High Resolution Characterization Throughout Project Lifecycle

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Presentation Outline

- Introduction to Kennedy Space Center (KSC)
- KSC Corrective Action Program
- Adaptive Site Management at KSC
- High Resolution Site Characterization (HRSC)
- Case Studies of HRSC at KSC
- Lessons Learned


Mosquito Lagoon
Launch Complex 39 Area
Indian River
Kennedy Space Center
KSC Visitor Complex
KSC Industrial Area
CCAFS Industrial Area
Banana River
CCAFS
Port Canaveral
Route 528 (Beeline Expressway)
Kennedy Space Center
Gulf of Mexico

Kennedy Space Center

- Topographic relief is slight (sea level to 20 feet on Recent dunes)
  - Sand ridges and swales
- Lithology is dominated by varying amounts of fine-grained sand, medium sand with shell fragments, fine sand with shell fragments, fine-silty sand, sandy clay with silt and shell fragments to approximately 120 feet below land surface (BLS) – Miocene to Recent
  - Eocene carbonate bedrock at approximately 150 feet BLS
- Depth to groundwater (3-6 feet BLS)
  - Groundwater classified as potential drinking water (G-II) based upon total dissolved solids
- Dynamic interaction of groundwater and the surficial geology - wetlands represent ~¼ KSC property

Aerial View of the LC39 Area of KSC

Site Background and History

- NASA's launch operations Center
- Built in the early 1960's to support the Apollo Program
- 1981 – 2011 – Space Transportation Program
- International Space Station flight hardware processing and final checkout
- Launch Services Program
  - Manages unmanned NASA missions

Site Background and History

- Commercial Crew Program
  - To provide access to the International Space Station
    - SpaceX
    - Boeing
- Space Launch System
  - NASA's next generation rocket
  - Ground processing and support
- Multi-User Spaceport
  - SpaceX operates LC39A
  - Boeing operations in the Orbiter Processing Facilities

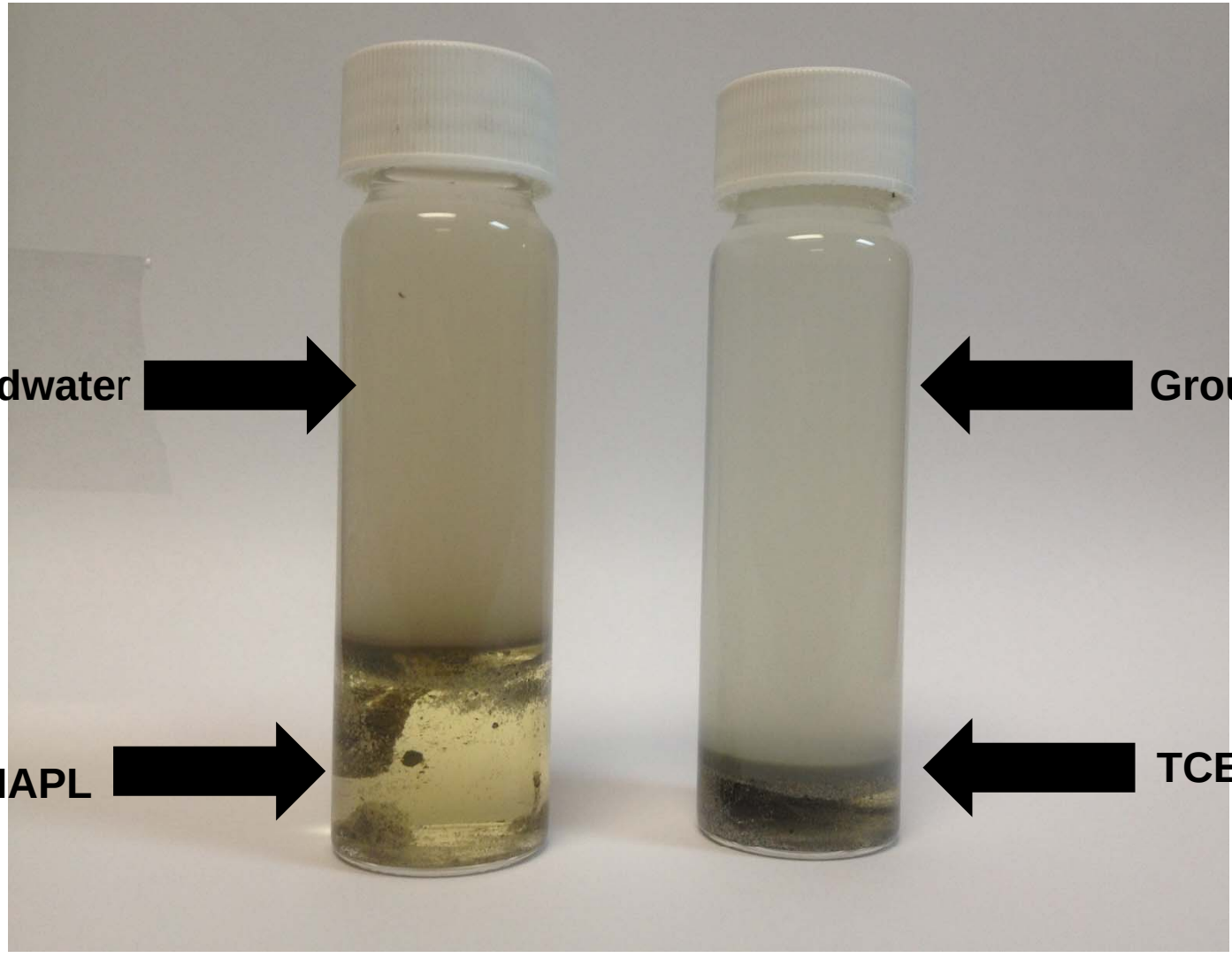
Remediation Program

- Regulatory Framework
  - Regulated under the Resource Conservation and Recovery Act (RCRA) and its Hazardous and Solid Waste Amendment
  - Overseen by the Florida Department of Environmental Protection (FDEP)
  - Toxics Substances and Control Act (TSCA) is managed by the Environmental Protection Administration (EPA) Region IV
- KSC Remediation Team (KSCRT)
  - Comprised of FDEP, NASA civil servants, three A&E's and KSC's environmental support contractor
  - Meets 1-2 days every 6 to 8 weeks to discuss site progress and make decisions on paths forward

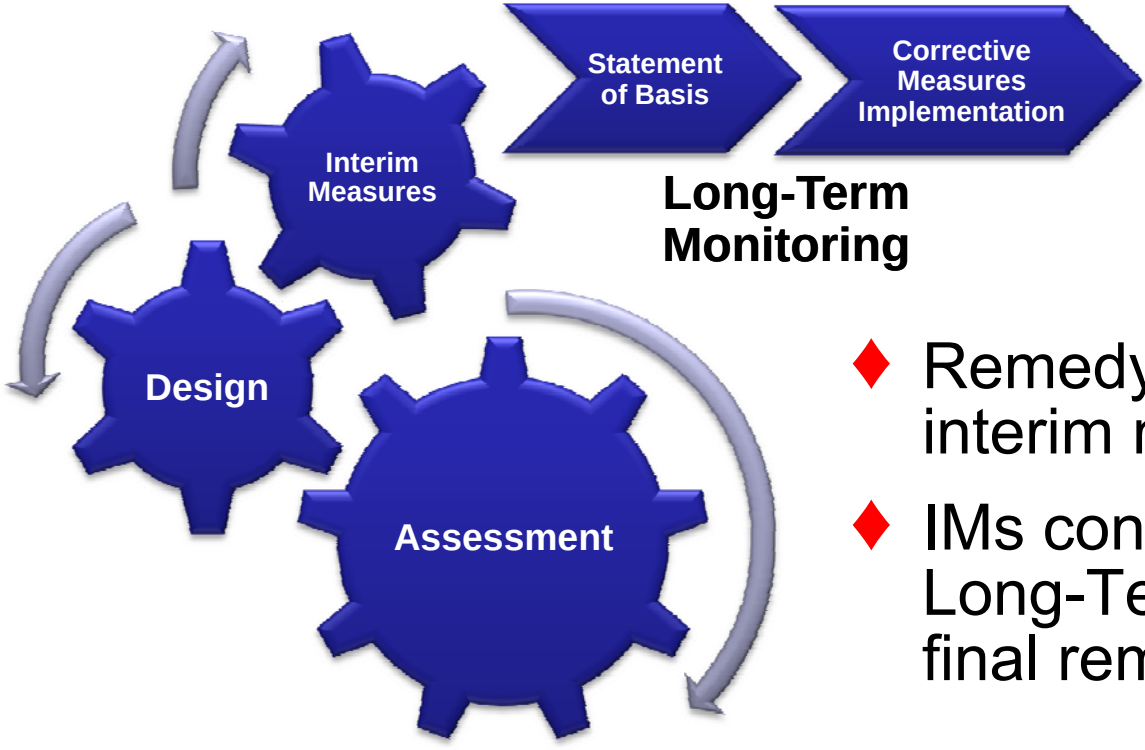
RCRA Corrective Action Inventory

Category	Number of Sites	Percentage of Total
No Further Action	151	59
Corrective Measures Implementation (CMI)	40	16
Corrective Measures Study (CMS)	4	1
RCRA Facility Investigation (RFI)	7	3
Confirmation Sampling (CS)	41	16
SWMU Assessment (SA)	7	3
Petroleum	4	2

Dense Non-Aqueous Phase Liquid



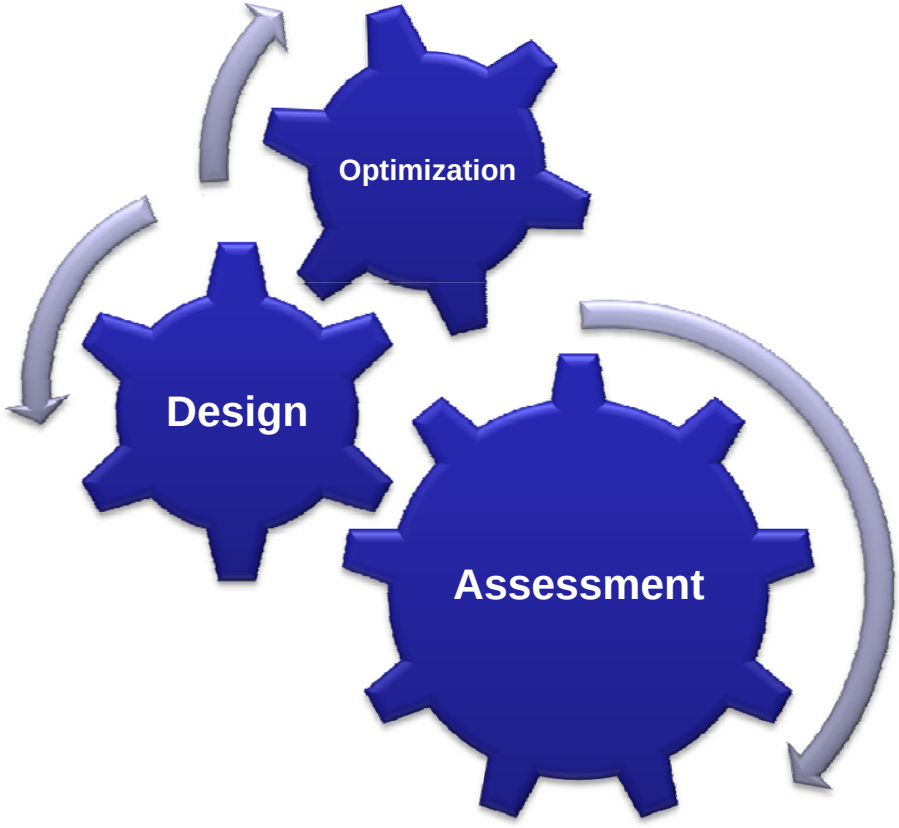
Adaptive Site Management Perspective



- Remedy conducted through interim measure(s) (IMs)
- IMs conducted such that Long-Term Monitoring is final remedy

Adaptive Site Management Perspective

- Assessment (*DOES NOT END WITH DESIGN*)
- Design (*DOES NOT END WITH IMPLEMENTATION*)
- Optimization Evaluations (*THROUGHOUT*)



High-Resolution Site Characterization

- KSC implemented the frequent use of high-resolution site characterization (HRSC) in 2008 following the conclusion that many of the legacy sites at the Center were under assessed horizontally and vertically
  - Previous groundwater delineation efforts had no minimum distance between sampling point (horizontally and vertically)
  - “Knife” edges both horizontally and vertically were found repeatedly at numerous sites that were at the time under investigation
- As a result a multi-step process was developed by the KSCRT
  - Adequate site characterization
  - Participate in evaluation of remedial technologies
  - Review preliminary designs
  - Evaluate efficacy of interim measures

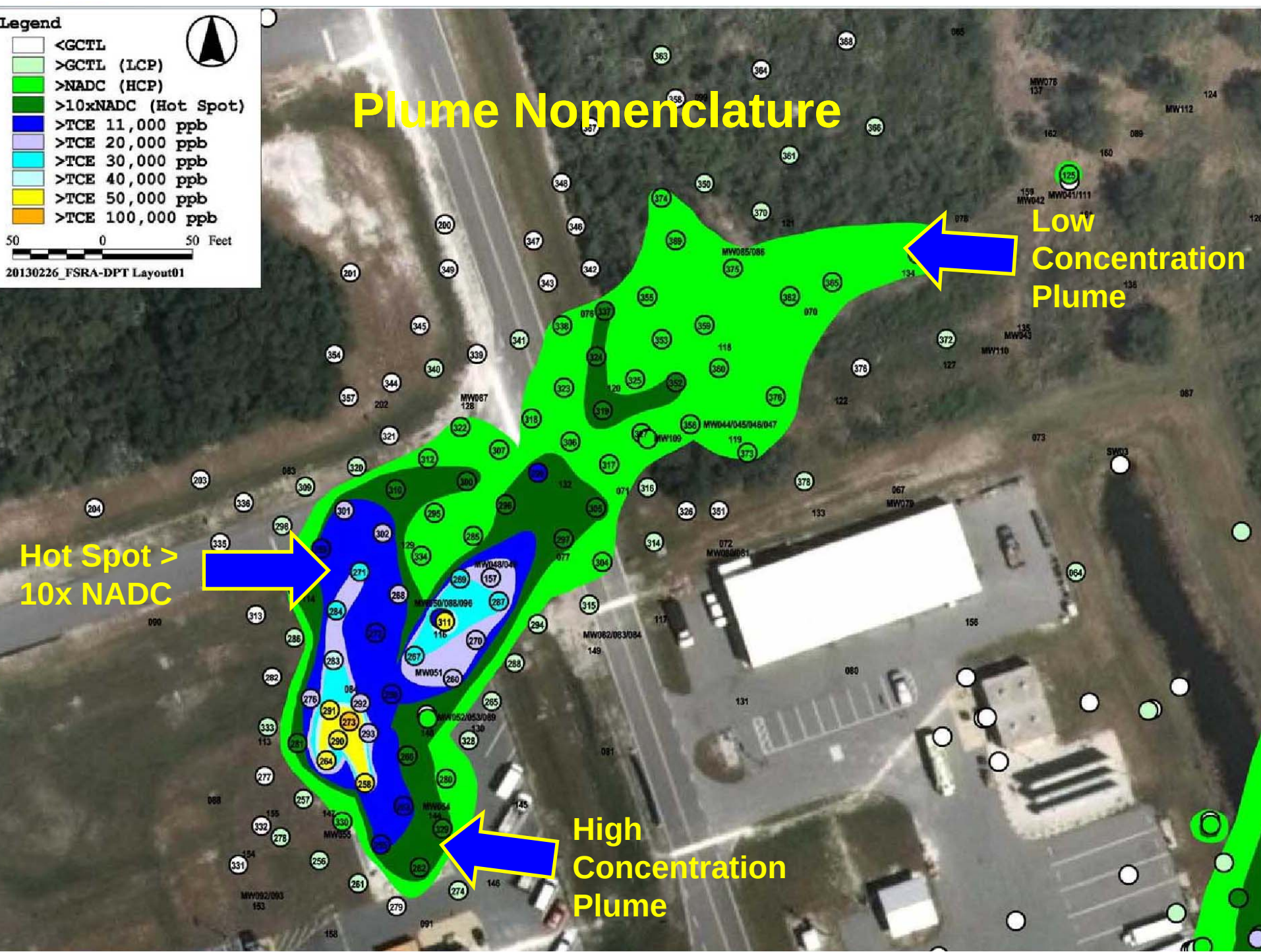
Multi-Step Engineering Evaluation Process

High-Resolution Site Characterization Tool Box

- Direct Push Technology (DPT) and Mobile Laboratories
- Membrane Interface Probe (MIP)
- Environmental Visualization Software (EVS)
- Hydraulic Profiling Tool (HPT)
- Saturated Soil Sampling

High-Resolution Site Characterization

- The multi-step process emphasizes the importance of HRSC for vertical and horizontal delineation of contaminated groundwater. As the process evolved a spacing was developed for horizontal site characterization
  - 100 ft spacing for low concentration plume (LCP, areas of affected groundwater with concentrations of contaminants of concern [COCs] greater than FDEP Groundwater Cleanup Target Levels [GCTLs])
  - 50 ft spacing for high concentration plume (HCP, areas of affected groundwater with concentrations of COCs greater than FDEP Natural Attenuation Default Concentrations [NADCs])
  - 25 ft spacing for hot spots (isolated areas of affected groundwater with concentrations of COCs greater than ten times FDEP NADCs), and
  - 10 ft spacing for Dense Non-Aqueous Phase Liquid (DNAPL) source areas.

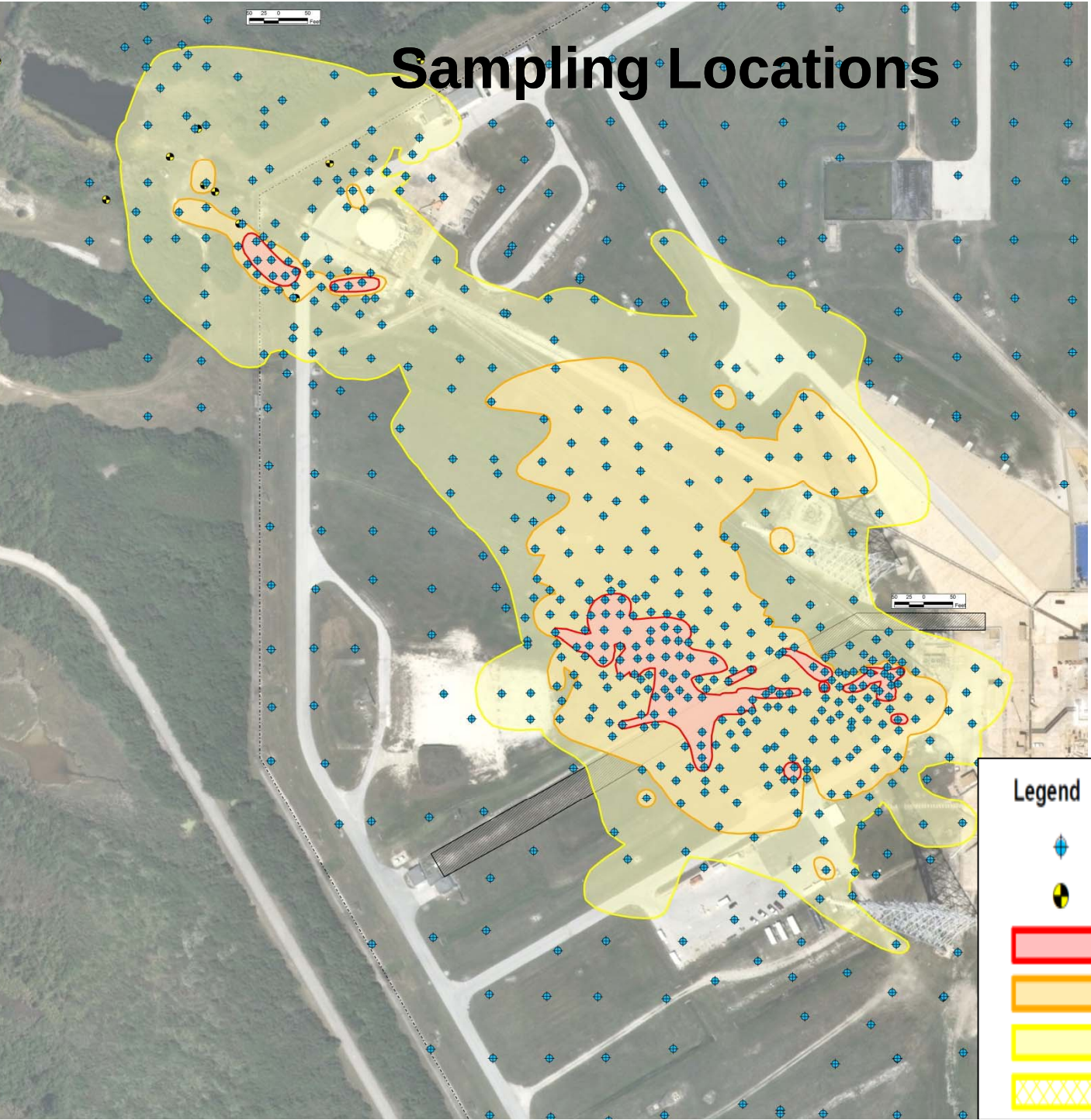

Legend
<GCTL
>GCTL (LCP)
>NADC (HCP)
>10xNADC (Hot Spot)
>TCE 11,000 ppb
>TCE 20,000 ppb
>TCE 30,000 ppb
>TCE 40,000 ppb
>TCE 50,000 ppb
>TCE 100,000 ppb
50 0 50 Feet
20130226_FSRA-DPT Layout01
Plume Nomenclature
Low Concentration Plume
Hot Spot > 10x NADC
High Concentration Plume

Sampling Locations

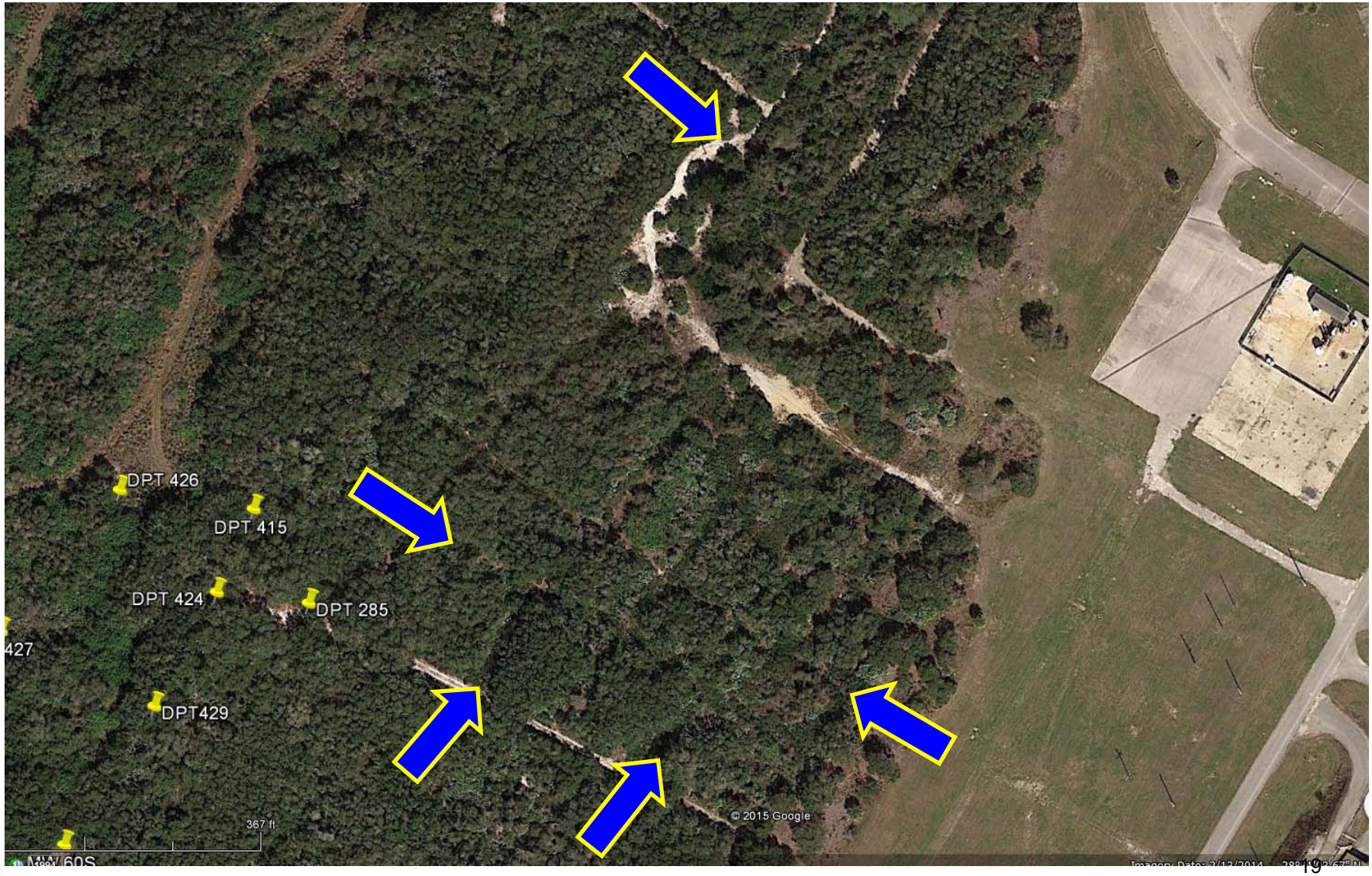
SPACEPORT INTEGRATION & SERVICES

Environmental Services Division

- Standardized and modified groundwater sampling grid
  - 100 ft
  - 50 ft
  - 25 ft



Standardized Sampling and Vegetation Clearing



Membrane Interface Probes

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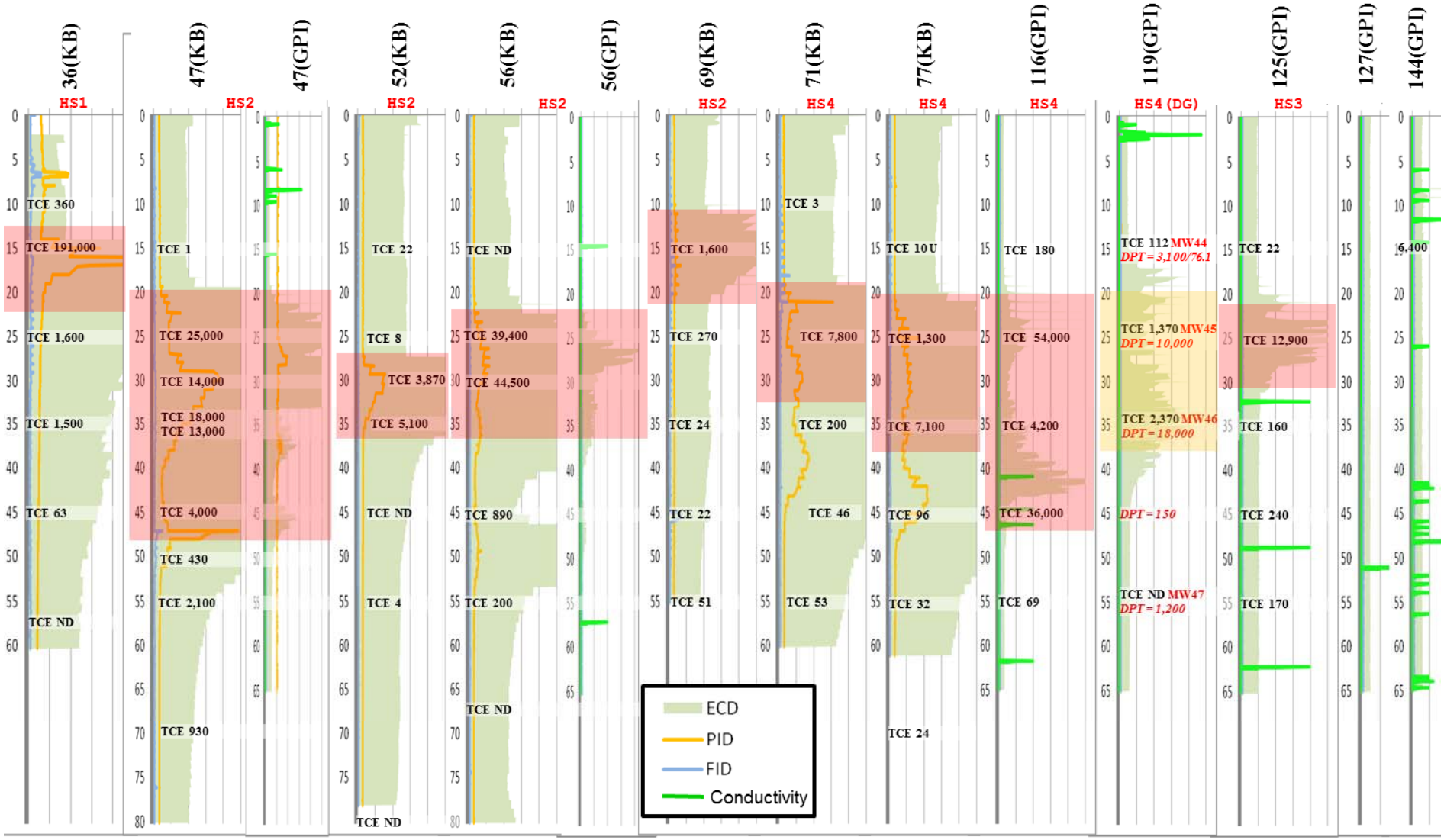
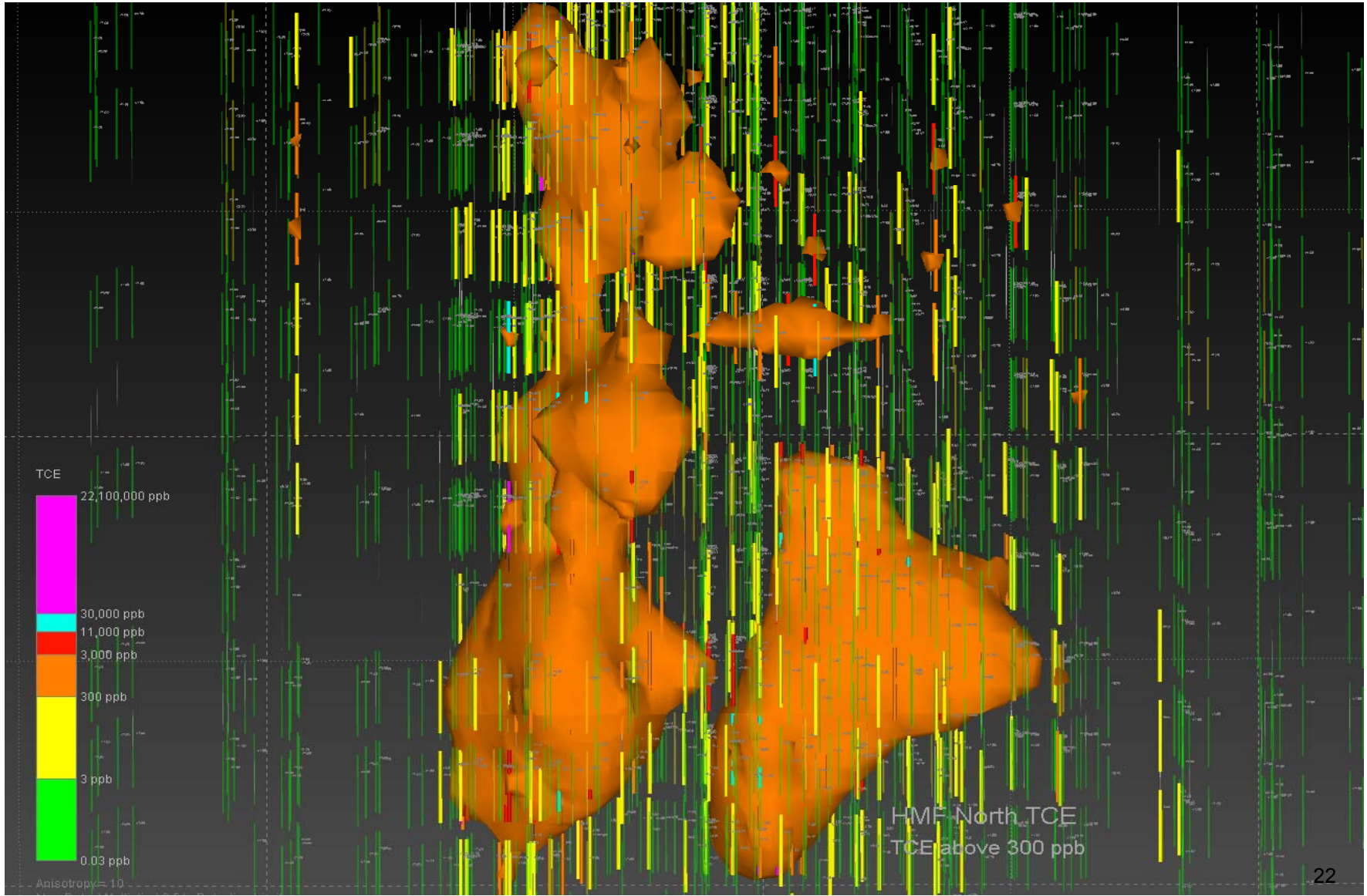


Environmental Visualization Software

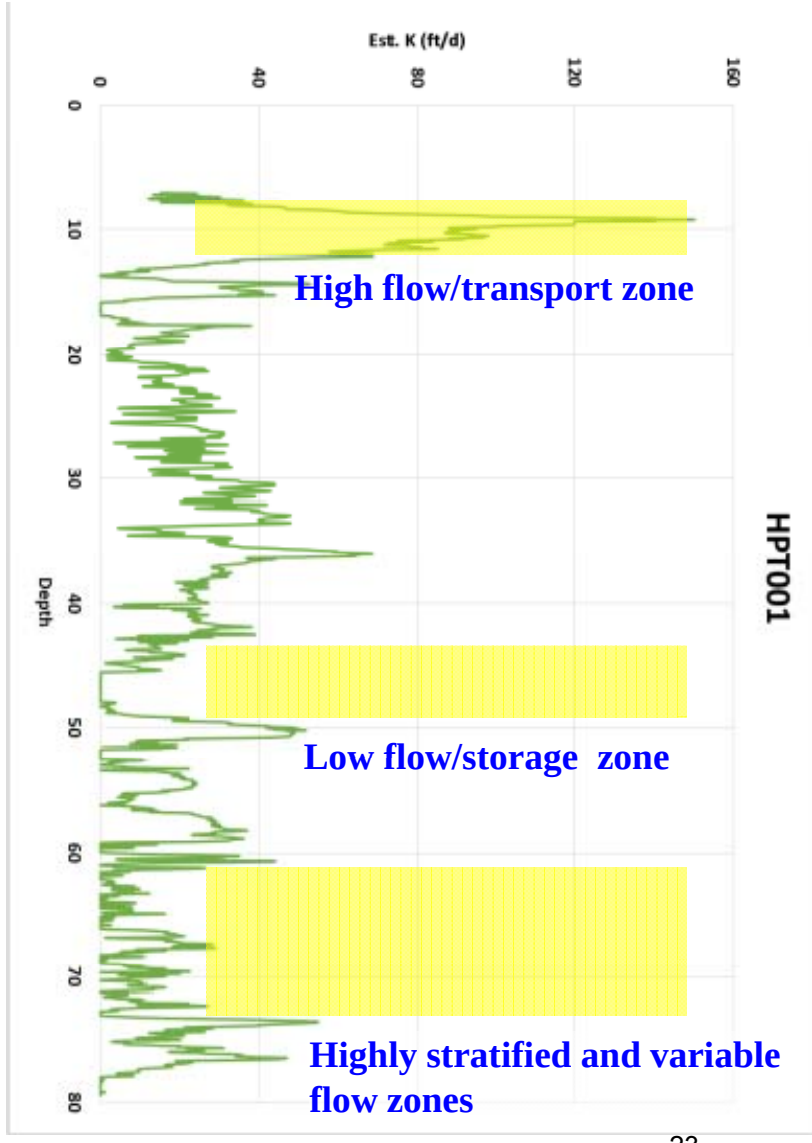
Kennedy Space Center Medical and Environmental Services Division

Environmental Visualization Software



Hydraulic Profiling Tool Overview

- Technology use: Real-time vertical hydraulic conductivity profiling
- Equipment: DPT Rig, HPT Tooling (pressure/conductivity sensor & water injector)
  - Water injected as tool is advanced
  - Pressure sensor measures response of soil to water injection
    - Identifies ability of soil to transmit water
- Measured data output: Electrical conductivity, injection flow and pressure
- K value calculated by HPT software using flow and pressure data
- Interpretation:
  - EC indicates changes in lithology
  - Peaks indicate high K/flow zones
  - Valleys indicate low K/flow zones



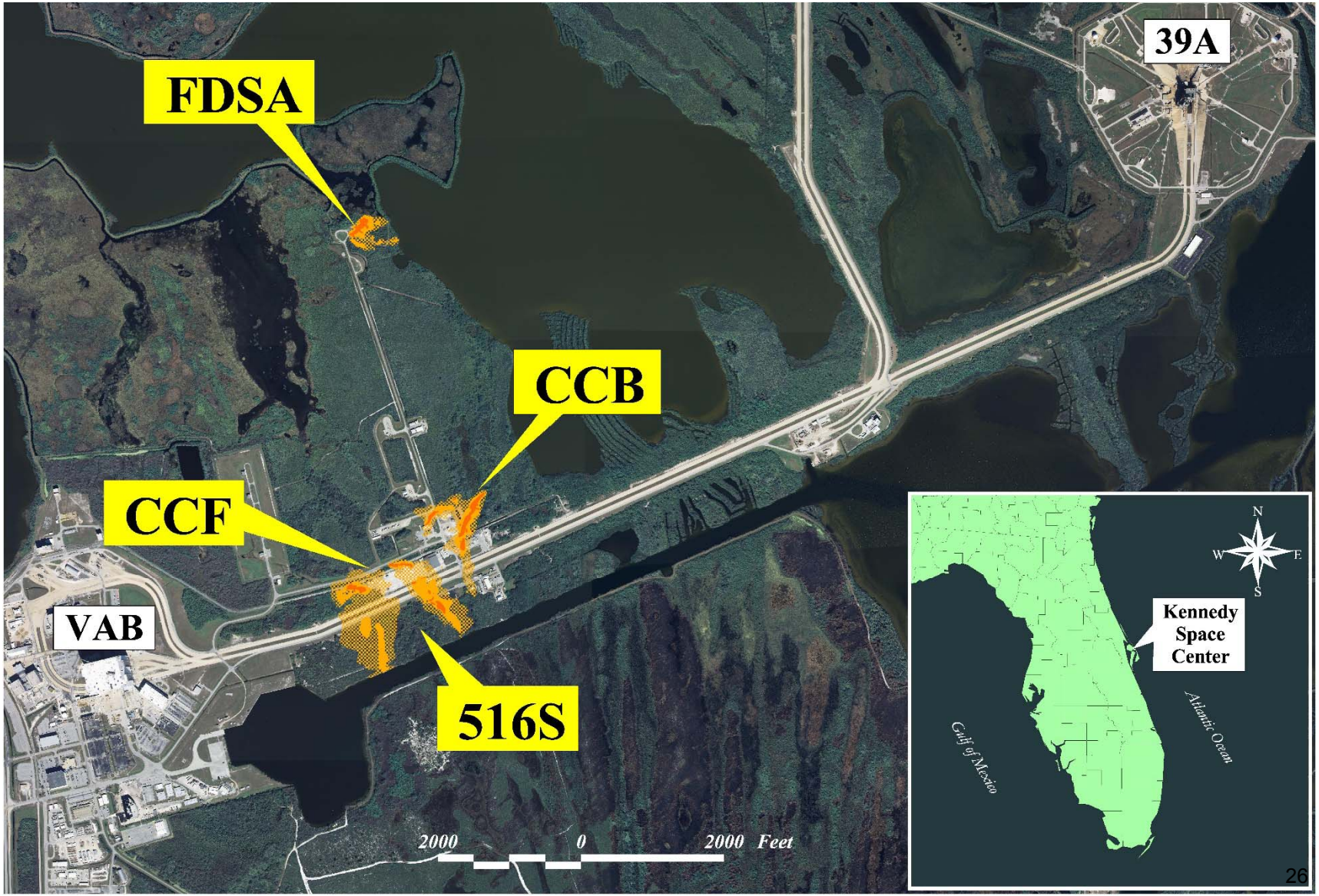
Saturated Soil Sampling

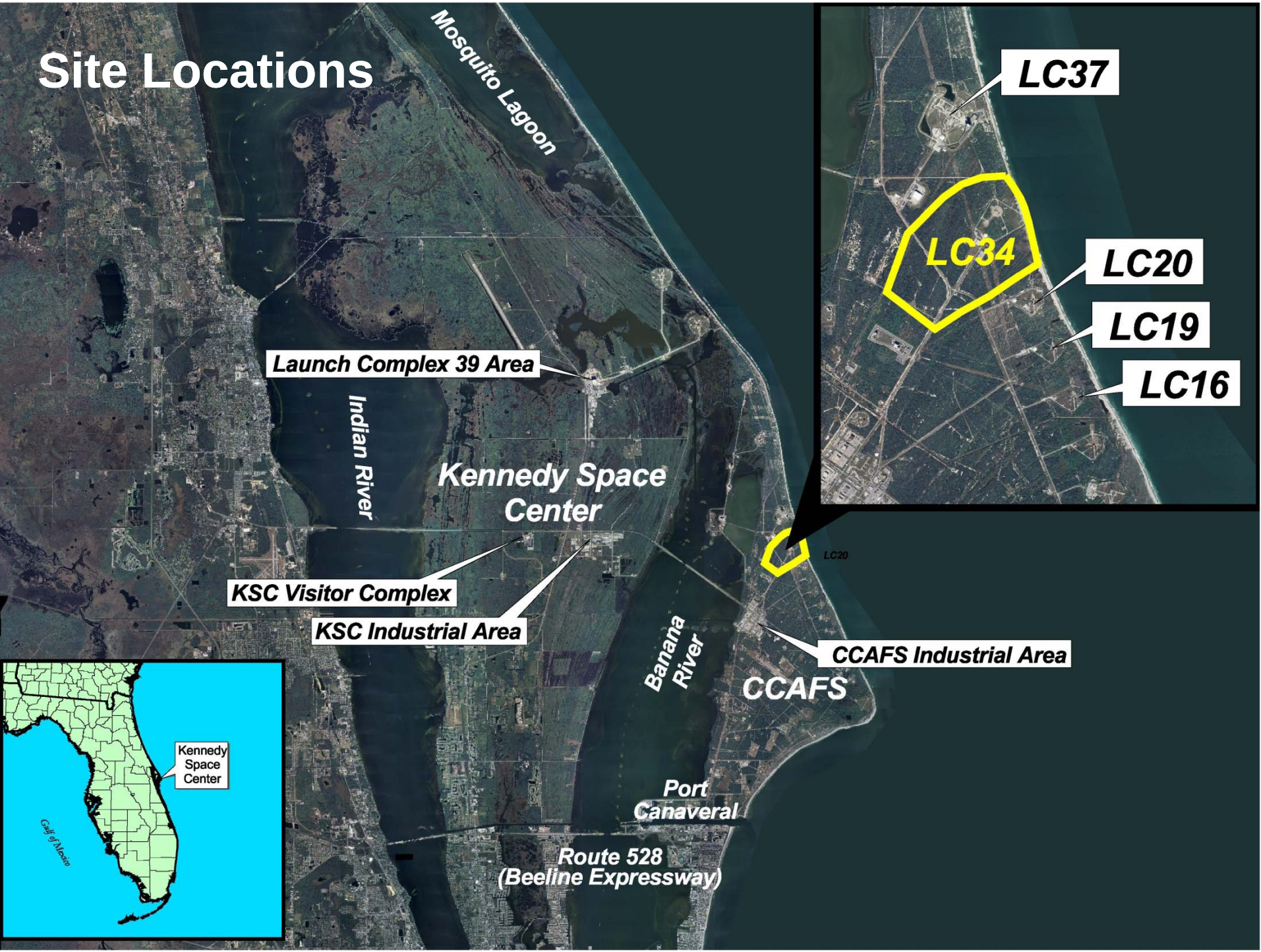
Location	Sample Date	Sample Depth (ft BLS)	Concentration (mg/kg)			
			Trichloroethene	cis-1,2-Dichloroethene	trans-1,2-Dichloroethene	Vinyl Chloride
LC34-DPT0332	08/03/2011	37.0	15	6.8	0.055 I	0.16 I
		43.5	70	4.5	0.11 U	0.13 U
		45.0	3.4	1.8	0.04 U	0.048 U
		48.0	1.8	1.5	0.037 U	0.046 U
		53.0	0.0098	0.0042 I	0.00042 U	0.00052 U
LC34-DPT0333	08/03/2011	37.0	46	6.5	0.083 I	0.075 U
		44.0	65	1.1 I	0.24 U	0.29 U
		45.5	64	3.3	0.064 I	0.062 U
		47.0	37	2.0	0.049 U	0.059 U
		48.5	5.7 L	0.73 L	0.0042 I	0.0015 I
		53.0	0.0095	0.002 I	0.00044 U	0.00054 U
LC34-DPT0334	08/03/2011	34.5	4.8	2.7	0.05 I	0.033 U
		37.0	6.8	7.1	0.042 I	0.30 I
		45.5	5.7 L	4.0 L	0.078	0.0028 I
		47.0	31	5.7	0.093 I	0.065 U
		48.5	5.3	1.4	0.034 U	0.041 U
		53.0	0.006 J	0.003	0.00032 U	0.00039 U

Case Studies

- 24 sites have been re-assessed/assessed utilizing HRSC at KSC
  - All phases of the RCRA Corrective Action Program (RFI - CMI) including treatment system optimization
- Converter Compressor Building (CCB) and Area South of K7-516 (516S) - RCRA Facility Investigation
- Launch Complex 34 (LC34) - Corrective Measures Study
- Former Drum Storage Area (FDSA) - Statement of Basis
- Components Cleaning Facility (CCF) - Corrective Measures Implementation (CMI)

Site Locations




Site Locations
Mosquito Lagoon
LC37
LC34
LC20
LC19
LC16
Launch Complex 39 Area
Indian River
Kennedy Space Center
LC20
KSC Visitor Complex
KSC Industrial Area
Banana River
CCAFS Industrial Area
CCAFS
Port Canaveral
Route 528 (Beeline Expressway)
Kennedy Space Center
Gulf of Mexico

Site Background

- Source concentrations by site

RCRA Site	Chlorinated Plumes	Maximum TCE Detection (ppb)	Site Background
Convertor Compressor Building (CCB)	11.4 acres water table to 60' bls	191,000	Provided compressed gases to support launch and launch preparation activities since 1965
Component Cleaning Facility (CCF) and Area South of K7-516 (516S)	34.1 acres water table to 75' bls	1,300,000 and 11,000	Precision cleaning facility from 1962 to 1999 and 516S was CCF support area
Former Drum Storage Area (FDSA)	4.1 acres, water table to 55' bls	4,400	Non-hazardous waste storage from early 1970s to early 1990s
Launch Complex 34	336.9 acres water table to 118' bls	1,400,000	Saturn 1 and 1B launch pad from 1959 to 1968 conducted precision cleaning of spaceflight hardware

RCRA Facility Investigation / Interim Measures

- Converter Compressor Building
  - A RCRA Facility Investigation (RFI) was implemented in multiple phases, starting in 2005, to delineate the nature and extent of groundwater contamination
  - HRSC was initiated at the site in 2009 following the discovery of high concentrations of TCE indicative of a DNAPL source
  - Multiple Hot Spots and DNAPL sources were delineated
  - DNAPL was identified which promoted fine tuning of the HRSC process to sample using a 10 ft horizontal spacing within DNAPL areas
  - Vertical delineation included use of MIPs that revealed a thin layer of DNAPL source area less than one foot in thickness
  - In 2012, HRSC was initiated at Hot Spots 3 and 4 based on the HRSC refinement of Hot Spots 1, and 5 lessons learned
  - DNAPL was identified at Hot Spot 4 and delineated using HRSC of 10 ft horizontal spacing

RCRA Facility Investigation / Interim Measures

- Converter Compressor Building
  - Low Concentration Plume, High Concentration Plume, Hot Spots, and DNAPL Source Zone were all evaluated by HRSC
  - Groundwater treatment was proposed to be implemented as a series of Ims
  - HRSC provided a well defined treatment zone
  - Air Sparging and In-situ Biogeochemical Transformation / Anaerobic Reductive Dechlorination were evaluated
  - Air Sparging of the HCP and Hot Spots were selected to be implemented as groundwater IMs
  - Hot Spot 1, 2, and 5 IM has operated for 1.5 years reducing maximum VOC concentrations by several orders of magnitude
    - 228 air sparge wells
  - System currently being expanded to include Hot Spots 3 and 4

RCRA Facility Investigation / Interim Measures

- Converter Compressor Building

Entire Site

	HRSC
LCP (acres):	12.5
HCP (acres):	5.8
Hot Spot (acres):	2.0
Sample Locations:	409
Samples:	2,176
Average distance between Sampling points (feet):	46

Hot Spots 3 and 4

	Pre HRSC	Post HRSC
LCP (acres):	4.0	5.1
HCP (acres):	1.1	2.7
Hot Spot (acres):	0.2	0.7
Sample Locations:	86	246
Samples:	446	1,379
Average distance between Sampling points (feet):	80	40

RCRA Facility Investigation / Interim Measures

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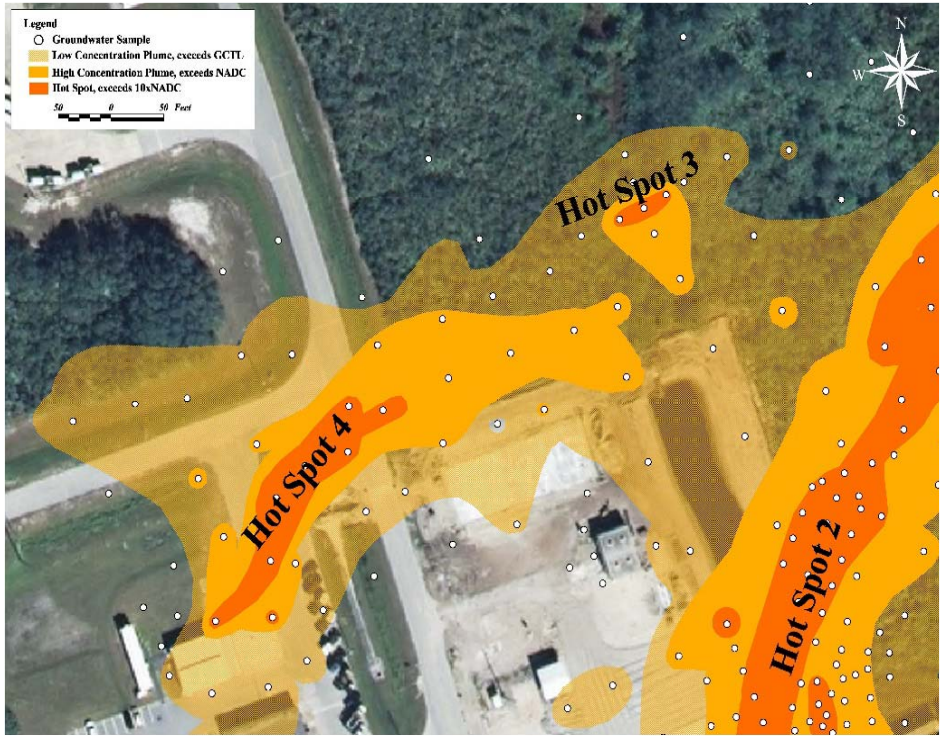
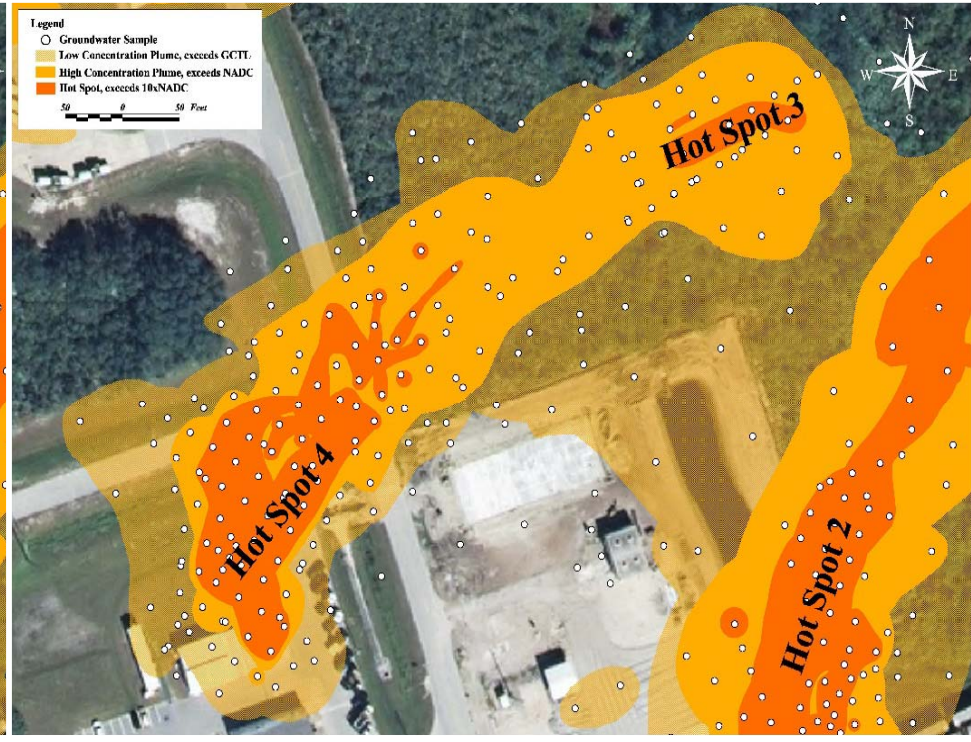
- Converter Compressor Building Hot Spots 3 & 4



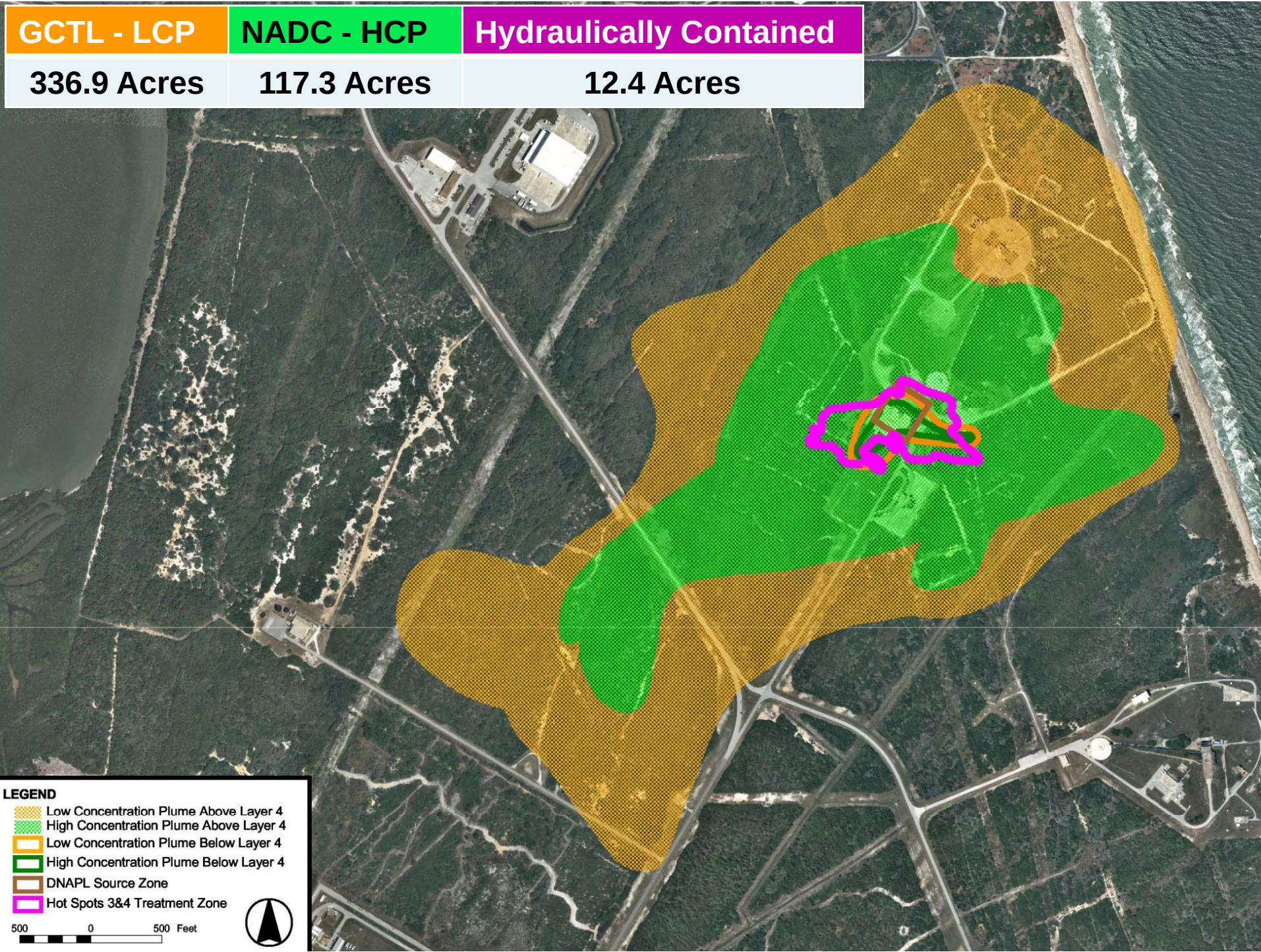
Hot Spots 3 & 4 Pre HRSC Plume Delineation



Hot Spots 3 & 4 Post HRSC Plume Delineation

Corrective Measures Study / Interim Measure

- Launch Complex 34
  - HRSC was implemented following the submittal and approval of the Corrective Measures Study in 2008
    - Recommended hydraulic containment of the DNAPL Source Zone and supplemental Hot Spot assessments
    - Initial Hot Spot assessments expanded the containment zone (hot Spots 1, 2, and 3)
    - Membrane Interface Probe (MIP) data collected in 2008 and direct push sampling data utilized (Hot Spot 4)
  - The shear magnitude of the size of the plume causes deviations from the agreed upon HRSC sampling intervals
  - Secondary round of MIPs data and Hydraulic Profiling Tool (HPT) utilized for hydraulic containment treatment system optimization
  - HRSC continues with the assessment of additional Hot Spots (Hot Spots 5 and 6)


GCTL - LCP
NADC - HCP
Hydraulically Contained
336.9 Acres
117.3 Acres
12.4 Acres
LEGEND
Low Concentration Plume Above Layer 4
High Concentration Plume Above Layer 4
Low Concentration Plume Below Layer 4
High Concentration Plume Below Layer 4
DNAPL Source Zone
Hot Spots 3&4 Treatment Zone
500 0 500 Feet

LC34 DNAPL Source Zone and Hot Spots

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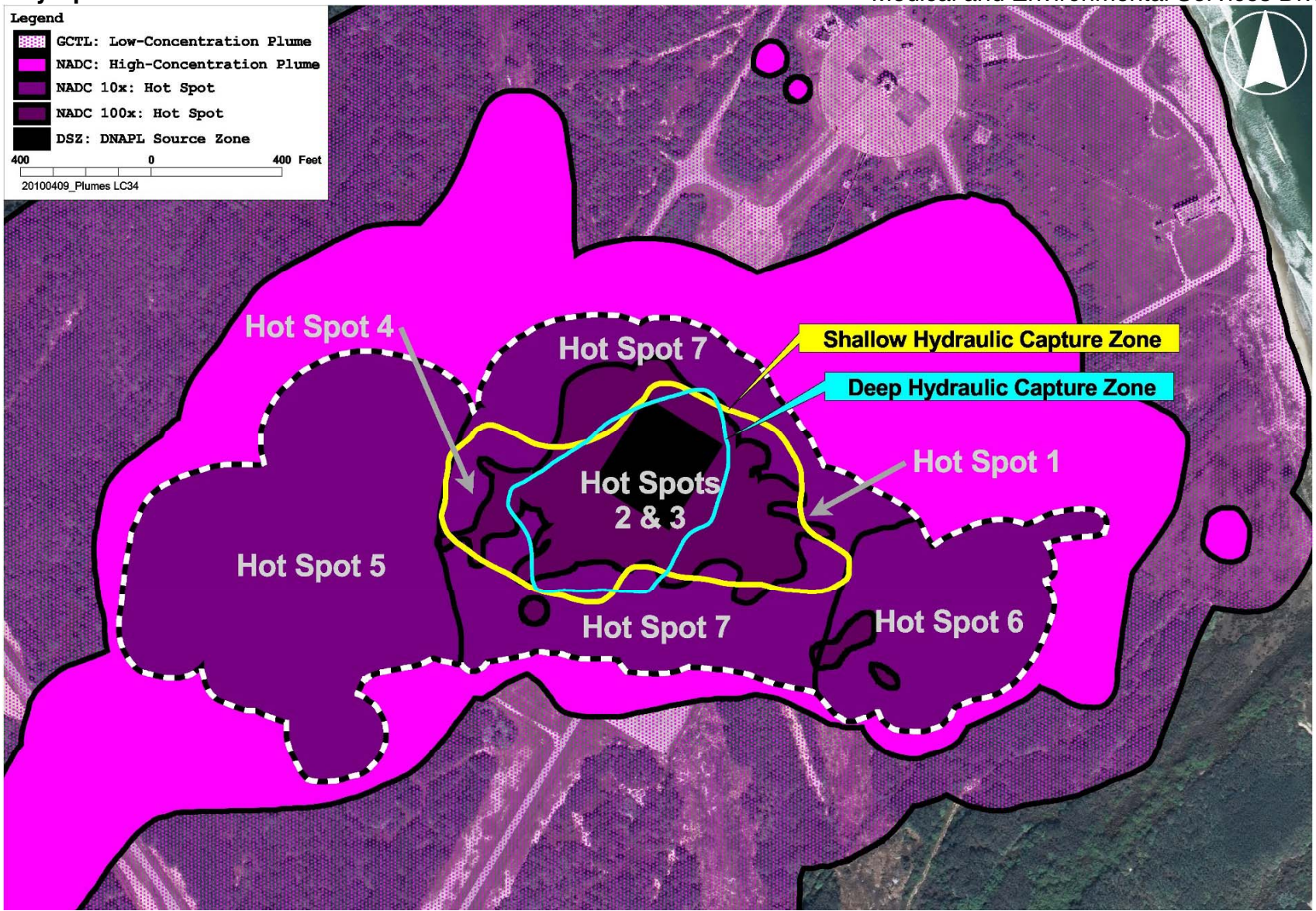

Corrective Measures Study / Interim Measure

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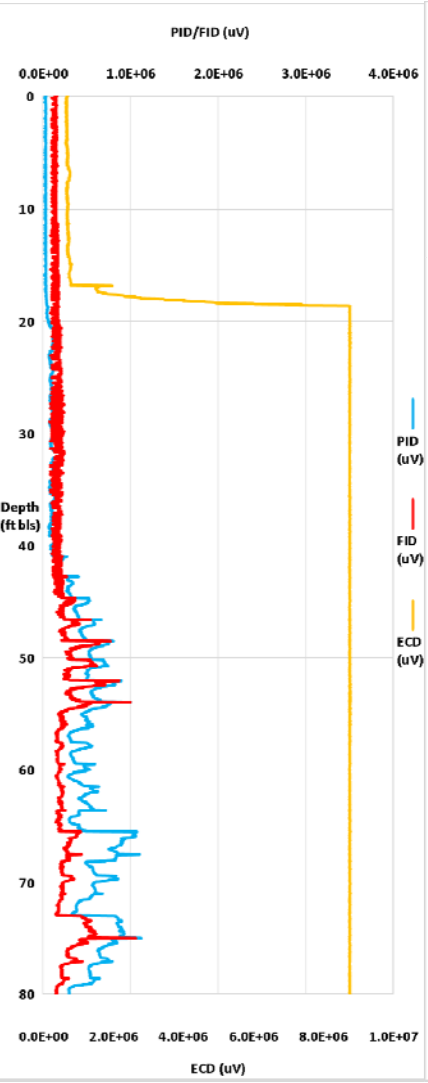
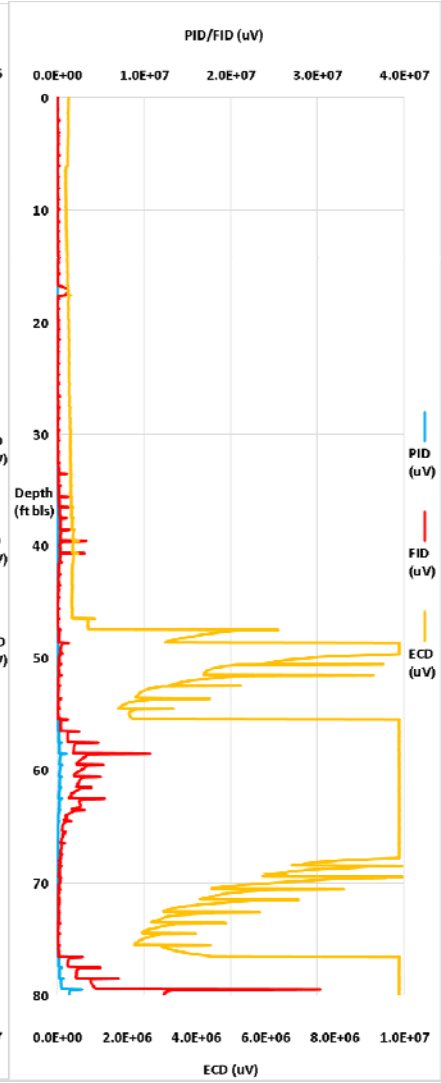
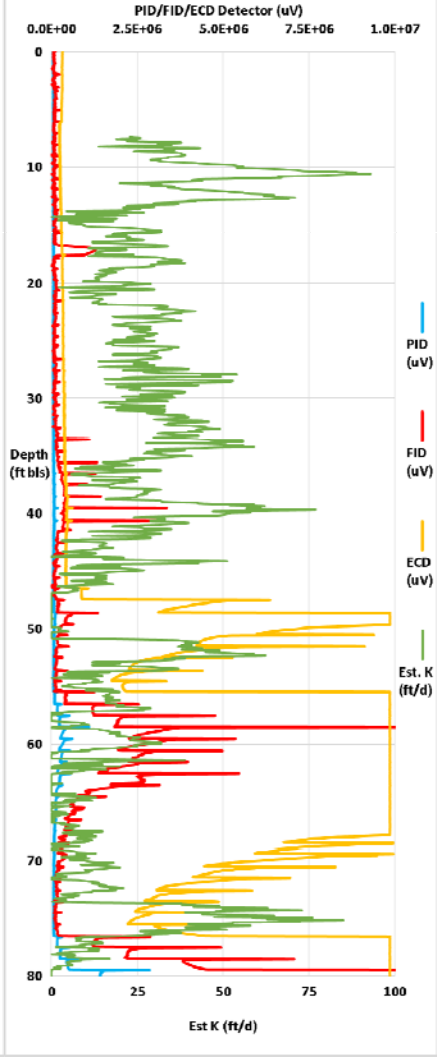
Pre-IM MIP:

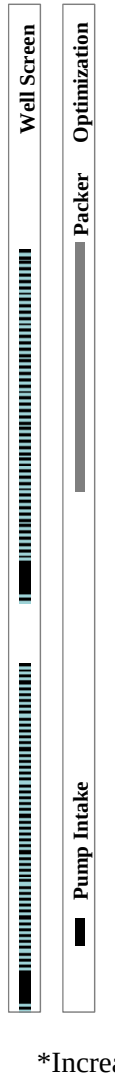


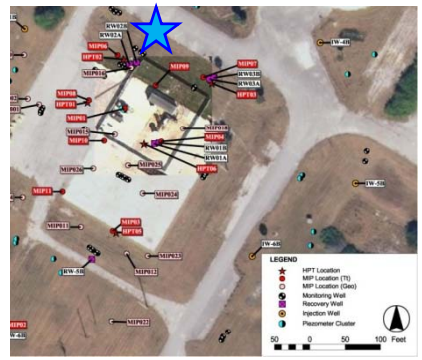
Jan 2013 MIP:



Jan 2013 HPT/MIP:







RW-2A Influent		
Date	**TCE (ppb)**	**Mass Recovery (lbs/d)**
1/20/2010	280,000	28.5
2/21/2011	3,630	4.4
2/2/2012	42,500	3.8
3/11/2013	39,000	3.2
4/3/2014	33,600	2.6

RW-2B Influent		
Date	**TCE (ppb)**	**Mass Recovery (lbs/d)**
1/20/2010	940,000	34.7
2/21/2011	203,000	7.4
2/2/2012	126,000	9.3
3/11/2013	66,300	4.2
4/3/2014	59,900	5.6

*Increase RW2B from 5 to 7.5 gpm

Corrective Measures Study / Interim Measure

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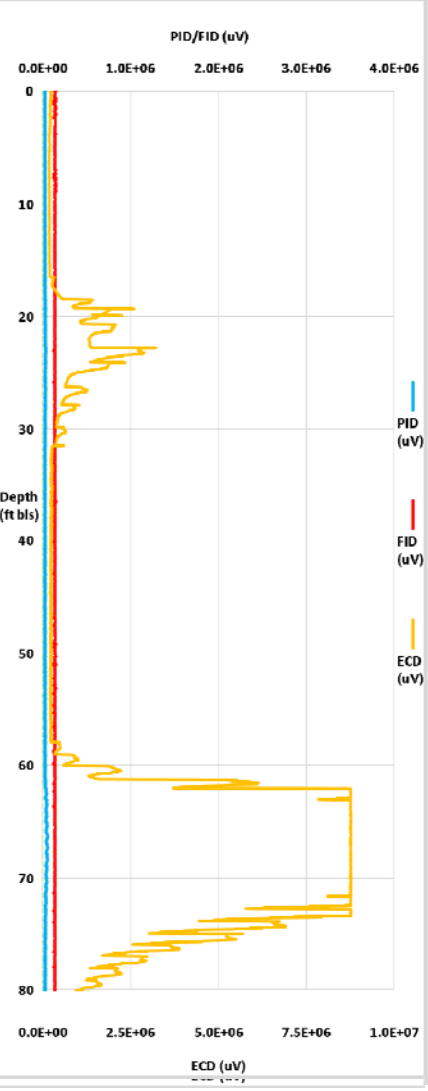
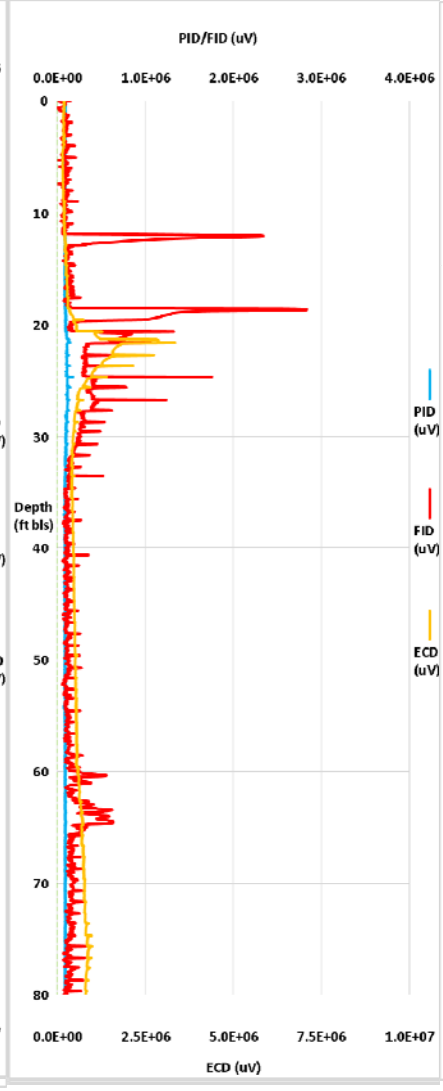
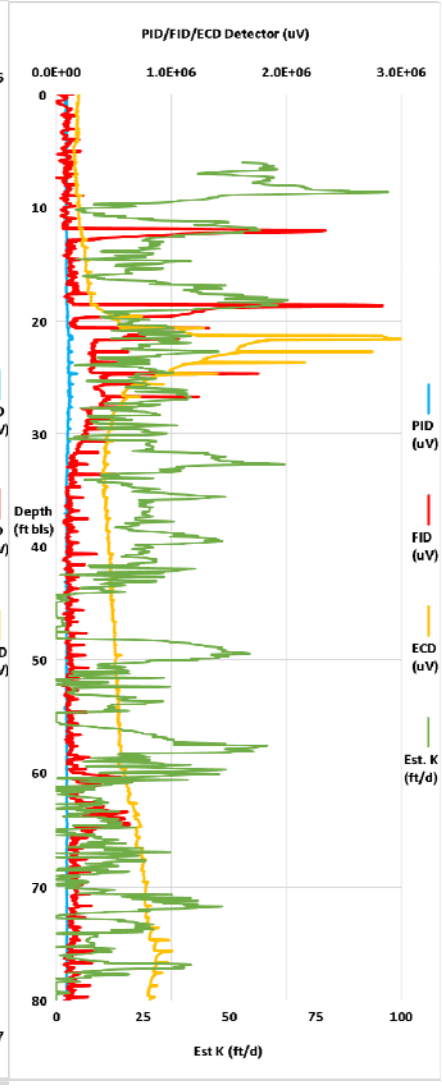
Pre-IM MIP:

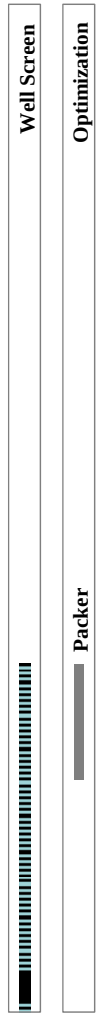


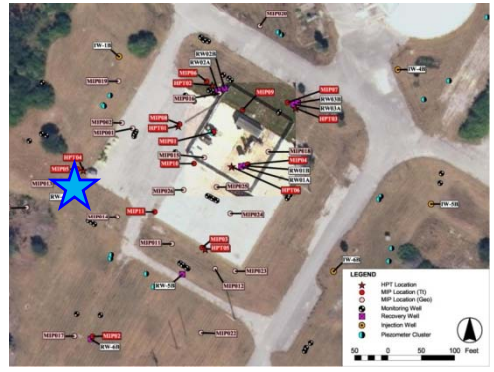
Jan 2013 MIP:



Jan 2013 HPT/MIP:







RW-4B Influent		
Date	**TCE (ppb)**	**Mass Recovery (lbs/d)**
1/20/2010	250,000	17.0
2/21/2011	54,100	3.5
2/2/2012	16,100	1.0
3/11/2013	2,640	0.2
4/3/2014	517	<0.1

*Reduce flow rate from 4 to 3 gpm (expansion flow budget variable)

Conceptual Model Refinement

- HRSC continuously refines the conceptual model for one of the most assessed sites in the state of Florida
  - Additional TCE mass identified between DPT sampling intervals +/- 18 feet bls in lower portion of Layer 1
    - MIPs identified an interval requiring VOC sampling
    - Delineated Hot Spot 4 with an estimated 4000 pounds of TCE
  - MIPS/HPTs confirmed extent of Layer 4 mass storage
  - HPTs identified that Layer 6 (60-80 feet bls) is more heterogeneous than identified via soil coring
  - MIP/HPT pairings narrowed the intervals capable of mass transport and storage within Layer 6
  - TCE concentrations > 250,000 ppb were remediated via pump and treat

Post Statement of Basis / Interim Measure

- Former Drum Storage Area
  - A RCRA Facility Investigation (RFI) was conducted in three phases, starting in 2006, to delineate the nature and extent of groundwater contamination
  - The RFI investigation was considered robust with a horizontal sample distribution of 125 feet
  - CMS was developed and approved in 2008
  - Statement of Basis recommending an In-situ Biogeochemical Transformation / Anaerobic Reductive Dechlorination remedy was submitted in 2009
  - Pilot Study initiated in 2009, monitoring wells identified elevated concentrations of COCs, determined plume interior was not adequately characterized
  - HRSC was initiated in 2009
  - HRSC horizontal spacing used in our EE process developed through investigation activities at this site

Post Statement of Basis / Interim Measure

- Former Drum Storage Area
  - HRSC provided a well defined treatment zone
  - Remedy was re-evaluated
  - Air Sparging and In-situ Biogeochemical Transformation / Anaerobic Reductive Dechlorination
  - Air Sparging of the HCP and Hot Spot was selected and implemented as an IM
    - 137 air sparge wells
  - Treatment system has successfully operated for one year reducing maximum VOC concentrations by several orders of magnitude

	Pre HRSC	Post HRSC
LCP (acres):	2.7	4.1
HCP (acres):	1.0	2.0
Hot Spot (acres):	-	0.5
Sample Locations:	54	248
Samples:	237	866
Average distance between Sampling points (feet):	125	40

Post Statement of Basis / Interim Measure

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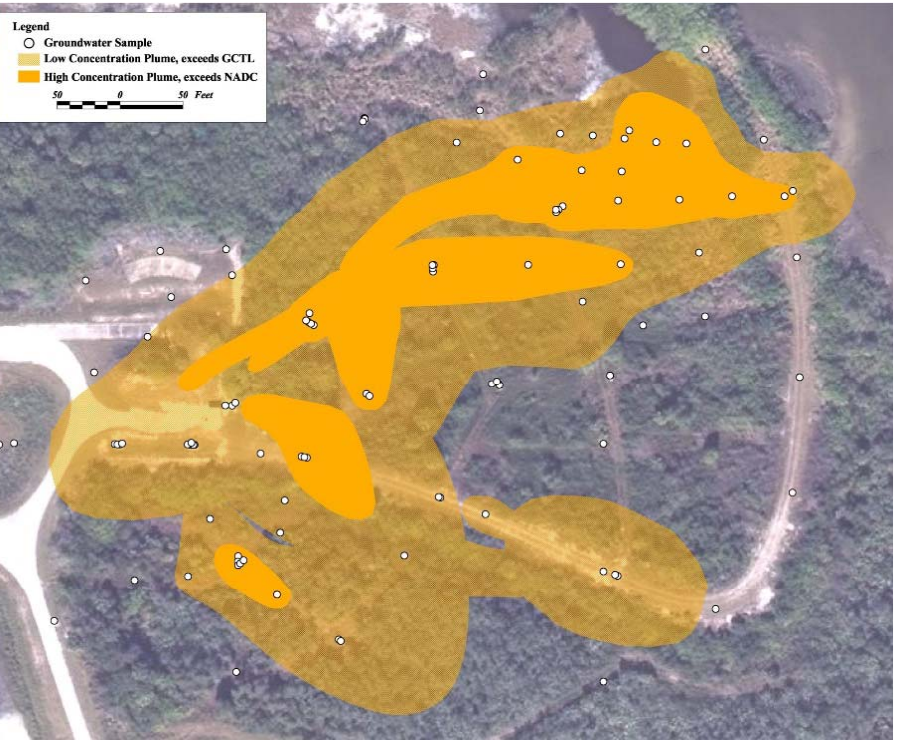
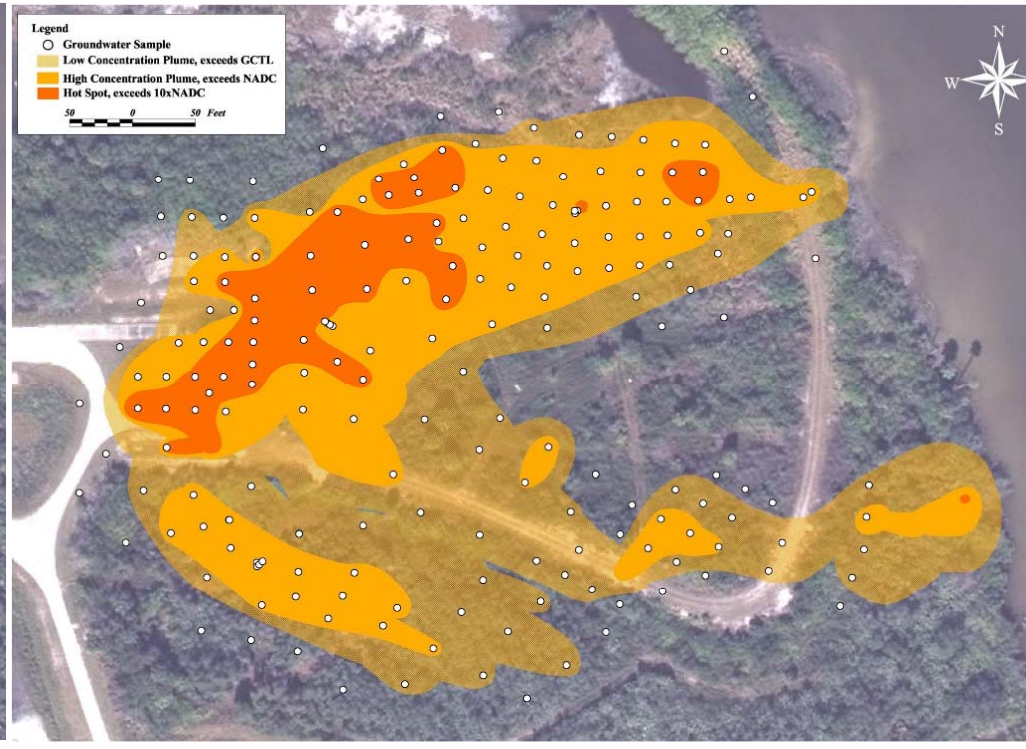
- Former Drum Storage Area



Pre HRSC Plume Delineation



Post HRSC Plume Delineation

Corrective Measures Implementation / RFI

- Component Cleaning Facility & Area South of K7-516
  - The RFI was conducted in the late 1990's and considered robust with a horizontal sample distribution of 125 feet
    - DNAPL investigation included a 3-D high resolution seismic survey, Sudan IV hydrophobic dye test, and membrane interface probes (MIPs).
    - Three Freon DNAPL areas and one Trichloroethene (TCE) DNAPL area were identified
  - Statement of Basis approved and CMI implemented in 2002
    - The shallow TCE DNAPL area was excavated in 2002 and in 2005 groundwater remedial action was implemented - air sparge/soil vapor extraction and hydraulic containment of the high concentration plume
  - Performance monitoring results showed increasing concentrations of COCs
  - HRSC was implemented upon the discovery of a potential secondary source area on the south side of the Crawlerway

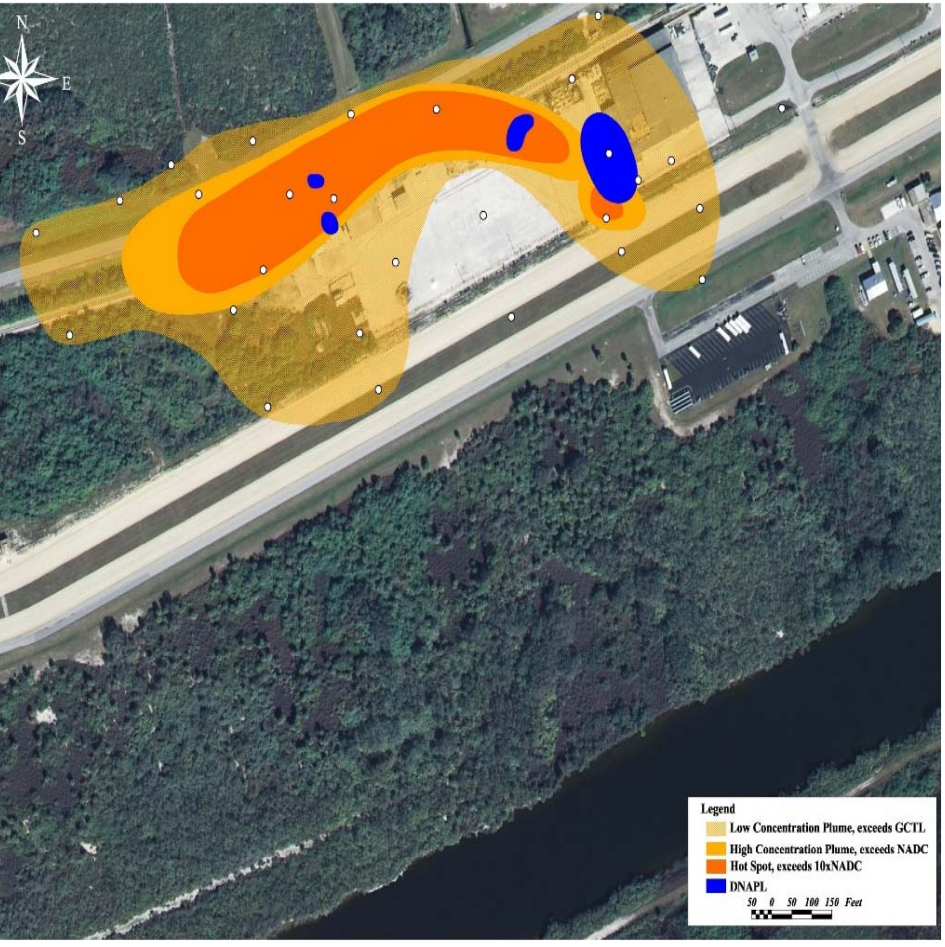
Corrective Measures Implementation / RFI

- Component Cleaning Facility & Area South of K7-516
  - HRSC changed the conceptual site model provided a well defined treatment zone
    - Led to re-evaluation of the original site
  - Air Sparging of the HCP and Hot Spot was selected and implemented at Area South of K7-516
    - 56 air sparge wells
  - Treatment system has successfully operated for one year
  - Vertical HRSC was conducted in one of the source zones
    - Determined mass in silty-clay
    - Re-evaluated source zone treatment evaluations
    - Electrical Resistance Heating selected as an IM

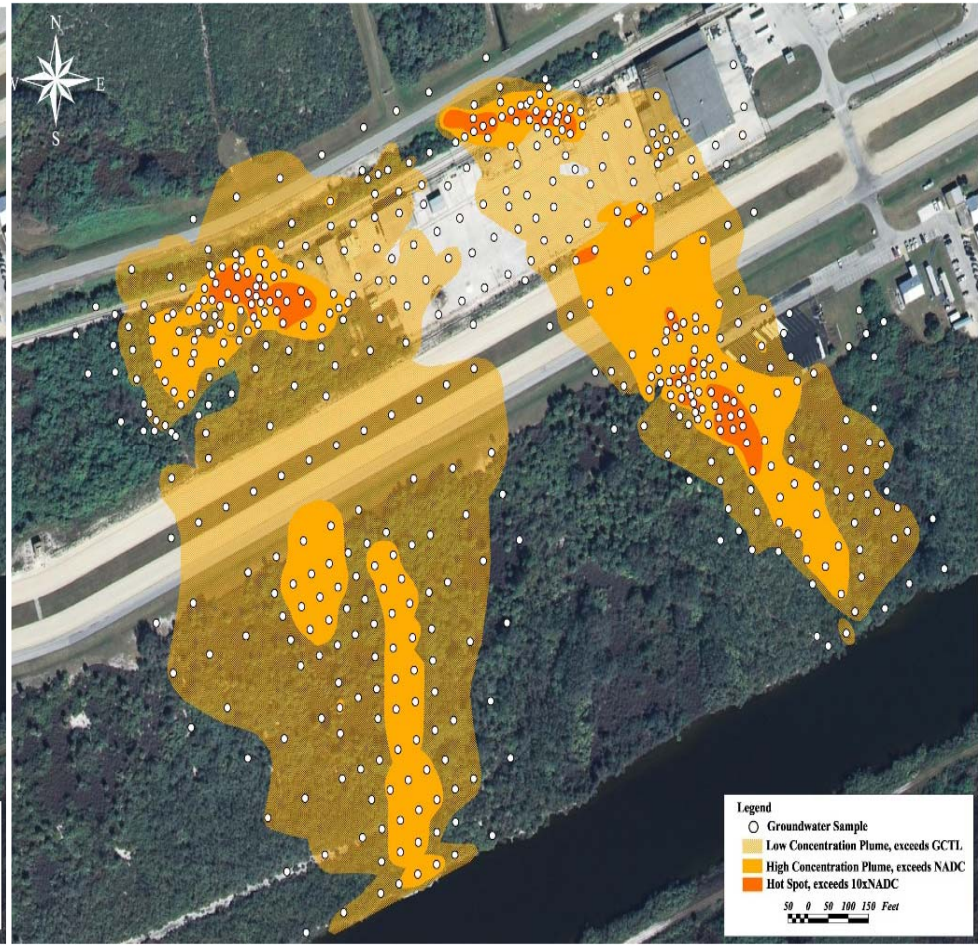
	Pre HRSC	Post HRSC
LCP (acres):	14.9	34.1
HCP (acres):	5.5	8.4
Hot Spot (acres):	3.3	1.0
Sample Locations:	82	469
Samples:	208	2,839
Average distance between Sampling points (feet):	250	65

Corrective Measures Implementation / RFI

- Component Cleaning Facility & Area South of K7-516



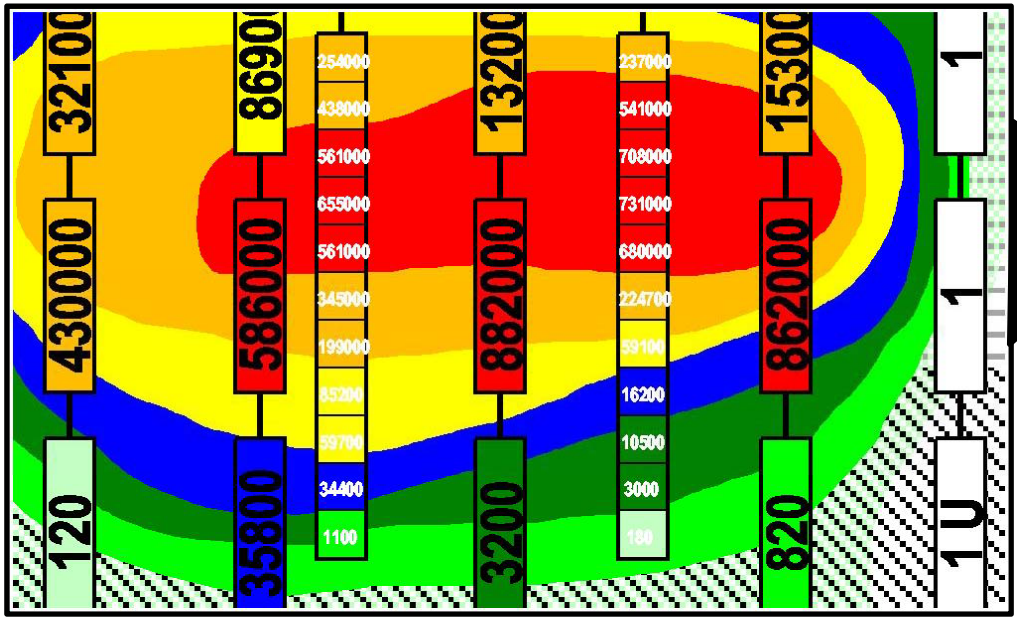
CCF/516S Pre HRSC

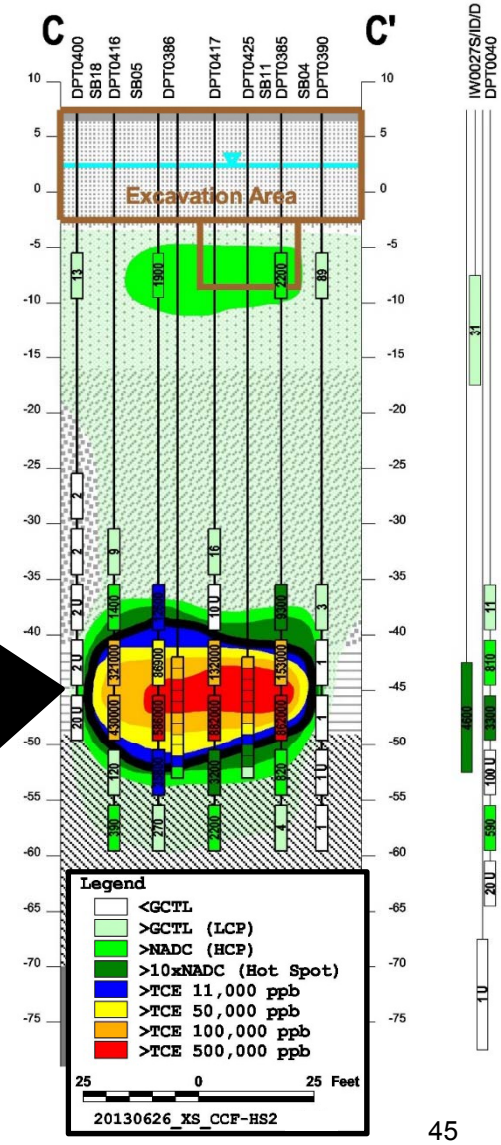


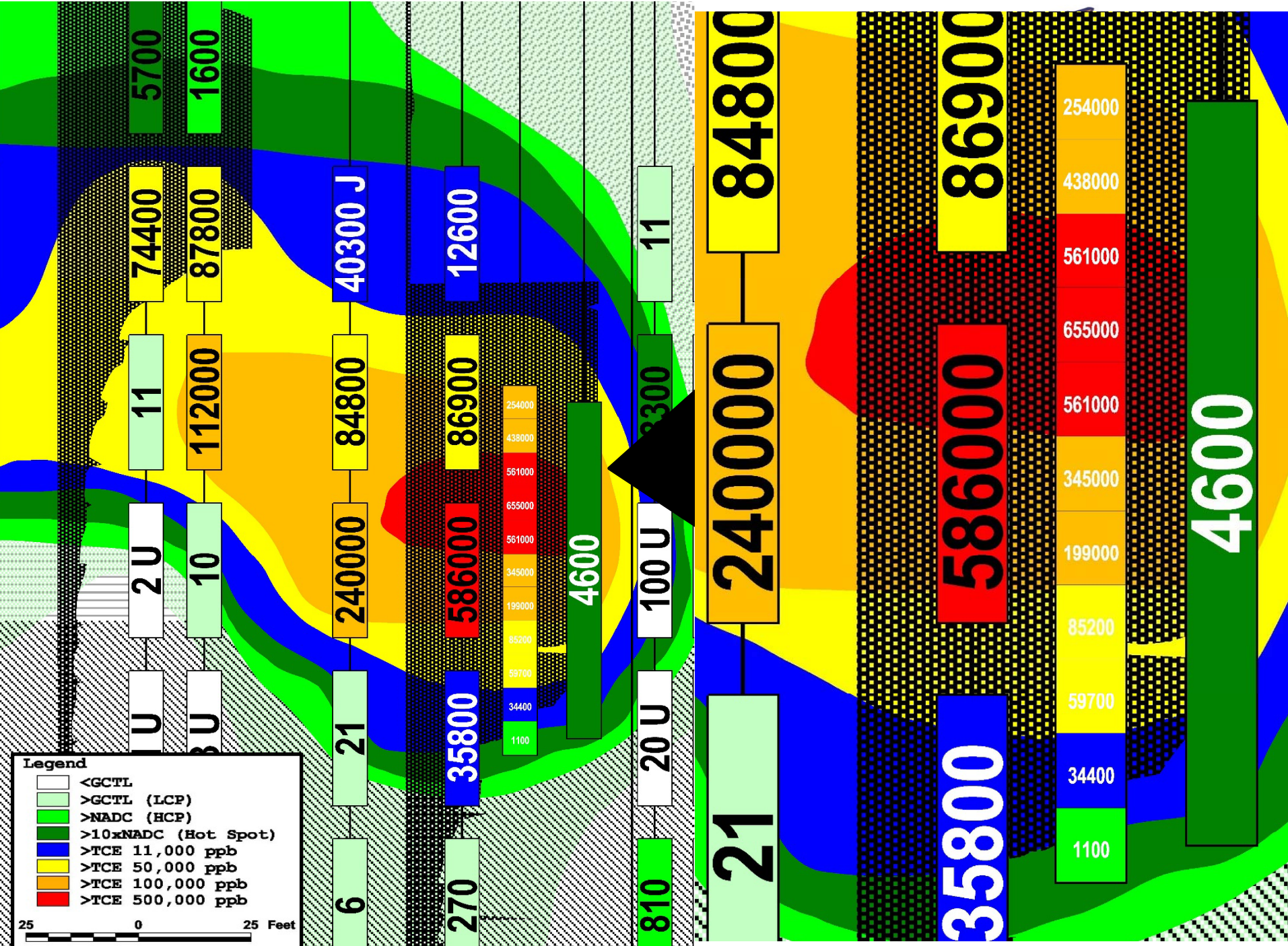
CCF/516S Post HRSC

Corrective Measures Implementation / Interim Measures

- Component Cleaning Facility
  - Vertical HRSC was implemented at Hot Spot 2 to refine the mass calculation of the source zone where TCE exceeded 50,000 µg/L.
  - One foot intervals were collected via DPT refining the zone to 3 to 4 feet thick.



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Legend
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20130626_XS_CCF-HS2 C-C

KSC Lessons Learned

- Most sites at KSC had over simplified conceptual site models
  - Groundwater plumes frequently have “knife” edges both horizontally and vertically at KSC
  - Slight changes in hydraulic conductivity have a large impact on contaminant distribution
- Inadequate groundwater plume delineation inhibits remediation efforts
- Develop a sampling frequency based on horizontal and vertical components, for example:
  - For sandy soils with silt a horizontal spacing of 10 feet for DNAPL source areas, 25 ft horizontal spacing for Hot Spots, 50 ft horizontal spacing for HCPs and 100 ft LCP is adequate for HRSC
  - Vertical spacing should be based on lithology and the use of MIPs

KSC Lessons Learned

- Maintain consistent vertical sampling intervals across the site
  - While it might appear to be a cost savings to reduce vertical sampling intervals, the KSCRT has learned that in most cases you will need to go back to locations to collect skipped vertical sampling intervals to fill data gaps
- KSC believes it is ultimately cheaper to assess and re-assess a site through HRSC than to implement a groundwater remedy and not reach cleanup objectives


Questions