Best Management and Technical Practices for Site Assessment and Remediation

Tribal Lands and Environment Forum: A National Conversation on Tribal Land and Water Resources

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Mohegan Sun ~ Uncasville, Connecticut

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Office of Research and Development
Superfund and Technology Liaison

EPA
United States
Environmental Protection
Agency

Best Management Practices for Site Remediation

United States
Environmental Protection
Agency

High-Resolution Site Characterization and Remediation

http://www.clu-in.org/characterization/technologies/hrsc/

- **Increases sampling density**
  - Delineates hydrogeology; focus on heterogeneity
  - Correlates contaminant mass locations to stratigraphy
- **Delineates zones of contamination (source mass)**
  - Targets application of remedies
  - Reduces remedy footprint and cost of operation
- **Uses collaborative data sets to manage uncertainty**
  - Verifies screening results with fixed-based analytical confirmation
  - Improves weight-of-evidence with multiple data types
- **Electronic databases and 3-D visualization of contaminant distribution**

- **More effective treatment**
  - Higher confidence that site is fully characterized for design
  - Tighter source identification and delineation
  - More accurate mass and volume estimates
  - Targeted vs. shotgun remedy design and implementation
  - Improved monitoring of remedy performance
- **Reduced treatment costs**
  - Treatment focused on the problem area
  - Reduced residual contamination
  - Saving in treatment compounds and waste handling
  - Reduced need for long-term O&M

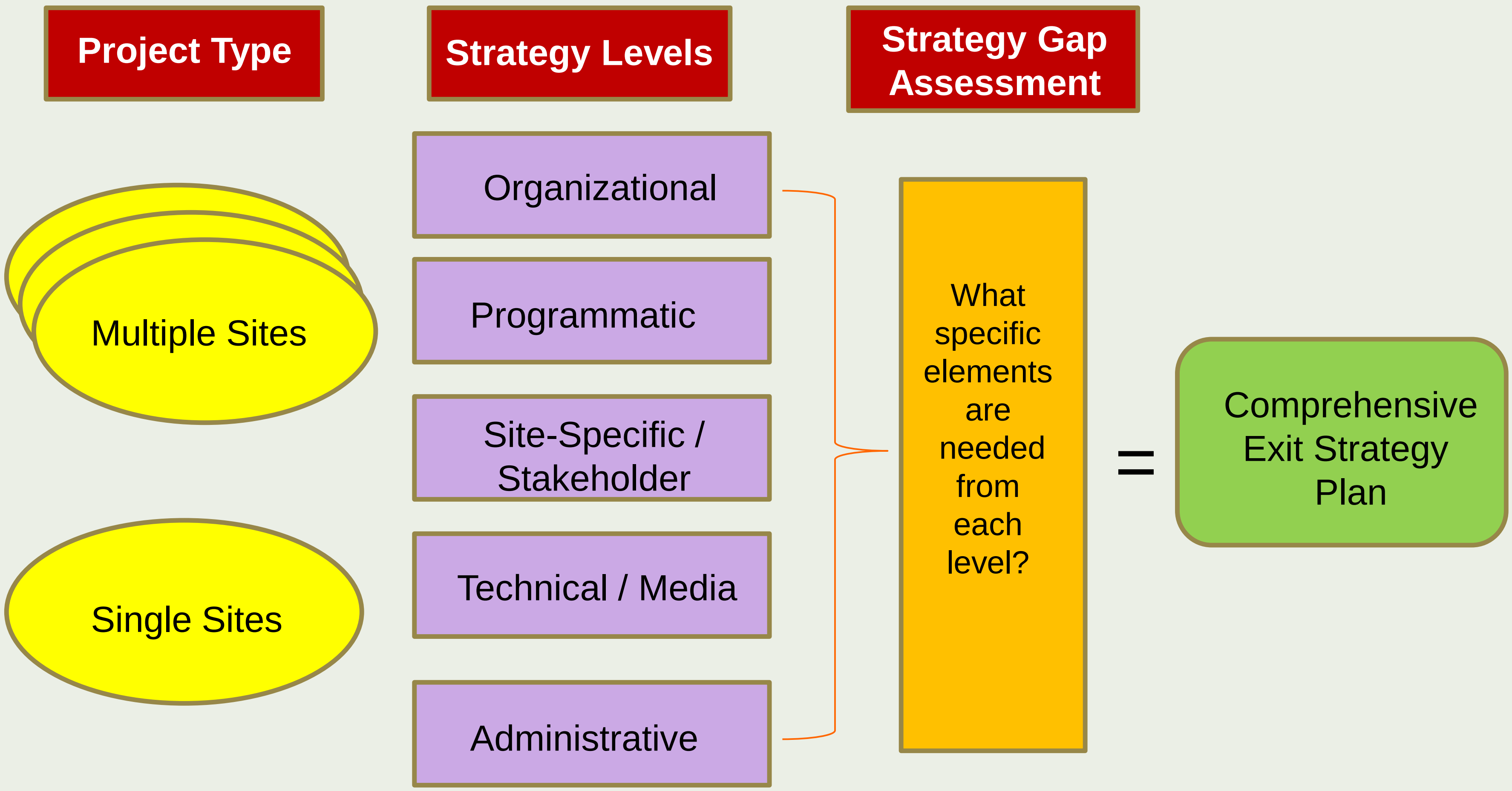
Importance of CSM to Remedial Design

- **Challenge for investigations → advance CSM sufficiently for remedial design with limited available funds**
- **CSM evolves and matures as additional data are acquired**
  - Use as a tool for stakeholder consensus
  - Strike balance between costs of investigation and remedy
- ***In situ* treatment design and application is most effective when based on a mature CSM**
- **Mature CSM gives more confidence in the remedy selection and design**
- **CSM can be used to guide design changes during remediation**

Use CSMs to Manage Remediation

- **Reach stakeholder consensus on remedial requirements**
- **Negotiate remedial option with regulatory authorities**
- **Benchmark remediation**
  - Determine what data are required to achieve each CSM version
- **Refine understanding of source area dimensions**
- **Demonstrate site no longer poses risk or unacceptable risk**
- **Use updated CSM to document "revised baseline" for future use**

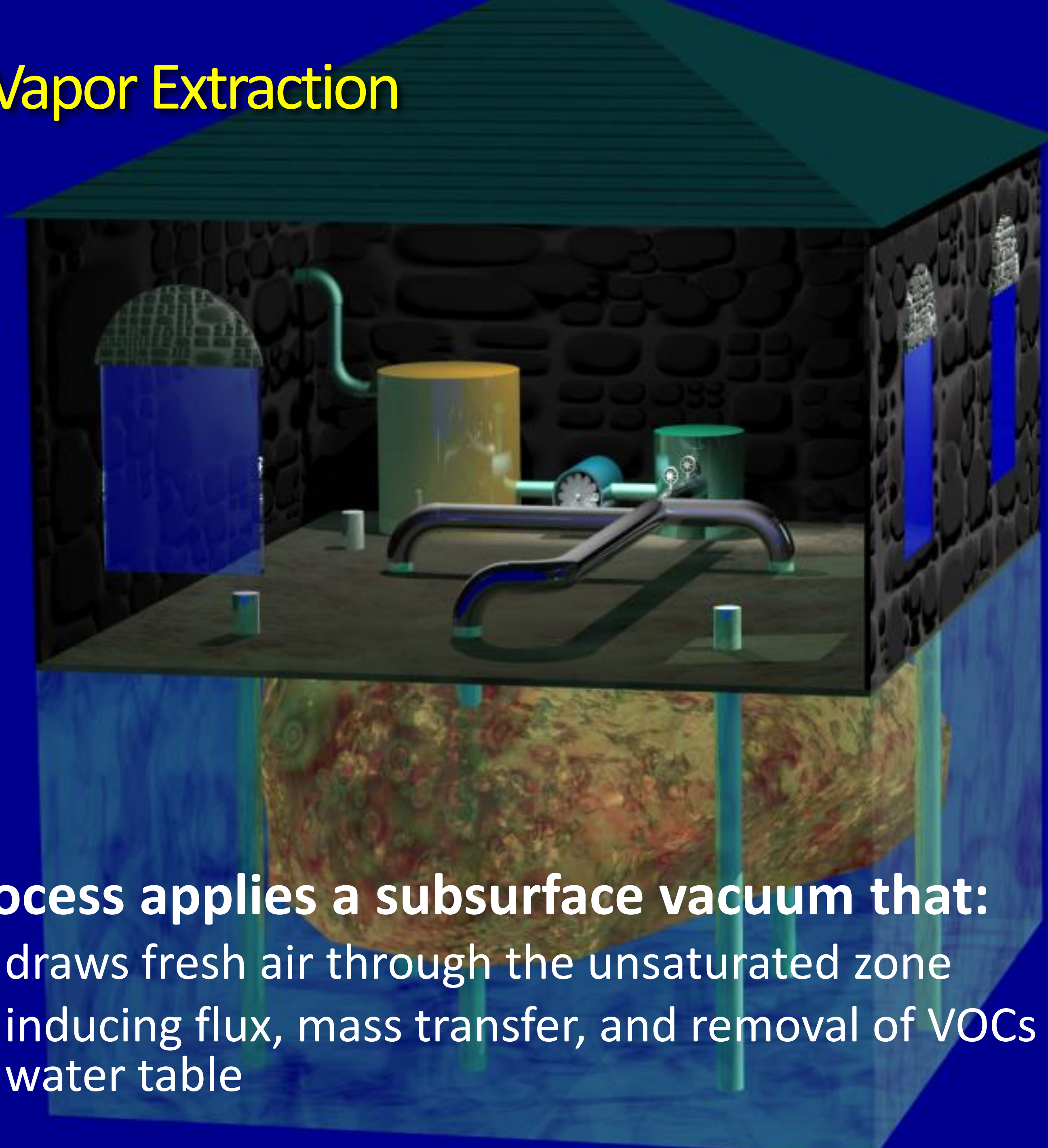
Comprehensive Exit Strategy Design



Components of an Exit Strategy

RAOs	• Short term and long-term
CSM	• Sources and release mechanisms - Detailed site hydrogeological model - Contaminant fate and transport - Current and future receptors - Uncertainties
Actions to be taken to achieve RAOs	• Individual components • Operation, control, monitoring
Performance metrics and decision logic	• Engineered components - Interim milestones for short-term RAOs - Final completion through achievement of RAOs
Contingency plans/ Alternative exit strategies	• Evaluating different approaches • Justifying alternative strategy

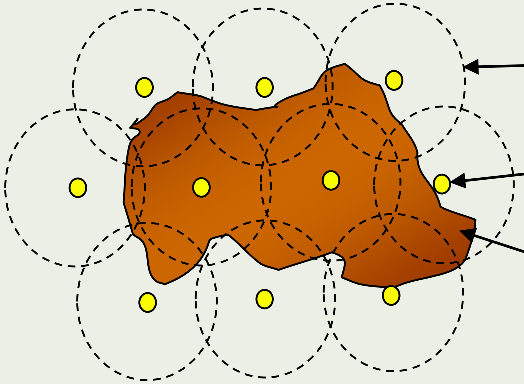
Soil Vapor Extraction



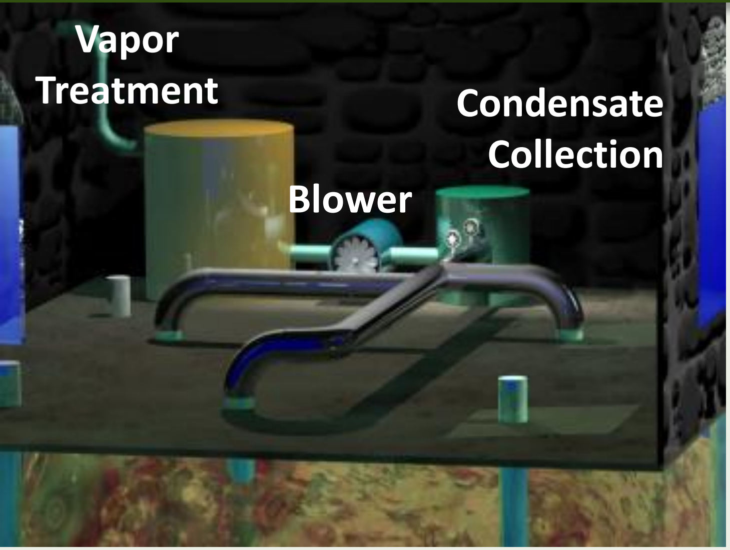
- **Process applies a subsurface vacuum that:**
  - » draws fresh air through the unsaturated zone
  - » inducing flux, mass transfer, and removal of VOCs in soil above water table

SVE System Extraction Wells

- Typically 2 to 4 inches in diameter, with a screen length of 10 to 15 feet
- Ideally spaced to achieve an overlapping of the ROI and adequate pore volume exchange
- Determine well spacing and configuration through pilot test or modeling
- May involve air injection in combination with air extraction



SVE: Factors Affecting Success - - Performance Considerations



- Contaminant characteristics
- Soil properties
- Site conditions
- System design
- Performance affected by several factors

- **Preferential flow**
  - Air will preferentially flow through higher permeability zones, providing less remediation to lower permeability zones
- **Asymptotic mass removal**
  - Remediation often limited by contaminant diffusion from lower to higher permeability zones where vapors are extracted
- **Short circuiting**
  - Short circuiting of air flow may occur in shallow or poorly constructed wells, reducing the ROI
- **High water table**
  - Rising water levels can blind screen intervals near the water table
- **Off-gas treatment**
  - Optimal method for off-gas treatment may vary over time as mass loading decreases
- **Aerobic degradation**
  - Increased air flow through subsurface can increase biodegradation of contaminants amenable to aerobic degradation

SVE Considerations to Avoid Overdesign

- **Recognize that majority of mass will be removed in a few months**
- **Mass removal after first few months will be diffusion limited**
- **All wells do not need to come online or be online at the same time**
- **Mass contributions after first few months come from more focused source areas rather than broader soil vapor plumes (some wells will no longer need to operate)**
- **Wells can be operated on a rotating basis to reduce costs while mass diffuses out of tighter parts of the formation**

SVE Considerations to Avoid Overdesign

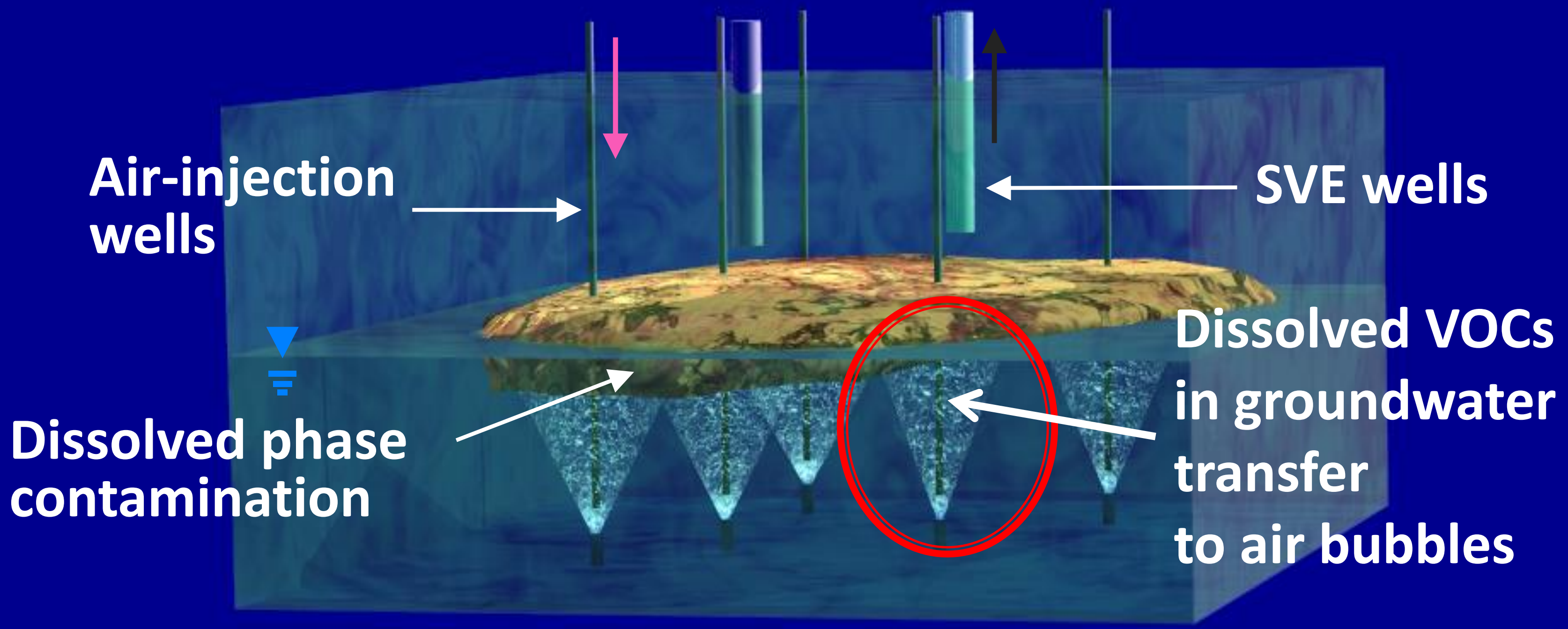
- **Off-gas treatment units (such as granular activated carbon [GAC] or thermal oxidizers) can be rented**
- **A system designed for maximum flow and maximum contaminant loading will be oversized (overdesigned in a few months)**
- **Pulsed operation of wells or operation of wells on a rotating schedule can be accomplished during weekly system checks**
  - Elaborate control systems and automated valves are often not needed
- **Fracking can increase flow rates, however, note that increased flow will be from preferential paths**

SVE Operational Data Considerations for CSM

- **What is the trigger point for shutting down the system and transitioning to monitoring only?**
- **What is the trigger point for changing off-gas treatment?**
- **Based on operating wells and extracted vapors, can you determine the approximate location of previously known source and better target that remaining source material?**
- **Would some existing vapor extraction wells serve as valuable vapor injection wells?**

Air Sparging

Direct injection of air below the water table.



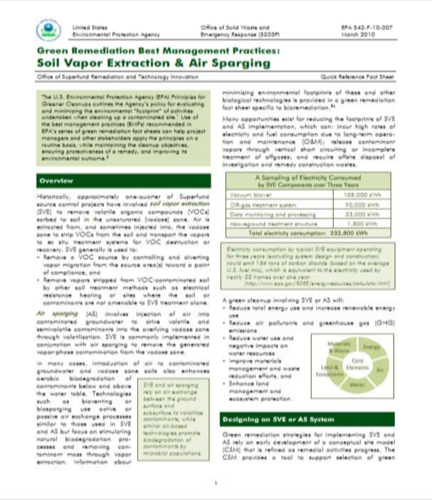
Must be operated in conjunction with an SVE system to collect vapors

AS: Factors Affecting Success - - Performance Considerations

- **Contaminant characteristics**
- **Soil properties (permeability)**
- **System design, including:**
  - » Air distribution (zone of influence)
  - » Air injection pressure and flow rates
- **In general, the ROI for AS wells is between 5 and 10 feet**
- **Channeling**
  - » Sparge bubbles will establish preferential pathways and leave some zones untreated
- **Aerobic degradation**
  - » Aerobic degradation of contaminants amenable to aerobic degradation may occur but is difficult to quantify
- **Adequate characterization needed to treat entire target volume**

AS Design and Operational Considerations

- **Recognize potential for:**
  - » Discontinuing operation of some sparge points
  - » Adding new sparge points during operation
- **Pulsed operation is beneficial but can be accomplished during weekly system checks**
  - » Elaborate control systems and automated valves are often not needed
- **Recognize diminishing returns and reduced risk and transition to monitoring only or another remedial technology**
- **Green considerations www.cluin.org/greenremediation**


United States Environmental Protection Agency
Office of Solid Waste and Emergency Response (5203P)
EPA 542-F-10-007 March 2010

Green Remediation Best Management Practices:
Soil Vapor Extraction & Air Sparging

Office of Superfund Remediation and Technology Innovation — Quick Reference Fact Sheet

The U.S. Environmental Protection Agency (EPA) Principles for Greener Cleanups outlines the Agency's policy for evaluating and minimizing the environmental "footprint" of activities undertaken when cleaning up a contaminated site.[1] Use of the best management practices (BMPs) recommended in EPA's series of green remediation fact sheets can help project managers and other stakeholders apply the principles on a routine basis, while maintaining the cleanup objectives, ensuring protectiveness of a remedy, and improving its environmental outcome.[2]

Overview

Historically, approximately one-quarter of Superfund source control projects have involved *soil vapor extraction* (SVE) to remove volatile organic compounds (VOCs) sorbed to soil in the unsaturated (vadose) zone. Air is extracted from, and sometimes injected into, the vadose zone to strip VOCs from the soil and transport the vapors to ex situ treatment systems for VOC destruction or recovery. [illegible]

minimizing environmental footprints of these and other biological technologies is provided in a green remediation fact sheet specific to bioremediation.[3,4]

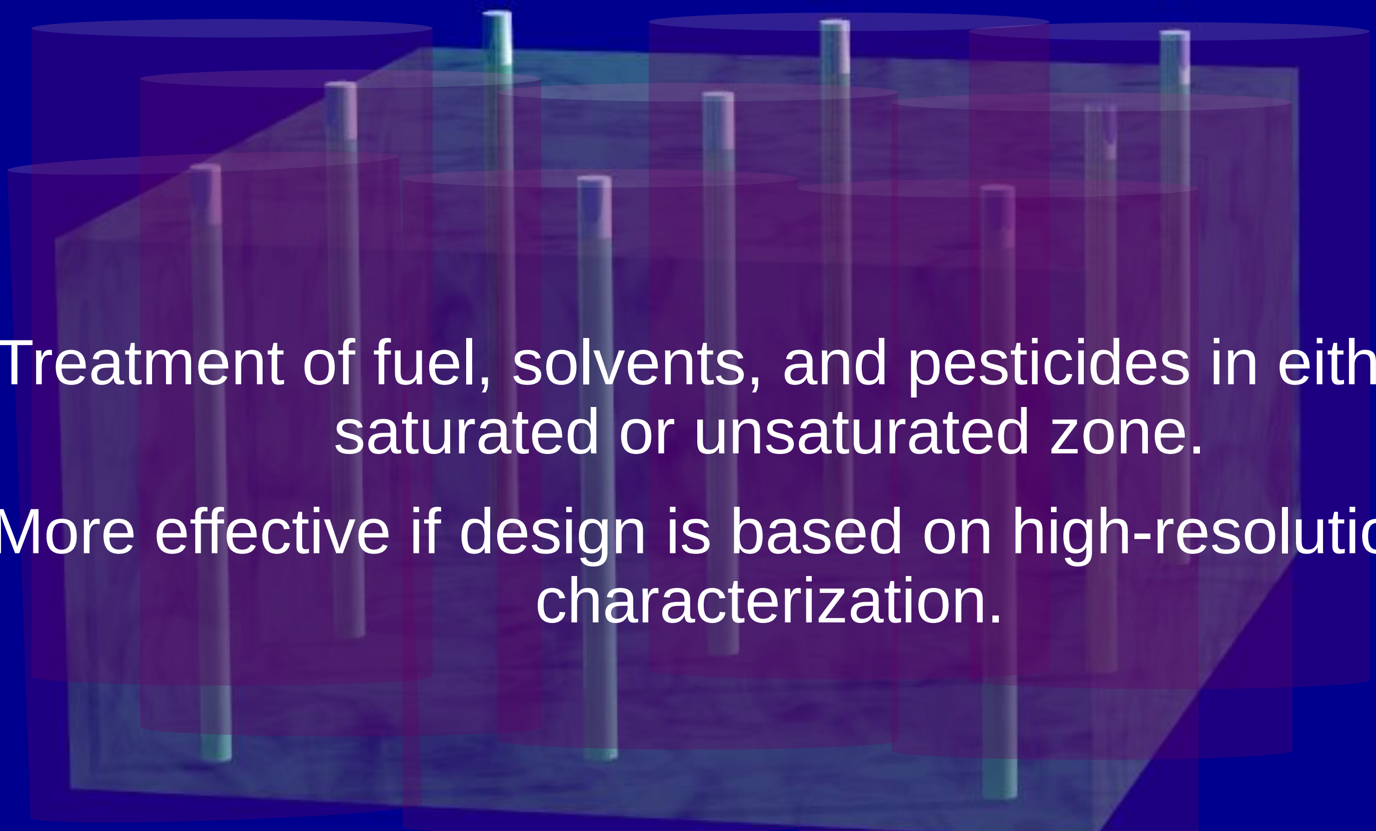
Many opportunities exist for reducing the footprints of SVE and AS implementation, which can: incur high rates of electricity and fuel consumption due to long-term operation and maintenance (O&M); release contaminant vapors through vertical short circuiting or incomplete treatment of offgases; and require offsite disposal of investigation and remedy construction wastes.

A Sampling of Electricity Consumed by SVE Components over Three Years	
Vacuum blower	108,000 kWh
Off-gas treatment system	90,000 kWh
Data monitoring and processing	33,000 kWh
Aboveground treatment structure	1,800 kWh
Total electricity consumption: 232,800 kWh	

ISCO

Treatment process in which oxidizing chemicals are placed in direct contact with the contaminant, destroying or immobilizing the contaminant.

- Minimal waste generation
- Targeted delivery
- Minimal surface impact
- Fast response
- Flexibility



Treatment of fuel, solvents, and pesticides in either the saturated or unsaturated zone.

More effective if design is based on high-resolution site characterization.

ISCO System: Factors Affecting Success

- **Optimal matching of oxidant and contaminants**
  - Treatability study may be necessary
  - Some oxidation products can be purchased "off the shelf"
    - Vendors will review site data for low or no cost
- **Level of definition of the contaminated zone**
- **Contact between oxidant and contaminant**
  - Inject oxidant directly into contaminated zone
  - Avoid "daylighting" reaction via multiple, smaller injections
  - Preferential flow paths can adversely affect oxidant delivery
- **Ensuring oxidant not affected by natural material**
  - Naturally occurring organic carbon will consume oxidant
  - Certain metals in soil and groundwater will impair performance

ISCO Design and Performance Considerations

- Injected reagents will follow preferential paths, including along a direct-push drive rod to the surface or the next most permeable interval
- Consider pros and cons of different delivery systems

	Pros	Cons
Permanent Injection Wells	• Available for multiple injection events • Can carefully construct to target specific intervals • Allows for recirculation systems • Can be sampled • Well-suited when injection is slow • Fewer refusal issues than direct push	• More costly to install each location/interval • Increases site infrastructure
Direct-Push	• Flexible with respect to locating new injection points/intervals • Ability to collect data in new locations	• Preferential flow along drive rods • Potential false impressive of targeting specific injection intervals • Potential for refusal • Costly when injection is slow

ISCO Design and Performance Considerations

- **Match the oxidant to the contaminant – engage multiple vendors for multiple products during design**

Table 1-6. Oxidant effectiveness for contaminants of concern

Oxidant	Amenable COCs	Reluctant COCs	Recalcitrant COCs
H_2O_2/Fe	TCA, PCE, TCE, DCE, VC, BTEX, CB, phenols, 1,4-dioxane, MTBE, *tert*-butyl alcohol (TBA), high explosives	DCA, CH_2Cl_2, PAHs, carbon tetrachloride, PCBs	$CHCl_3$, pesticides
Ozone	PCE, TCE, DCE, VC, BTEX, CB, phenols, MTBE, TBA, high explosives	DCA, CH_2Cl_2, PAHs	TCA, carbon tetrachloride, $CHCl_3$, PCBs, pesticides
Ozone/H_2O_2	TCA, PCE, TCE, DCE, VC, BTEX, CB, phenols, 1,4-dioxane, MTBE, TBA, high explosives	DCA, CH_2Cl_2, PAHs, carbon tetrachloride, PCBs	$CHCl_3$, pesticides
Permanganate (K/Na)	PCE, TCE, DCE, VC, BTEX, PAHs, phenols, high explosives	Benzene, pesticides	TCA, carbon tetrachloride, $CHCl_3$, PCBs
Activated Persulfate	PCE, TCE, DCE, VC, BTEX, CB, phenols, 1,4-dioxane, MTBE, TBA	PAHs, explosives, pesticides	PCBs

Technical and Regulatory Guidance for In Situ Chemical Oxidation of Contaminated Soil and Groundwater Second Edition, ITRC – January 2005

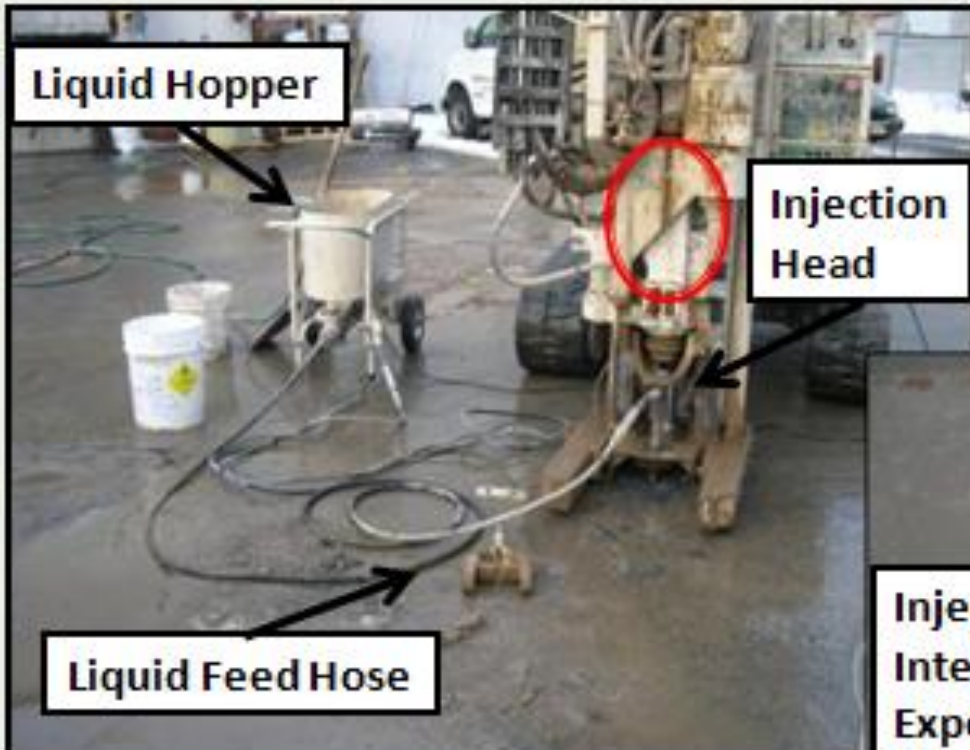
ISCO Design and Performance Considerations

- **Use pilot testing to confirm natural oxidant demand and success of delivering reagents**
- **Consider reactivity when selecting oxidant concentrations**
  - High peroxide concentrations will generate gas and backpressure
  - Other oxidants may cause floc formation and fouling
  - Some oxidants (such as permanganate) can be added as a slurry for longer-term activity
- **Consider oxidant persistence (implications for injection approach)**
  - Fenton's reagent and ozone are consumed in minutes to hours
  - Permanganate and persulfate last days to weeks to months

ISCO Design and Performance Considerations

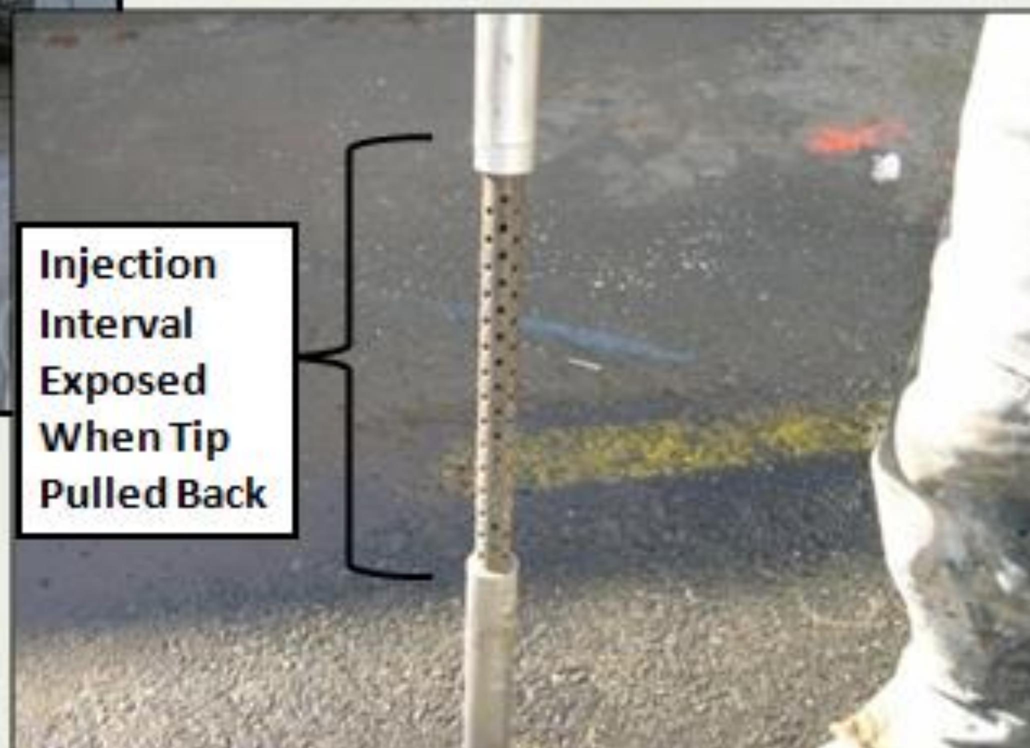
- **Remediation after first one or two events will be diffusion limited (rebound)**
- **Measure backpressure during injections and analyze results**
  - More permeable vs. less permeable zones
  - Fracturing caused by injections
  - Failure of seals
  - Confirm reagent goes where you want it to go based on initial characterization
- **Additional safety precautions/procedures when treating LNAPL with ISCO due to heat generation and reactivity, temperatures can rise above flashpoint**

ISCO Remediation Designed Using High-Resolution Site Characterization and 3-D Visualization



Injection Assembly

Injection Nozzle



Soil Excavation and Off-Site Disposal

- **Common refrain - "Just dig it up and get rid of it"**
- **Not that easy - Must ask these questions first:**
  - Is contaminated area fully delineated?
  - Is size and depth of the excavation clearly established?
  - What is the depth to groundwater?
  - Does remedy require excavation below the water table
    - Is dewatering necessary to support redevelopment construction?
    - Does UST removal or soil remediation require over-excavation, as is sometimes done in certain State programs?
  - What are the consequences of leaving some contamination in place?
    - Are the impediments to "getting it all" really that much greater than years of long-term remediation?

(continued)

Soil Excavation and Off-Site Disposal

- **Not that easy - must ask these questions first:**
  - Have cleanup standards and RAOs been clearly established?
  - Has a method for determining completion been established?
  - What are the disposal requirements for the contaminants?
  - What are the acceptance criteria for the disposal facility; and how far away it is?
  - Have site logistics such as contaminated/clean backfill soil staging and equipment storage been addressed?
- **Disposal of PHC soils easier/less expensive than CVOC-contaminated soils disposal**
- **Be cognizant of State guidance to avoid over-excavation**
  - Accurately estimate soil volumes to limit scale of land-farming or disposal

Pre-Excavation Design Considerations

Characteristics of soil to be handled

- Volume - Moisture content – wet/dry - Soil properties – clay soil will expand after excavation

Location

- Proximity of buildings – Accessibility with basic excavation equipment - Availability and location of staging areas

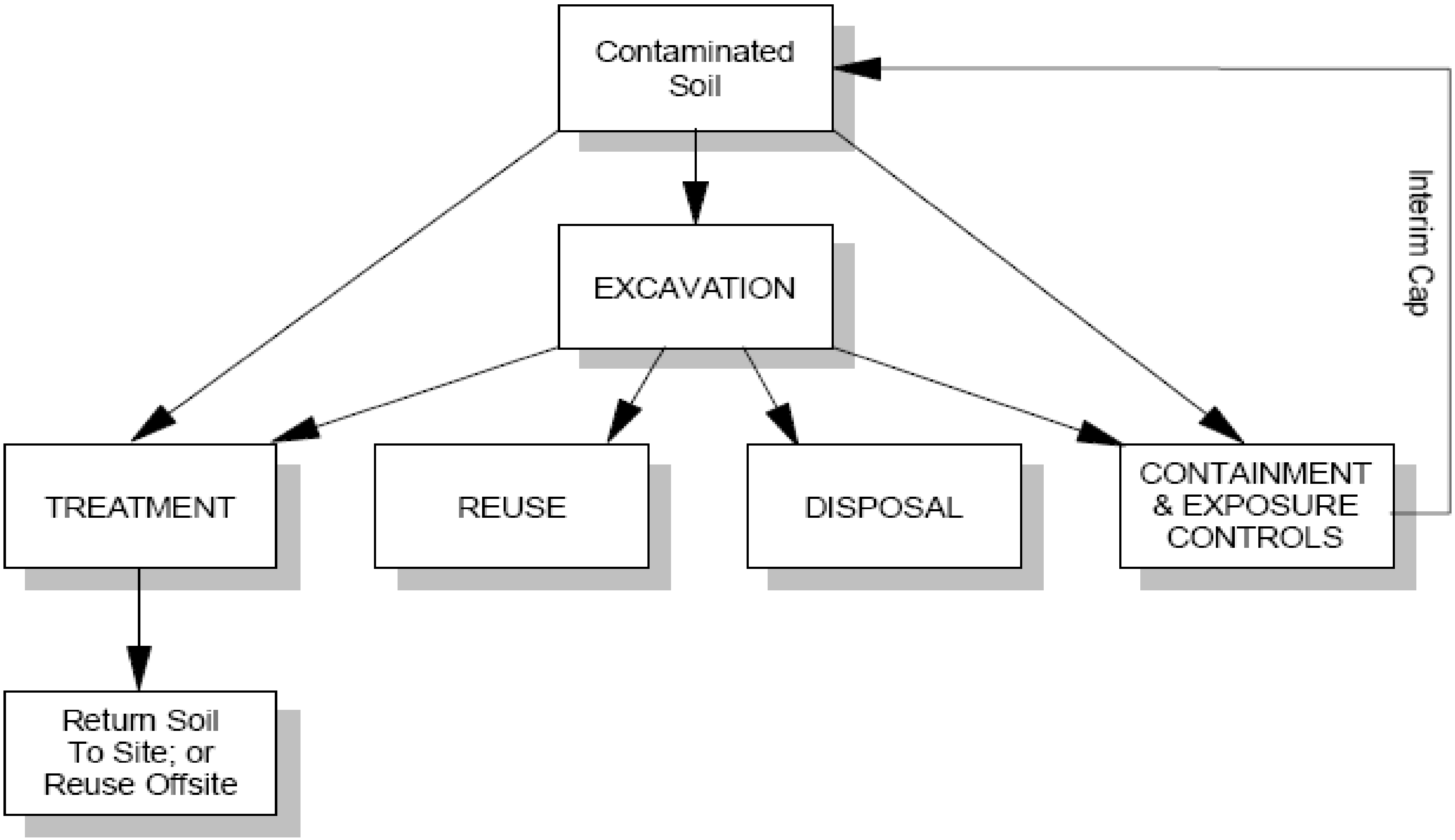
Type of contamination

- Worker protection - Disposal/reuse options - Air/dust generation and monitoring - Transportation regulations

Engineering practice

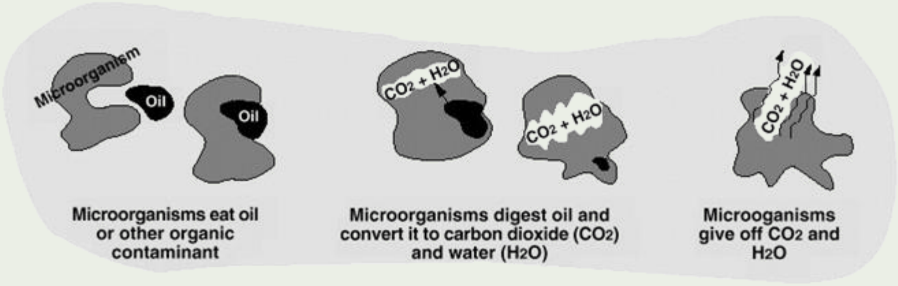
- Excavation stability – OSHA - Water control - Material segregation - Seasonal variation in handling characteristics

Post-Excavation Design Considerations



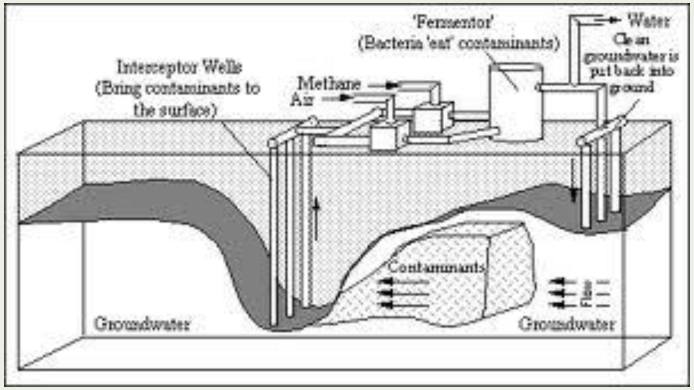
Bioremediation

- **Remediation of contaminants by enhancing microbial activity to degrade (or stabilize) contaminants by oxidation, reduction, or cometabolism…**
  - Oxidation (aerobic degradation of benzene)
  - Reduction (reductive dehalogenation of TCE)
  - Cometabolism – degradation of a variety of contaminants by enzymes produced by bacteria using other compounds for energy
- **Biostimulation – Amendments added to enhance microbial activity**
- **Bioaugmentation – Addition of microbes for remediation**
- **Various approaches**
  - Direct-push injections
  - Discrete injections in permanent injection points
  - Recirculation systems
  - Source area treatment or biobarriers
- **Various amendment options**



Bioremediation: Factors Affecting Success

- **Contaminated media**
- **Aerobic or anaerobic conditions**
- **Physical parameters**
  - » pH
  - » Temperature
  - » Naturally occurring organic matter (carbon)
  - » ORP
  - » DO
- **Moisture content of unsaturated zone**
- **Existing microbial populations**
- **Mature CSM; impact area well-defined**

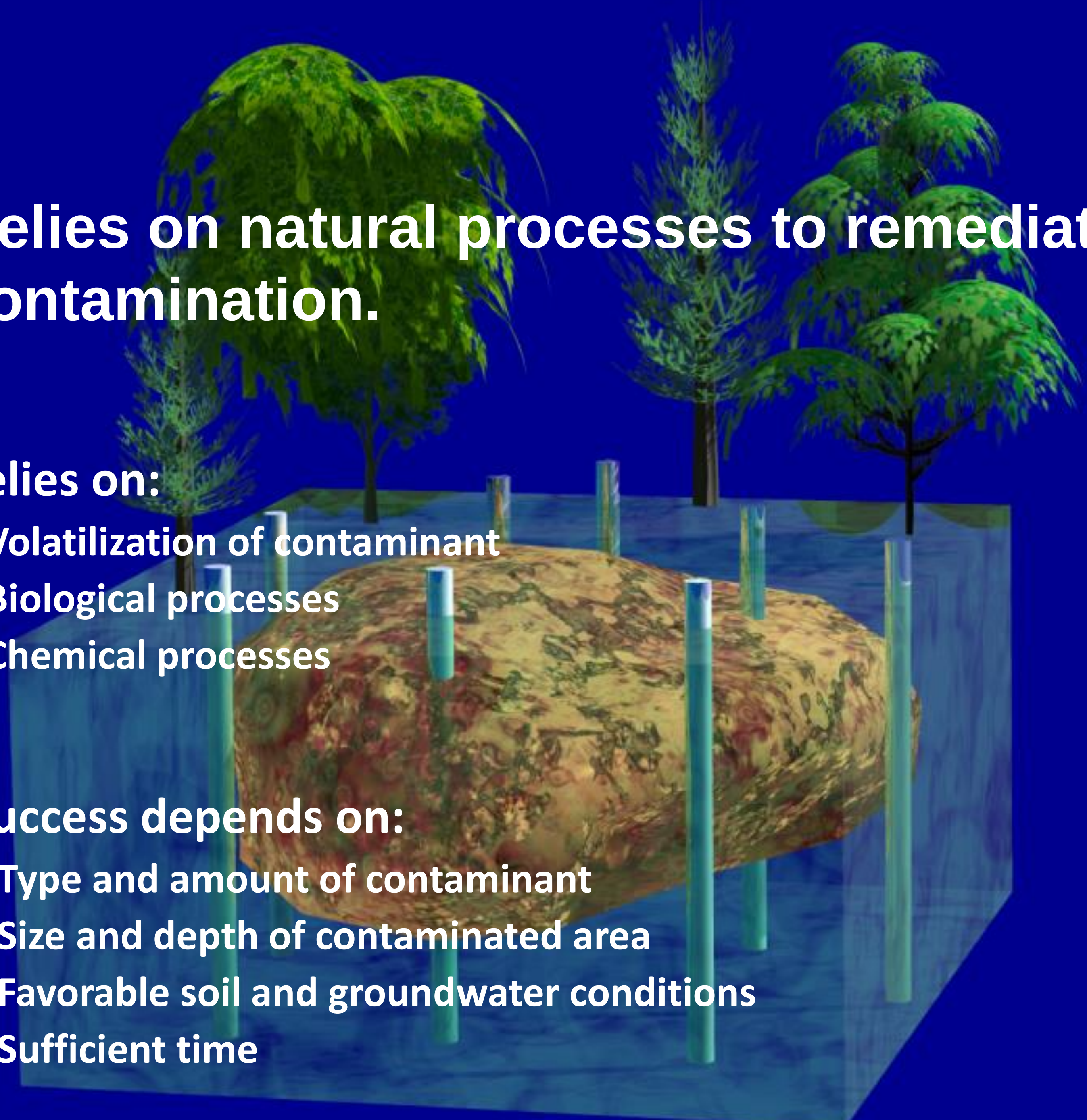


Bioremediation Design and Performance Considerations

- **Different schools of thought on "fast-burn" vs. "slow-burn" substrate for treating chlorinated solvents**
- **Different options for delivering oxygen for treating BTEX**
  - ORC injections
  - ORC socks or *in situ* submerged oxygen curtain (iSOCs™)
  - Air sparging with or without ozone or oxygen addition
  - Nutrient addition may also be needed
- **Consider injection approaches (see ISCO discussion)**
- **Recirculation help disperse reagents and reduce number of injection points**
- **Design a robust performance monitoring program. Multiple events will likely be needed. Have the data to optimize the next event**
  - DO, ORP, Fe+2, NO_3^-, SO_4^{2-}, VOCs, pH, alkalinity
  - Increase frequency of monitoring (such as monthly instead of quarterly), additional performance monitoring events…
    - Help confirm results
    - Provides additional insight
    - Helps better distinguish between effects/results from consecutive injection events

MNA

Relies on natural processes to remediate contamination.



Relies on:

- Volatilization of contaminant
- Biological processes
- Chemical processes

Success depends on:

- Type and amount of contaminant
- Size and depth of contaminated area
- Favorable soil and groundwater conditions
- Sufficient time

General MNA Considerations

- **May require ICs**
- **Usually applied to low-level groundwater impacts**
- **1999 OSWER directive 9200.4-17P**
  - Requires rigorous site characterization
  - Evaluate efficacy of MNA using “lines of evidence”
  - Performance monitoring
- **Impose a stewardship obligation on property owner**
- **Requires a groundwater monitoring system**
  - Upgradient monitoring wells
  - In-plume monitoring wells
  - Downgradient sentinel wells

Initial Screening of MNA Applicability

- **Do state regulations allow MNA as a remedial method?**
  - Many States require majority of source mass be removed
  - Presence of mobile LNAPL may preclude consideration
  - May be acceptable for limited non-mobile, residual phase LNAPL
- **Has the source been removed to the maximum extent practicable?**
- **Is plume size and concentration reducing such that remediation will be achieved within a reasonable time?**
- **Are there any receptors that could be affected?**

Key Components of Typical MNA CAP

- **Documentation of adequate source control**
- **Comprehensive site characterization**
- **Showing lines of evidence to support MNA**
- **Performance objectives**
  - Tools are available to support remedy evaluation
    - remfuel http://www.epa.gov/ada/csmos/models/remfuel.html
- **Evaluation of timeframe for meeting remediation objectives**
- **Long-term performance monitoring**
- **Contingency plan**

Pilot Studies

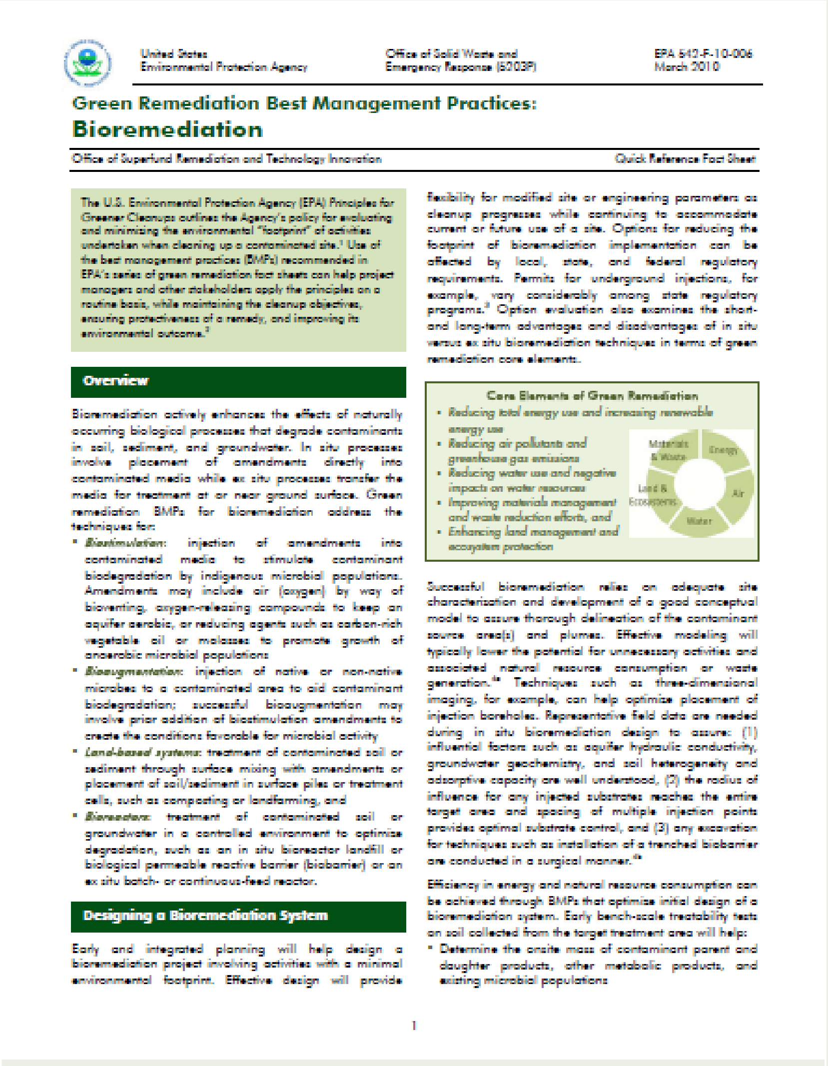
- **Before conducting a pilot test, confirm (to the degree possible) that full-scale application is practical and appropriate**
  - » Don't conduct unnecessary pilots
- **Collect too much rather than too little data**
- **Several phases of successful pilot studies could actually be a successful full-scale remedy**
- **Evaluate failed pilot study results to confirm implementation issues were not the reason for failure. Consider the benefit of redoing a pilot study before abandoning a technology**
- **Increase the likelihood of success through sound research and bench-scale studies**
- **Be sure the pilot test addresses the most critical parts of the remedy (such as reagent delivery to the tough locations)**

Treatment Trains

- **Combination of remediation technologies usually applied in a "treatment train" via flexible record of decision/CAP**
  - Aggressive ISCO to treat source
  - PRB or PRZ to treat plume
  - MNA for "tail" of plume with low concentrations
  - State requirements-"make every conceivable effort, utilizing every available technology"
- **Prepare a corrective action plan to outline the preferred cleanup option for the site**
  - Public has the opportunity to comment on preferred option
  - Consider the comments and may revise final cleanup
  - Determination of the final cleanup for a site is documented in its final site closure documents

Green BMPs for Characterization and Remediation

- For more information on Green BMPS for Bioremediation, refer to this fact sheet
- www.cluin.org/greenremediation



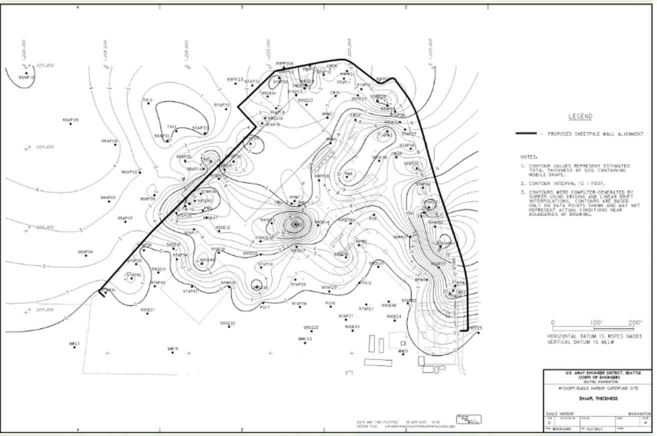
Select Case Studies

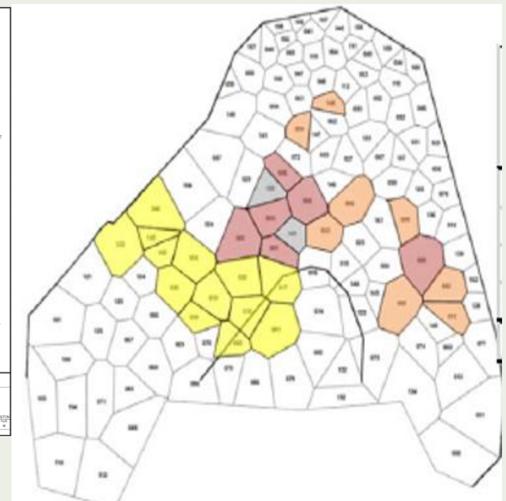
United States Environmental Protection Agency

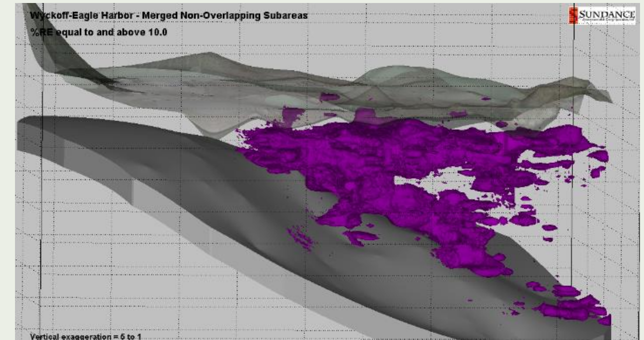
Example 1- Wyckoff Region 10

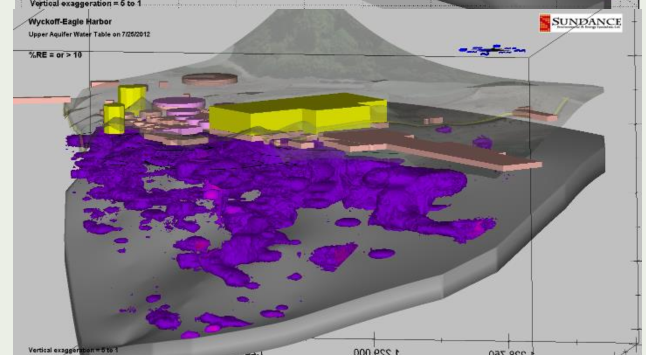
FFS- TarGOST® and 3D Visualization

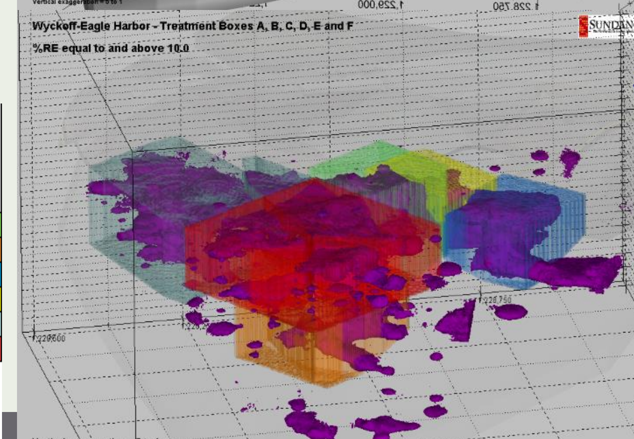
Existing Work Products











Wyckoff Geology

Wyckoff TarGOST

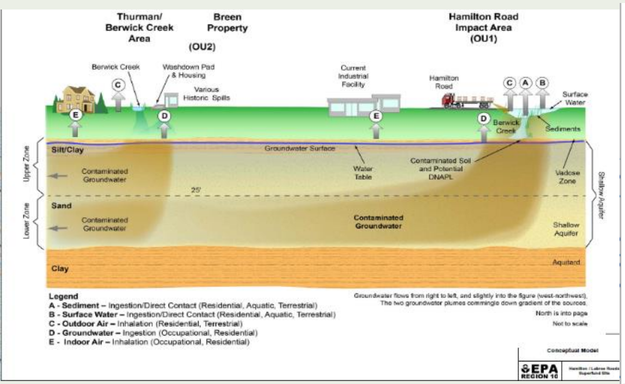
Wyckoff Treatment

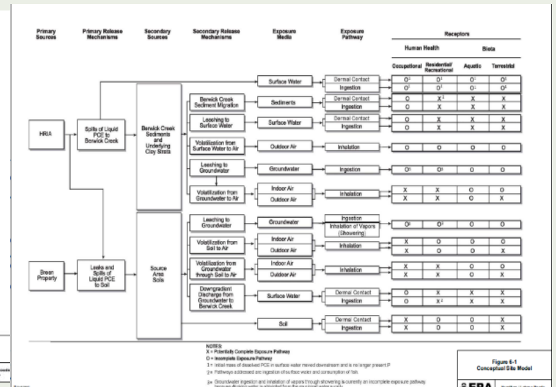
	Y-Length, ft	X-Width, ft	Z-Height, ft	Treatment Box Soil Volume, cu. yds.	TarGOST Impacted Soil Volume @ 10 %RE in Treatment Box, cu. yds.	TarGOST 10 %RE Percent of Treatment Box Volume, cu. yds.	TarGOST 20 %RE Percent of Treatment Box Volume, cu. yds.	TarGOST 50 %RE Percent of Treatment Box Volume, cu. yds.	TarGOST 100 %RE Percent of Treatment Box Volume, cu. yds.
Box A	160.00	170.00	45.00	33,836	12,883	38%	9%	0%	0%
Box B	200.00	210.00	30.00	38,538	5,524	14%	7%	1%	0%
Box C	180.00	165.00	23.00	18,302	6,491	35%	19%	5%	1%
Box D	180.00	132.00	10.00	5,861	2,253	38%	15%	0%	0%
Box E	305.00	300.00	28.00	77,146	13,371	17%	3%	0%	0%
Box F	300.00	300.00	22.00	72,706	14,734	20%	7%	1%	0%
TOTAL				246,389	55,255	22%			
				Total 10 %RE TarGOST Impacted Soil Volume Inside Wall	59,489				
				% Captured in Boxes	93%				

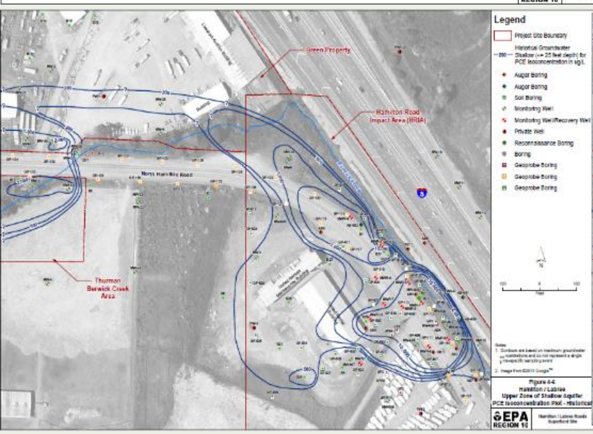
Example 2- Hamilton Labree Region 10

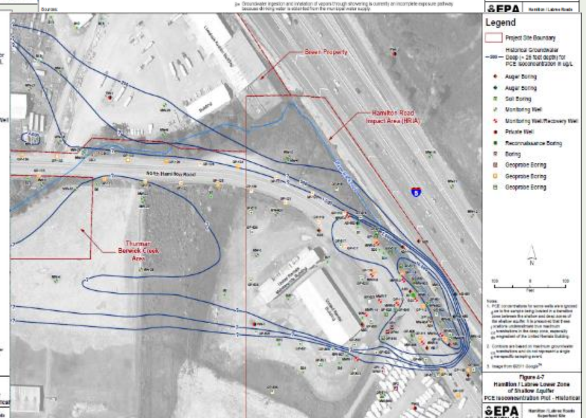
PDI- MIP, HPT, 3D

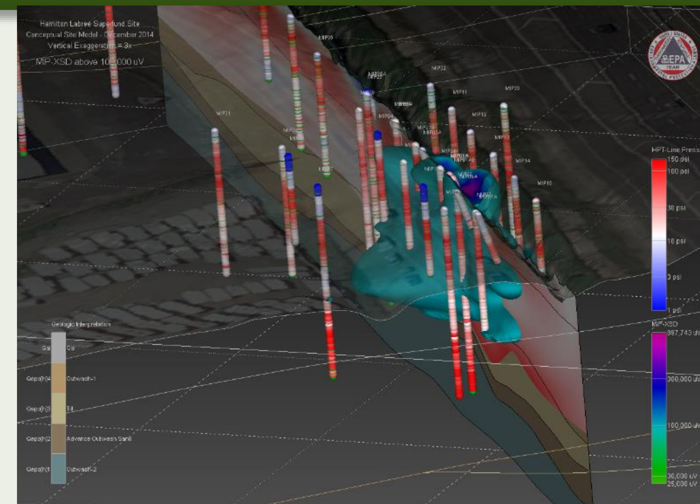
HRIA RI work products

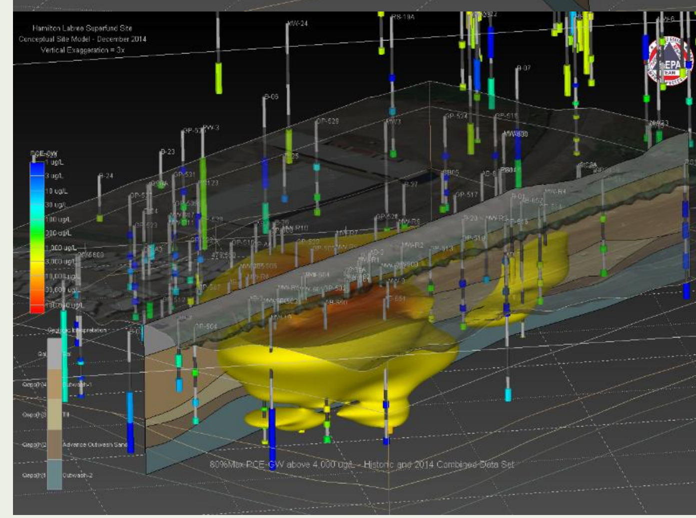












HRIA MIPHPT Geology

HRIA PCE GW

HRIA PCE Soil

Superfund Soil Cleanup CO Smelter

1.2 PROJECT OBJECTIVES

The objective of the DMA is to e
the Colorado Smelter RI:

1. Can consistent compara
laboratory methods (EP
long-term decision-maki
2. Is 30-point incremental s
composite sampling ade
quality data for the Site?
3. Are triplicate samples ne
samples be collected at
4. Is sampling at all four of

- **RPM must balance**
  - Technical challenges, variability in soil, sampling design
  - Risk management- exposure/pathway, background, risk assessment
  - Community needs/input
  - Resources, budget

- **Enter the Demonstration of Applicability (DMA)**

Initial site-specific performance evaluation for a wide range of sampling, testing, and data management tools

- Establishes that proposed technologies and strategies
  - provide information appropriate to meet project decision criteria
  - perform as advertised by the vendor
- Assesses performance of field analytical technology compared to fixed-base laboratory
- Highlights laboratory and field method advantages and challenges
- Provides initial look at CSM assumptions; augments planned data collection/CSM development
- Develops relations between visual observations and direct sensing tools
- Provides flexibility to change tactics based on DMA rather than full implementation
- Optimizes sequencing, staffing, load balance, unitizing costs

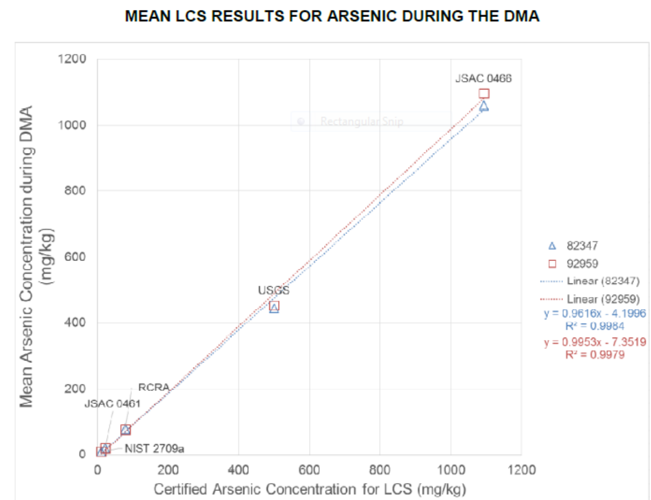
Colorado Smelter OU1
DMA- May/June 2015

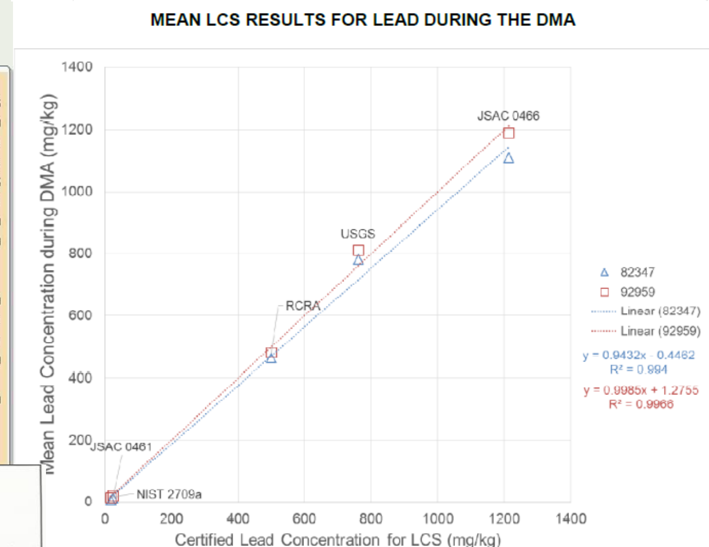
- **OU1**
  - 12 Residential properties, 0.07-0.47 acres
  - 52 total DU's
    - 3-6 DU's/property- front, side, back, drip zone, garden, play area, carport/earthen drive, apron
    - 4 depth horizons- 0-1/0-2', 2-6', 6-12', 12-18'
    - 5-point and 30-point incremental samples
    - Triplicates

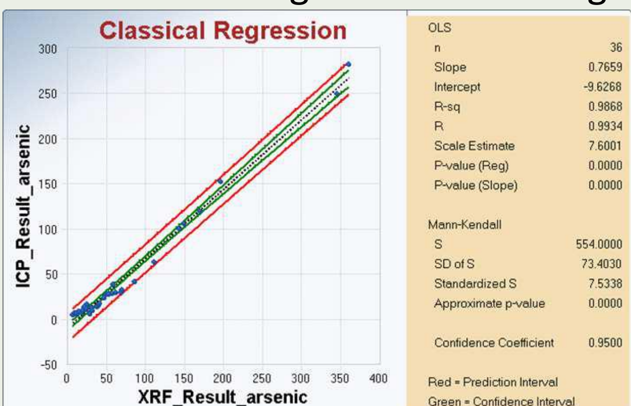
- **OU2**
  - 6 Slag/smelter areas
    - 0-2' interval, 5 point incremental samples
- **XRF (bulk, prepped, subsampled)**
  - ICP 20% of DU/depth, bioaccessability and geospeciation (Pb, As)

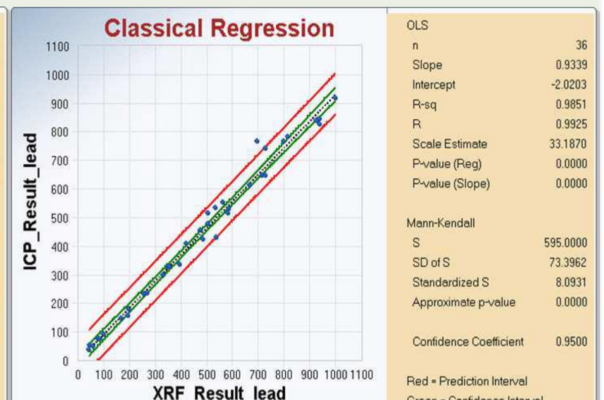
DMA Findings and Recommendations-

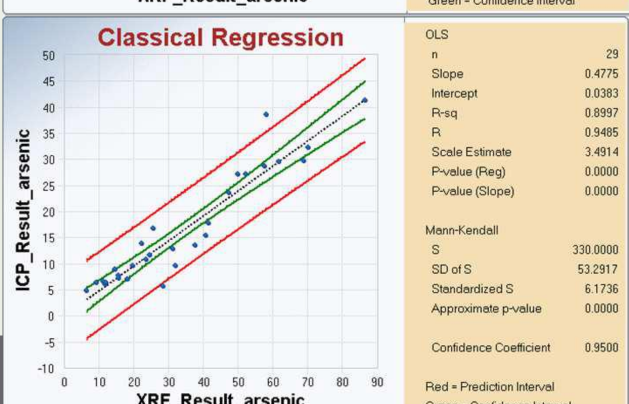
- **XRF performance/comparability**
  - As and Pb compared to 5 SRMs
    - 2 instruments- High R^2 on linear regressions
  - As and Pb compared to ICP
    - High R^2 on linear regressions

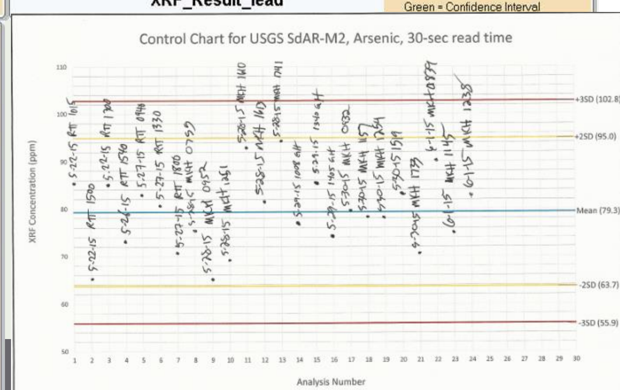












DMA Findings and Recommendations-

- **Sampling design and sample prep**
  - Design evaluated 30-pt, 5-pt, triplicates, depths
    - 154 5-pt/depth intervals, 20 30-pt/depth intervals
    - Variability in triplicates- 30-pt performs slightly better
    - Decision error rates- 5-pt and 30-pt comparable, 5-pt easily meets objectives (<20% false pos, <5% false neg)
    - Triplicates- not necessary at all DUs, 5% to measure variability and monitor decision error rates
    - Depth profiles- clarify 0-2', all 4 intervals necessary
- **Sample prep/subsampling**
  - Higher variability in bulk samples expected
  - Variability low in replicates of prepped samples
  - Potential for subsampling error removed
    - Submitting entire sample for digestion

TABLE 6-3

COMPARISON OF VARIABILITY FOR 5-POINT COMPOSITE SAMPLES TO 30-POINT INCREMENTAL SAMPLES

DU ID	RSD						DU Size (square feet)
	Arsenic			Lead			
	5-point	30-point	Difference	5-point	30-point	Difference	
SY-0269	17.2%	3.7%	13.5%	1.3%	3.6%	-2.3%	1,025
SY-0269	9.3%	2.4%	6.9%	9.8%	3.6%	6.2%	1,025
BY-0389	19.4%	11.6%	7.9%	5.4%	2.6%	2.7%	1,780
BY-0389	12.1%	14.2%	-2.1%	8.2%	8.1%	0.1%	1,780
BY-0423	9.4%	6.6%	2.9%	3.7%	2.9%	0.8%	1,623
BY-0423	3.5%	4.9%	-1.5%	5.7%	10.5%	-4.8%	1,623
SYE-0423	5.0%	8.9%	-3.9%	12.3%	4.5%	7.8%	12,626
SYE-0423	28.6%	16.8%	11.8%	80.4%	14.2%	66.1%	12,626
SYE-0423	21.9%	10.7%	11.2%	102.7%	59.5%	43.3%	12,626
SYE-0423	22.5%	8.4%	14.1%	83.9%	69.6%	14.3%	12,626
BY-1076	17.1%	15.6%	1.5%	7.8%	3.7%	4.2%	1,115
BY-1076	3.4%	8.2%	-4.8%	6.4%	1.4%	5.0%	1,115
BY-1504	14.3%	1.9%	12.4%	5.3%	1.8%	3.5%	1,896
BY-1504	4.4%	7.2%	-2.8%	20.5%	5.3%	15.2%	1,896
FY-1504	11.5%	24.3%	-12.7%	4.0%	1.9%	2.1%	1,738
FY-1504	17.0%	23.0%	-6.0%	7.4%	9.0%	-1.5%	1,738
BY-1615	8.0%	8.9%	-0.9%	3.9%	2.5%	1.4%	990
BY-1615	15.7%	19.0%	-3.3%	5.0%	5.5%	-0.5%	990
FY-1654	22.3%	14.9%	7.4%	29.0%	9.1%	19.9%	1,197
FY-1654	20.2%	15.9%	4.3%	18.0%	17.0%	1.0%	1,197
Mean	14.1%	11.4%	2.8%	21.0%	11.8%	9.2%	NC
Median	15.0%	9.8%	2.2%	7.6%	4.9%	3.1%	NC
Standard Deviation	7.3%	6.5%	NC	30.3%	18.6%	NC	NC

TABLE 6-7

DECISION ERROR SUMMARY

	Arsenic	Lead	Combined
Total samples	462	462	924
Positive results	82	157	239
True positives	75	149	224
False positives (results suggest dirty when actually clean)	7	8	15
False positive rate	**8.5%**	**5.1%**	**6.3%**
Effective false positives	4	5	9
Effective false positive rate	4.9%	3.2%	3.8%

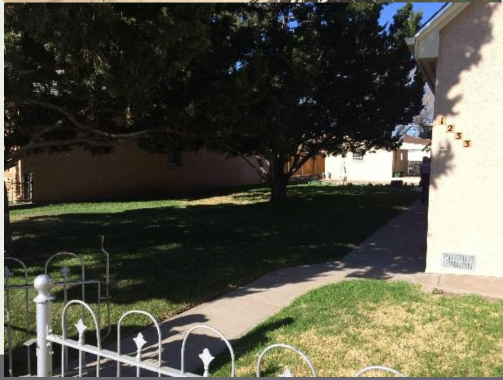
	Arsenic	Lead	Combined
Total samples	462	462	924
Negative results	380	305	685
True negatives	377	292	669
False negatives (results suggest clean when actually dirty)	3	13	16
False negative rate	**0.8%**	**4.3%**	**2.3%**
Effective false negatives	1	4	5
Effective false negative rate	0.3%	1.3%	0.7%

DMA Findings/Recommendations-
Addressing Hotspot/Dilution Concern

- **Hotspots**

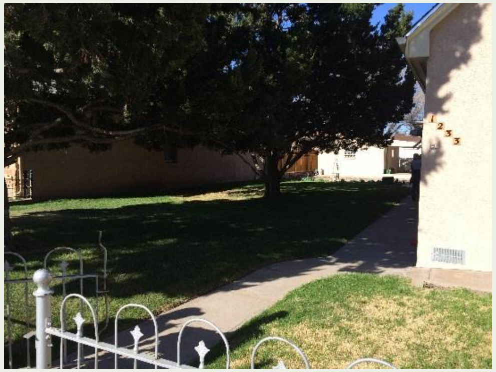
  "Even an ant walks off a wine cork at some point"- Marc Stifelman RA EPA R10

  – Accounted for in exposure scenarios/risk assessment
  – Release and transport mechanisms not consistent with hotspot potential
  – Most DU's extremely small, good coverage
  – Variability in triplicates low
  – Variability between 30-pt and 5-pt limited
  – Decision error rates relatively unchanged, exceed project goals



DMA Findings/Recommendations-
Addressing Hotspot/Dilution Concern

- **Dilution**
  - All samples are some form of a composite
  - We actually want an estimate of the mean
  - DU's sized to represent exposure scenarios
  - No mixing of increments from DU's, properties, OU's etc.
    - Where dilution can be a consideration
  - Variability in triplicates low
  - Variability between 30-pt and 5-pt limited
  - Decision error rates relatively unchanged

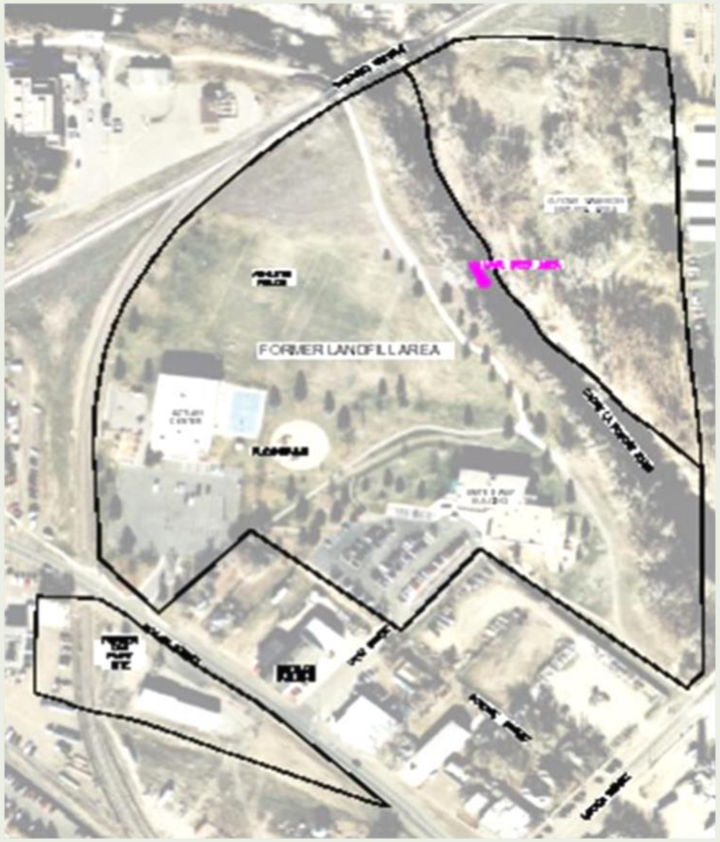


Cache La Poudre River Fort Collins, Colorado Case Study

United States Environmental Protection Agency

Site History and Background

- **City of Fort Collins awarded a brownfields grant in 2001**
  - Expand existing community center over old city landfill
  - Initiated investigation targeting the potential impacts of the landfill and the surrounding area on indoor air quality of the proposed building



Brownfields Investigation

- Landfill operated from late 1930s until 1963
- A MGP operated from 1904 until 1927 immediately across the street
- Post 1927, a gasoline distribution business (including a gas station) operated on the MGP parcel
- Machine shop operated to the immediate southwest of the landfill
- Sites adjacent to major recreational use river
- Varying stakeholder views on sources and causes – managed through use of evolving CSM

NAPL Discovery

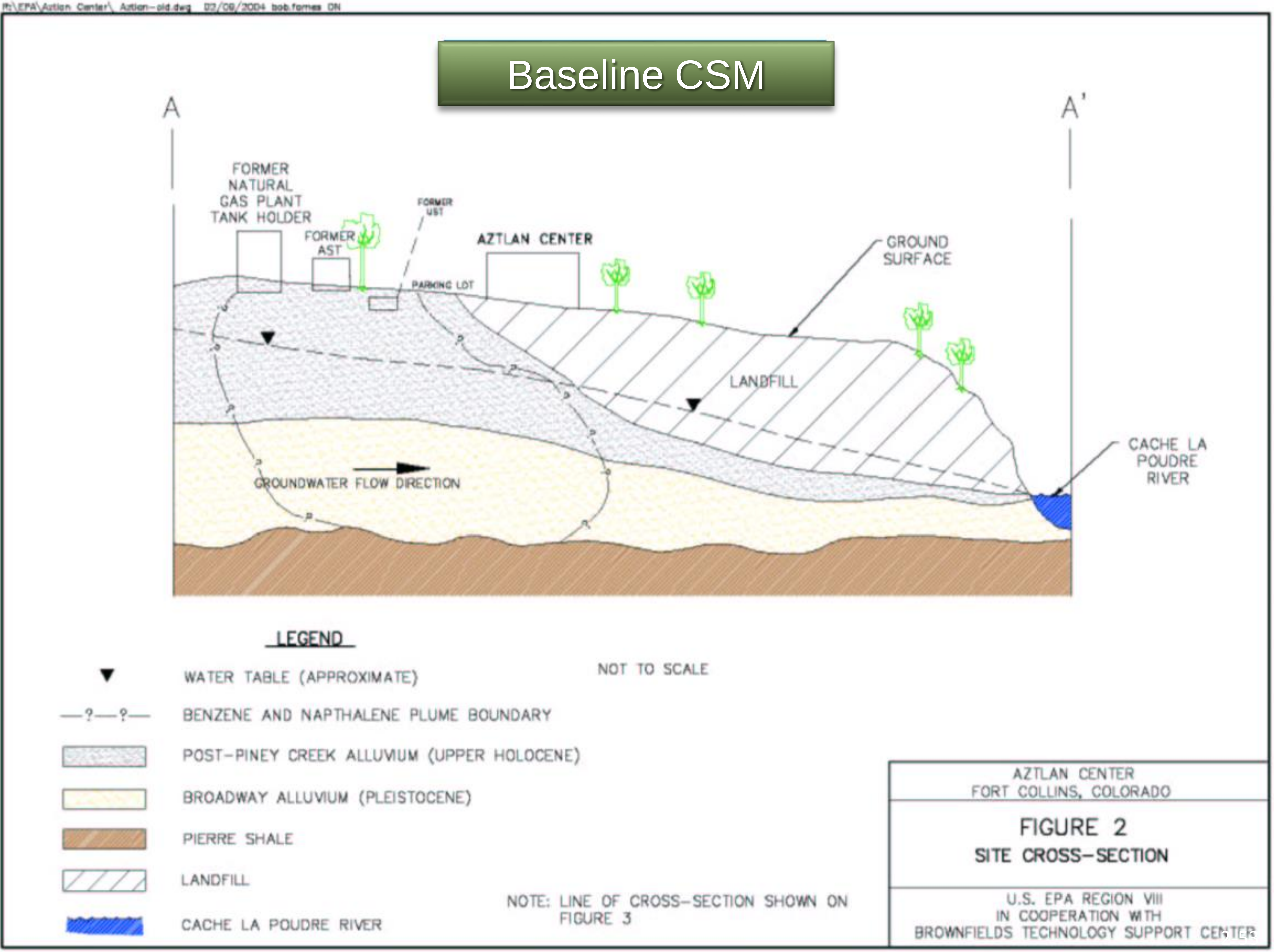
- October 2002, NAPL liquid (previously not observed on-site) discovered in the river
- Subsequent investigation by Brownfields Program indicated it to be fairly substantial
- October 2003, site referred to the removal program and site assessment performed by the Superfund Technical Assessment and Response Team 2 contract

Contaminants

- **Groundwater**
  - BTEX, MTBE plume
  - PAH plume
  - TPH
  - Chlorinated solvent plume
- **Subsurface soil and river sediments**
  - NAPL containing PAHs
  - BTEX
  - TPH

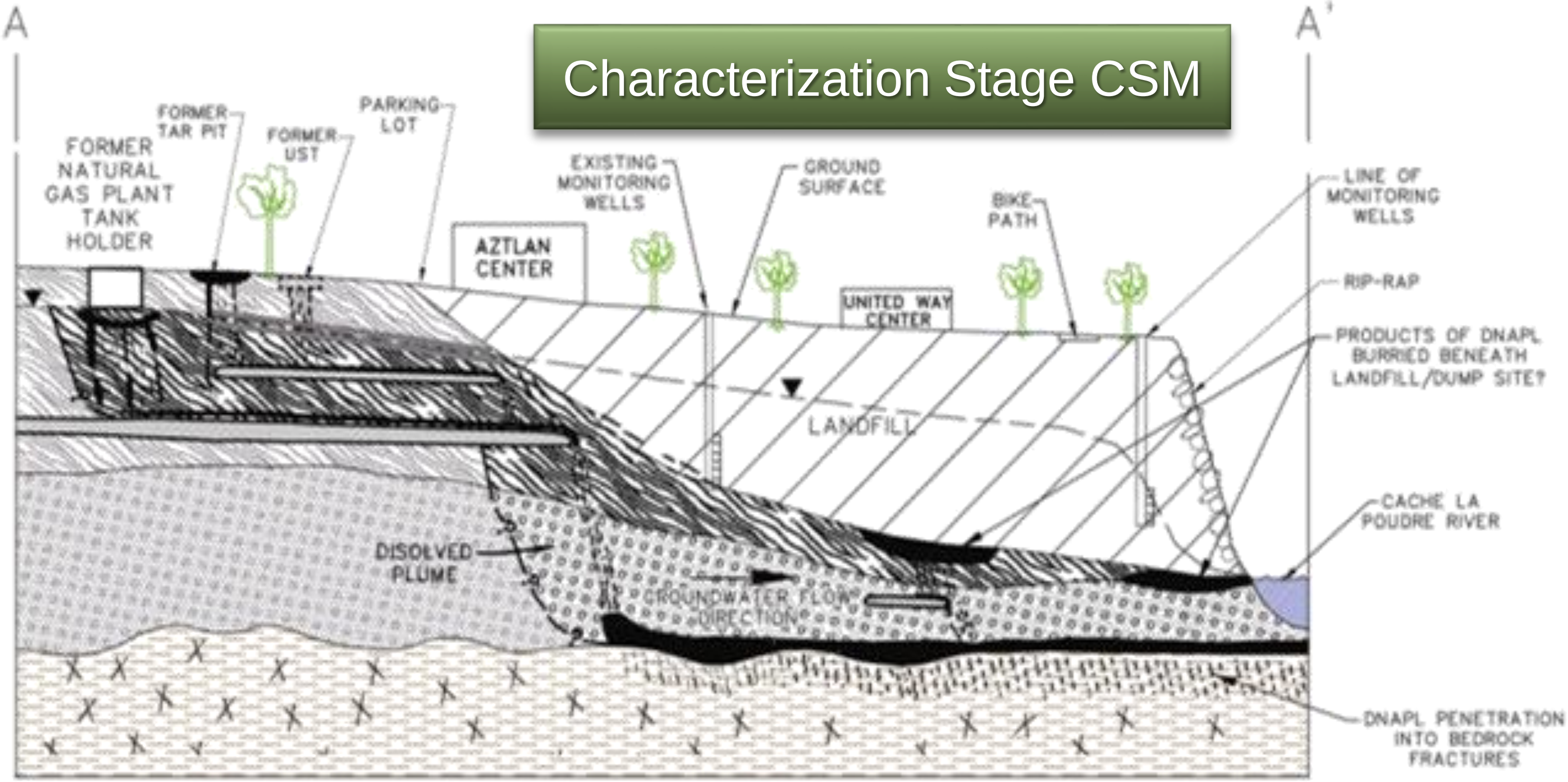
Investigation Techniques

- **Conventional**
  - Exploratory trenches in the river
  - Soil gas sampling over the entire landfill and river bank
  - Soil borings and groundwater well installation
- **Innovative/Real-Time Measurement**
  - Direct-push groundwater sampling methods
  - Electromagnetic geophysical methods
  - High-resolution resistivity geophysical methods
  - On-site GC/MS analysis of VOCs in groundwater
  - Passive soil gas
  - Passive diffusion bag groundwater sampling methods
  - Open-path Fourier transform infrared spectroscopy



Baseline CSM
A
A'
FORMER NATURAL GAS PLANT TANK HOLDER
FORMER AST
FORMER UST
PARKING LOT
AZTLAN CENTER
GROUND SURFACE
LANDFILL
GROUNDWATER FLOW DIRECTION
CACHE LA POUDRE RIVER
LEGEND
WATER TABLE (APPROXIMATE)
BENZENE AND NAPTHALENE PLUME BOUNDARY
POST-PINEY CREEK ALLUVIUM (UPPER HOLOCENE)
BROADWAY ALLUVIUM (PLEISTOCENE)
PIERRE SHALE
LANDFILL
CACHE LA POUDRE RIVER
NOT TO SCALE
NOTE: LINE OF CROSS-SECTION SHOWN ON FIGURE 3
AZTLAN CENTER
FORT COLLINS, COLORADO
FIGURE 2
SITE CROSS-SECTION
U.S. EPA REGION VIII
IN COOPERATION WITH
BROWNFIELDS TECHNOLOGY SUPPORT CENTER

Characterization Stage CSM



NOT TO SCALE

LEGEND

- POST–PINEY CREEK ALLUVIUM (UPPER HOLOCENE)
- BROADWAY ALLUVIUM (PLEISTOCENE)
- WEATHERED AND FRACTURED PIERRE SHALE
- LANDFILL
- INTERBEDDED CALICHE/CEMENTED SANDSTONE LAYERS
- —?—?— PETROLEUM HYDROCARBONS AND NAPTHALENE DISOLVED PLUME BOUNDARY
- NON–AQUEOUS PHASE LIQUIDS (DNAPL)
- LIGHT NON–AQUEOUS PHASE LIQUIDS (LNAPL)
- ▼ WATER TABLE (APPROXIMATE)
- WELL SCREEN INTERVAL

NOTE: LINE OF CROSS–SECTION SHOWN ON FIGURE 3

AZTLAN CENTER
FORT COLLINS, COLORADO

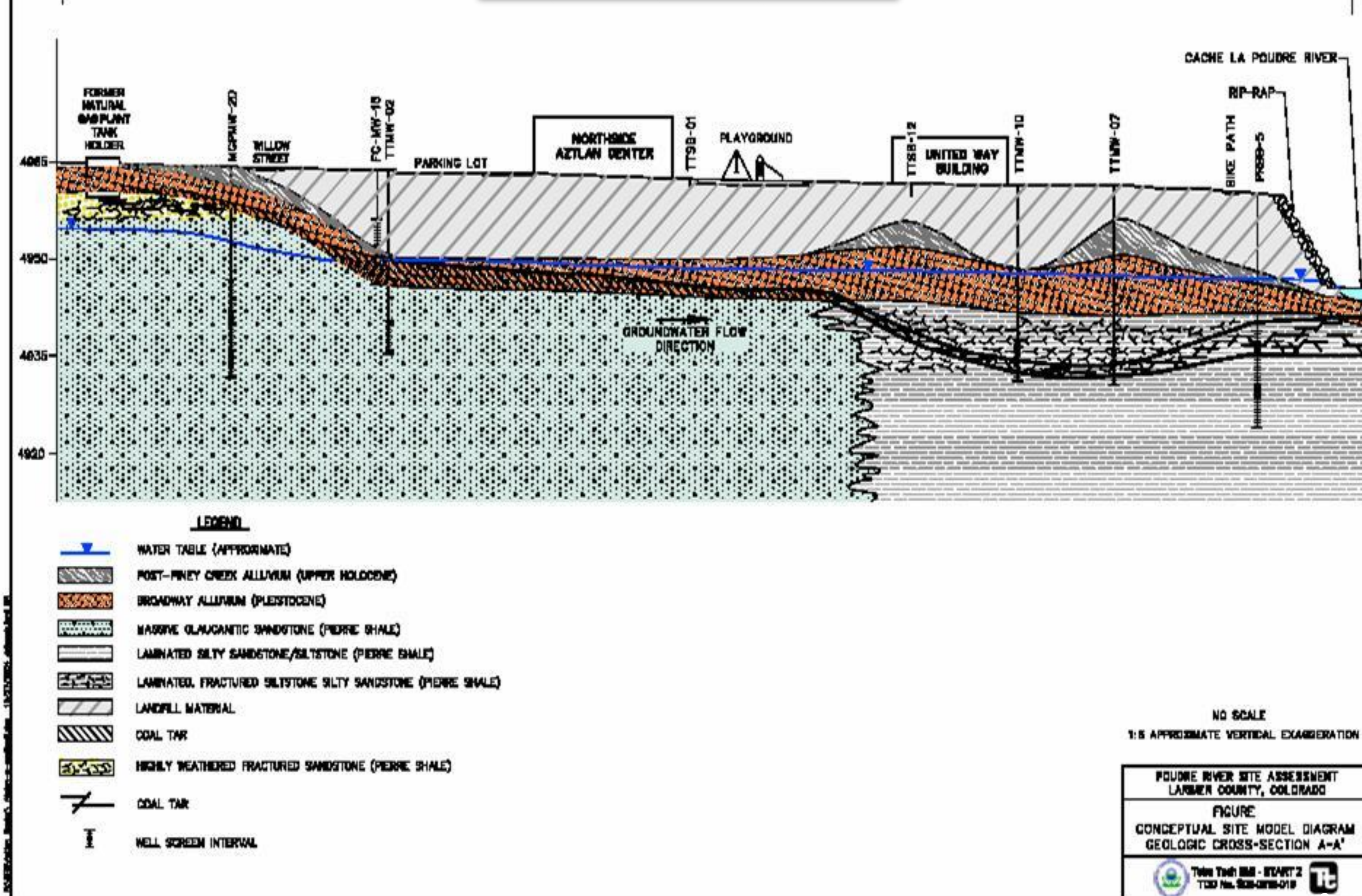
FIGURE 2
CONCEPTUAL SITE MODEL DIAGRAM AND GEOLOGIC CROSS–SECTION

U.S. EPA REGION VIII
IN COOPERATION WITH
BROWNFIELDS TECHNOLOGY SUPPORT CENTER

Results of Investigation

- NAPL = coal tar, likely mixed with gasoline and diesel components
- NAPL sank down through the alluvium to the top of area bedrock and traverses toward the river
- Near the landfill, NAPL moved entirely into fractures in the bedrock, eventually accumulating under river
- NAPL in the river sediments over a 300' stretch
- Underneath the river in the bedrock over a 600' stretch
- NAPL migrated slightly past the river in deep bedrock (20-25' bgs) fractures

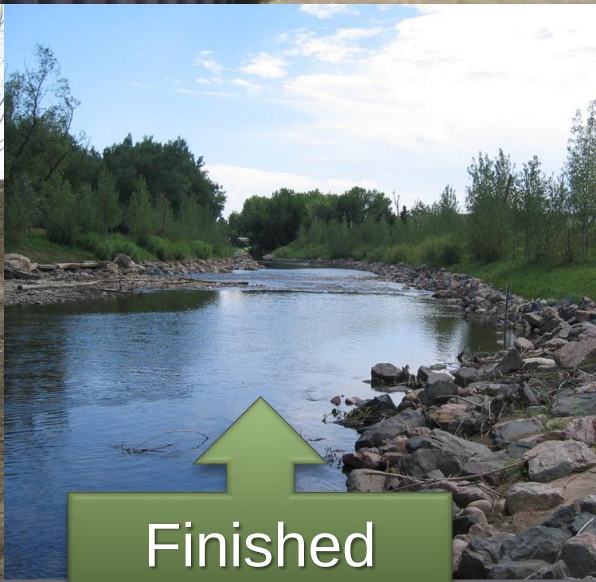
Design Stage CSM



After Friendly Negotiations

- Excavated the contaminated sediments and bedrock in and underneath the river
- Installed a vertical sheet pile barrier with hydraulic controls to intercept the NAPL
- Provided for long-term water treatment

Remediation in a Nutshell



Finished Product

Benefits of Triad BMPs for Characterization / Remediation

- ♦ **Estimated cost savings of ~30% compared with more traditional approach (multiple mobilizations, fixed-based analytical methods)**
- ♦ **Increased size and quality of data set used to make decisions**
- ♦ **Adequate characterization assured functional mitigation strategy was installed appropriately in first attempt**
- ♦ **Difficult to evaluate cost savings associated with installation of poorly-designed initial remedy**
  - » Remedy cost was ~$13 million
  - » Installation of poorly designed system would have been very expensive in long run

Award-winning site Brownfields Redevelopment Effort

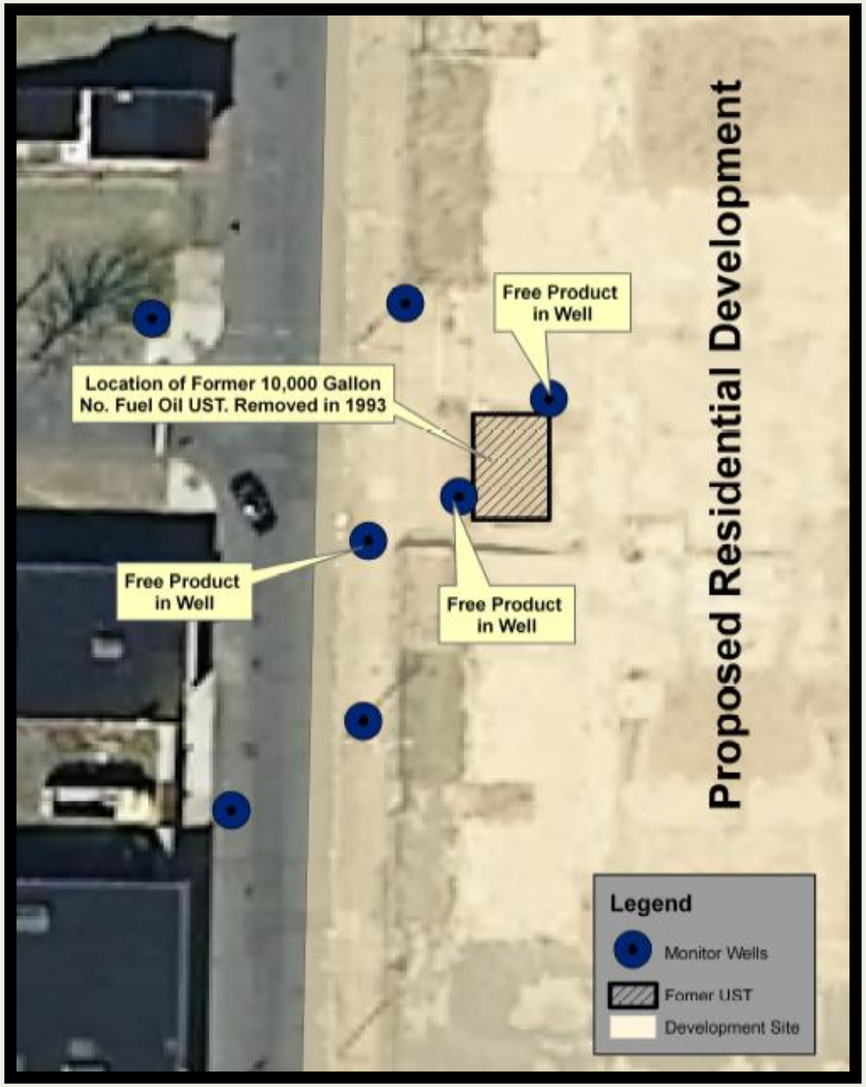
- **First community center in the United States certified Leadership in Energy and Environmental Design (LEED®) Gold**

North Aztlan Community Center

Case Study: Excavation of TPH-Contaminated Soil – Removal

EPA
United States
Environmental Protection
Agency

Case Example – Delineation of TPH Contamination from UST Release Using Collaborative Data Sets and Imaging

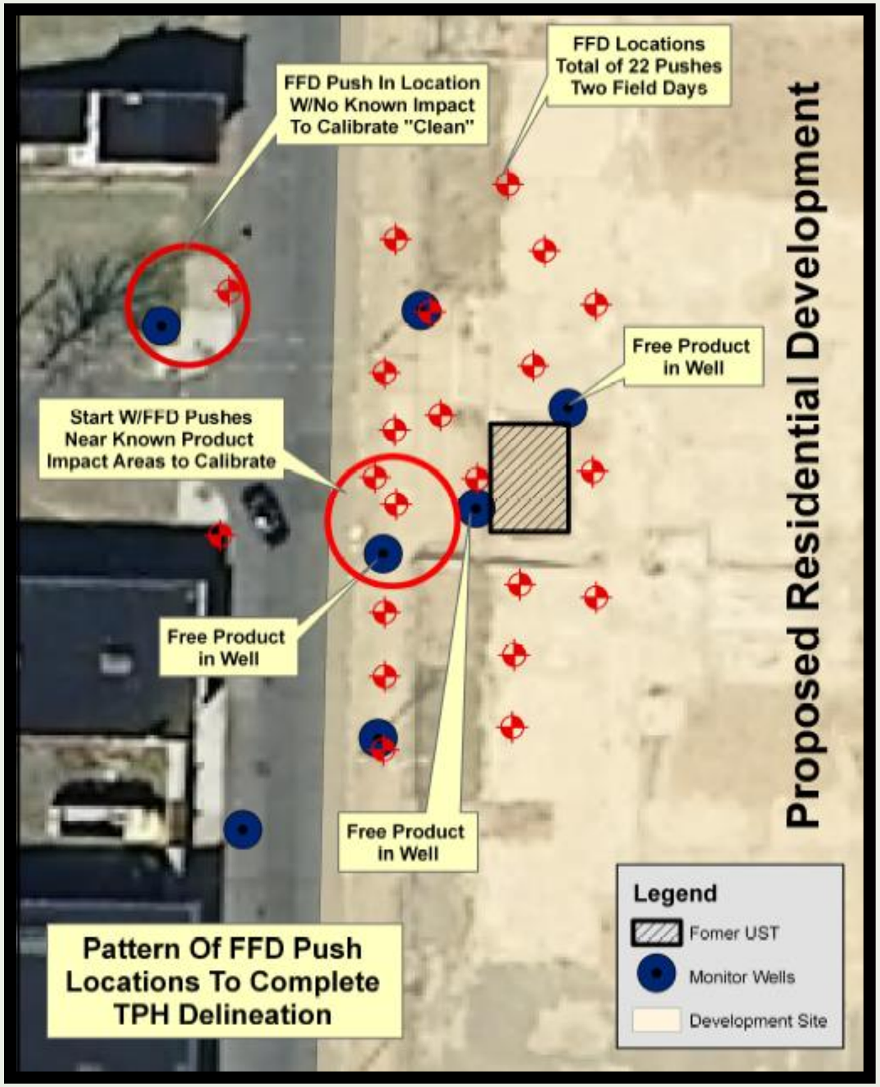


- 10,000 gallon heating oil UST leaked released No. 2 fuel oil
- Limited site investigation consisted of monitoring wells
- Proposed residential development on former school site
- Delineate TPH contamination zone and define core impact area for the purposes of remediation

Delineation of PHC Contamination in Soil Caused By UST Release

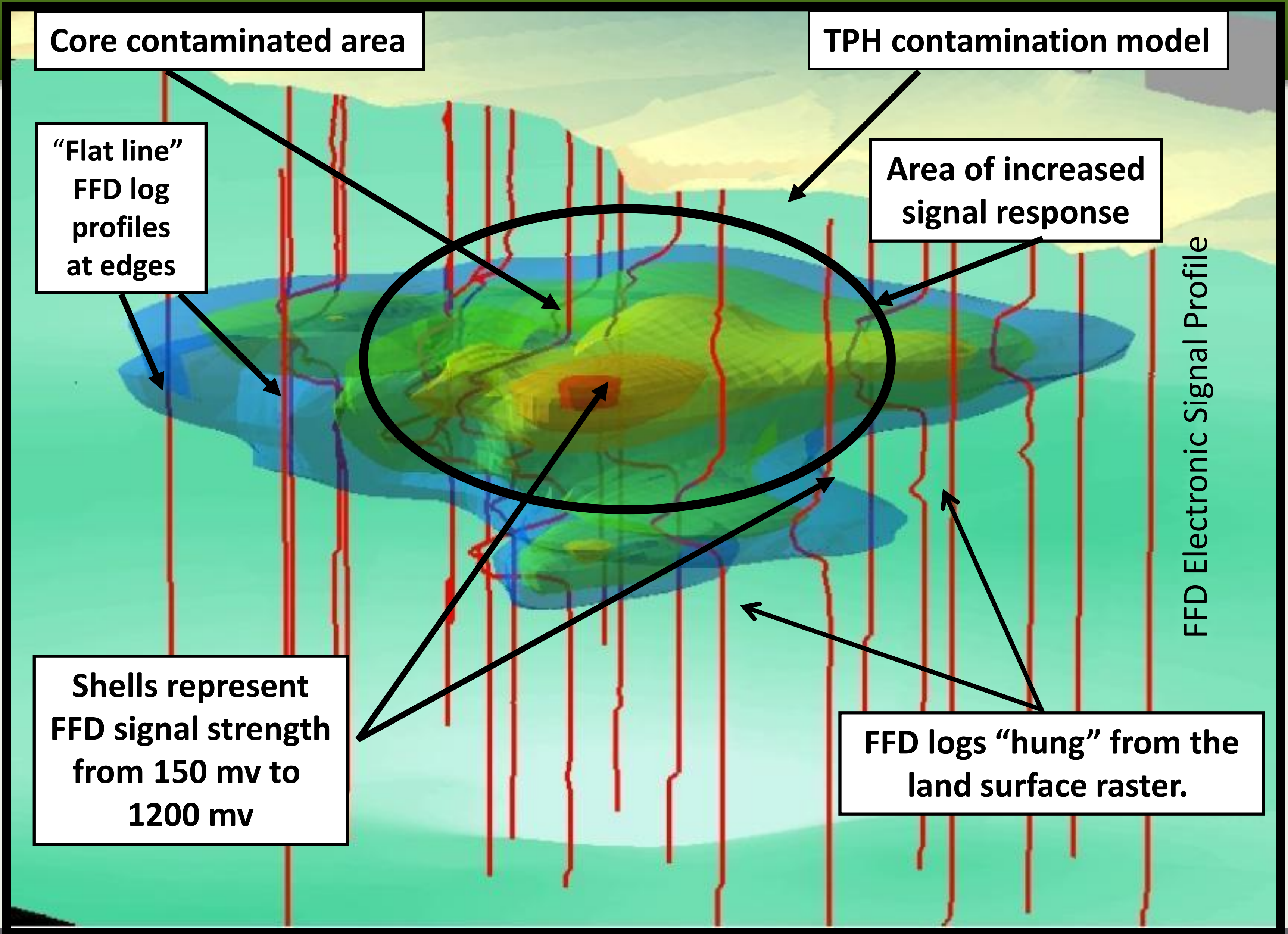
- **PHC in soil delineated using an FFD**
  - Employs UV light source to locate TPH
- **Locations of depth-discrete soil and groundwater samples were selected based on FFD Logs**
- **Data sets were imaged using ArcGIS 3-D Imaging Software to depict contaminated zone**
- **To support remedial action design, visualization used to:**
  - Gain regulatory acceptance regarding completeness of delineation
  - Decide on limits of excavation before construction
  - Design the excavation project and estimate volumes

FFD Pushes Used to Delineate Extent of Contamination

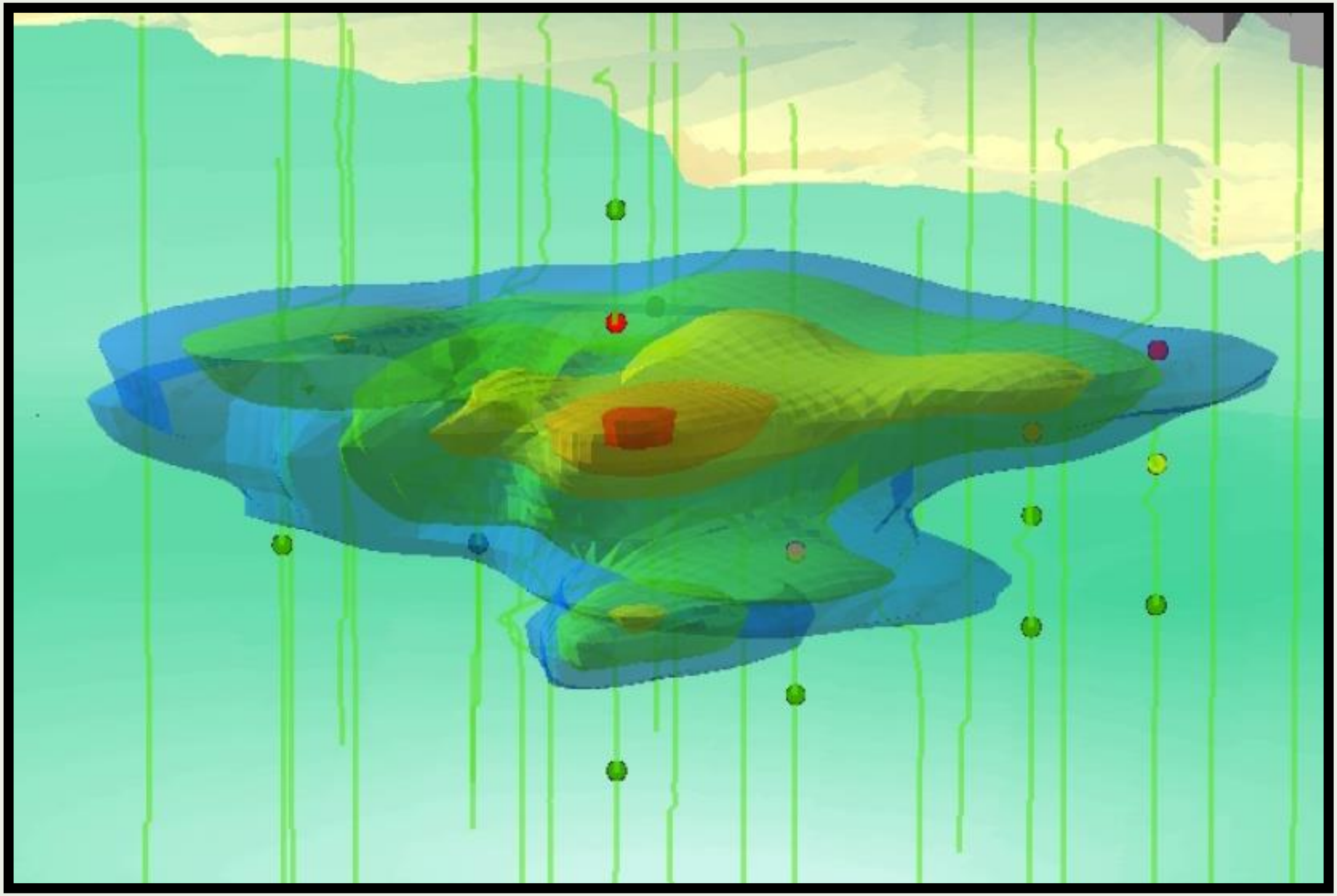


- Begin at locations of known highest TPH impact or free product in well
- Test instrument response
- Next "go to" location with little to no TPH impact
- Perform dynamic field based "step outs" to instrument "flat line"
- When FFD shows no response ("flat Line") confident TPH below 100 ppm

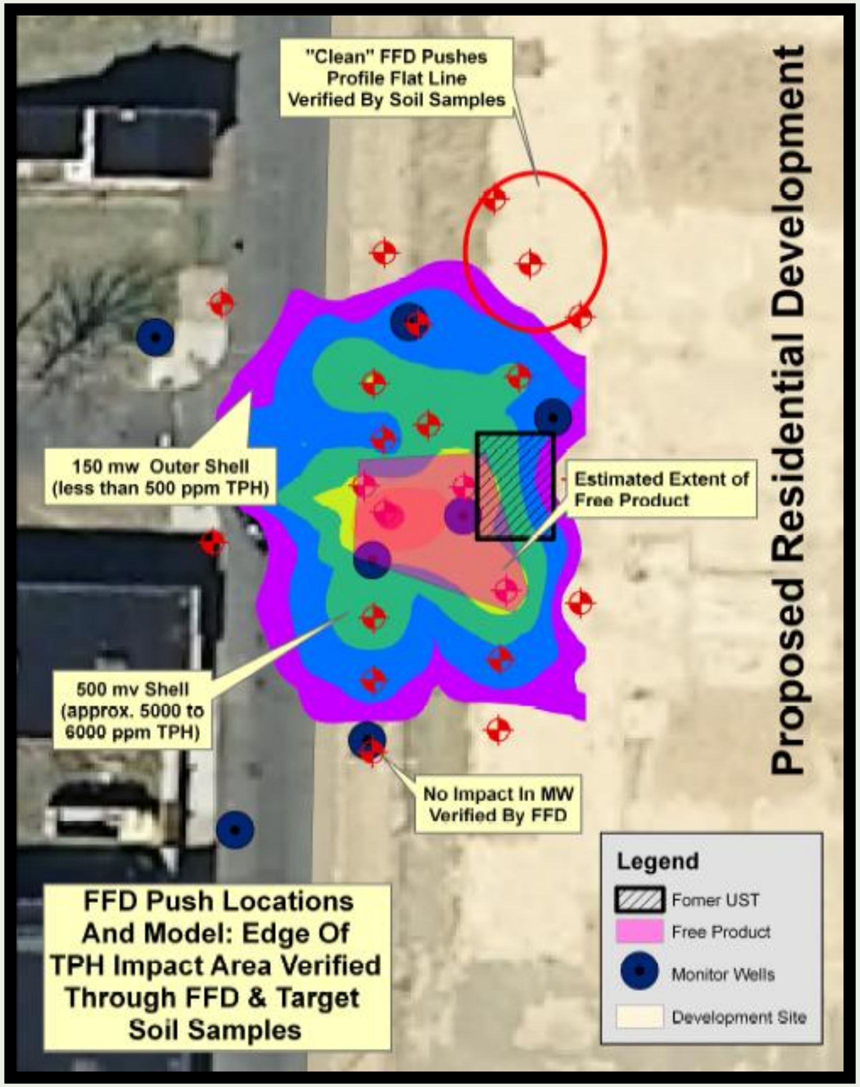
TPH Contamination Area 3-D Visualization Built From FFD Profiles



Collaborative Data Sets Demonstrate Delineation

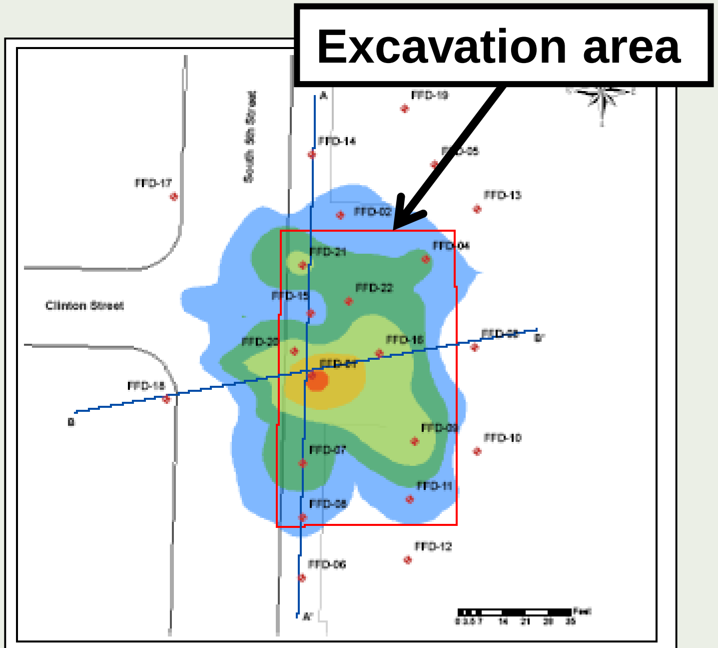


TPH-Contaminated Area Delineated

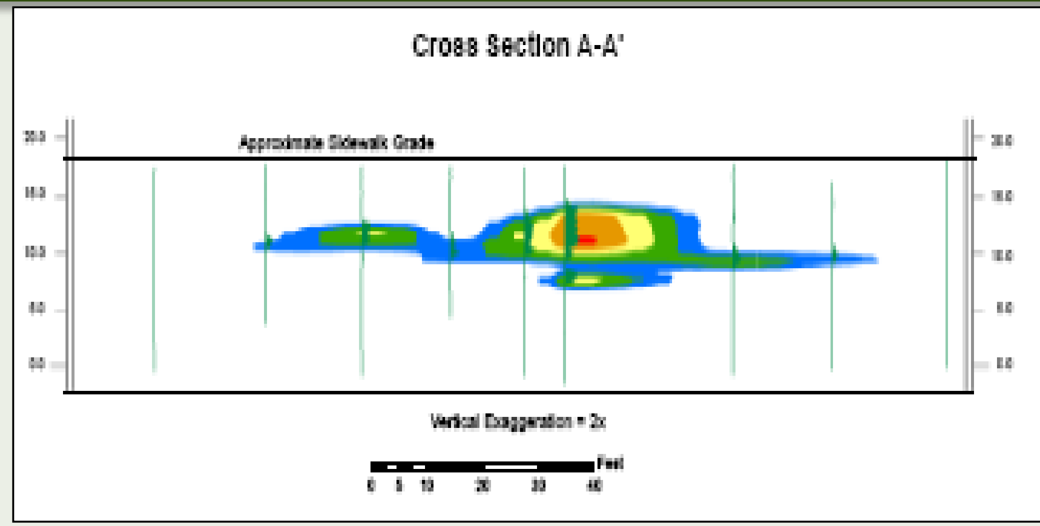


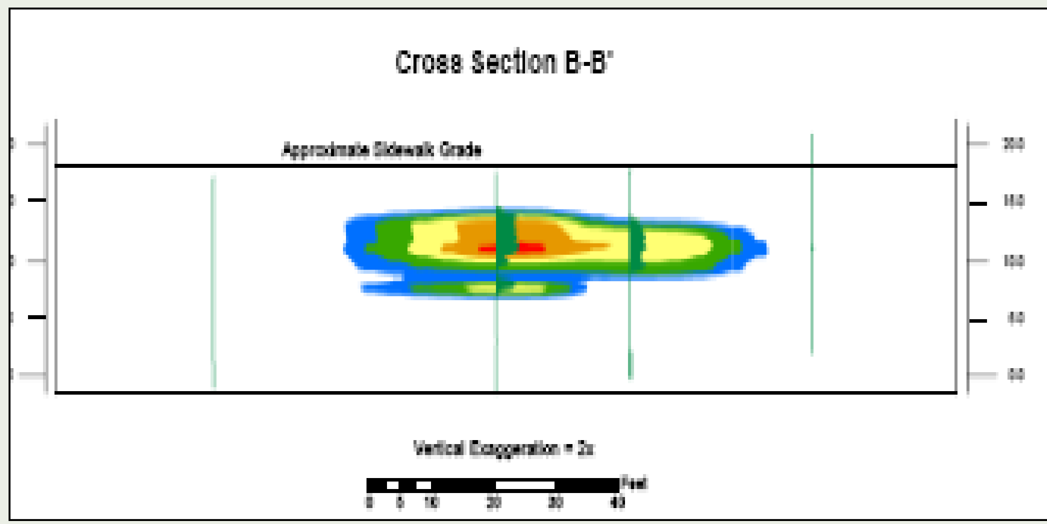
- **Extent of TPH-contamination verified through collaborative data set and visualization**
- **Various cleanup options can be quickly evaluated:**
  - Total removal to beyond 150 mv shell
  - Removal to extent of 500 mv shell which correlates with approximately 5 to 6,000 ppm TPH
  - Free product and core contaminated area removal for maximum risk reduction benefit

Engineering Analysis – Cross Sections Showing Distribution of Fuel Contamination and Location of Excavation



Fuel Fluorescent Detector (FFD)
Model Results - Plan View



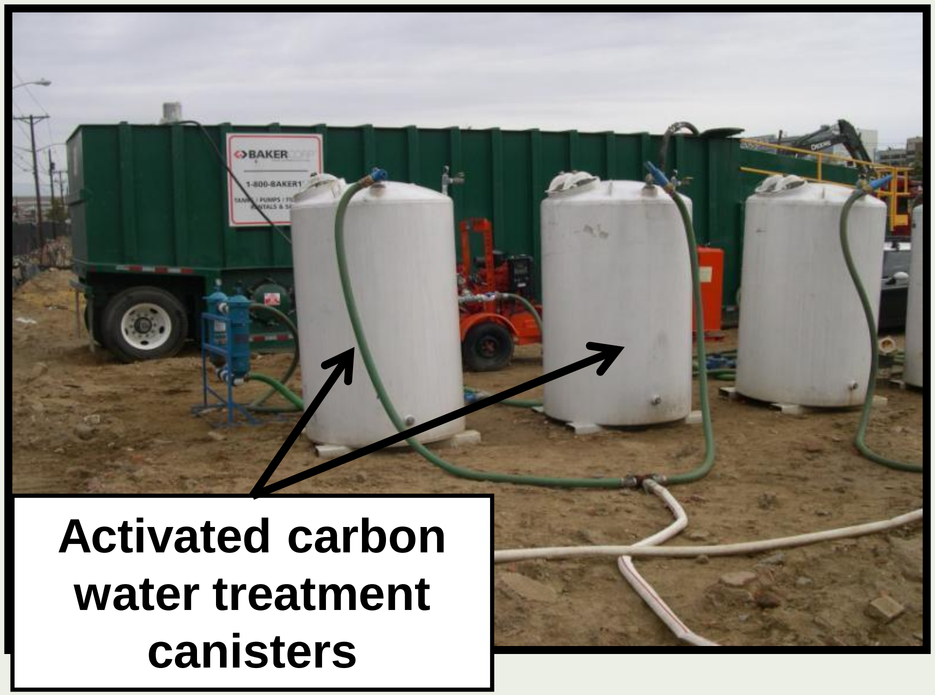


Sheet Piling Cutoff Wall Installed Along Edge of Roadway

- **TPH-contaminated area near a roadway excavated**
- **Sheet piling installed along border between school site and roadway**

Well Point Dewatering System

- TPH-contaminated soil extended below water table
- Well point system installed to depress water table at location where TPH-contaminated soil was excavated

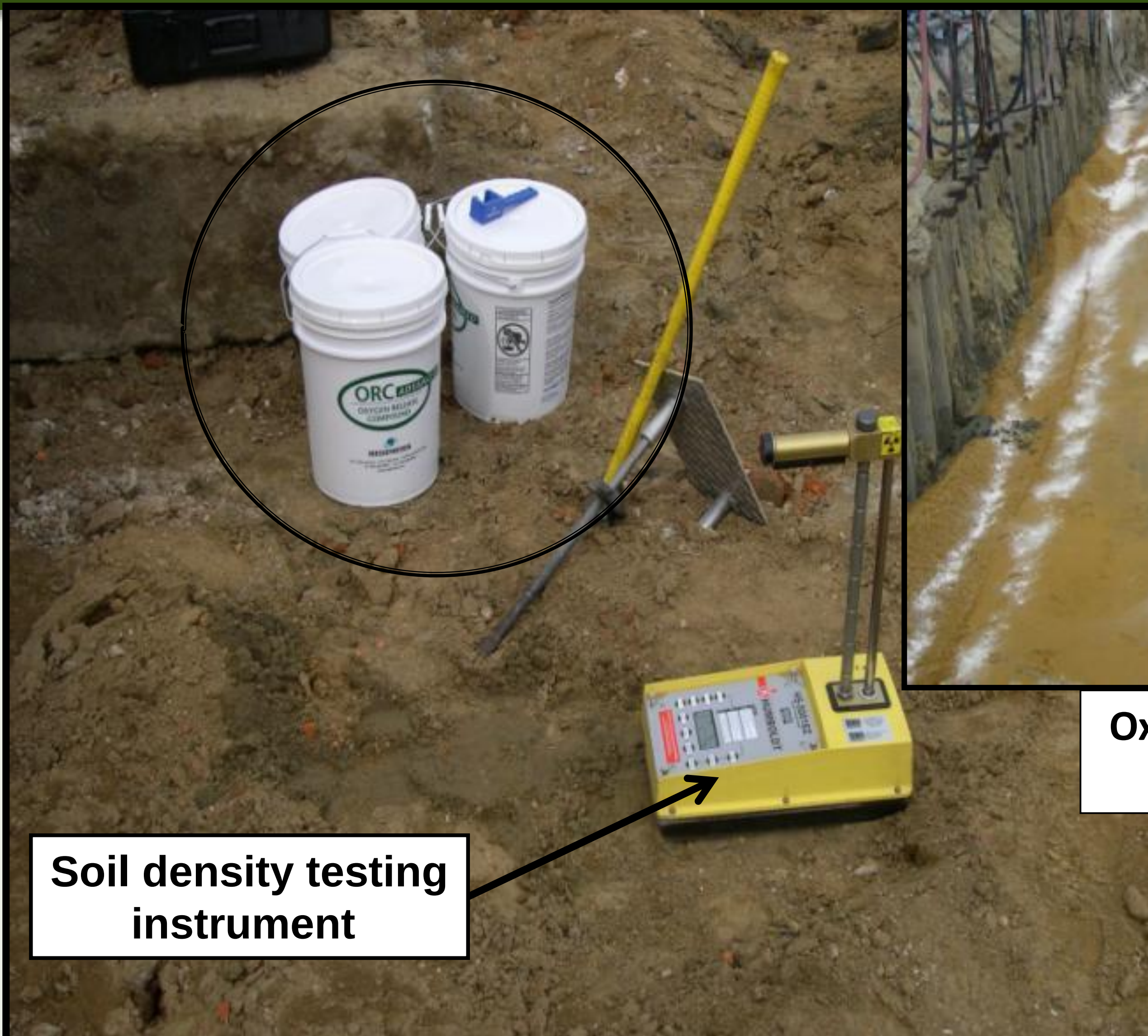


TPH-Contaminated Soil Removal

- Soil contaminated with PHC from UST Release
- Clean backfill staged on site prior to excavation to minimize open excavation time
- Excavated with dewatering system support
- Oxygen Release Compound spread in with backfill to promote biodegradation of residual TPH compounds
- Backfill material spread and compacted

Excavation of TPH-contaminated Soil

Oxygen Release Compound Added to Promote Biodegradation of Residual TPH



Soil density testing instrument

Oxygen Release Compound spread in backfill

Stockpiling, Spreading, and Compacting Cleanup Backfill

Summary

- ♦ **Real-time measurement technologies can provide high-density data sets that can rapidly advance the CSM**
- ♦ **Probe electronic signals are compatible with ArcGIS and other imaging software and can be easily visualized in 3-D**
- ♦ **Sorting image by signal strength can provide indication of contaminant concentration distribution**
- ♦ **Discrete sample soil and groundwater locations can be selected to verify signal strength, concentration correlation and confirm delineation**
- ♦ **Image (the CSM) is recreated using collaborative data**
  - » Electronic signals from probe
  - » Discrete sample analytical results
- ♦ **Mature CSM 3-D visualization can be used for selection and design of remedial action**

Case Study – Fannon Petroleum Site, Virginia

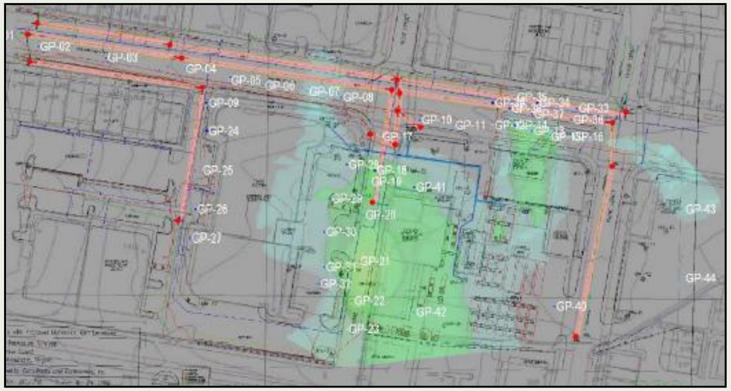
- Fuel Depot since late 1800s
- Most recent facility since 1962
- ASTs and USTs
- > 500,000 gallon capacity
- Early 1980s release

Systematic Planning Considerations

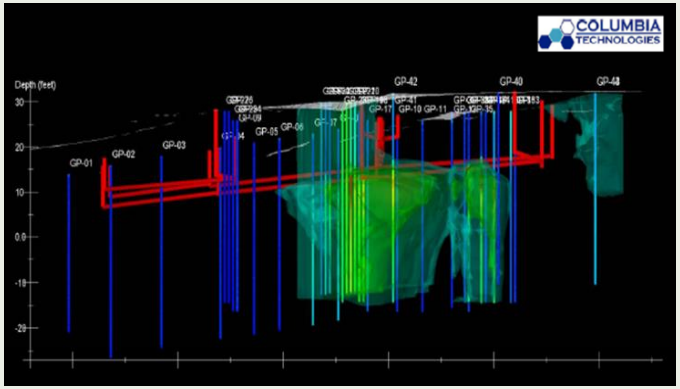
- **Unconsolidated geology (relatively uncomplicated)**
  - MIP with collection of soil samples for laboratory analysis
- **Developer with plan (residential)**
- **Identify hot spots requiring remediation**
- **Define threshold contamination level above which remediation was necessary**
- **Stakeholder concurrence and acceptance**
  - City, owners, citizens
- **Identified receptors**

MIP Survey

MIP Results



- Closely correlated with plume defined by conventional investigation methods
- MIP identified previously unknown contamination
- Plume appeared to intersect sanitary/storm sewer system
- Some adjustments to construction plan (such as depth of structures)
- Negotiated environmental redevelopment actions which could be potentially be reimbursed under state UST fund



Remedial Actions

- ♦ **Excavation and removal of 28 USTs**
- ♦ **Excavation and disposal of 35,317 tons of petroleum-impacted soil**
- ♦ **Recovery and disposal of 1,000 gallons of free-phase petroleum**
- ♦ **Ongoing subsurface remediation at down-gradient adjacent property**
- ♦ **Continued reduction in amount of subsurface contamination**
- ♦ **Post-CAP monitoring in near future**

Redevelopment 2008/2009

Before

After