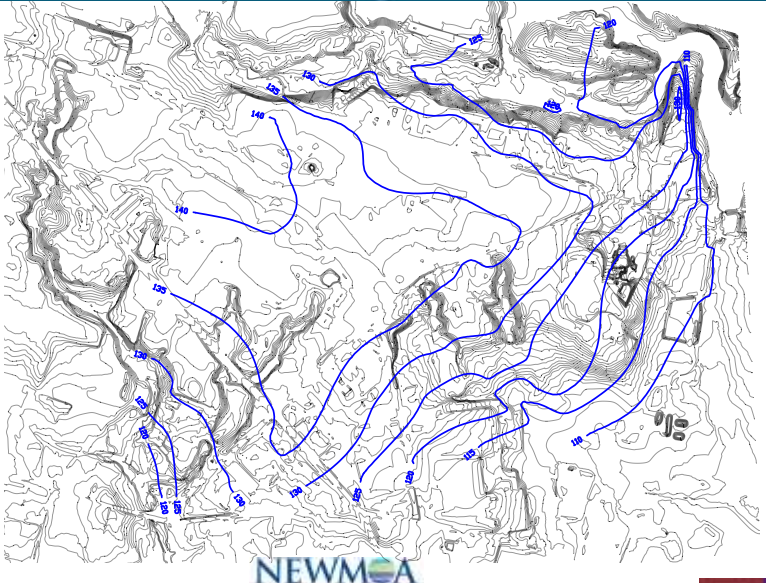
Intermediate Groundwater Contour



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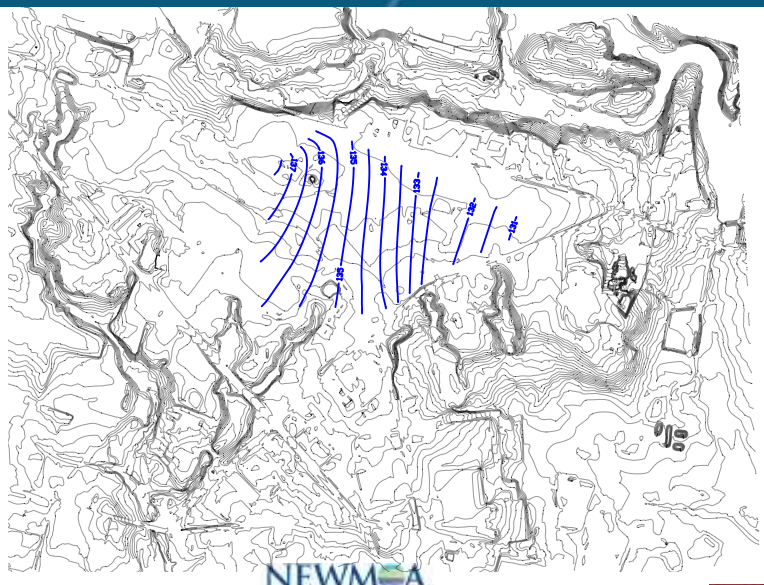
Deep Groundwater Contour



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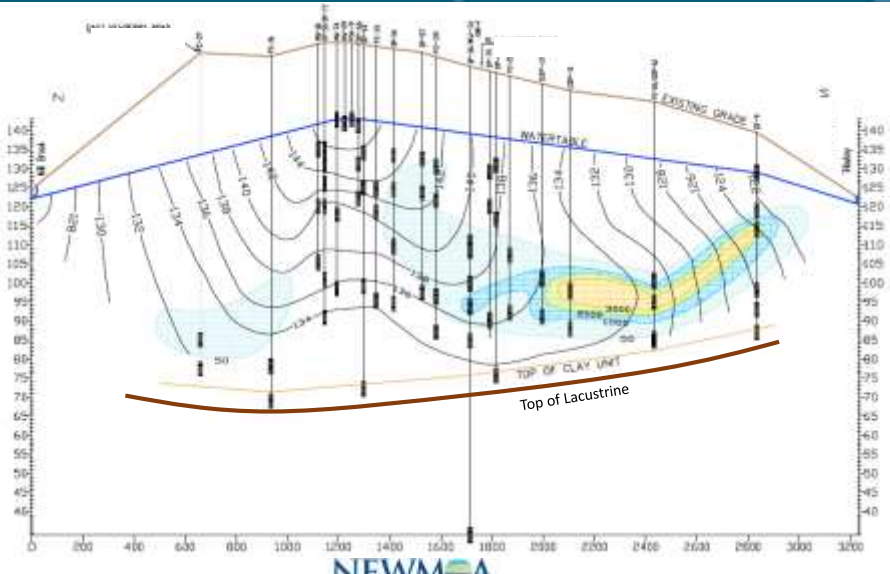
Hydraulic Flow Net



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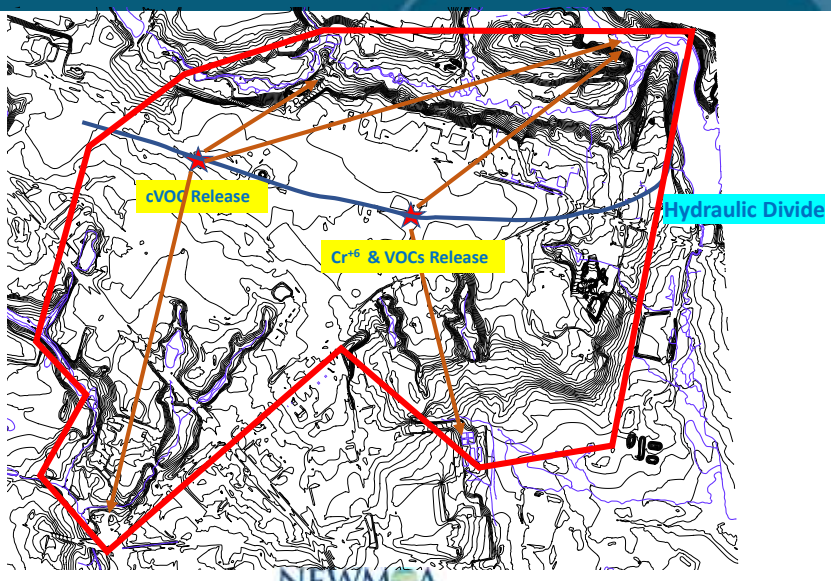
Regional Topographical Influences on Migration



Site Drilling Issues

- Poor soil resolution:
  - Auger Split spoon sampling (40 to 80% recovery)
  - 5-foot direct push continuous soil sampling (50 to 75% recovery)
  - Drive and wash – slow, introduction of fluids with 40 to 75% recovery

- Good soil resolution:
  - Dual Rotary – however sampling was collected at cyclone, not depth specific
  - RotoSonic – 80 to 100% recovery (sample disturbed during extrusion)
  - 2-foot direct push continuous soil sampling (75 to 95% recovery)
- High resolution soil profiling:
  - Membrane Interface Probe (MIP) – 100% at 0.1-foot resolution
  - Waterloo Profiling – 100% at 0.1-foot resolution

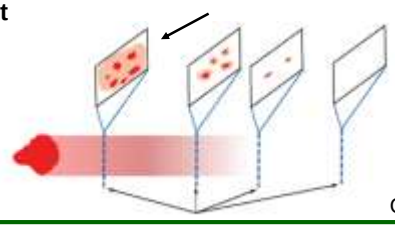
Mass Flux Plume Evolution

Early Phases – Plume Expanding

Expanding contaminant plume

Diffusion into lower-K zones

Active Source



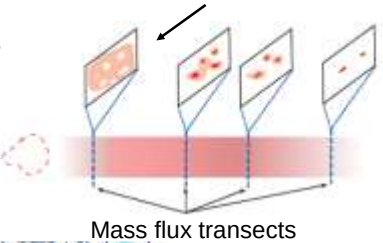
Groundwater transport direction

Later Phases – Source Depleted

Expanding clean water front

Back-diffusion from lower-K zones

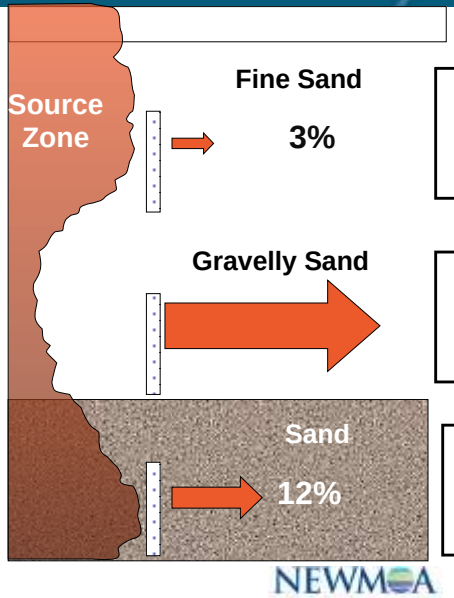
Source Depleted



Mass flux transects

Changes in Mass Flux based upon Lithology

High Resolution



Mass Flux (*J*) = KiC

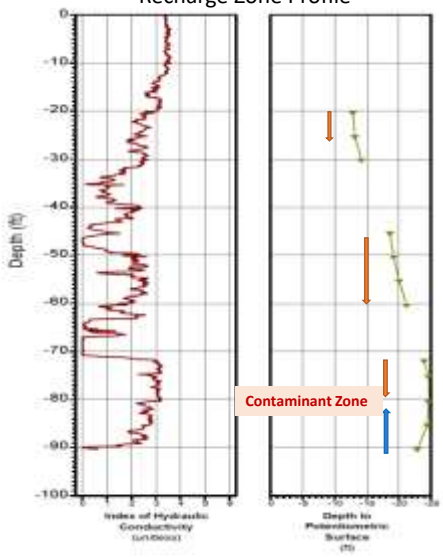
K = 1.0 m/day
i = 0.003 m/m
C = 10,000 µg/L
Mass Flux = 0.03 g/day/m²

K = 33.3 m/day
i = 0.003 m/m
C = 10,000 µg/L
Mass Flux = 1 g/day/m²

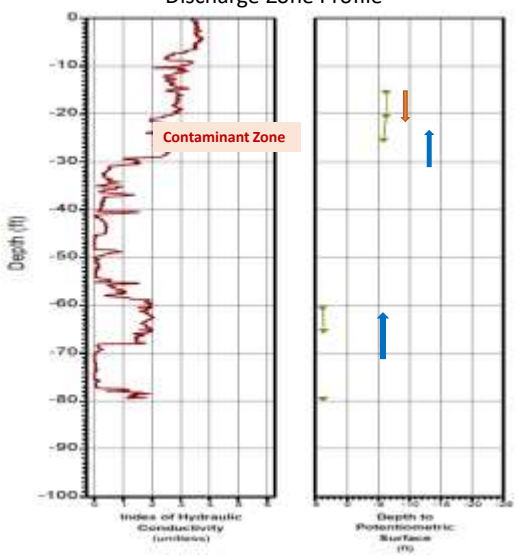
K = 5.0 m/day
i = 0.003 m/m
C = 10,000 µg/L
Mass Flux = 0.15 g/day/m²

HRSC – Lithology & Vertical Gradients

Recharge Zone Profile



Discharge Zone Profile



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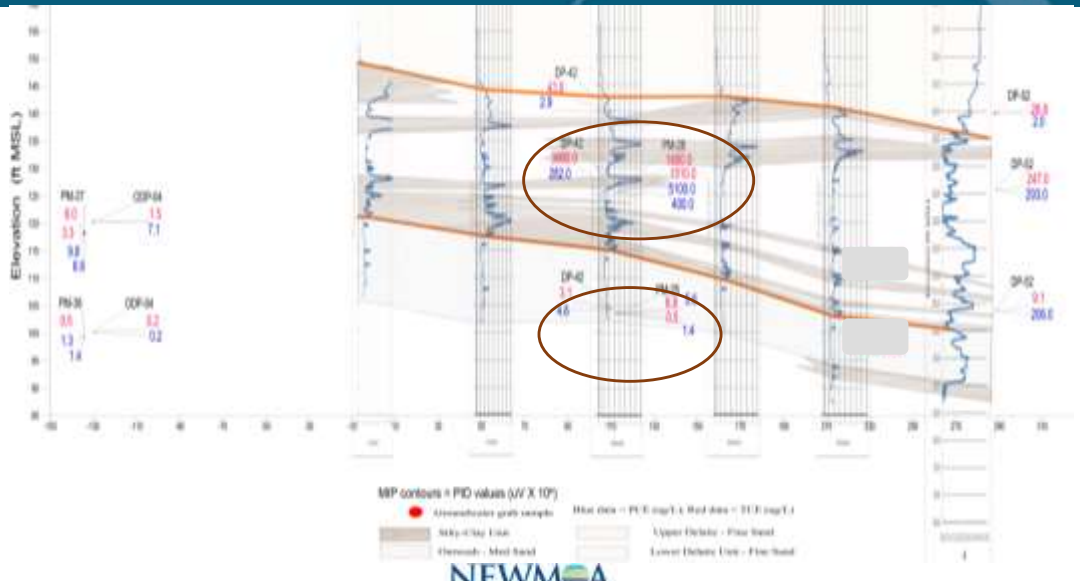
HRSC – Transect Lithology Profile



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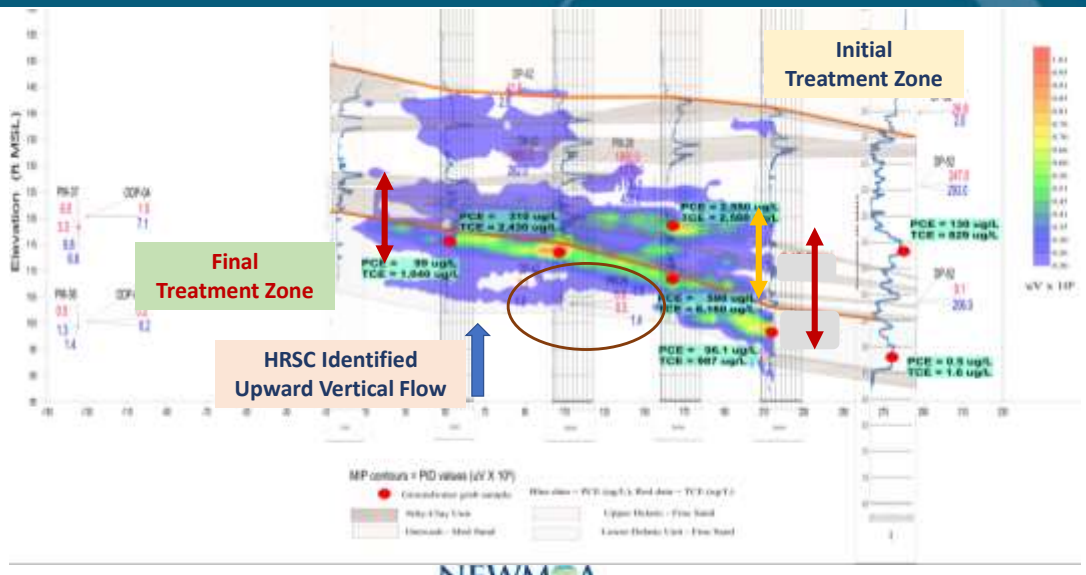
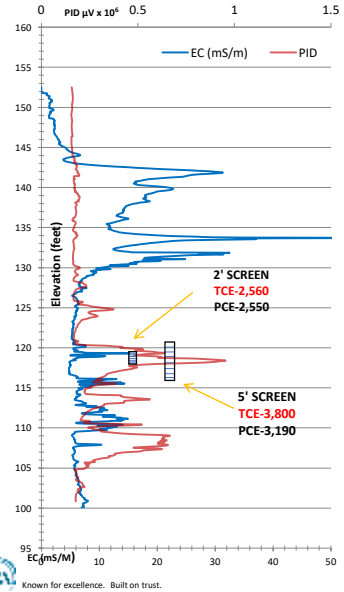
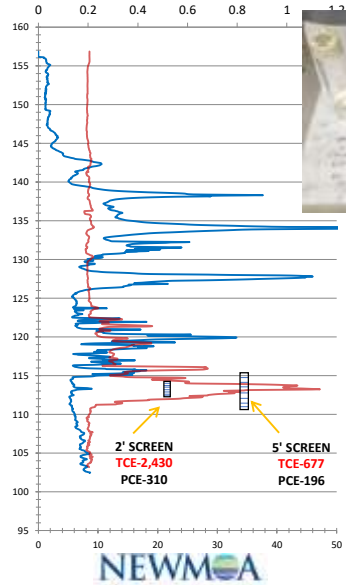
HRSC – Transect Lithology & PID Profile



HRSC – Importance of Heterogeneities

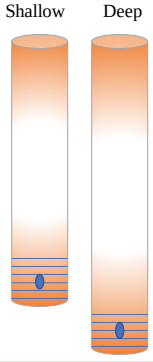




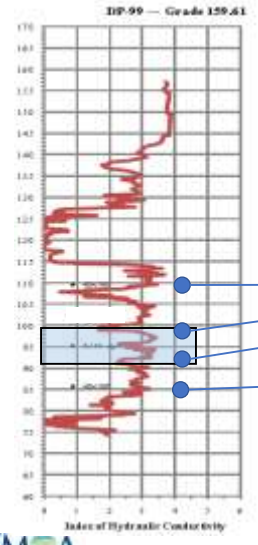
Field PID & Hexavalent Chromium Results

Depth (ft)	Inches	PID (ppb)	Hexavalent Chromium (ppb)	Treatment Zone (Yes/No)
45-47.5	6	0	24	
	12	30		
	18	70	59	
47.5-50	6	40	17	
	12	170	209	48.5
	18	160		
	21	180	133	Yes
50-52.5	6	720	251	
	12	1,500		52.5
	18	720	635	
52.5-55	3	240	58	
	6	0		
	12	0		
	17	0	1	
	18	0	7	
	24	0		
	30	0	24	
55-58	6	0	1	
	12	0	4	
	18	0		
	24	0	15	

Well Placement Issue

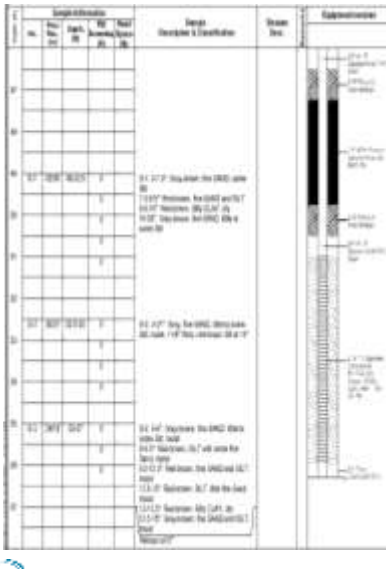


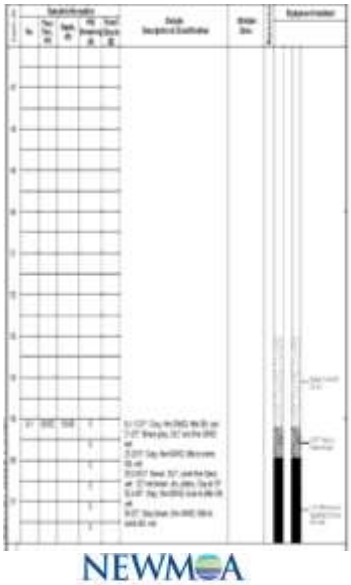
Elev.	96.62 ft MSL	91.24 ft MSL
Conc.	180 µg/L	5,100 µg/L

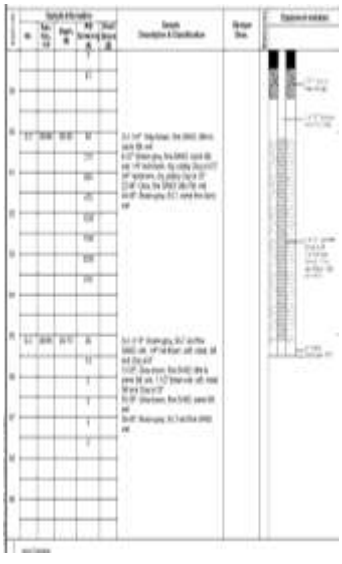


ND <10.0 µg/L
180 µg/L
5,100 µg/L
ND <10.0 µg/L

Typical Boring Log







Geologic Depositional Units with Field Screening

Point ID	Sample Interval	sample top	sample bottom	PID	Cr^{+6}	Description
PM-125	49-52.5	108.38	107.76	0	no color	S-1: 0-7.5": Gray-brown, fine SAND, some Silt
PM-125	49-52.5	107.76	107.59	0	no color	7.5-9.5": Red-brown, fine SAND and SILT
PM-125	49-52.5	107.59	107.55	0	no color	9.5-10": Red-brown, Silty CLAY, dry
PM-125	49-52.5	107.55	105.88	0	no color	10-30": Gray-brown, fine SAND, little to some Silt
PM-125	52.5-55	104.88	103.13	0	no color	S-2: 0-21": Gray, fine SAND, little to some Silt, moist, <1/8" thick, red-brown Silt at 15"
PM-125	55-57	102.38	101.88	0	no color	S-3: 0-6": Gray-brown, fine SAND, little to some Silt, moist
PM-125	55-57	101.88	101.59	0	no color	6-9.5": Red-brown, SILT with some fine Sand, moist
PM-125	55-57	101.59	101.34	0	no color	9.5-12.5": Red-brown, fine SAND and SILT, moist
PM-125	55-57	101.34	101.30	0	no color	12.5-13": Red-brown, SILT, little fine Sand, moist
PM-125	55-57	101.30	101.26	0	no color	13-13.5": Red-brown, Silty CLAY, dry
PM-125	55-57	101.26	101.13	0	no color	13.5-15": Gray-brown, fine SAND and SILT, moist
PM-126	55-60	102.38	100.63	0	0.04	S-1: 0-21": Gray, fine SAND, little Silt, wet
PM-126	55-60	100.63	100.30	0	no color	21-25": Brown-gray, SILT and fine SAND, wet
PM-126	55-60	100.30	100.01	0	no color	25-28.5": Gray, fine SAND, little to some Silt, wet
PM-126	55-60	100.01	99.84	0	no color	28.5-30.5": Brown, SILT, some fine Sand, wet, 1/2" red-brown, dry, platy, Clay at 30"
PM-126	55-60	**99.84**	**98.21**	0	**0.27**	30.5-50": Gray, fine SAND, trace to little Silt, wet
PM-126	55-60	**98.21**	**98.05**	0	**0.59**	50-52": Gray-brown, fine SAND, little to some Silt, wet
PM-126	60-65	**97.38**	**96.88**	**80**	**1,140.00**	S-2: 0-6": Gray-brown, fine SAND, little to some Silt, wet
PM-126	60-65	**96.88**	**95.55**	**213-604**	**1,460.00**	6-22": Brown-gray, fine SAND, some Silt, wet, 1/4" red-brown, dry, platy Clay at 6.5", 3/4" red-brown, dry, platy Clay at 20"
PM-126	60-65	**95.55**	**93.71**	**470-2030**	**0.17**	22-44": Gray, fine SAND, little Silt, wet
PM-126	60-65	**93.71**	**93.38**	**814**	no color	44-48": Brown-gray, SILT, some fine Sand, wet
PM-126	65-70	**92.38**	**91.13**	**95-14**	no color	S-3: 0-15": Brown-gray, SILT and fine SAND, wet, 1/4" red-brown, soft, moist, Silt and Clay at 9"
PM-126	65-70	91.13	89.46	0	no color	15-35": Gray-brown, fine SAND, little to some Silt, wet, 1-1/2" brown-red, soft, moist Silt and Clay at 29"
PM-126	65-70	89.46	89.21	0	no color	35-38": Gray-brown, fine SAND, some Silt, wet
PM-126	65-70	89.21	88.63	0	no color	38-45": Brown-gray, SILT and fine SAND, wet

Contaminant Zone
99.8 to 93.4 ft MSL (± 6.5-feet)

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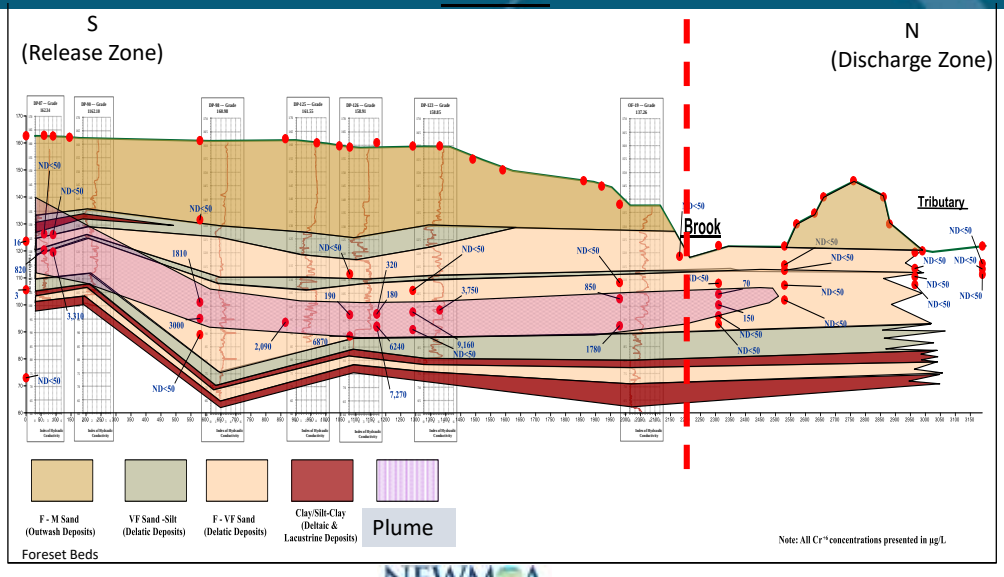
Geologic Cr^{+6} Cross-Section South-North



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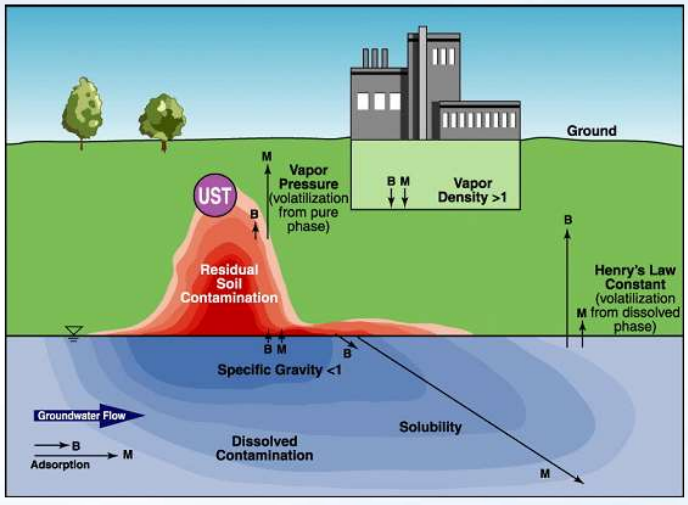
Optimizing Feasibility Studies and Presumptive Remedies

Information Needed to Develop Site Plans



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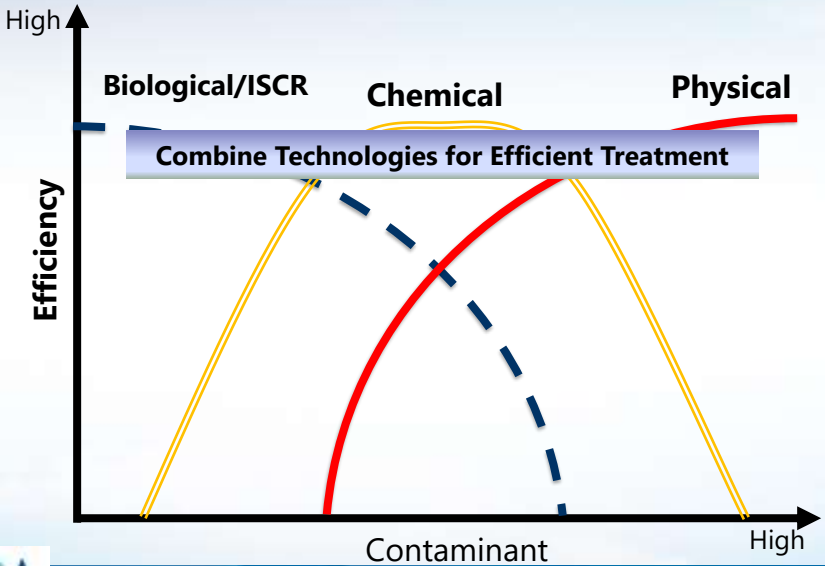
Site Remediation Strategies



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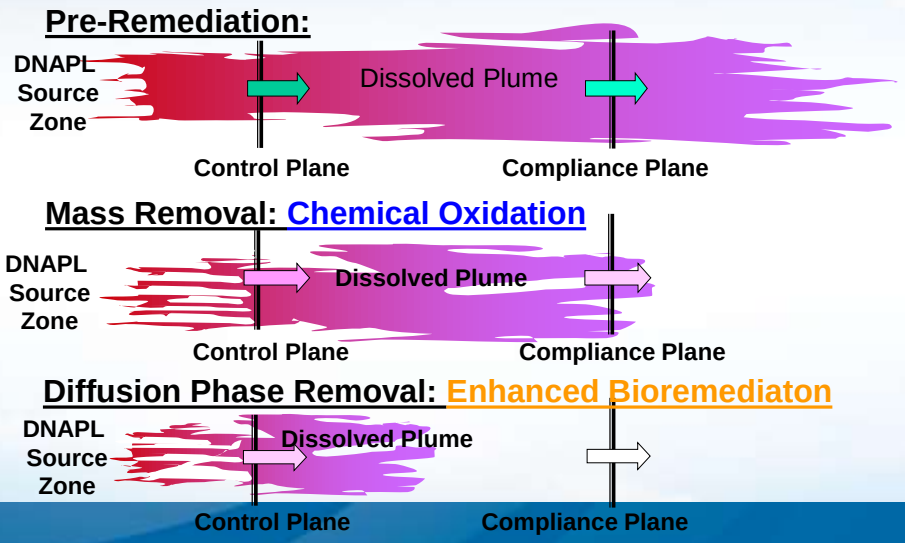
Example of the Relationship Between Mass Removal and Groundwater Concentration



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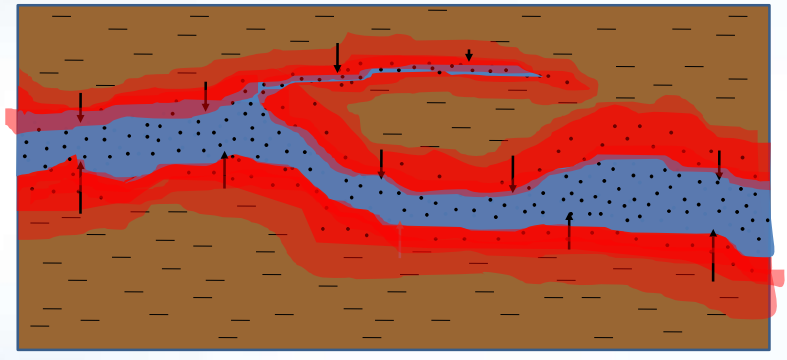
Heterogeneous Aquifer Model

Upon Flushing and Removal of Adsorbed Mass "Back Diffusion" Continues



Groundwater Flow

Challenges

- Meet Low Targets
- Rebound
- Remediation Time

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IN SITU TECHNOLOGY CLASSES:

- Enhanced Aerobic Biodegradation
- Enhanced Anaerobic Biodegradation
- *In Situ* Chemical Oxidation (ISCO)
- *In Situ* Chemical Reduction (ISCR)
- Bioaugmentation
- Metals Immobilization
- *In Situ* Sorption and Biodegradation

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Multiple Options!!!

- **Site Characteristics**
- **Contaminant Concentrations**
- **Treatment Goals**
- **Time Required to meet Objectives**

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What Reagents Are Possible?

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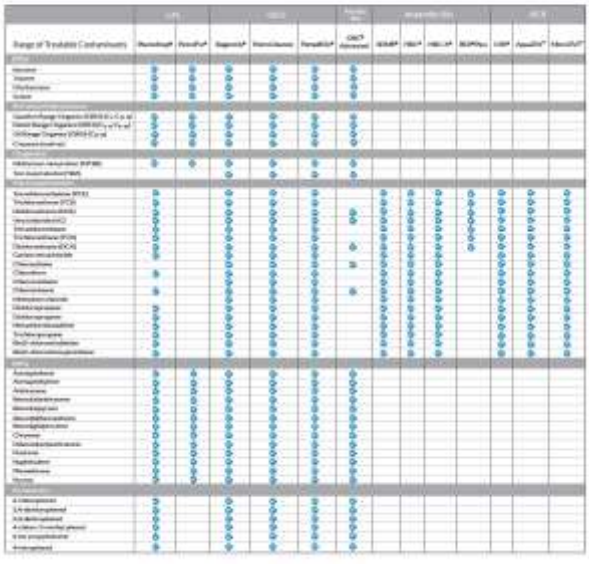
Range of Treatable Contaminants

REGENESIS products have been used to effectively treat a broad range of groundwater contaminants from petroleum hydrocarbons, to chlorinated solvents, pesticides, and metals. Contact us to discuss the treatability of your contaminant of concern and site details so that we can recommend the most effective REGENESIS solution.



On website or can email as reference

Identify Target Contaminants and determine what Biological, Abiotic or "Sorption"/Stabilization Options are possible

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Application Options

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REMEDIAL APPROACHES OFFERED:

DIRECT PUSH INJECTION
- In-Situ Chemical Oxidation (ISCO)
- In-Situ Chemical Reduction (ISCR)
- Bioaugmentation
- In Situ Sorption & Biodegradation
- Enhanced Aerobic Bioremediation
- Enhanced Anaerobic Bioremediation

HORIZONTAL DRILL:
- ISCO
- ISCR
- Bioaugmentation
- In Situ Sorption & Biodegradation
- Enhanced Aerobic Bioremediation
- Enhanced Anaerobic Bioremediation

WELLS
- ISCO
- ISCR
- Sorption
- Enhanced Anaerobic Bioremediation

EXCAVATION
- Soil Mixing & Handling

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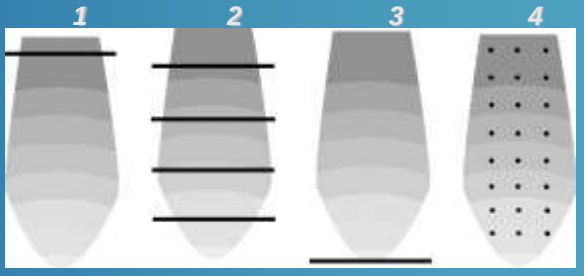
Reagent Application

- Delivery Systems - injection via direct-push technologies or wells
- Designs for Barriers and Source Treatment

1. Upgradient Barrier
2. Series of Barriers
3. Downgradient Barrier
4. "Grid" of HRC injection points



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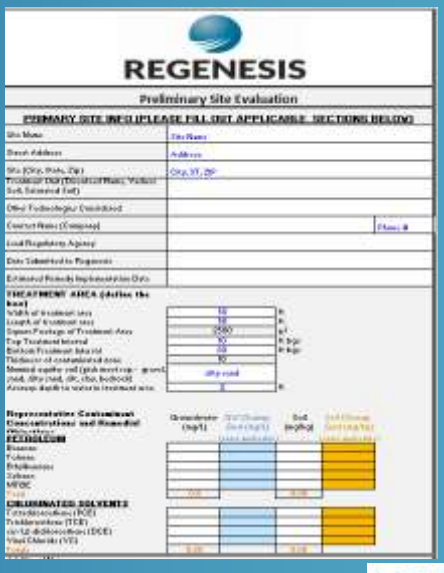
SITE INFORMATION

- Defined Treatment Area (Vertical and Horizontal)
- Soil and GW Data
- Well/Boring Logs
- Cross-Sections
- Site Impediments
- Clients Expectations
  - Remedial Goals
  - Timeframe to Closure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Preliminary Site Evaluation

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OUR OUT PUT

- Reagent Quantity
- Volume Required

Project Info		
Subject Site		
Site		
Plume		
Prepared For:		
GZA		
Target Treatment Zone (TTZ) Info	**Unit**	**Value**
Treatment Area	ft^2	5,000
Top Treat Depth	ft	5.0
Bot Treat Depth	ft	10.0
Vertical Treatment Interval	ft	5.0
Treatment Zone Volume	ft^3	25,000
Treatment Zone Volume	cy	926
Soil Type	---	silty sand
Porosity	cm^3/cm^3	0.33
Effective Porosity	cm^3/cm^3	0.20
Treatment Zone Pore Volume	gals	61,714
Treatment Zone Effective Pore Volume	gals	37,403
Treatment Zone Pore Volume	liters	233613
Treatment Zone Effective Pore Volume	liters	141584
Fraction Organic Carbon (foc)	g/g	0.003
Soil Density	g/cm^3	1.6
Soil Density	lb/ft^3	100
Soil Weight	lbs	2.5E+06
Hydraulic Conductivity	ft/day	10.0
Hydraulic Conductivity	cm/sec	3.53E-03
Hydraulic Gradient	ft/ft	0.005
GW Velocity	ft/day	0.25
GW Velocity	ft/yr	91
Sources of Hydrogen Demand	**Unit**	**Value**

PlumeStop® Application Design Summary		
Plume		
PlumeStop		**Technical Notes/Discussion**
Application Method	**Direct Push**	
Spacing Within Rows (ft)	10	
Spacing Between Rows (ft)	10	
Application Points	**50**	
Areal Extent (square ft)	5,000	
Top Application Depth (ft bgs)	5	
Bottom Application Depth (ft bgs)	10	
PlumeStop to be Applied (lbs)	**13,200**	**PSTOP Injection Concentration (mg/L)**
PlumeStop to be Applied (gals)	1,582	**4,000**
In Situ Chemical Reduction - AquaZVI		
AquaZVI to be added to PlumeStop (lbs)	**1,300**	
AquaZVI to be added to PlumeStop (gals)	97	
PlumeStop + AquaZVI Volume Totals		
Mixing Water (gal)	14,241	
Total Application Volume (gals)	**15,921**	
Injection Volume per Point (gals)	318	
Anaerobic Bioremediation - HRC		
HRC Application Points	50	
HRC to be Applied (lbs)	280	
HRC per point (lbs)	6	
Total Application Volume (gals)	26	
Injection Volume per Point (gals)	0.5	
Bioaugmentation - BDI Plus		
BDI Plus Application Points	**50**	
BDI Plus to be Applied (Liters)	**15**	
BDI Plus per point (Liters)	0.3	
Assumptions/Qualifications		

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Do I Have Enough Information To Develop a Design

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DESIGN VERIFICATION

- What is Design Verification?
  - Pre-application field-verification of remedial design parameters
  - High-resolution identification of COC transport zones
  - Enables accurate placement of reagents for maximum
  - flux-interception
- Why is it necessary?
  - Site investigations typically focus on liability and risk assessment
    - Emphasis on contaminant identification, plume dimensions and migration pathways
  - Design verification focuses on efficient reagent-contaminant contact
    - Emphasis on identification of principal impacted strata, contaminant mass distribution and reagent delivery

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Design Verification Process

Aids the Designer

- ID Technical Blind Spots
  - Refines design assumptions
- Reagent Selection
- Calibrate Reagent Design
  - COC Mass vs Reagent Volume/Mass
  - Can we fit reagent volumes in the TTZ?
- Calibrate TTZ's accommodation rates and volumes
  - ID Hydraulic Limitations

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Design Verification: Components

- Continuous Core Logging
  - Recording sedimentology based and geological processes
  - Settling Tube
- COC Lab analysis
- Clear Water Injection
- High Resolution Methodology

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Design verification: evaluation/analysis

Contaminant Type
- 35% Petroleum
- 61% CVOC's
- 4% Comingled

General Soil Type
- 50% Fine grained (Clays & Silts)
- 50% Coarse grained (Sand & Gravel)

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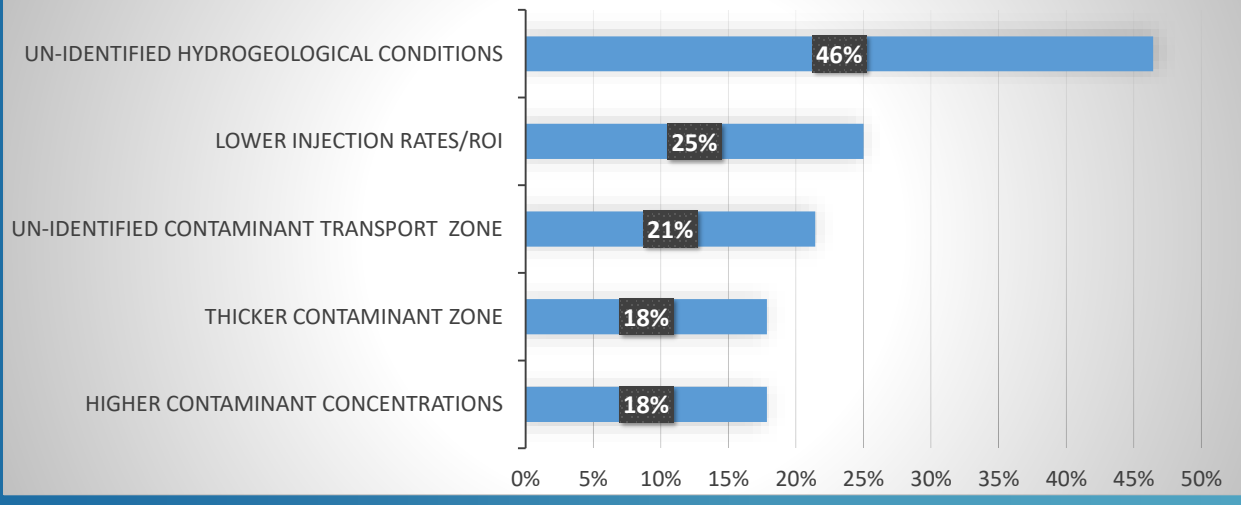
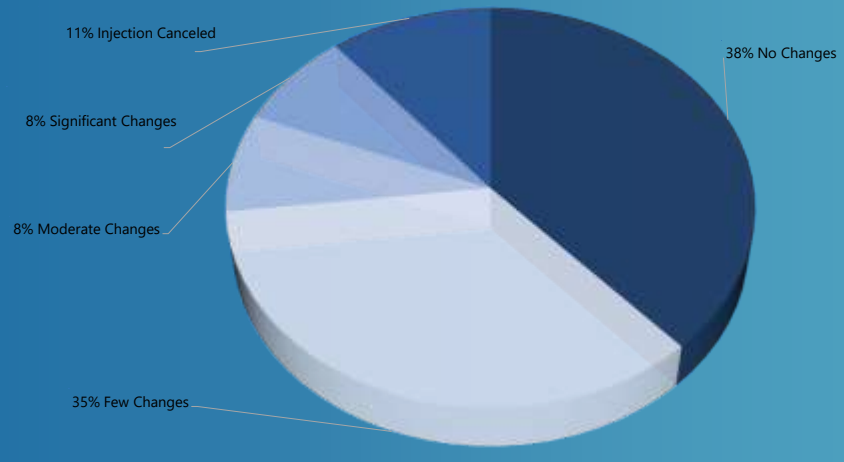
TECHNICAL BLIND SPOT analysis



REGENESIS

Design Verification results → Design changes

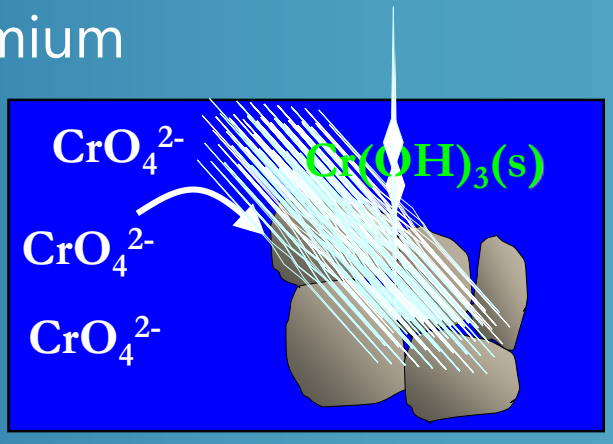


REGENESIS

SUBJECT SITE: Chromium

- Chromium Plume
  - Presumptive Remedy : Create reducing conditions to convert CRVI to CRIII ppt

Critical Issues
Site Chemistry (pH, redox conditions)
Distribution – Large Treatment Area
Reagent Longevity



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Chromium Site

- Evaluate different Reagent Mixes under Bench and Pilot conditions.
- Collect site samples to better understand contaminant distribution and site chemistry
- High Resolution Methodology employed by GZA to identify treatment zones

GOAL FILL DATA GAPS TO DEVELOP FINAL DESIGN

RESULTS: Reagent mix with both short and extended longevity that could be distributed at large radius of influence identified

REGENESIS

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Chlorinated Solvent Site

- Contaminant Concentrations: Maximum 6100ug/L , multiple locations below 1000ug/L
- Very Large Treatment Area, permeable zones with interbedded zones of reduced permeability
- Generally a Bioremediation Remedy would be considered based upon the large treatment area and moderate to low cVOC levels. – HOWEVER conditions were very oxidative, little to no microbial activity , and pH was elevated so ISCO was ultimately identified as presumptive remedy.

REGENESIS

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Factors Influencing Feasibility & Remedies

1. Geology (regional and local)
   a) Depositional Environment
   b) Stratigraphy, mineralogy, grain size, FOC,
   c) Bedrock (fractures, aperture, connectivity, RQD)
2. Aquifer Properties
   a) Hydraulic conductivity
   b) Porosity (total and effective)
   c) Groundwater flow, velocity boundary conditions
   d) Heterogeneity and anisotropy
   e) 3D extent of plume distribution
3. Geochemistry
   a) Field parameters (DO, ORP, pH, temp)
   b) COD, SOD/NOD, TOC,
   c) Sulfate, sulfide, sulfite
   d) Nitrate, nitrate
   e) Anion/cations
   f) Iron (Fe^2, Fe^3), arsenic, chromium
4. Microbial
   a) Dehalococcoides, phospholipid fatty acids
5. Degradation
   a) Isotope analysis, dissolved gases (methane, ethane, ethene, propane, propene)

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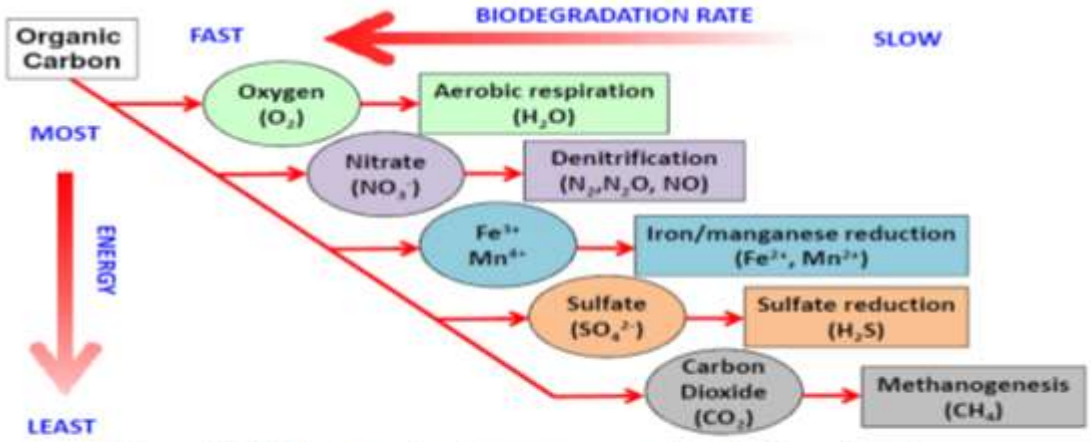
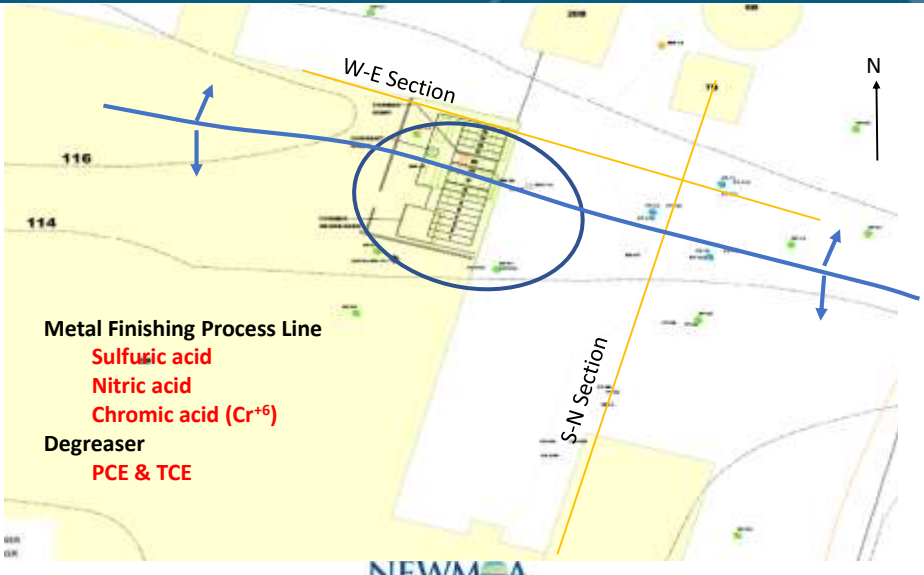
Terminal Electron Acceptors

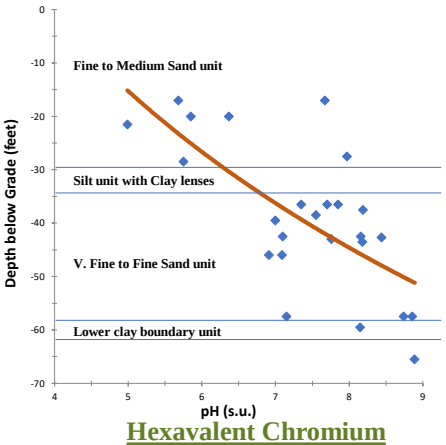


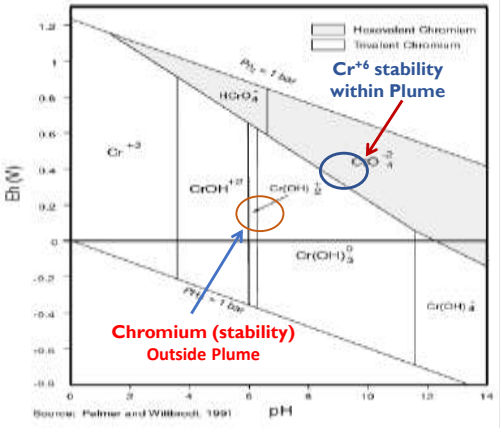
Microbial TEA reduction occurs in defined order based on energy yield

Release Area Pilot



pH Changes with Depth





Hexavalent Chromium

- Not naturally occurring
- Acutely toxic/less stable
  - *Chromate CrO_4^{-2}*
  - *Dichromate $Cr_2O_7^{-2}$*

Trivalent Chromium

- Naturally occurring
- Stable/low toxicity
  - *Trivalent Chromium Cr^{+3},*
  - *Chromium Oxide Cr_2O_3*

Geochemical Parameters

Parameters	Low Level	High Level
Hexavalent Chromium	0.41 mg/L	38.2 mg/L
Dissolved Oxygen	4.0 mg/L	8.6 mg/L
Nitrate	2.9 mg/L	6.5 mg/L
Sulfate	266 mg/L	4,570 mg/L
pH	6.1	9.5
ORP	116 mV	550 mV
Heterotopic Plate Counts	64 cfu/mL	1,030cfu/mL

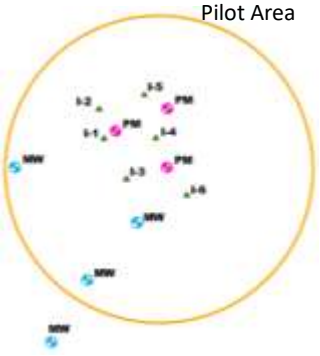
cfu = colony-forming unit

Pilot Design

Design/Layout

- Evaluated products for BOD/TOC:
  - dextrose, HRC_{primer}/3-DMe, molasses, EDC:
    - ❖ HRC/3-DMe selected
- 6- injection points;
- 6-performance wells in 3-clusters;
  - 12 to 17 feet from injection points;
- 1-downgradient well;
- 6-adjacent monitoring wells;

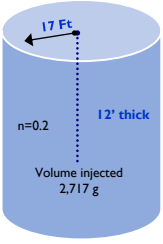
Pilot Area



Duration

- Injected February 2008;
- Monitored 11-years
- Methanogens conditions

Design Configuration



- To estimate volume and effective radius of influence ($V = \pi * r^2 * h * n$)
  - (r - radius, h- thickness, n – effective porosity)
- $V = \pi * (17)^2 * 12 * 0.2 = 2{,}179$ -gallons 181.5 gallons per foot;
- Total injection zone – 16,300 gallons (2,717 gals per point);

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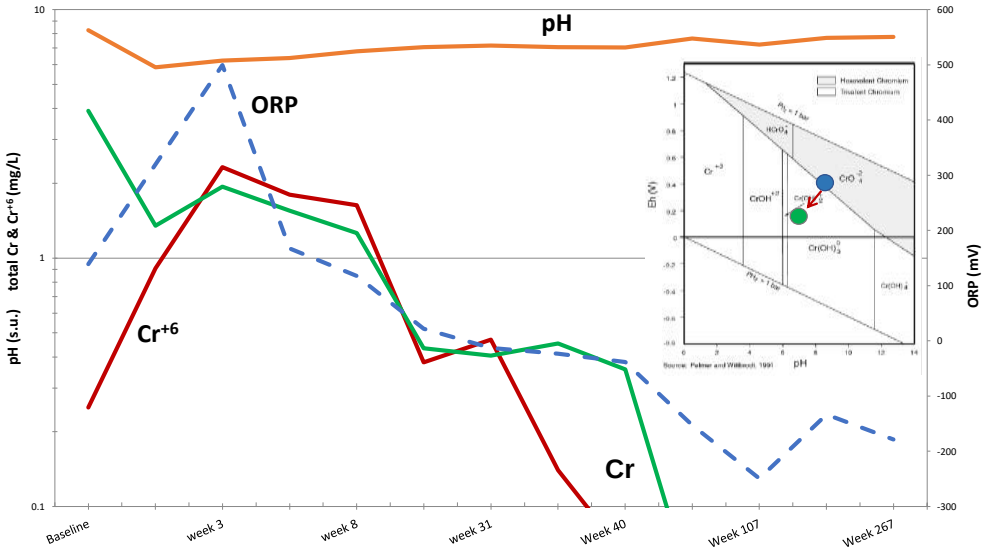
Pilot Results



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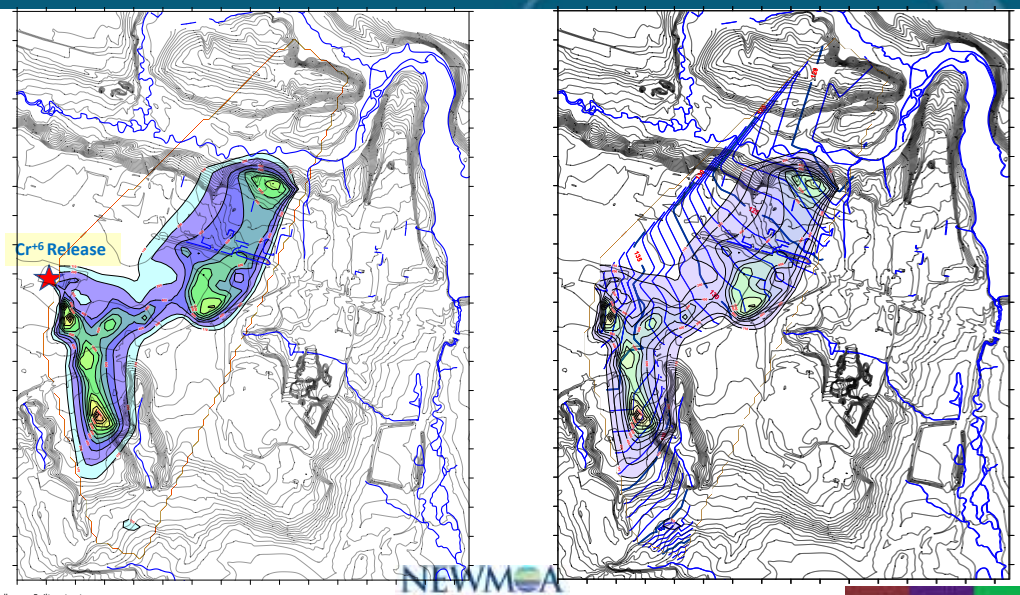
Hexavalent Chromium Plumes



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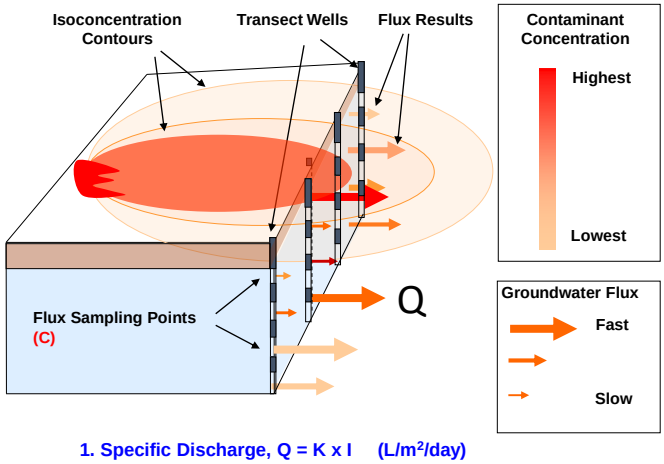
Contaminant Migration/Mass Flux



1. Specific Discharge, Q = K x I (L/m^2/day)
2. Average concentration, C_{avg} (g/L)
3. Mass Flux, (J) = Q x C (g/m^2/day)

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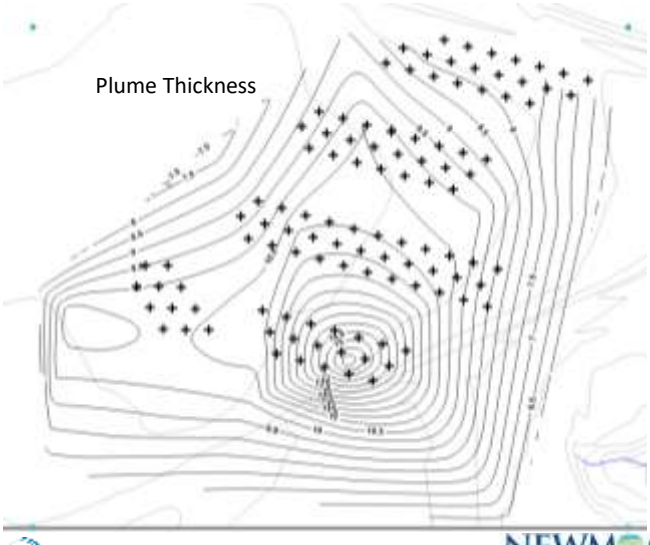
Hexavalent Chromium Design

Plume Thickness



Seepage velocity	35-feet/year
Effectiveness of Pilot	8+ years Plume
migration	280-feet
Distance between injection zones	80-feet
Effective radius of influence	15-feet (177 sf)
Sodium Lactate	2.7 to 3.3 gallons per foot
3-DMe	3.7 to 6.0 gallons per foot
Total injection area (barrier)	5-acres, 155-points
Total if injected 30 ft on center	**5-acres, 1,230-points**

1-foot injection probe, Bottom-up injection

Injection Thickness	10 to 29 -FEET

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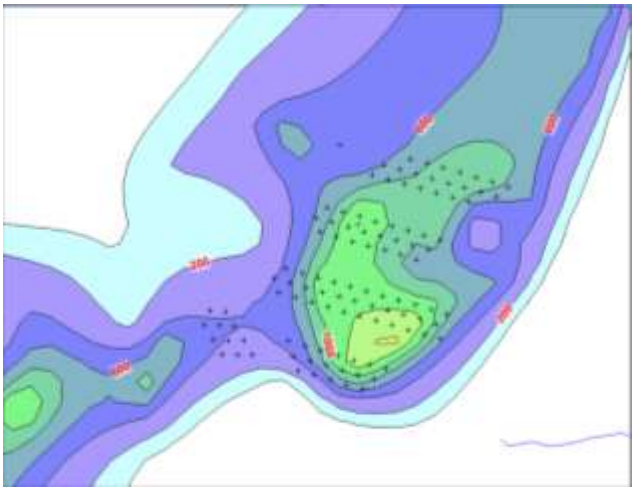
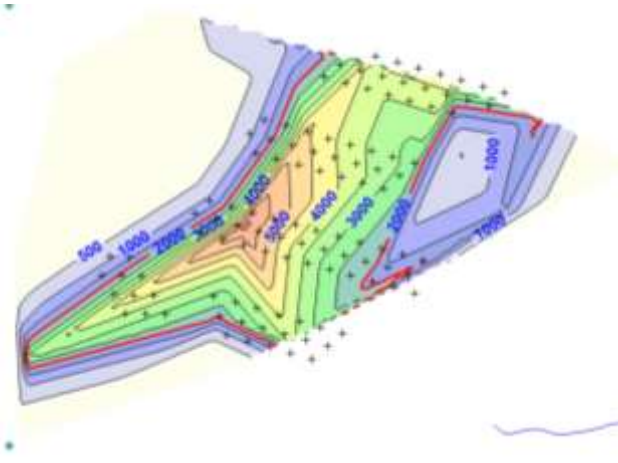
Injection Plume Design

Injection Points (Plume Concentrations)



Injection Points (Mass)



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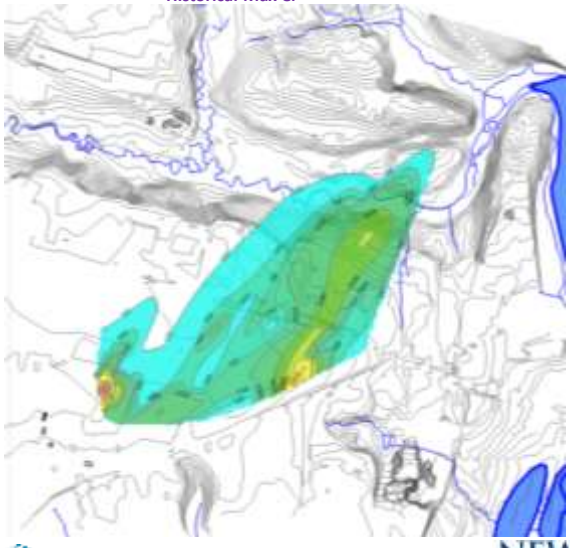
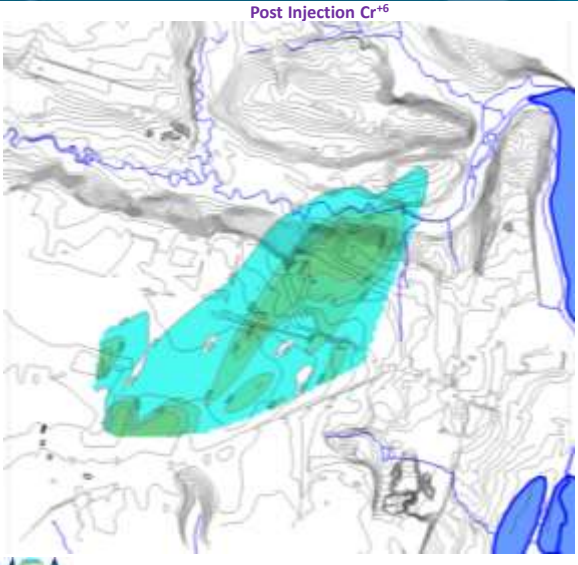
Northern Hexavalent Chromium Plume

Historical Max Cr^{+6}



Post Injection Cr^{+6}



Northern Hexavalent Chromium Plume Results

Post Injection

Release Zone (R)

- Cr^{+6} = 92% Reduction in all Concentrations
  - Max = 38,200 µg/L, now 8.2 µg/L

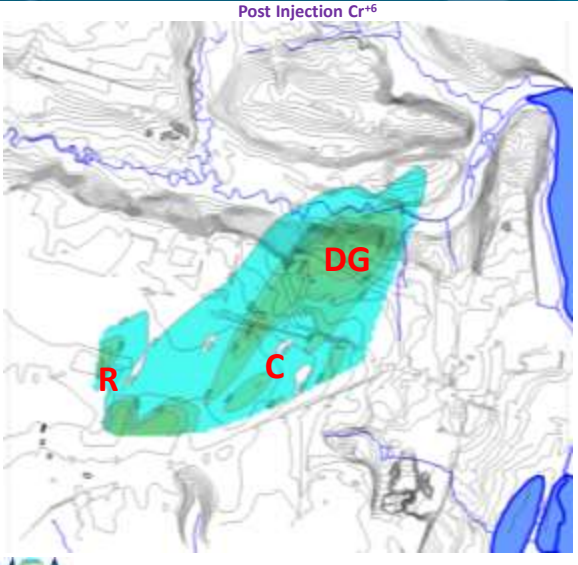
Core Zone (C

- Cr^{+6} = 80% Reduction in all Concentrations
  - Max = 7,270 µg/L, now 355 µg/L

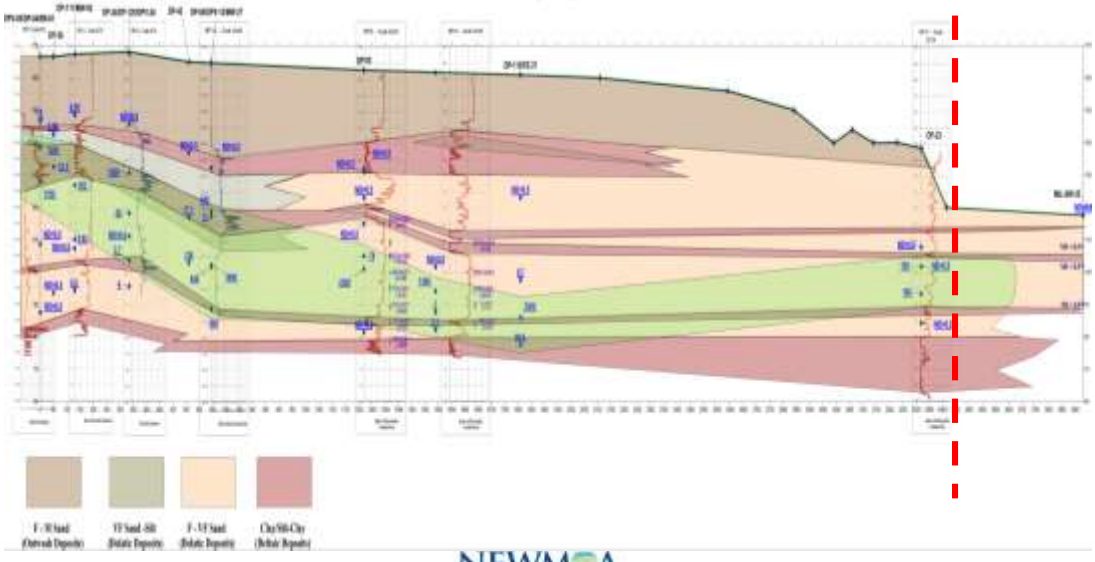
600-Feet Down Gradient (DG)

- Cr^{+6} = 53% Reduction in all Concentrations
  - Max = 3,390 µg/L, now 1,570 µg/L

Post Injection Cr^{+6}



TCE Nature & Extent



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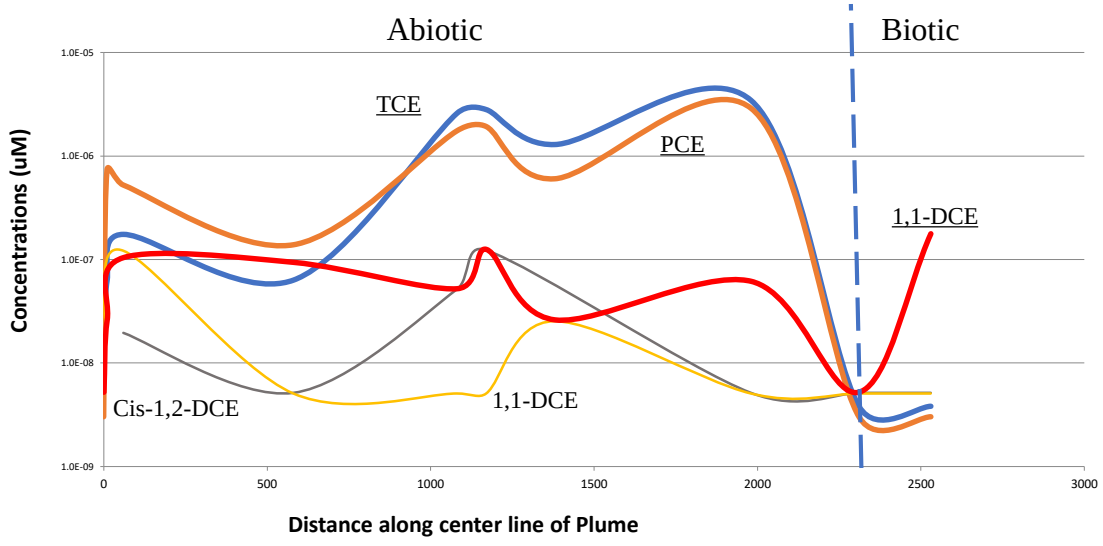
Abiotic vs. Biotic cVOC Degradation



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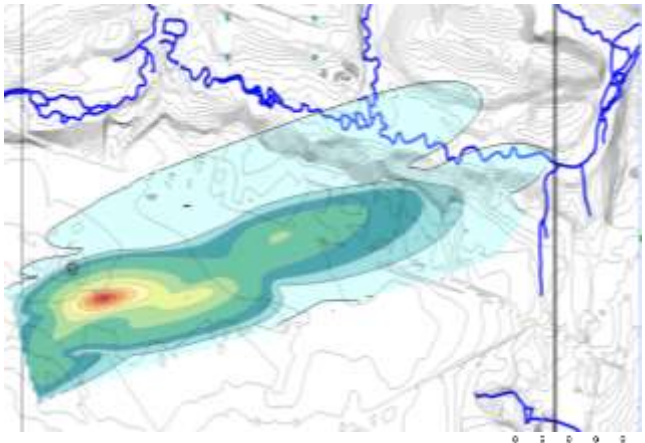
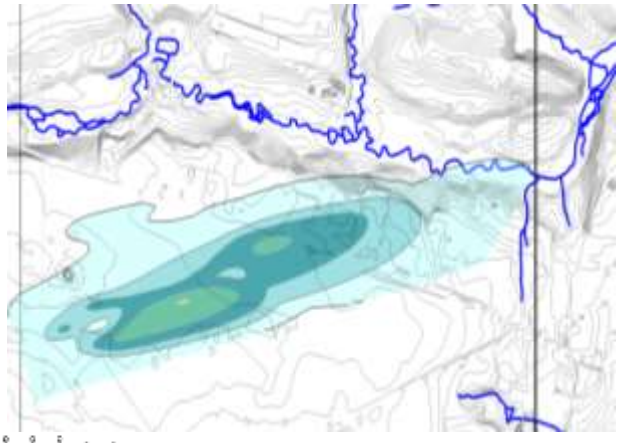
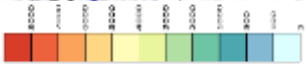
TCE Plume Migration

Historic Max TCE



Current TCE





TCE Plume Migration

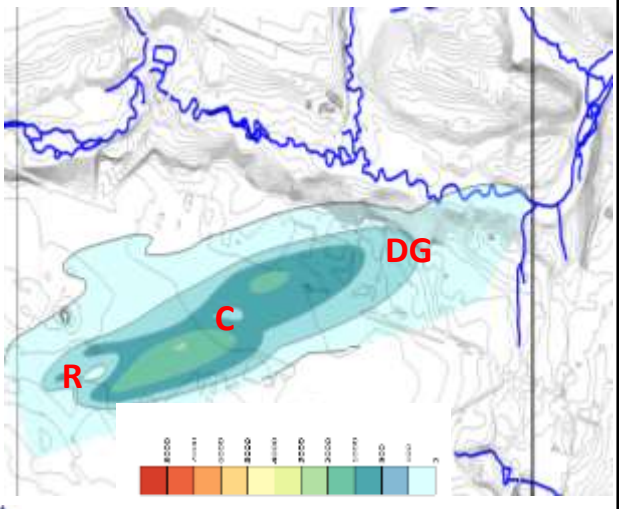
Post Injection

Release Zone (R) ISCO Injection
- TCE = 84% Reduction in all Concentrations
  - Max = 9,400 µg/L, now 672 µg/L

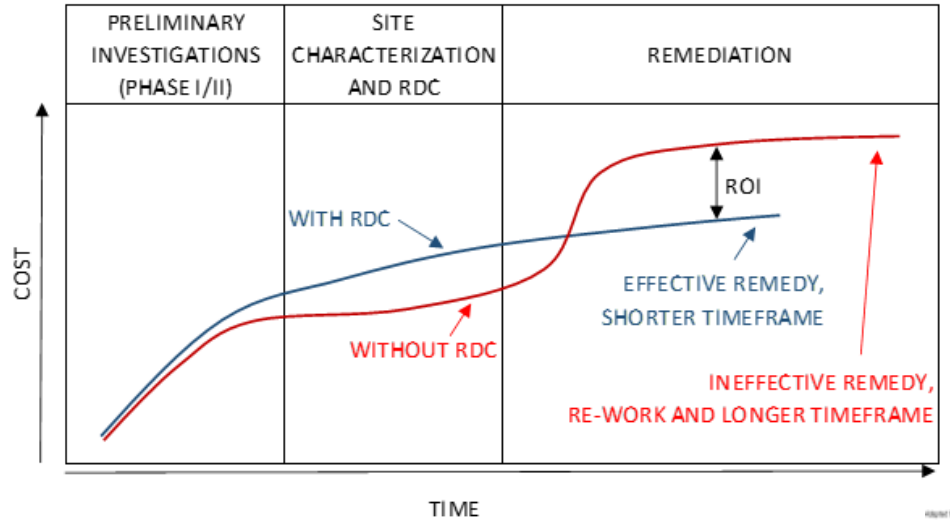
Core Zone (C) ISCO Injection
- TCE = 61% Reduction in all Concentrations
  - Max = 4,370 µg/L, now 2,300 µg/L

1,200-Feet Down Gradient (DG)
- TCE = 52% Reduction in all Concentrations
  - Max = 454 µg/L, now 139 µg/L

Current TCE



Cost Benefits of Enhanced Characterization



Cost Benefits of Enhanced Characterization

- Reduced uncertainties, improving your CSM by better delineating the vertical and horizontal nature and extent of the contaminants;
- Reduced uncertainties lead to more cost effective remediation solutions.
- Identified that geologic conditions resulted in natural attenuation, prior to discharge.
- Remedy focused on a mass reduction, followed by MNA, rather that treating the entire 2,500 to 4,500 foot plumes.
  - Resulting in significant cost savings.
- In-Situ ISCO and ISCR was very effective when specifically targeting the contamination within unique hydrostratigraphic units.
- The incidental characterization costs are more than out weighted by the remedial cost savings.

Question

Optimizing Feasibility Studies & Presumptive Remedies

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