Kennedy Space Center Remediation Program Overview

Streamlined RCRA Remediation via Engineering Evaluation Process

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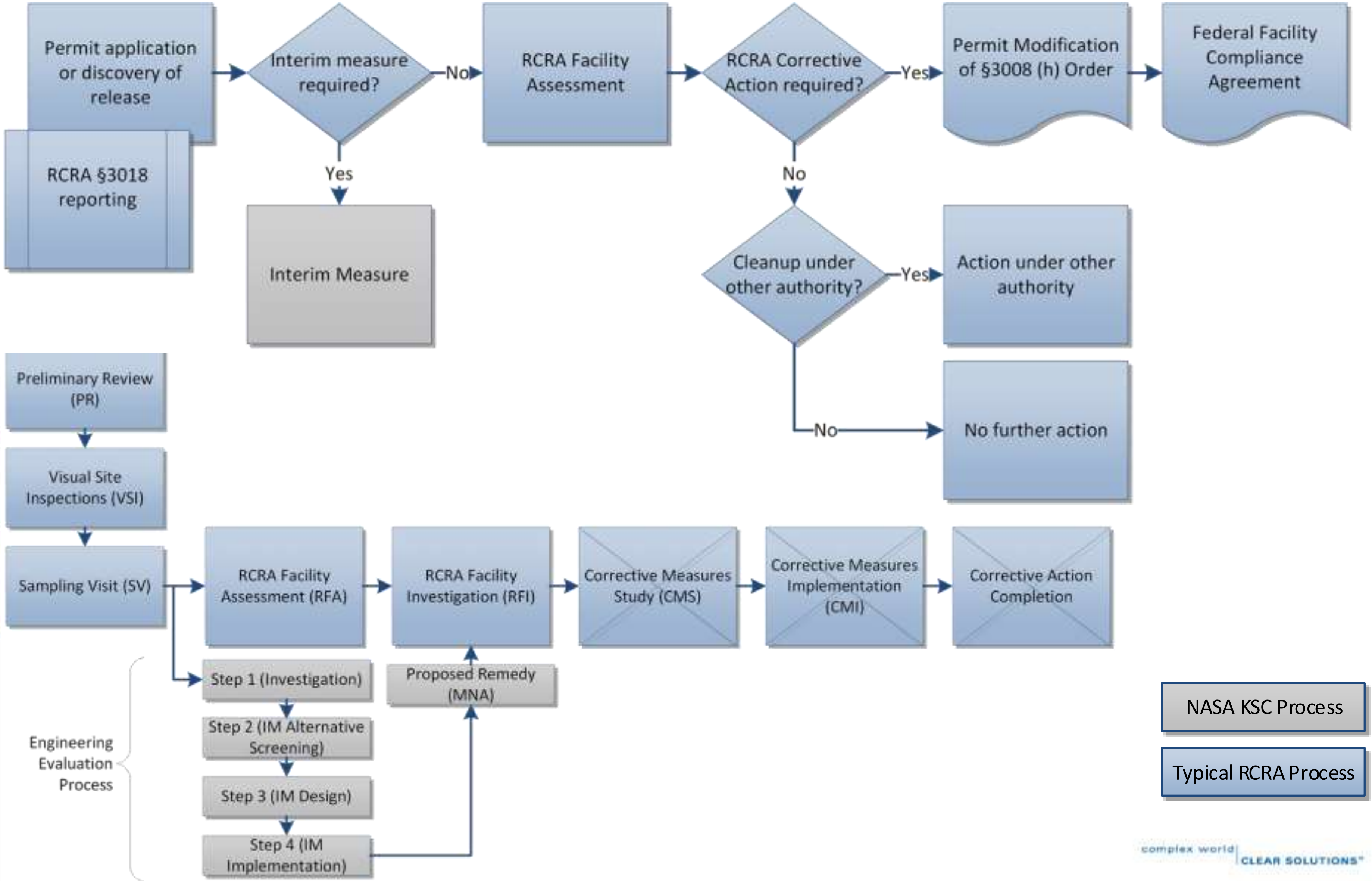
Objectives

- Typical RCRA Process
- Kennedy Space Center (KSC) Remediation Team
- Overview KSC Engineering Evaluation (EE) Process
  - Preliminary Assessment/Possible Release Locations
  - Step 1 EE – Characterization
  - Step 2 EE – Remedy Alternative Screening
  - Step 3 EE – Remedy Design
  - Step 4 EE – Remedy Implementation

RCRA Corrective Action



KSC Remediation Team (KSCRT)

- Interdisciplinary team:
  - NASA KSC Remediation Project Managers (RPMs)
  - Regulators (FDEP)
  - A/E Contractors:
    - Tetra Tech
    - Jacobs
    - Geosyntec
- Each member reviews and comments on each EE and consensus for these submittals is requested at meeting
- A master KSC schedule for projects and deliverables used to track/coordinate meeting topics and maintain permit compliance
- Meet every 2 months at KSC

Engineering Evaluation Process

- Multi-step process developed to ensure:
  - Adequate site characterization
  - Participate in evaluation of remedial technologies
  - Review preliminary designs
  - Evaluate efficacy of interim measures
- Decouples RFI and CMS Work Plan process
- Remedy conducted through interim measures (IMs)
- IMs conducted such that Long Term Monitoring is final remedy
- Allows prompt action to mitigate and prioritize risks
  - 1 to 3 years versus 5 to 10+ years!

Step I EE – Site Characterization

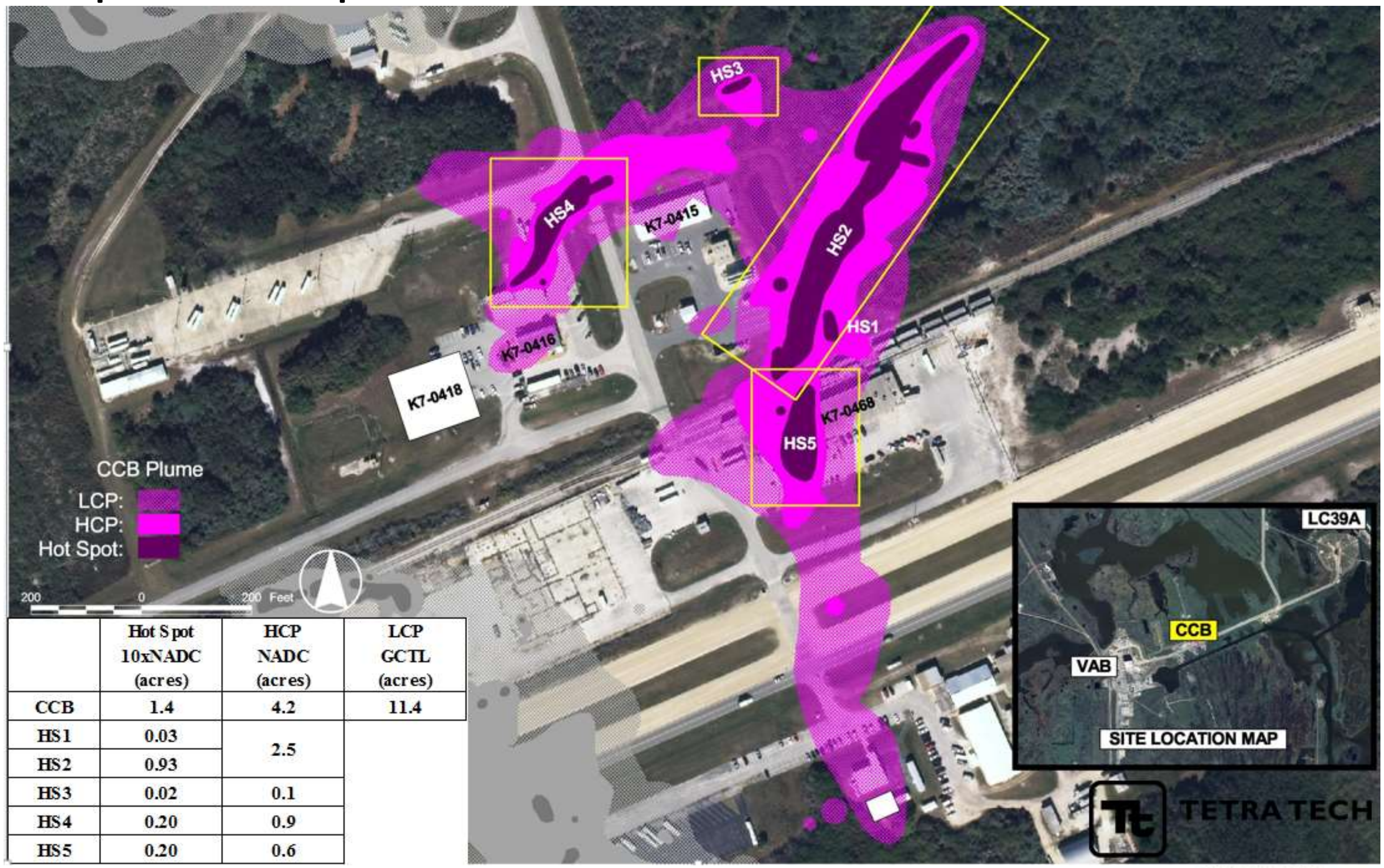
- Goals:
  - Is groundwater contamination fully delineated?
  - Is sufficient data available for site conceptual model and remedial decision making?
- Content:
  - Objectives/Site History
  - Site Conditions (e.g., terrain, hydrogeology, lithology)
  - Assessment summary (results, locations, intervals, mass)
  - Results Visualization (interval/COC plume maps, cross sections, electronic visualization software)
  - Preliminary Remedial Technology Screening

Step I EE – Field Investigation

- Direct push technology sampling/mobile laboratory based on adaptive grid investigation technique:
  - 100’ spacing in Low Concentration Plume (>GCTL, <NADC)
  - 50’ spacing in High Concentration Plume (>NADC, <10X NADC)
  - 25’ spacing in Hot Spot Plume (>10X NADC)
  - 10’ spacing in parent source zone (chemical specific: TCE – 1%)
- Membrane interface probe (generally source areas)
- Soil coring (lithologic/geotechnical/physical/chemical)
- Establish monitoring well network/sampling program

Step 1 EE – Example Excerpts

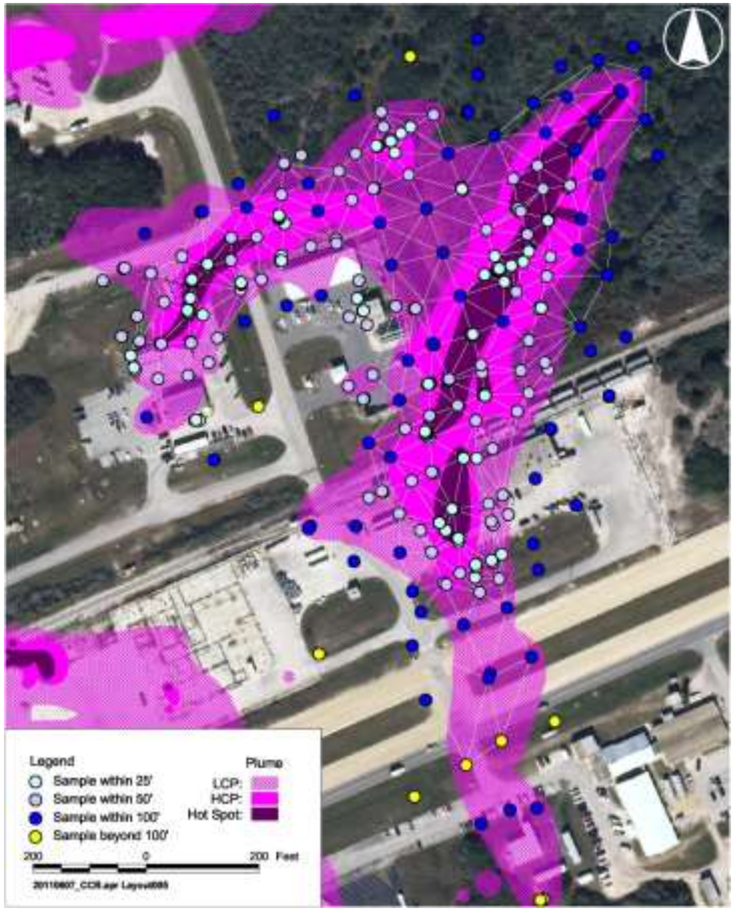
- Example multi-plume site:



	Hot Spot 10xNADC (acres)	HCP NADC (acres)	LCP GCTL (acres)
CCB	1.4	4.2	11.4
HS1	0.03	2.5	
HS2	0.93		
HS3	0.02	0.1	
HS4	0.20	0.9	
HS5	0.20	0.6	

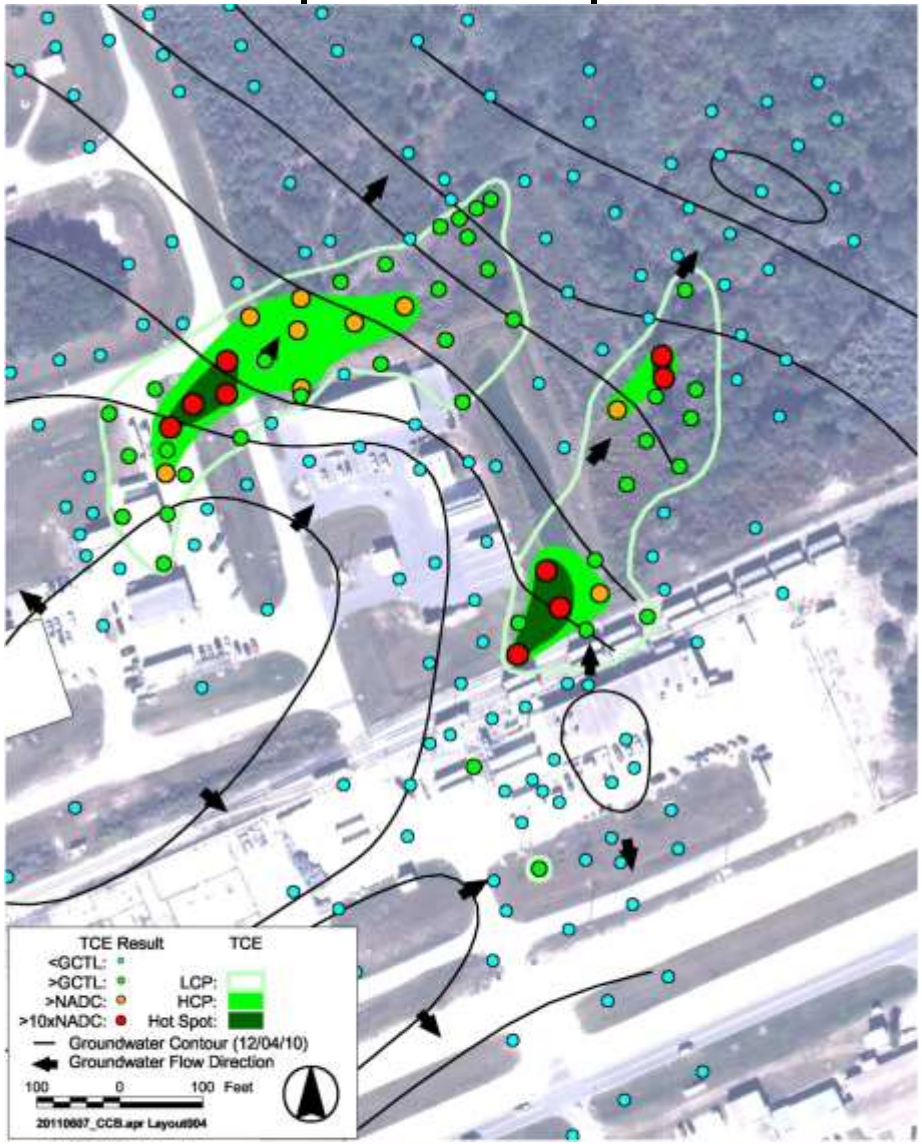
Step I EE – Data Interpretation

- DPT data obtained in near real-time
  - Future DPT location/spacing determined based on result
- Final DPT data set compiled and visualized
  - Plan view plume contours (10’ vertical intervals)
  - Combined with lithologic data for cross section view
  - MIPs data evaluated with DPT/lithologic data
  - 3D plume model created via EVS (krigging)
- Contaminant mass calculated
- Engineering data to support preliminary remedial technology screening (biological, chemical, geochemical, physical, etc)
- Data and conclusions compiled into a presentation (Advanced Data Package)
- ADP published to team for review/comment
- Presented at meeting for discussion and consensus



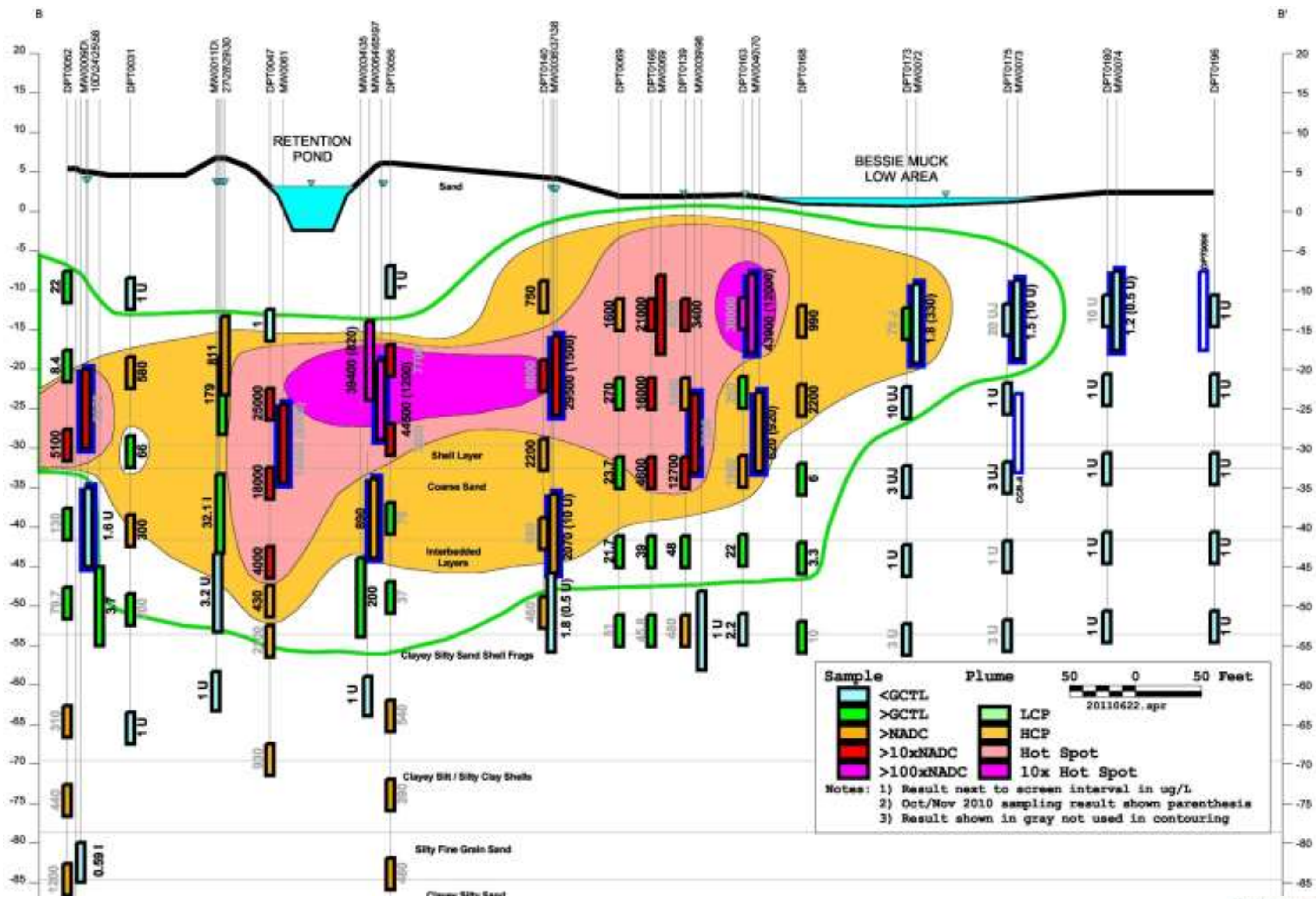
Step 1 EE – Example Excerpts

- TCE plume slice at specific depth interval:



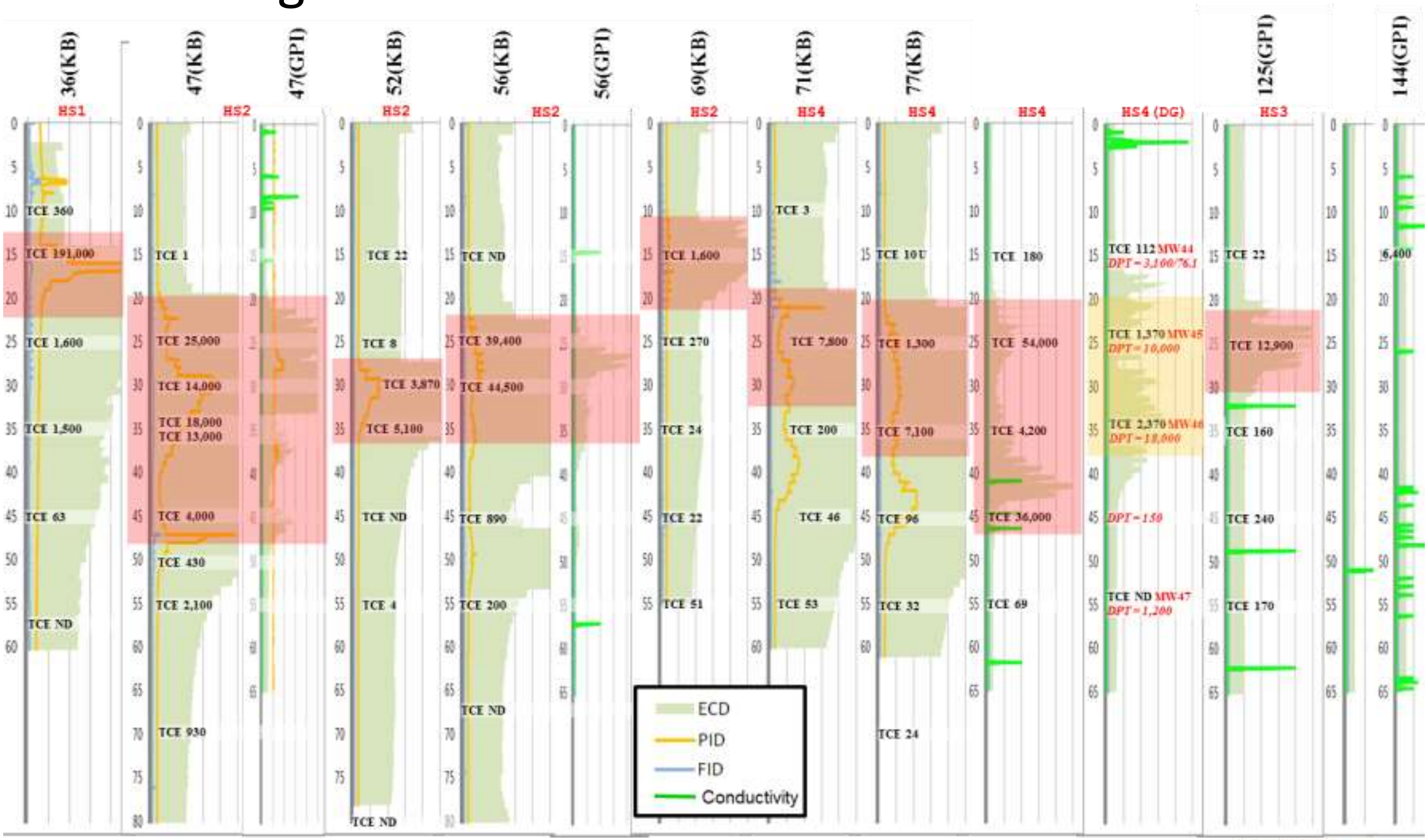
Step 1 EE – Example Excerpts

- Example cross section:



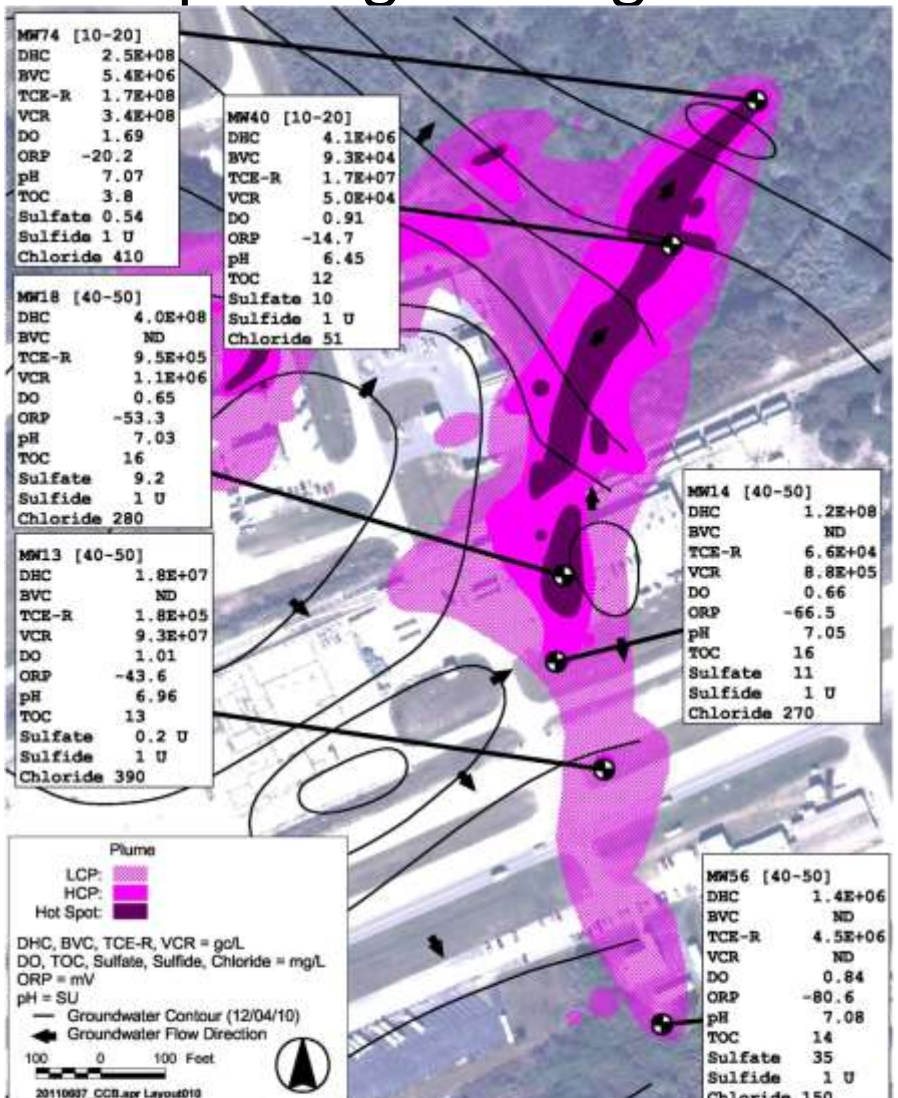
Step 1 EE – Example Excerpts

- MIP logs:



Step I EE – Example Excerpts

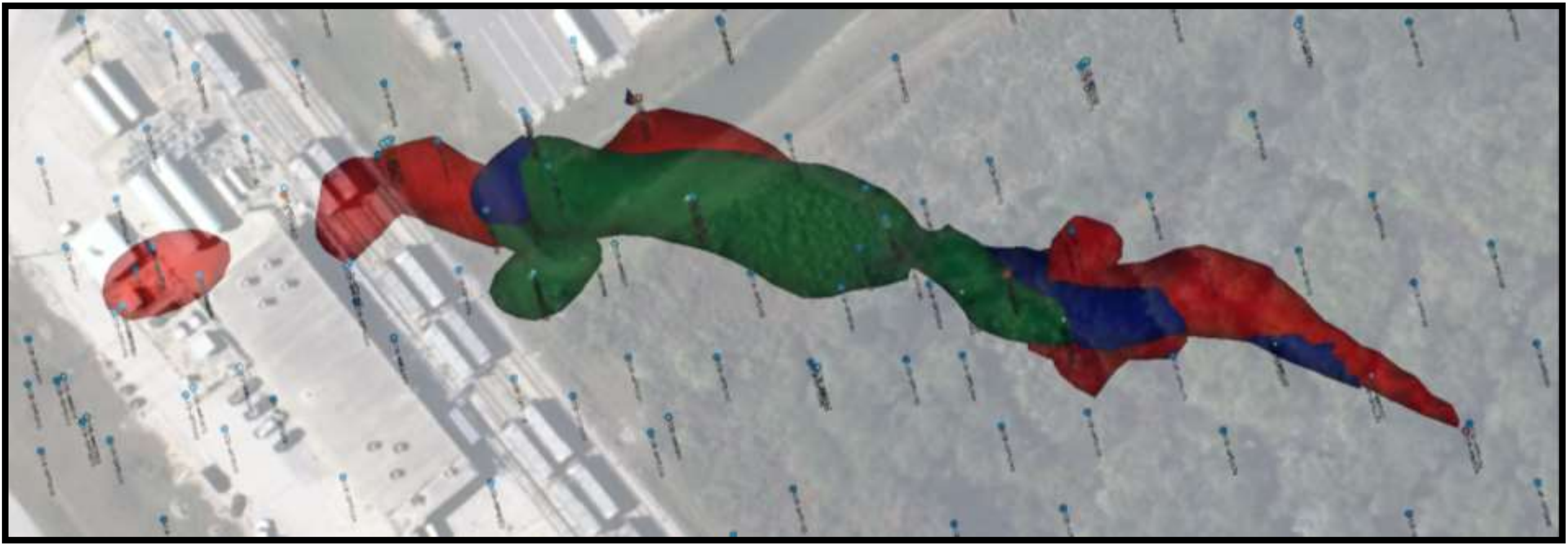
- Sample engineering data:



Parameter	Min.	Max.	Average	Units
Dehalococcoides	1.4E+06	4.0E+08	1.3E+08	gene copy/L
TCE r-dase	6.6E+04	1.7E+08	3.2E+07	gene copy/L
BAV1 VC r-dase	0.5 U	5.4E+06	9.1E+05	gene copy/L
VC r-dase	2.5 U	3.4E+08	8.7E+07	gene copy/L
Ethane	0.17 U	2.4	1.1	µg/L
Ethene	2.9	140.0	46	µg/L
Methane	80	2,700	1,300	µg/L
Hydrogen	0.84	1.30	1.05	nmol
Total Organic Carbon	3.8	16 V	12.5	mg/L
Carbon Dioxide	210 V	980	605	mg/L
Hydrogen Sulfide (HS2)	0 (ND)	0.5	--	mg/L
Hydrogen Sulfide (S-2)	0 (ND)	0 (ND)	--	mg/L
Chloride	51	410	258.5	mg/L
Nitrate-N	100 U	100 U	100 U	µg/L
Nitirite-N	100 U	100 U	100 U	µg/L
Sulfate	200U	35	11	mg/L
Sulfide	1000 U	1000 U	1000 U	µg/L
Ferrous Iron	0.20	2.20	0.87	mg/L
Iron (total)	0.84	12	3.3	mg/L
Manganese	0 (ND)	130	36	mg/L
Alkalinity	50 U	450	375	mg/L
Conductivity	666	2,014	1,522	mS/cm^2
DO – Field Kit	0.8	1.0	0.9	mg/L
DO – Meter	0.65	1.69	0.96	mg/L
ORP	-80.6	-14.7	-46.5	mV
pH	6.5	7.1	6.9	S.U.
Temperature	22.7	26.1	24.5	C
Turbidity	4.2	8.7	5.8	µg/L

Step 1 EE – Example Excerpts

- EVS View:



Plumes: TCE (green), cDCE (blue), VC (red)
Sample Locations:
Blue all parameters < 10x NADC
Red one or more parameters >10x NADC

Step 1 EE Excerpts

- Remedial technology screening

General Action	Technology	Process Option	Retain?	Rationale
In-Situ Treatment	Biological	Anaerobic Enhanced Bioremediation	Retain	Site conditions suggest favorable conditions for anaerobic reductive dechlorination and this technology has been successfully applied widely at KSC. Utilization of compatible cosolvents and/or surfactants may be needed for dissolution and contact of microbes to SZ impacts.
		Aerobic Enhanced Bioremediation	Eliminate	Aerobic technologies are typically most appropriate for less oxidized contaminants such as vinyl chloride. Due to presence of TCE in SZ, aerobic bioremediation is generally not appropriate.
		Bioaugmentation	Retain	Populations of CVOC dechlorinators such as DHC are present at high levels, but the presence of functional genes for CVOC degradation vary. Addition of commercial dechlorinating cultures may be appropriate in select regions with deficient indigenous dechlorinating potential.
	Chemical/Physical	Air Sparging (AS)	Retain	Air sparging could be effective in volatilizing high concentrations of dissolved phase mass. In situ treatment of sorbed and residual NAPL mass would be dispersion/dissolution limited and may extend air sparge duration to reach treatment objectives.
		Large Diameter Auger (LDA) Mixing	Eliminate	Utility features at the site would limit the footprint that could be excavated via LDA.
		Chemical Oxidation (ISCO)	Eliminate	Effective technology to destroy high concentrations of COCs such as that in the SZ. Concern of shallow oxidant injection and interaction with metallic high pressure utilities.
		Chemical Reduction (EZVI)	Retain	Strategic injections within the SZ can be an effective treatment technology to treat high concentrations and residual mass via abiotic and biotic mechanisms.
		Permeable Reactive Barrier (PRB)	Eliminate	Inadequate hydrogeological conditions for plume treatment (e.g., low groundwater velocity). Sorbed mass unlikely to flow through PRB.
		Co-Solvent Flushing	Eliminate	Due to the limited source zone extent, dissolution via groundwater recirculation is assumed to provide sufficient contact with residual mass for in-situ treatment processes.
	Thermal	Steam Enhanced Extraction	Eliminate	Substantial unit cost for treatment of a small 70 sqft area. Considerable worker safety risk, energy usage, and logistical intensity.
		Electrical Resistance Heating	Eliminate	Substantial unit cost for treatment of a small 70 sqft area. ERH could effectively volatilize dissolved-phase COCs and residual NAPL within the SZ.
		Thermal Conduction Heating	Eliminate	Substantial unit cost for treatment of a small 70 sqft area. Better suited for low permeability, low-conductivity lithologies. Significant energy usage.
Disposal	On-Site Disposal	Re-Injection Wells	Retain	Discharge of treated, ammended, and/or recirculation water may be needed depending on assembly of alternatives. Discharge quality requirements would be dependent on application.

Step 2 EE – Remedial Alternative Evaluation

- Goals:
  - Compile technologies into remedial alternatives
  - Provide unbiased screening and comparison of technologies
  - Select best suited remedial alternative
- Content:
  - Conceptual designs (layouts, design criteria, cost estimates, etc.)
  - Comparative analysis of alternatives (similar to RCRA selection criteria)
  - Supplemental attachments: cost estimates, design calculations, models, alternative narratives

Step 2 EE – Example Excerpts

No.	Alternative	General Components
G-1	Air Sparging	AS wells (6 shallow, 18 shallow-intermediate, and 40 intermediate), AS system (rotary claw compressed air pump, heat exchanger, and instrumentation), and conveyance trenching and piping.
G-2	Anaerobic Bioremediation with Recirculation	Injection and extraction wells for application of substrate through recirculation (30 injection wells and 8 extraction wells). Extraction pumps, substrate mixing, and conveyance piping/tubing.
G-3	Anaerobic Bioremediation with Recirculation and EZVI Injection in HS1 SZ	Injection and extraction wells for application of ethyl lactate through recirculation (30 injection wells and 8 extraction wells). Extraction pumps, substrate mixing, and conveyance piping/tubing. Injection of EZVI at 2 locations at HS1.
G-4	Anaerobic Bioremediation with Recirculation and Selective Treatment	Injection and extraction wells for application of ethyl lactate through recirculation (30 injection wells and 8 extraction wells). Extraction pumps, infiltration gallery, air stripper, substrate mixing, and conveyance piping/tubing.
G-5	Anaerobic Bioremediation with Recirculation, Selective Treatment, and EZVI Injection in HS1 SZ	Injection and extraction wells for application of ethyl lactate through recirculation (30 injection wells and 8 extraction wells). Extraction pumps, infiltration gallery, air stripper, substrate mixing, and conveyance piping/tubing. Injection of EZVI at 2 locations at HS1.

Step 2 EE – Example Excerpts

- Enhanced reductive dechlorination alternative example:

<u>Alternative G-2 Summary</u>

- Biological and geochemical conditions favorable for enhanced anaerobic bioremediation
- Soluble electron donor substrate (e.g., LactOil) distributed by cycled groundwater recirculation
- Target substrate concentration of 550 mg/L
- Six recirculation zones, consisting of:
  - 8 extraction wells within 3 extraction transects
  - 30 injection wells within 4 injection transects
- Treatment zones would be operated in phases, under the below groupings:
  - Sequence 1: Zone 1, 4, and 6
  - Sequence 2: Zones 2 and 5
  - Sequence 3: Zone 3
- 30 day sequence duration; 2 pore volumes for each sequence; 90 days per sequence cycle

Step 2 EE – Example Excerpts

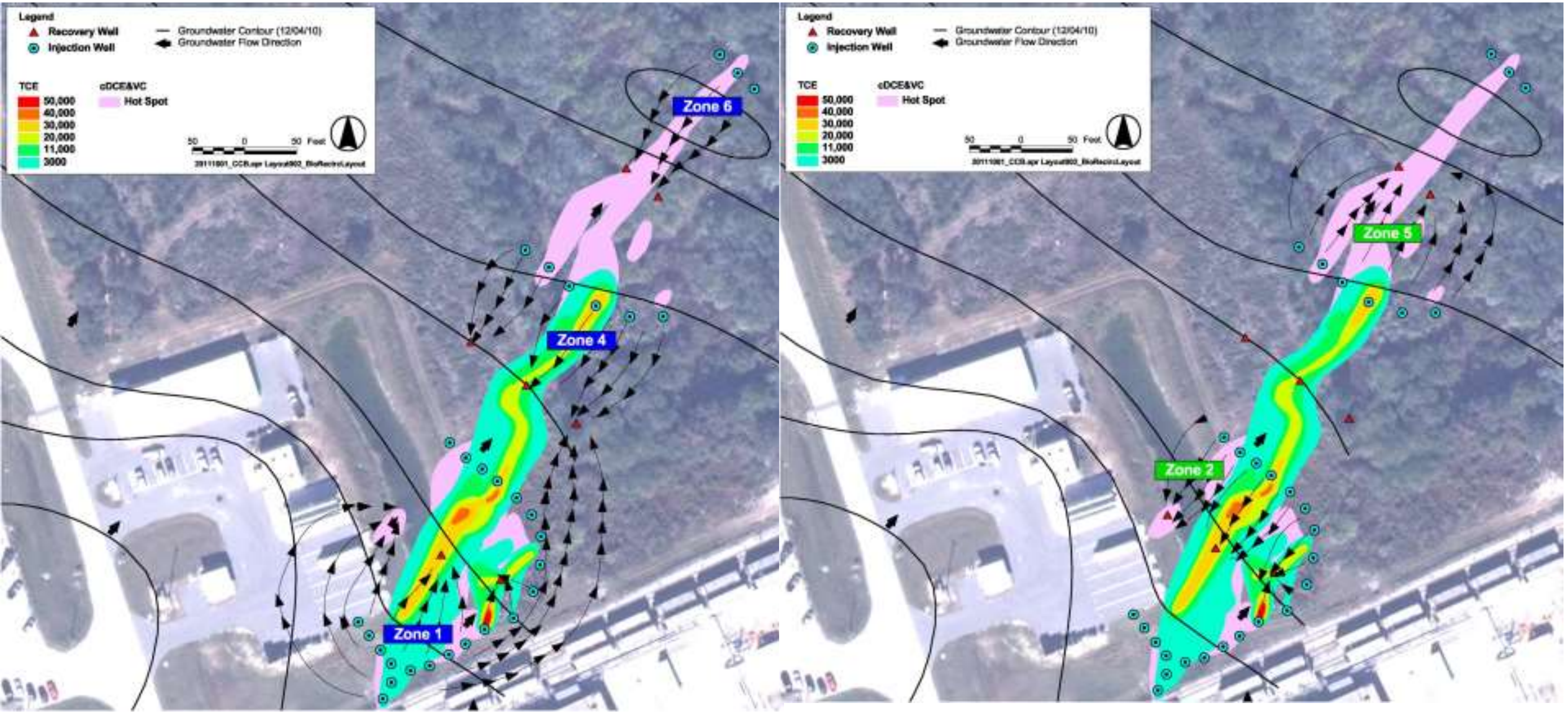
- Enhanced reductive dechlorination alternative example:

Alternative G-2 Summary

- Extracted fluids would be directed to one of two manifolds – a high concentration manifold and a low concentration manifold
- Flexible manifold design allows all injection/extraction well laterals to be easily interchangeable between low and high concentration manifolds
- Substrate mixing, injection equipment, tanks, and pumps would be housed in a trailer
- 5,300 gallons (~100 drums) 60% soybean water-in-oil emulsion injected through the recirculation zones.
- Estimated time to reach treatment goals: ~3 years
- Estimated Cost: $879K (~$7.3K per pound of total TCE, cDCE, and VC mass)

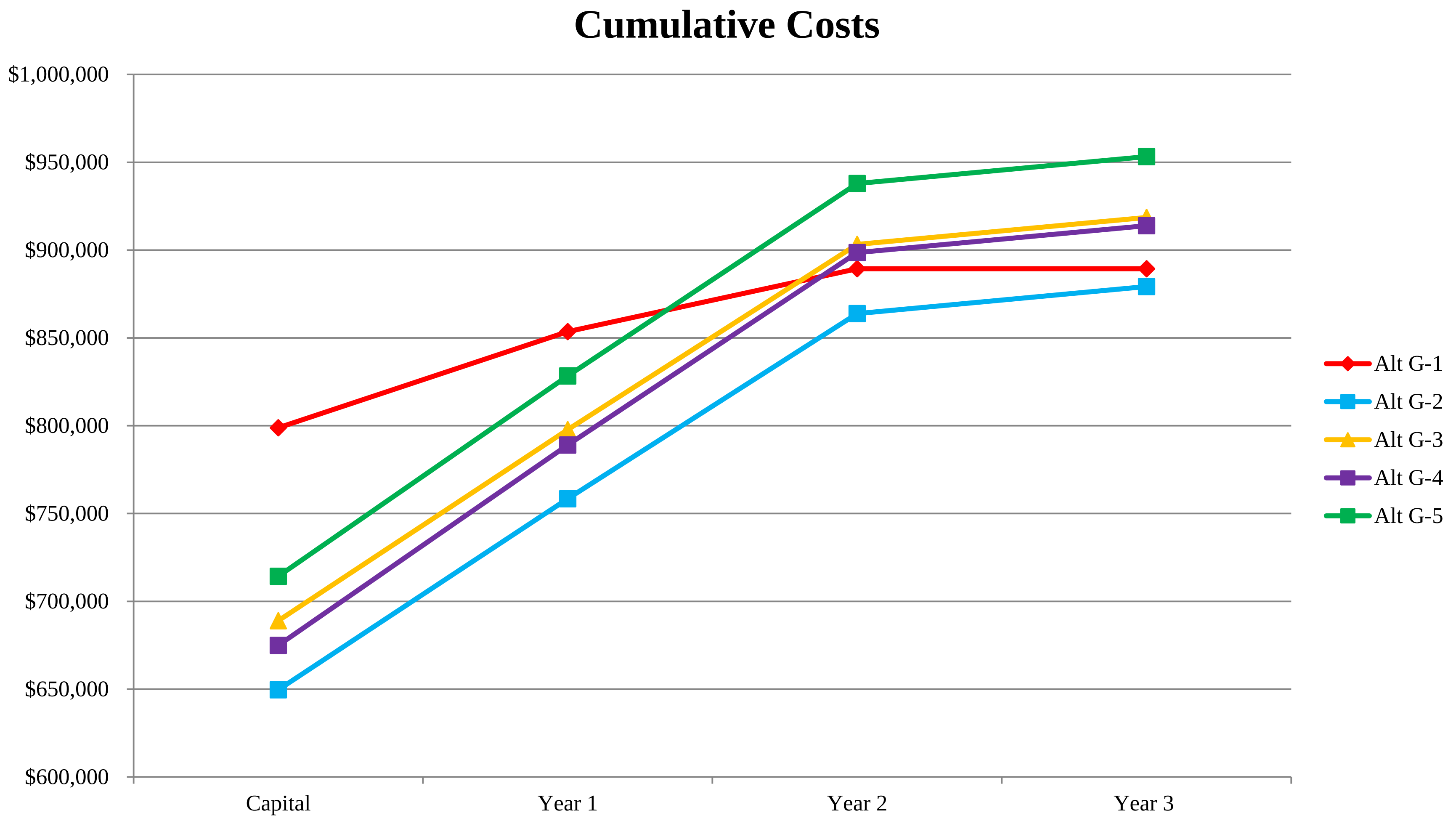
Step 2 EE – Example Excerpts

- Enhanced reductive dechlorination example:



Step 2 EE – Example Excerpts

- Cost evaluation:



Step 2 EE – Example Excerpts

- Alternative screening:

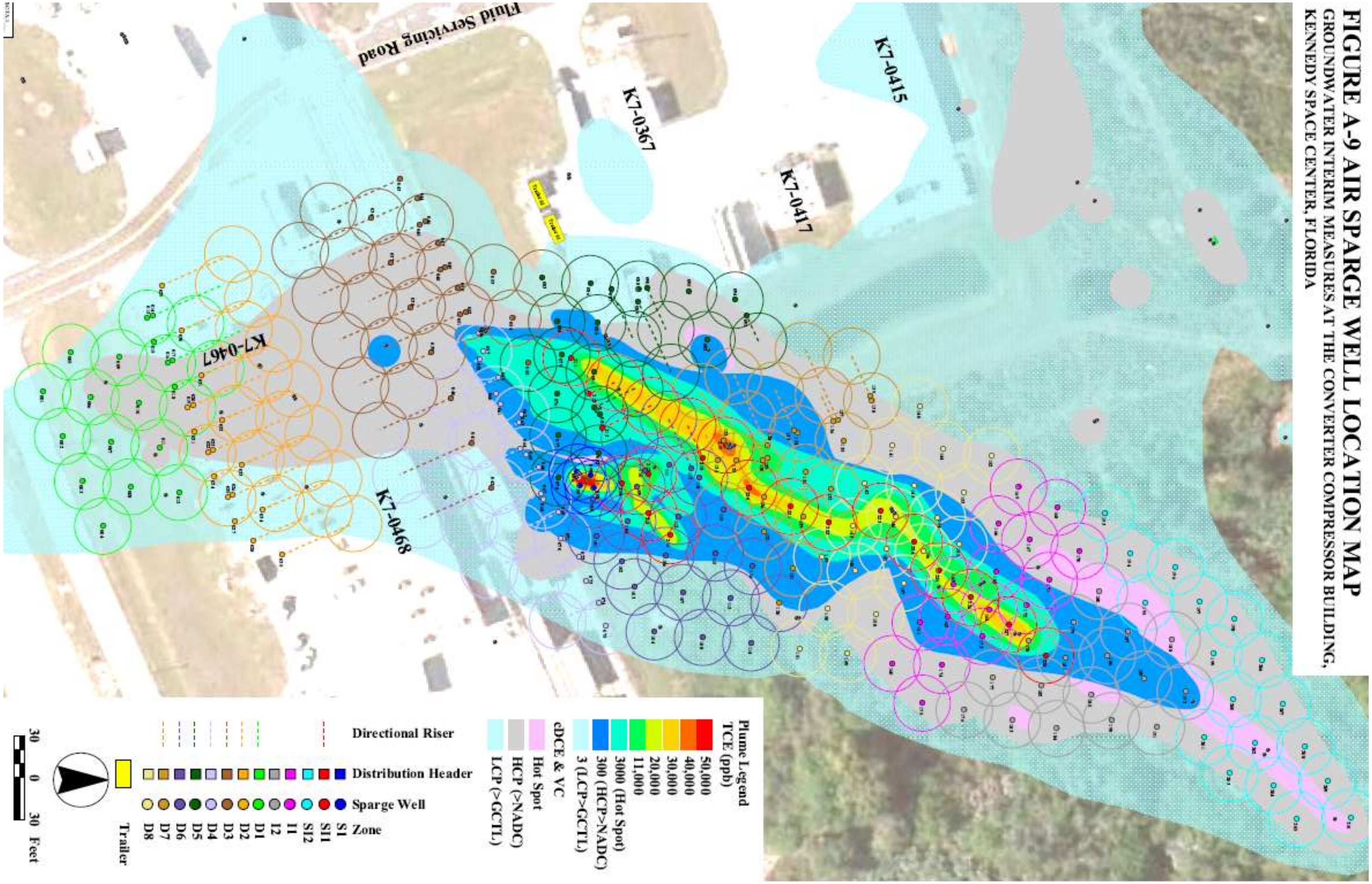
Comparative Analysis of IM Alternatives

ALTERNATIVE	LIMITATIONS	ADVANTAGES	DISADVANTAGES	SUSTAINABILITY	COST
Alternative G-1 Air Sparging	-Treatment of potential NAPL ganglia dissolution limited -Air distribution in heterogeneous lithologies	-Effective technology widely applied and understood at KSC -Large mass reduction in short timeframe -Operations are easily adjustable and flexible	-Capture of volatilized COCs not feasible. -Potential HS plume expansion into HCP -Fairly energy intense -Preferential pathways may result in pockets of untreated zones	CO2e: 263 tonnes NOx: 0.45 tonnes SOx: 0.59 tonnes PM10: 0.0125 tonnes Energy: 4,519 MMTBU Water: 181,000 gal	Capital: $799K Year 1 Costs: $55K Total Costs: $889K Cost/lb VOC Mass: $7.4K
Alternative G-2 Anaerobic Bioremediation with Recirculation	-Distribution uniformity of substrate predicated by lithology -Treatment timeframe generally unpredictable -Treatment of potential NAPL ganglia limited to dissolution interface	-Proven technology at nearby VAB area -Flexible, substrate selection and dosage can be modified according to results -Injection/extraction flow rates can be optimized -Easily expandable into HCP	-Closed loop recirculation does not fully contain plume footprint -Competing microbes and electron acceptors result in higher substrate loading	CO2e: 134 tonnes NOx: 0.31 tonnes SOx: 0.28 tonnes PM10: 0.0124 tonnes Energy: 3,252 MMBTU Water: 78,000 gal	Capital: $650K Year 1 Costs:: $109K Total Costs: $879K Cost/lb VOC Mass: $7.3K
Alternative G-3 Anaerobic Bioremediation with Recirculation and EZVI Injection	-Alt. G-2 limitations -Contact of potential NAPL with EZVI requires NAPL to transport into EZVI droplets. -Distribution is variable and general injection technologies are complex	-Inclusive of Alt. G-2 advantages -Aggressive treatment of high TCE concentrations -Biotic and abiotic mechanisms accelerated	-Distribution of EZVI can be preferential and viscous properties can limit distribution -Potential secondary groundwater quality impacts by mobilization of metals and sulfide production.	CO2e: 142 tonnes NOx: 0.31 tonnes SOx: 0.28 tonnes PM10: 0.0125 tonnes Energy: 3,469 MMBTU Water: 82,000 gal	Capital: $689K Year 1 Costs: $108K Total Costs: $918K Cost/lb VOC Mass: $7.7K
Alternative G-4 Anaerobic Bioremediation with Recirculation and Selective Treatment	-Alt. G-2 limitations -Fluctuations in initial influent concentrations may require adaptive flow diversion to maintain emission compliance.	-Inclusive of Alt. G-2 advantages -Continuous operation of recirculation zones -Most conservative recirculation scenario -Hydraulic containment of plume footprint -Mass removal -No treatment residuals generated	-Additional component of discharge compliance monitoring -Additional equipment operation and maintenance	CO2e: 157 tonnes NOx: 0.34 tonnes SOx: 0.33 tonnes PM10: 0.0131 tonnes Energy: 3,610 MMBTU Water: 93,000 gal	Capital: $675K Year 1 Costs:: $114K Total Costs: $914K Cost/lb VOC Mass: $7.6K
Alternative G-5 Anaerobic Bioremediation with Recirculation, Selective Treatment, and EZVI Injection in HS1 SZ	-Alt. G-3 and G-4 limitations	-Inclusive of Alt. G-3 and G-5 advantages -Highest level of certainty between biological alternatives	Alt. G-3 and G-5 disadvantages	CO2e: 165 tonnes NOx: 0.34 tonnes SOx: 0.33 tonnes PM10: 0.0133 tonnes Energy: 3,827 MMBTU Water: 97,000 gal	Capital: $714K Year 1 Costs:: $114K Total Costs: $953K Cost/lb VOC Mass: $8.0K

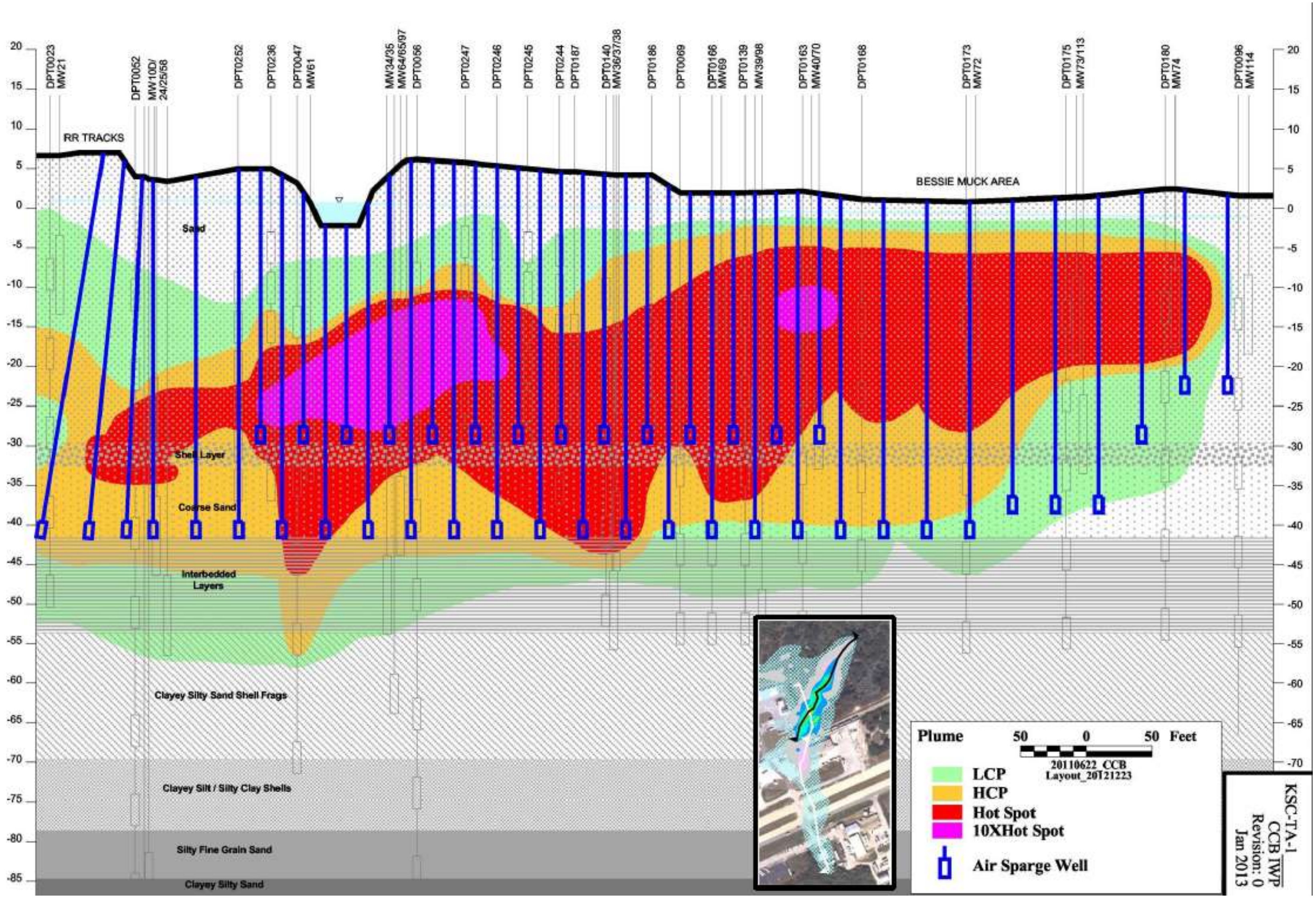
Step 3 EE – Remedial Design

- Goals:
  - Present remedial design to KSCRT
  - Opportunity to review and comment on focused design
- Content:
  - Interim Measure Objectives
  - Design and Process Calculations and Drawings
  - Design description
  - Performance specifications
  - Detailed costing and duration modelling
  - Performance monitoring/exist strategy

Step 3 EE – Example Excerpts



Step 3 EE – Example Excerpts



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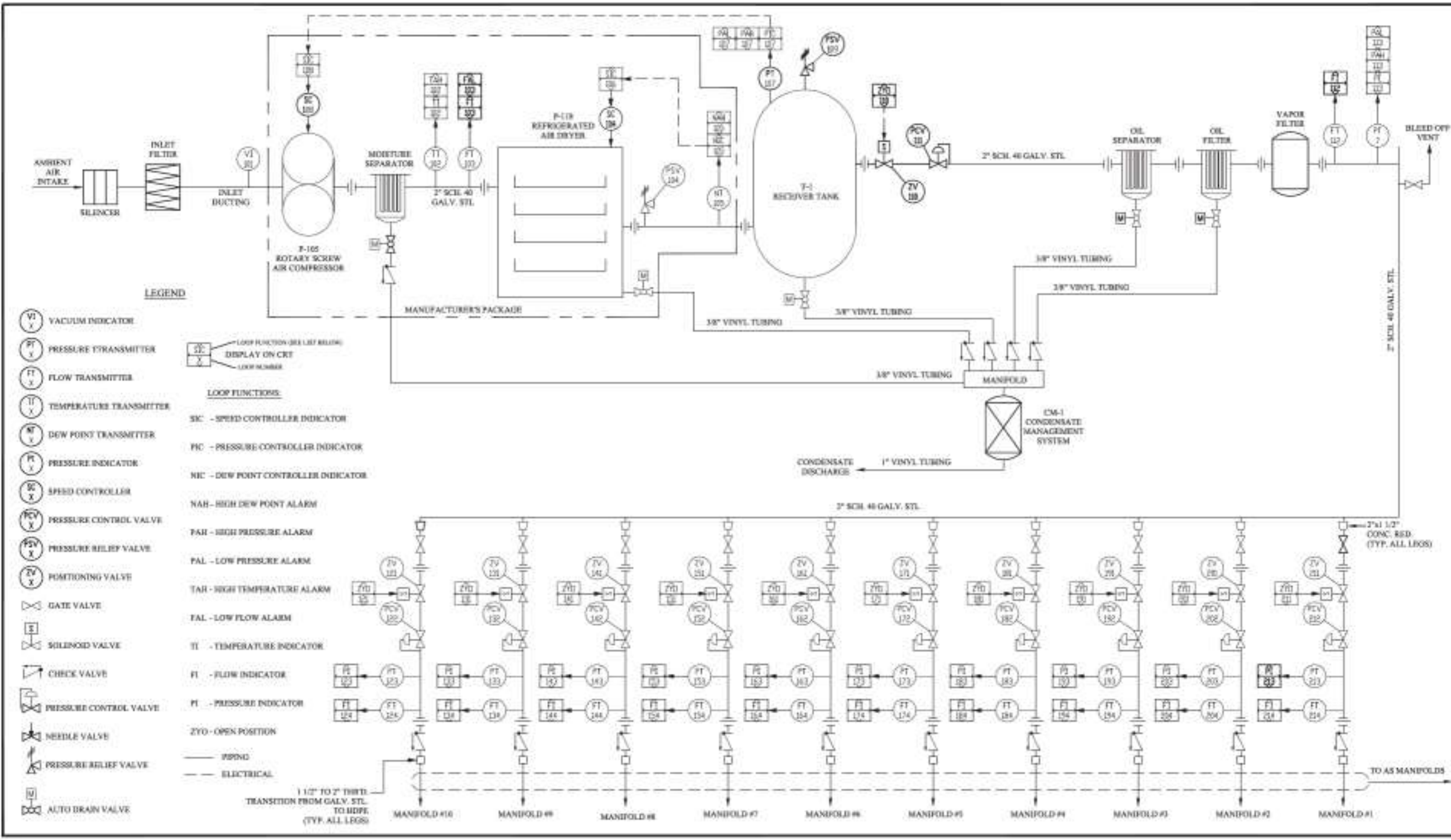
Step 3 EE – Example Excerpts



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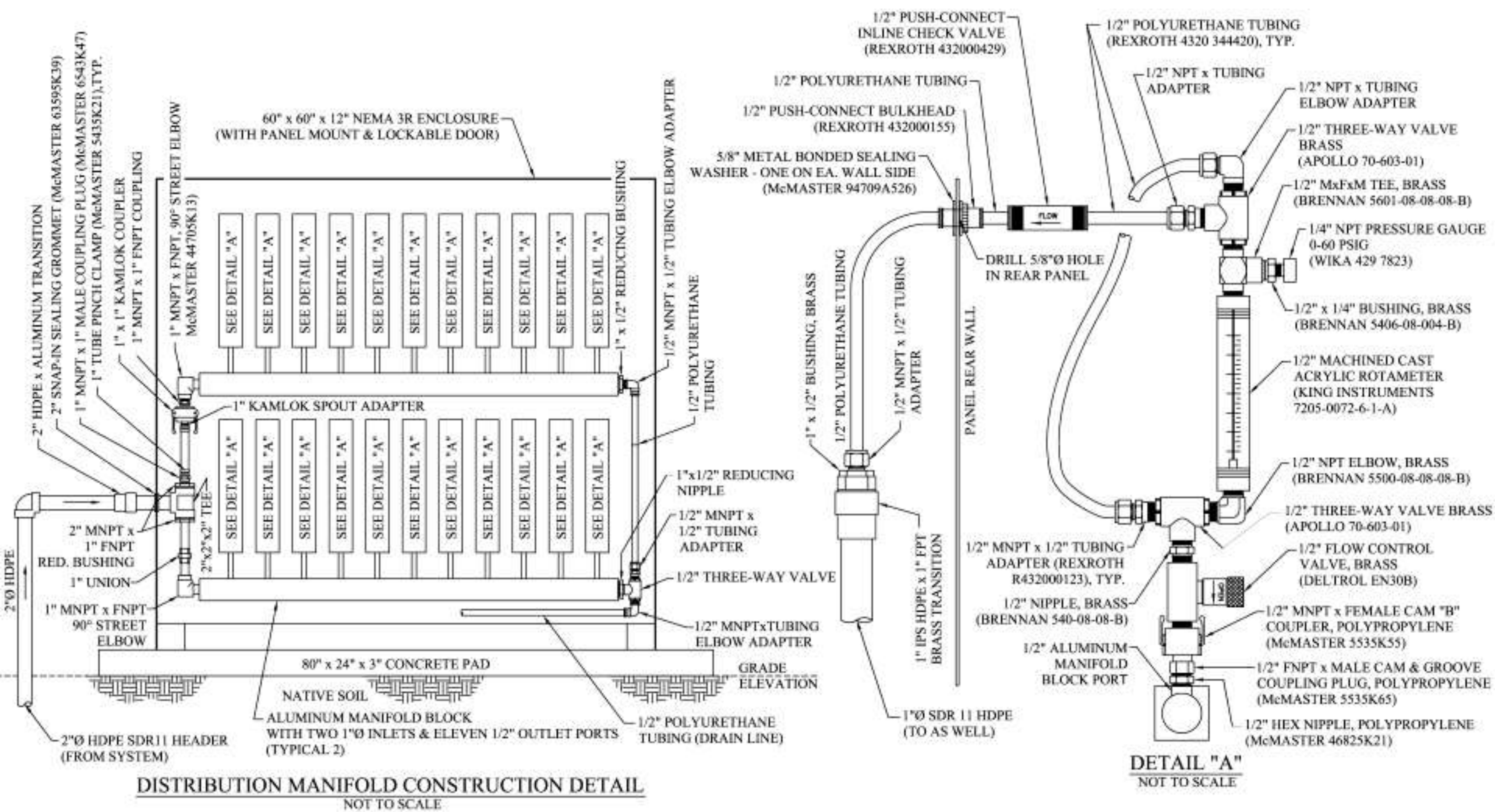
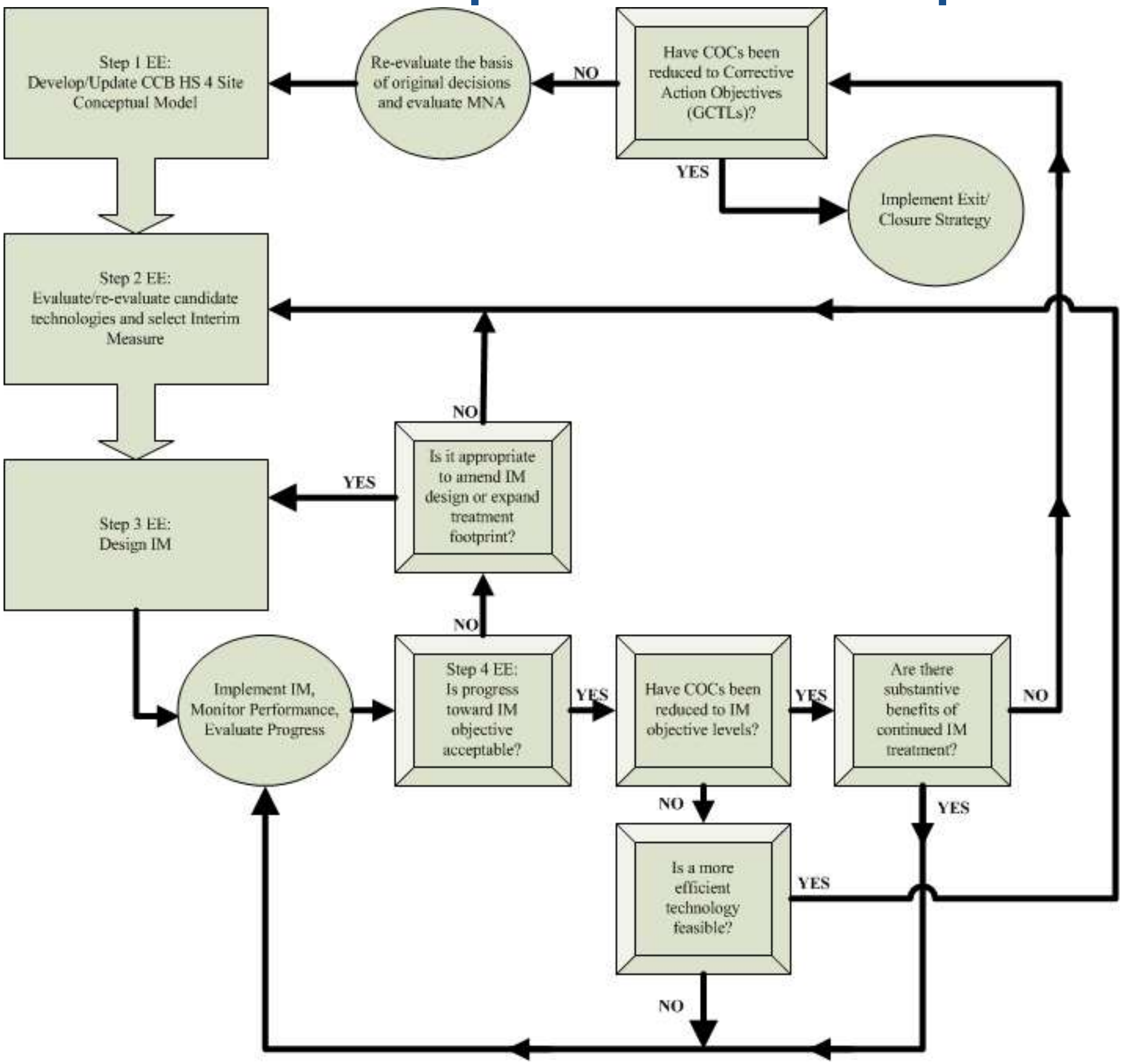
Step 3 EE – Example Excerpts



Step 3 EE – Example Excerpts



Step 4 EE - Remedy Implementation

- Goals:
  - Present remedy construction/implementation
  - Optimize ongoing remedy
  - Refine exit strategy on updated data sets
- Step 4 EE (Construction Completion):
  - Overview of remedy design and construction
  - Lessons learned and health and safety
  - Baseline data
- Step 4 EE (Operation, Maintenance, and Monitoring):
  - Evaluation of performance metrics (GW data, run-time, …)
  - Cost evaluation and mass removal
  - IM optimization
  - Exit strategy update/refinement
  - Planned activities

Step 4 EE - Construction Photos

TETRA TECH

Step 4 EE - Construction Photos

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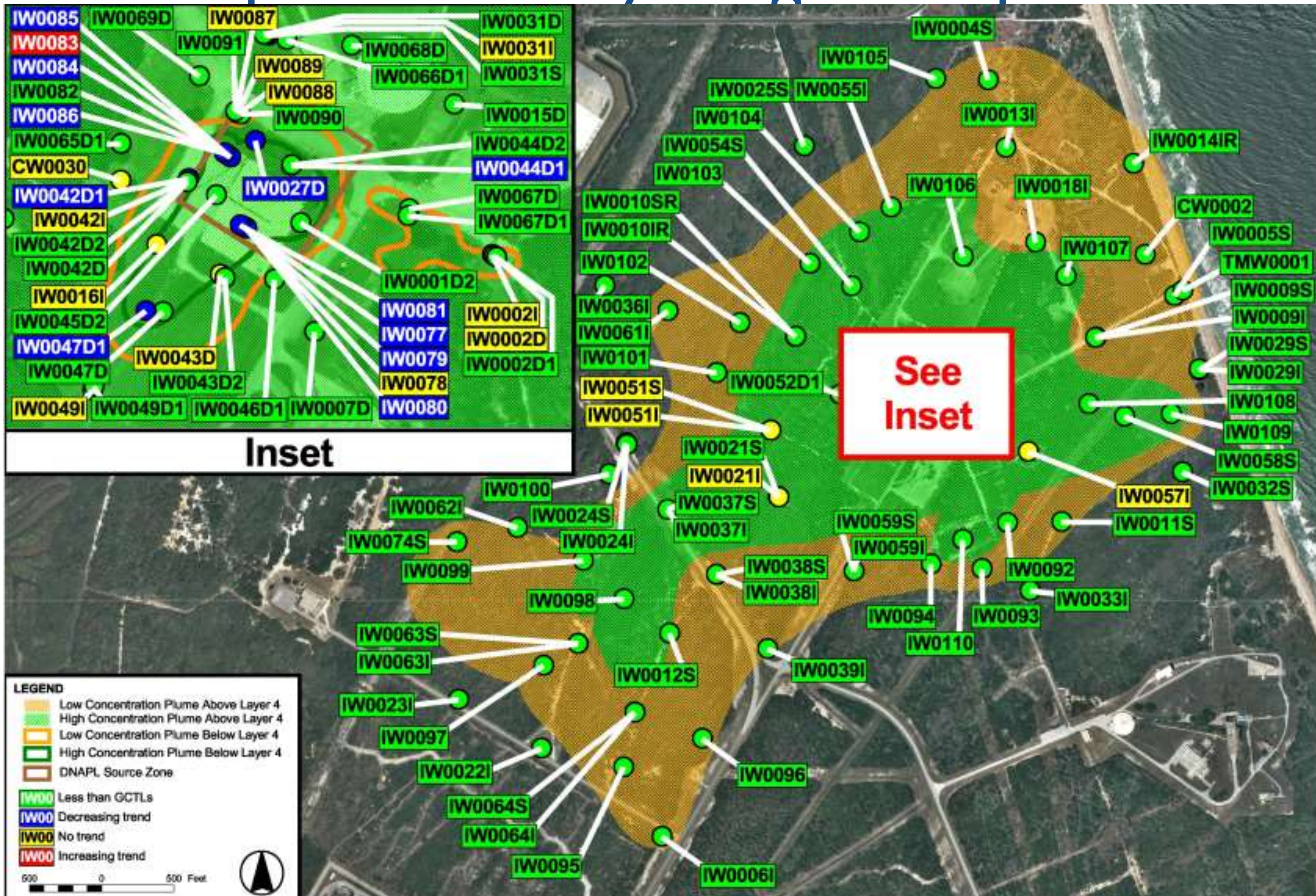
Step 4 EE - LDA/Steam/ZVI Photos

Photographs courtesy of Jacobs Engineering

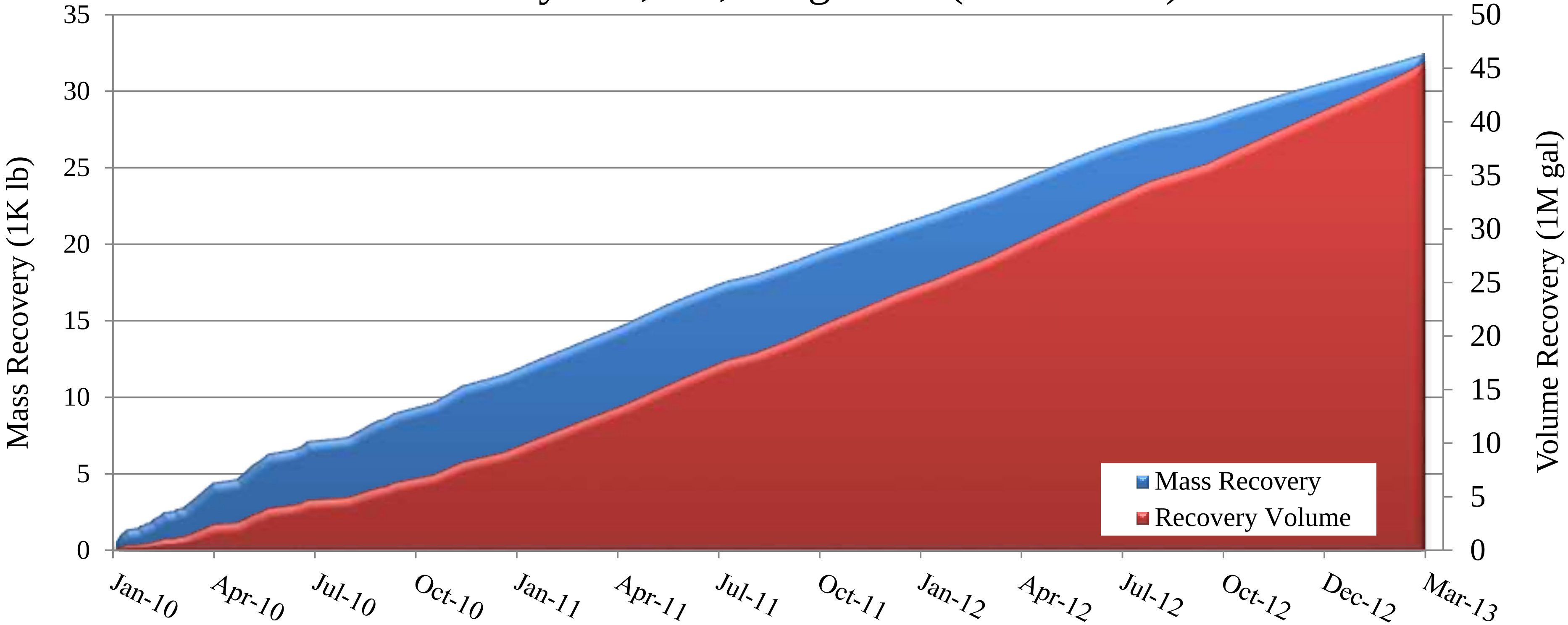
Step 4 - Remedy Progress/Optimization



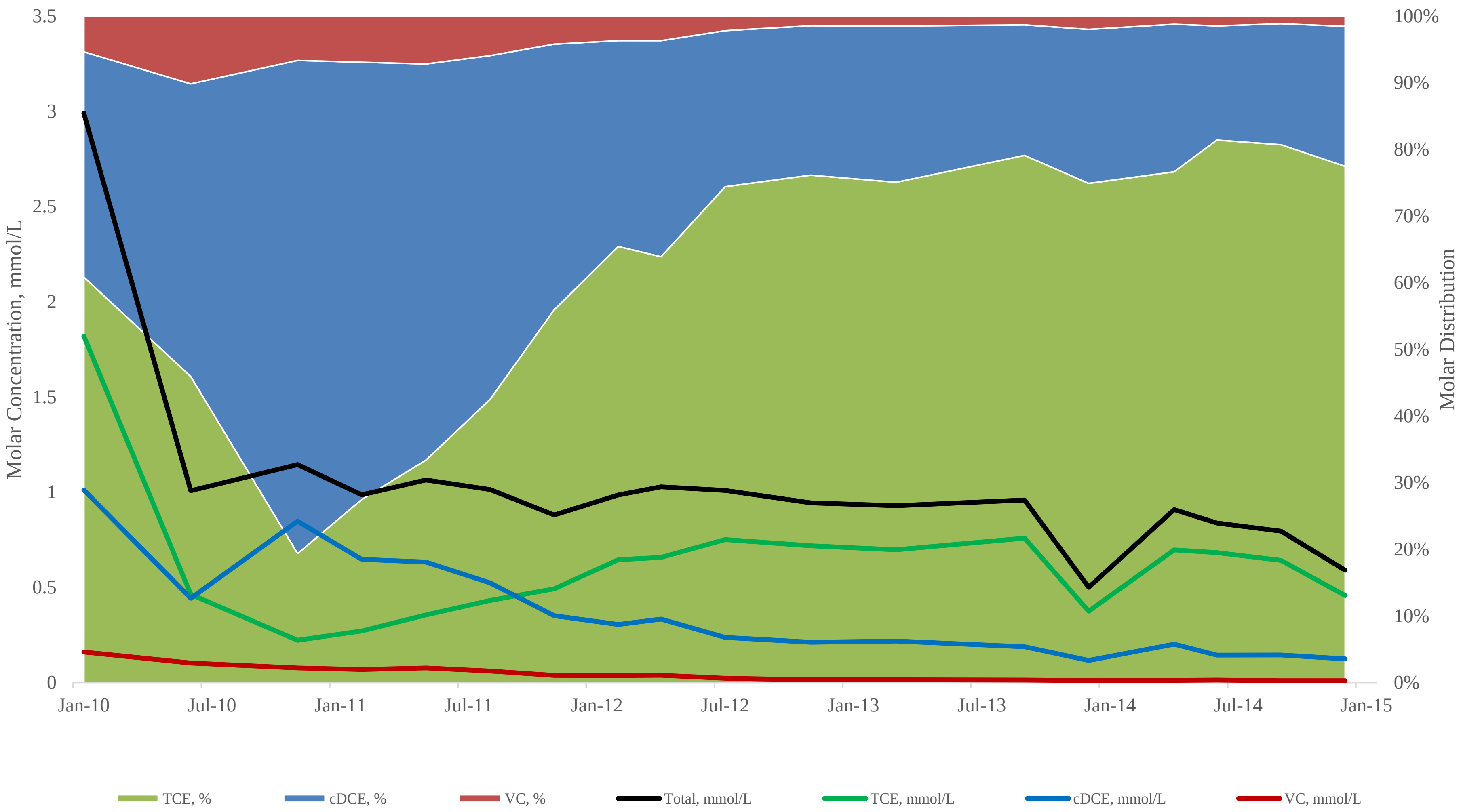
Mann Kendell Analysis (sitewide)

Step 4 - Remedy Progress/Optimization

- cVOC Mass recovery: 32,042 lb (03/11/2013); 24 lb/d average (Yr 3)
- Cost per pound of cVOC mass recovered: $94/lb (Previous Yr: $119/lb)
  - Capital cost driven, figure continues to decrease as operation continues
- Groundwater recovery: 44,601,839 gallons (03/11/2013)



Step 4 - Remedy Progress/Optimization



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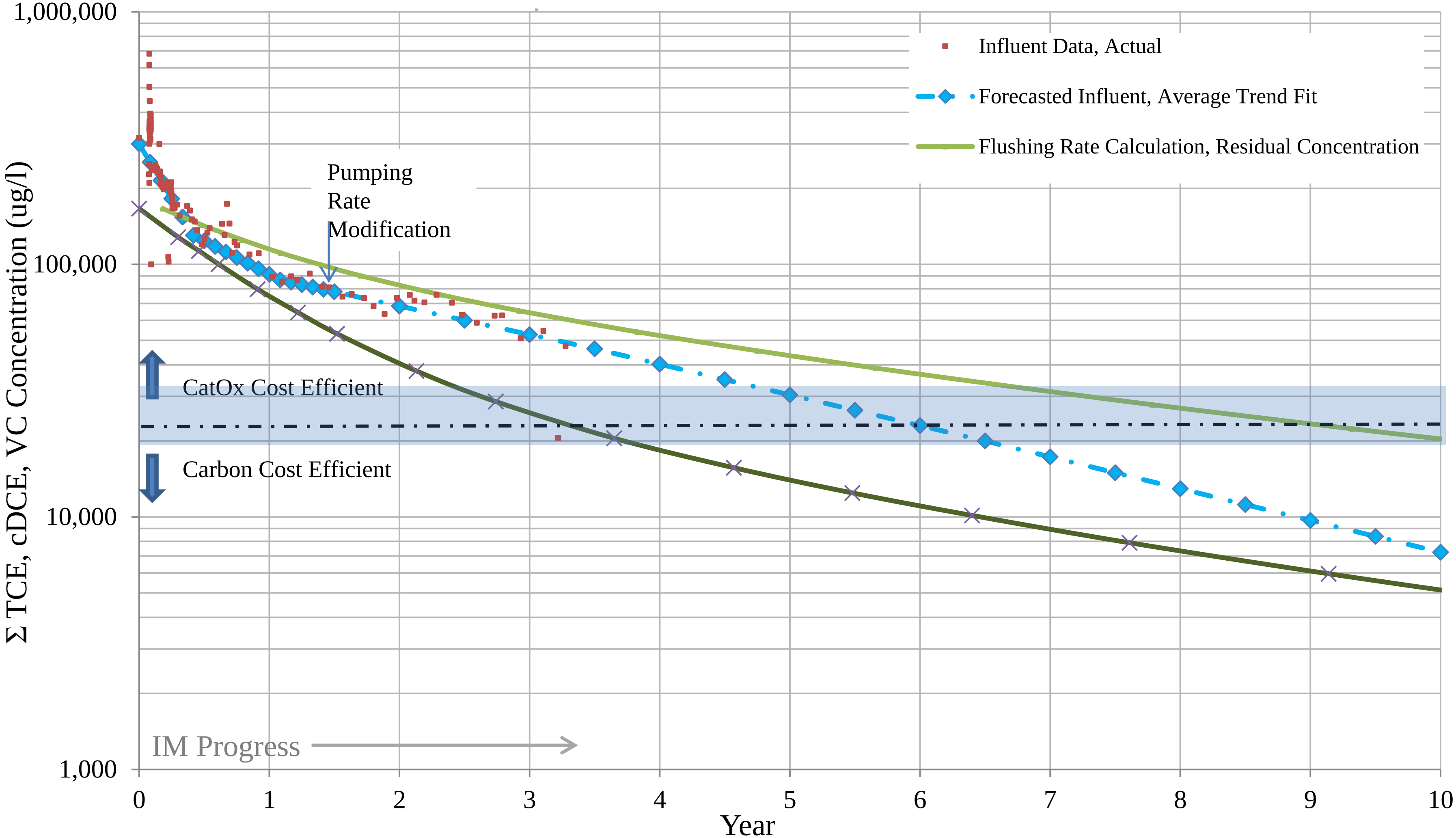
Step 4 - Remedy Progress/Optimization



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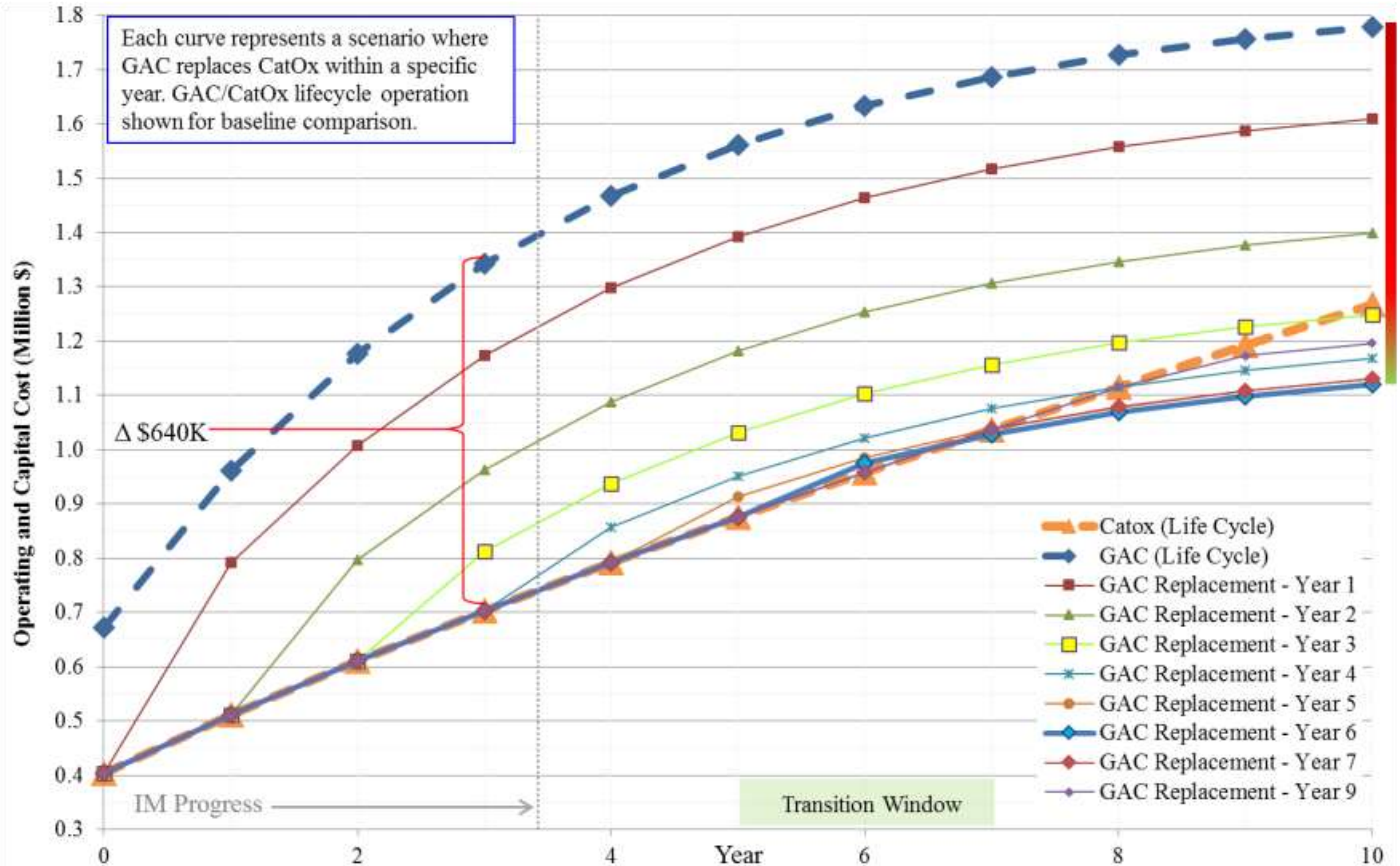
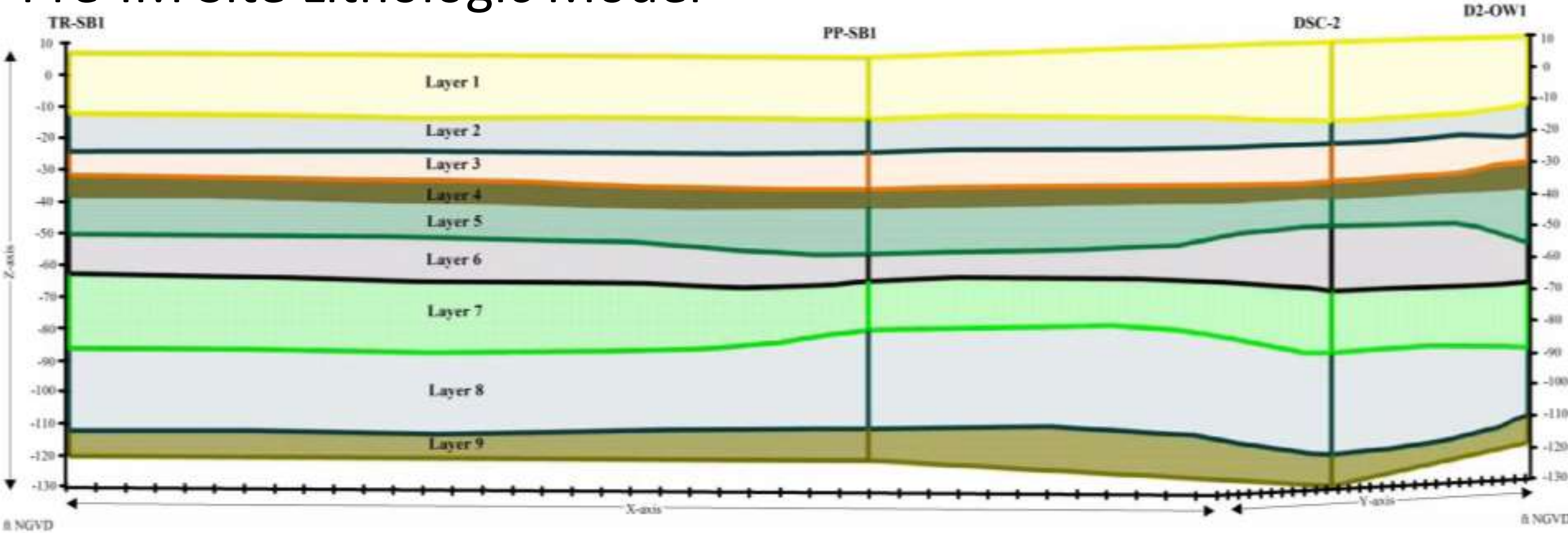
Step 4 - Remedy Progress/Optimization



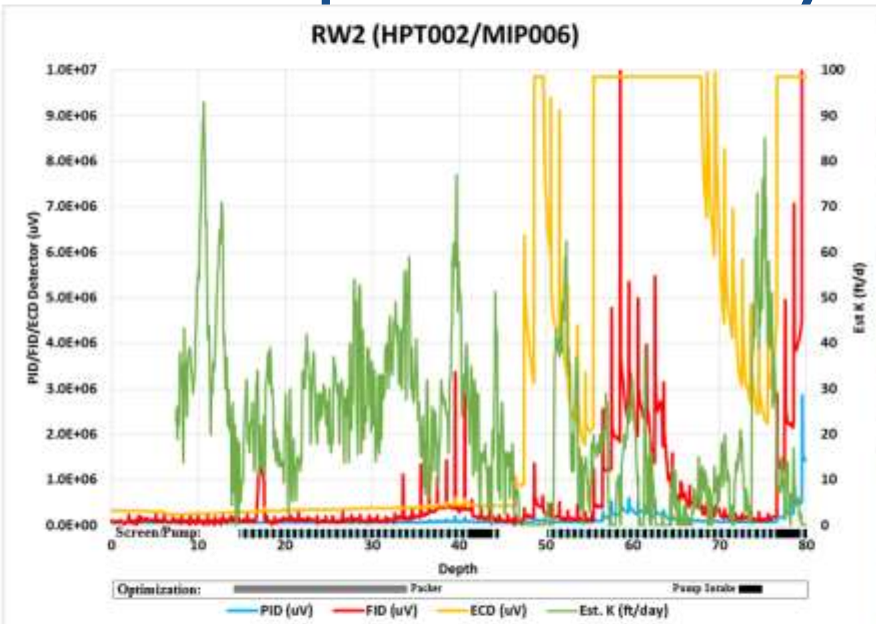
Step 4 - Remedy Progress/Optimization

Pre-IM Site Lithologic Model



Layer 1: Sand (Upper sand unit; S zone; 30 LTM wells; 10 foot screen interval 1'-17' range; 3 System Performance Wells 13'-23')
Layer 2: Fine silty sand (Middle fine-grained unit; I zone; 39 LTM wells; 5 foot screen interval 20'-35' range; 3 SPW 20'-28')
Layer 3: Coarse to silty sand (Lower sand unit; D zone; 11 LTM wells; 5 foot screen interval 35'-45' range; 3 SPW 28'-43')
Layer 4: Silt and clay (Lower clay unit, ~ 5 feet thick; no wells in this layer)
Layer 5: Fine to coarse silty sand with shell fragments (3 SPW 45'-55'/47'-57'/52'-57')
Layer 6: "Salt and pepper" sand (D1 zone; 10 LTM wells; 10 foot screen interval 50'-75' range; 6 SPW 60'-70'/70'-80')
Layer 7: Silty to clayey sand (IW42D2 screened 87'-92')
Layer 8: Fine to coarse sand (D2 Zone; 5 LTM well; 10 foot screen interval 105'-115' range)
Layer 9: Clay to sandy clay (Hawthorn confining unit; no wells in this layer)

Step 4 - Remedy Progress/Optimization



RW2A (15-45' bls screen)

- Primary mass transport at 33-45' bls
- Isolate well pumping screen from 33-45' bls

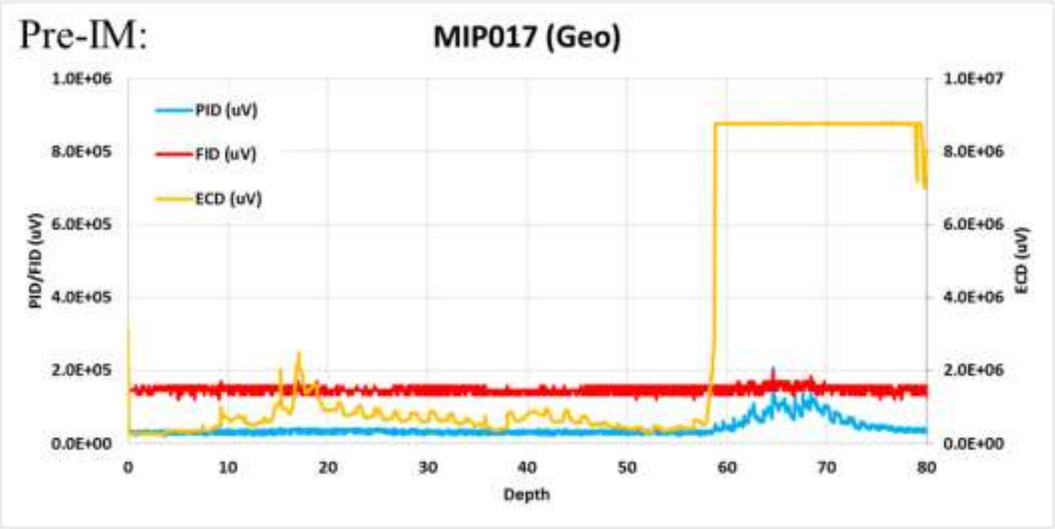
RW2B (50-80' bls screen)

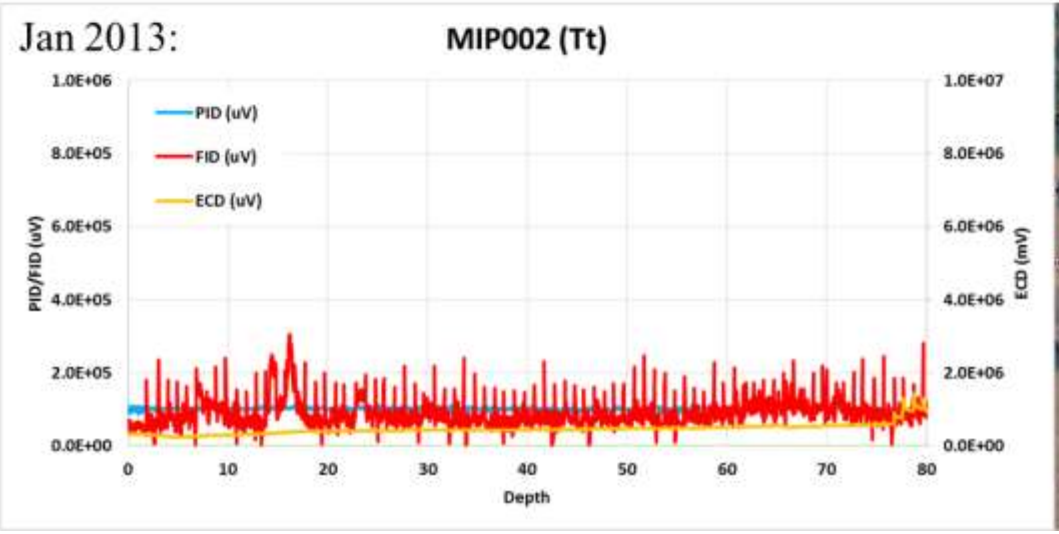
- Mass storage at 47-50'bls
- Mass transport at 53-73' bls
- Move pump intake to 73' bls

*Layer 4 and 7 mass storage

RW-2A Influent				RW-2B Influent			
Date	TCE (ppb)	Total VOCs (ppb)	Mass Recovery (lbs/d)	Date	TCE (ppb)	Total VOCs (ppb)	Mass Recovery (lbs/d)
1/20/2010	280,000	474,000	28.5	1/20/2010	940,000	964,000	34.7
6/23/2010	82,500	137,700	8.3	6/23/2010	363,000	371,060	13.4
11/22/2010	58,500	99,750	6.0	11/22/2010	248,000	253,860	9.1
2/21/2011	3,630	72,780	4.4	2/21/2011	203,000	206,811	7.4
5/18/2011	50,400	80,400	4.8	5/18/2011	152,000	155,300	5.6
8/10/2011	48,500	75,020	4.5	8/10/2011	138,000	141,390	5.1
11/10/2011	40,500	62,280	3.7	11/10/2011	102,000	105,290	3.8
2/2/2012	42,500	62,910	3.8	2/2/2012	126,000	129,350	9.3
4/4/2012	49,000	70,960	4.3	4/4/2012	91,400	94,090	6.8
7/26/2012	38,500	53,240	3.2	7/26/2012	94,000	96,380	6.9
11/26/2012	39,000	53,110	3.2	11/26/2012	78,100	81,010	5.8

Step 4 - Remedy Progress/Optimization





Notable Current Activities at KSC

- Large diameter auger/steam/ZVI TCE source zone IM
- EZVI/bioremediation PCE source zone IM
- Enhanced anaerobic reductive dechlorination at several sites
- Air sparging successfully applied at many sites and continuing to be applied at new sites
- Centralized multi-site air sparging integration (now at 365 wells)
- Highly successful source zone containment/mass removal via pump and treat
- Planned electrical resistance heating project

Overview of KSC Interim Measure Process

- Engineering evaluations significantly streamline and enhance documentation and design process
  - Multi-disciplinary team of stake-holders vested in a common goal of project success
  - Investigation to remedy timeframe drastically shortened
  - Adaptive and progressive investigation and design methods
  - Savings from reduced reporting and enhanced designs applied to effective investigations and interim measures

Kennedy Space Center Remediation Program Overview

Questions/Comments

Acknowledgements: KSC Remediation Program Branch

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