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Use of Geostatistical 3-D Data Visualization/Analysis in Superfund Remedial Action Investigations

Delivered: September 23, 2011, 1:00 PM - 3:00 PM, EDT (17:00-19:00 GMT)

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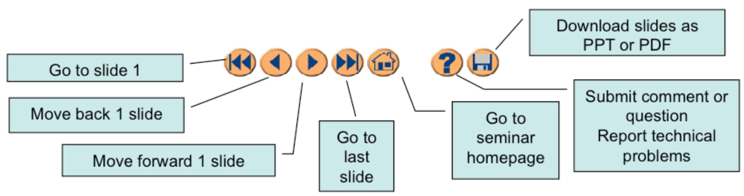

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With that, please move to slide 3.

Use of Geostatistical 3-D Data Visualization / Analysis in Superfund Remedial Action Investigations

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(Under Subcontract to Tetra Tech EMI)

September 23, 2011

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Overview

- Making the Case: 3-D Visualization / Analysis in Superfund Remedial Action
- Case Study –
  - Introduction to the Time Oil / Well 12A Superfund Site
  - Use of 3-D visualization / analysis to:
    - Identify data gaps and controls on remediation
    - Optimize remedy implementation
- Best Management Practices
- Additional Resources

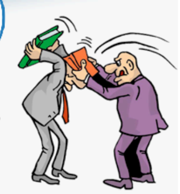
Making the Case: Why 3-D, Why Now?

- Rapid acceleration of benefit and utility of visualization platforms in the environmental industry
- Conceptual site models (CSMs) support decision making
  - Moving beyond conceptual “cartoons”, pathway-receptor network diagram-based CSMs
  - Geo-referenced geologic, hydrogeologic, and analytical data facilitate resolution of technical challenges
- Reconstruction limits data “interpretation bias”
  - For information value, data must be interpreted, but interpretations can be incorrect or incomplete
- EPA renewed emphasis and new focus areas
  - Renewed emphasis on high quality characterization in support of remedy selection, design and optimization
  - New focus on more meaningful and effective community engagement

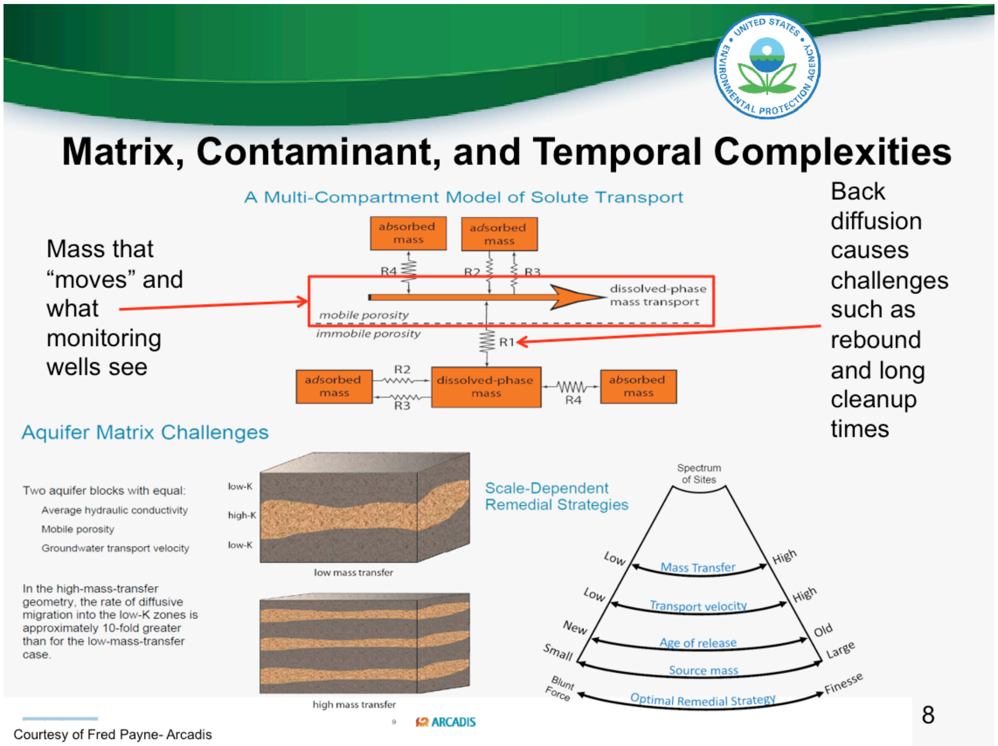
Programmatic Remediation Costs

- Remediation can be an order of magnitude or more higher than other pipeline costs
  - 3-D can help in any stage
- Groundwater, volatile organic compounds (VOCs), dense non-aqueous phase liquid (DNAPLs) - particularly challenging for Superfund Program, reaching Maximum Contaminant Levels (MCLs)
  - Small plume footprints - intensive treatment can overwhelm matrix
  - Large plume footprints - intensive treatment of entire footprint is not likely cost-effective
    - Leaves combined remedies and active treatment zones / clean water flushing
    - Target compounds, age of release, and aquifer matrix structure are critical determinants of how easily MCLs can be achieved

Challenge #1 - Technical Disagreements Among Stakeholders



- Often attributable to competing CSMs
  - 3-D visualization / analysis helps us understand the “Rumsfeld Principle”
- Changing Project Managers (PMs), contractors, property owners
  - Variability often compromises quality of data and conclusions
  - 3-D visualization / analysis treats all data equally
- Data type and density versus resources and Standard Operating Procedures (SOPs)
  - Analytical and direct sensing quality vs. spatial and temporal measurement density


Matrix, Contaminant, and Temporal Complexities
A Multi-Compartment Model of Solute Transport
Mass that "moves" and what monitoring wells see
Back diffusion causes challenges such as rebound and long cleanup times
absorbed mass
adsorbed mass
R4
R2
R3
dissolved-phase mass transport
mobile porosity
immobile porosity
R1
adsorbed mass
dissolved-phase mass
absorbed mass
Aquifer Matrix Challenges
Two aquifer blocks with equal:
Average hydraulic conductivity
Mobile porosity
Groundwater transport velocity
In the high-mass-transfer geometry, the rate of diffusive migration into the low-K zones is approximately 10-fold greater than for the low-mass-transfer case.
low-K
high-K
low-K
low mass transfer
high mass transfer
Scale-Dependent Remedial Strategies
Spectrum of Sites
Low Mass Transfer High
Low Transport velocity High
New Age of release Old
Small Source mass Large
Blunt Force Optimal Remedial Strategy Finesse
Courtesy of Fred Payne- Arcadis
ARCADIS
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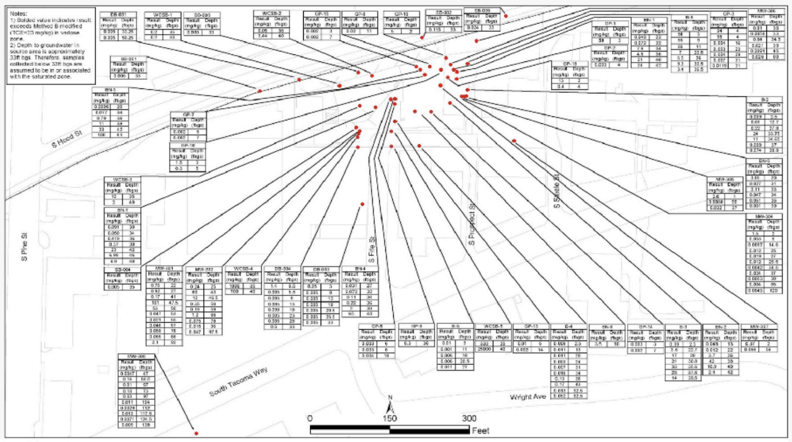
Challenge #2 - Social Aspects Can Complicate Technical Problems

- Stakeholder / Community Engagement
  - How to convey technical information in a meaningful way to non-technical audiences?
  - 2-D visualizations have limited capability to integrate chemical, geologic, and hydrogeologic information
    - Disconnected plan view and cross-sectional data subject to significant spatial extrapolation; thus potentially results in differing interpretation
  - Often large quantity of data but require careful consideration of performance metrics, trigger points, combined remedies
  - 3-D visualizations integrate multiple data types into unified representations

How Effectively Can Stakeholders Understand Contaminant Distribution and Relevance With This 2-D Visualization?



Well 12A Superfund Site
Tacoma, Washington

Figure 2-6
Trichloroethylene in Soil

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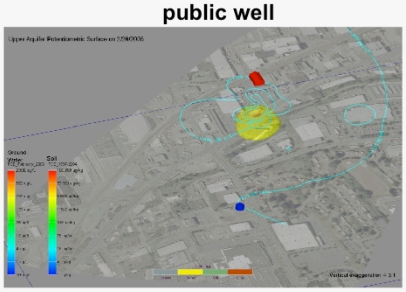
Here is the Same Data Set Integrated with Hydrogeology

3-D Visualization of TCE Plume Escaping Groundwater Extraction Treatment System (GETS)

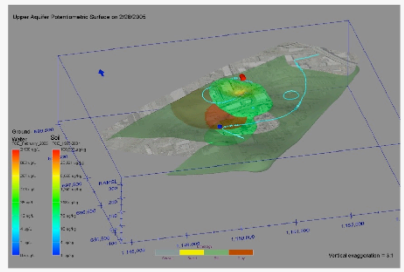
Provides easy understanding of threat to public well



12A Plume and GETS

TCE Plume Configuration and Extent is Controlled by Geology

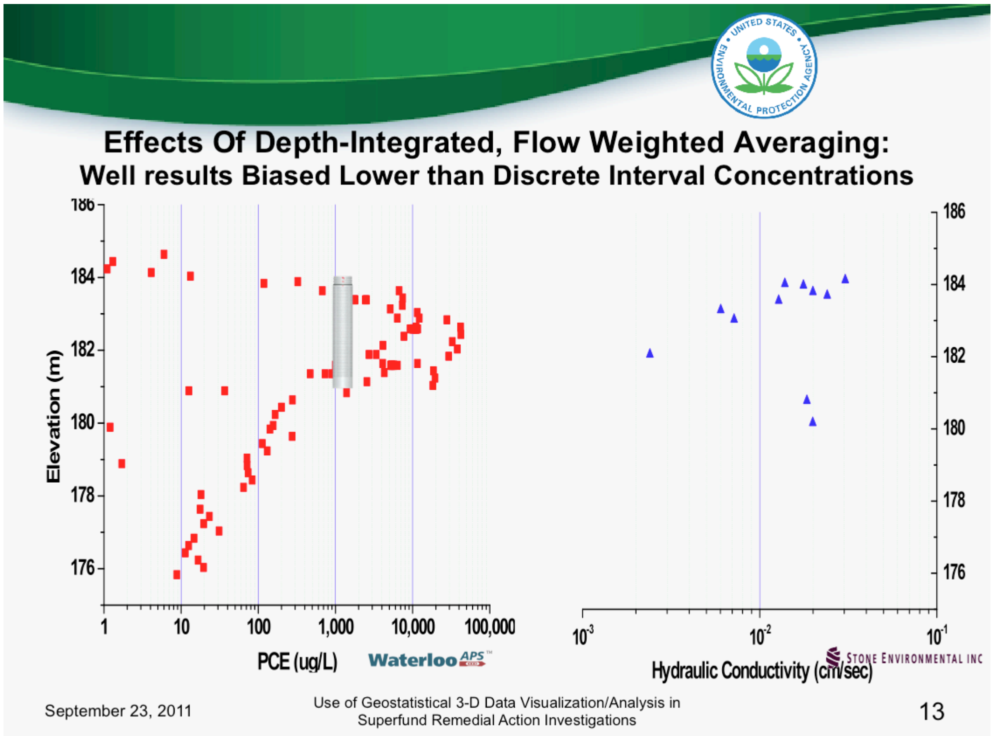
Control must be addressed in management strategies



12A Geology and Plume Morphology

Challenge #3 - Responsible Party Challenges

- Presence of inconvenient truths
  - Responsible Parties / Potentially Responsible Parties - core business is not cleaning up contaminated sites
  - Must make business vs. strictly technical decisions
- Can’t see the forest because of those pesky trees
  - Reviewers / regulators receive select data that can obscure reality or incur data overload that makes interpretation difficult
- Stakeholders don’t always like what data reconstructions in 3-D visualization do to the CSM


Effects Of Depth-Integrated, Flow Weighted Averaging:
Well results Biased Lower than Discrete Interval Concentrations
Elevation (m)
PCE (ug/L)
Waterloo APS
Hydraulic Conductivity (cm/sec)
STONE ENVIRONMENTAL INC
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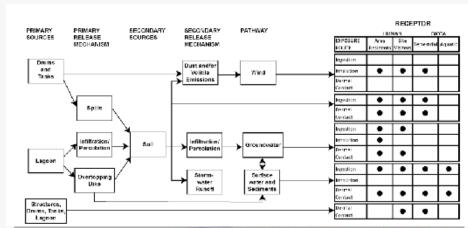
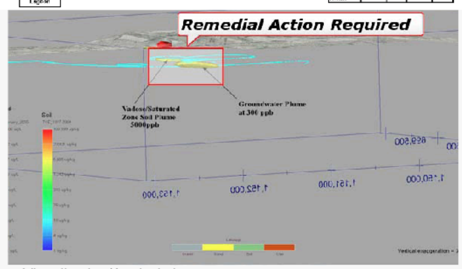
Types of Software for Environmental Data Visualization / Analysis

- Geographic Information Systems (GIS)
  - Examples – Google Earth Pro, ArcGIS, RockWorks™
  - Map (2-D) view of information
  - Useful in looking at data distributions and details of some data sets
  - Doesn't allow analysis of data with depth or elevation changes
  - Prerequisite to running of most 3-D programs
- 3-D & 4-D visualization / analysis programs
  - Examples – EarthVision®, EVS / MVS, GMS, RockWorks™, ArcGIS 3D analyst
  - Allows analysis of environmental data as a function of space (3-D) / time (4-D)
    - e.g., hydrogeology, bedrock, vadose / saturated zone distributions, sampling protocols – discrete intervals versus lengthy well screens, source to plume linkages
  - Important differentiation in types of data analysis produced by different programs
    - Geostatistical versus subjective correlations
    - Flexible (accepts all site data) versus fixed program structure

Role of the CSM and 3-D Visualization at Time Oil / Well 12A

- CSM life cycle
- Use 3-D data visualization
  - Identify and delineate specific areas that may require action
  - Understand (spatially) key hydrogeologic features controlling fate and transport

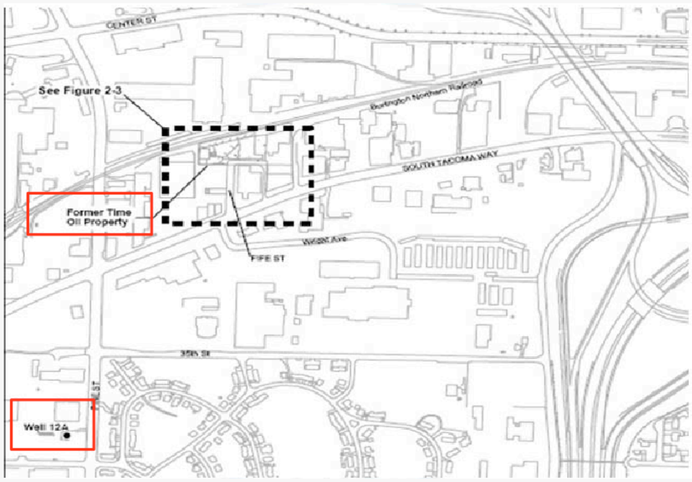




General Environmental Cleanup Steps	CSM Life Cycle	Best Management Practices: SPP	Best Management Practices: DWS/ RTMT	CERCLA - Superfund	RCRA	Brownfields	UST	VCUP Varies by State	IRP/ERP	MMRP
Site Assessment	Conceptual Preliminary CSM ↓ Baseline CSM			Preliminary Assessment (PA) Site Inspection (SI) National Priorities List (NPL) No Further Remedial Action Planned (NFRAP)	Facility Assessment (RFA)	Phase I Environmental Site Assessment (ESA)	Initial Site Characterization Initial Response	PA SI	PA SI	PA SI MR Site Prioritization Protocol (MRSPP)
Site Investigation and Alternatives Evaluation	Characterization CSM Stage			Remedial Investigation/ Feasibility Study (RI/FS) Removal Actions - Emergency/ Time Critical/Non-Time-Critical	Facility Investigation (RFI) Corrective Measures Study (CMS)	Phase II ESA	SI Corrective Action Plan (CAP)	RI/FS	RI/FS NFRAP	RI/FS
Remedy Selection	Design CSM Stage			Proposed Plan Record of Decision (ROD)	Statement of Basis (SB) Final Decision and Response to Comments	Remedial Action Plan (RAP)	Cleanup Selection	ROD	Proposed Plan ROD	Remedy Selection
Remedy Implementation	Remediation/ Mitigation CSM Stage			Remedial Design (RD) Remedial Action (RA) – Interim and Final	Corrective Measure Implementation (CMI)	Cleanup and Development	Corrective Action - Low-impact site cleanup - Risk-based remediation - Generic remedies - Soil matrix cleanup	RD RA	RD RA – Interim and Final Remedy in Place (RIP)	RD Time Critical Removal Action (TCRA) RA RIP
Post-Construction Activities	Post-Remedy CSM Stage			Operational & Functional Period Operation & Maintenance (O&M) Long term monitoring (LTM) Optimization Long Term Response Action (Fund-lead groundwater/surface water restoration)	O&M On-site inspections and oversight	Property Management Long-term O&M Redevelopment Activities (Private- and Public-led)	LTM	O&M LTM	Shakedown period Operating Properly and Successfully O&M LTM	Shakedown period Long Term Management
Site Completion	Quantitative			Construction Complete (CC) Preliminary or Final Close Out Report (PCOR/FCOR) Site Completion - FCOR Site Deletion O&M as appropriate	Certification of Completion Corrective Action Complete with Controls or without Controls	CC Property Management	No Further Action (NFA)	CC	Response Complete (RC) NFA	RC NFA

Abbreviations:
SPP = Systematic Project Planning
DWS = Dynamic Work Strategies
RTMT = Real Time Measurement Technologies
CERCLA = Comprehensive Environmental Response, Compensation and Liability Act
RCRA = Resource Conservation and Recovery Act
UST = Underground Storage Tanks
VCUP = Voluntarily Clean Up Programs
IRP/ERP = Installation Restoration Program/ Environmental Restoration Program
MMRP = Military Munitions Response Program

History and Setting of Time Oil / Well 12A



History and Setting of Time Oil / Well 12A (Cont)

- In 1981, chlorinated organic solvents (TCE, PCE, DCE, PCA) were detected in groundwater at Well 12A
- EPA investigations linked the contamination found at Well 12A to the Time Oil site

History and Setting of Time Oil / Well 12A (Cont)

- Oil recycling and solvent processing – 1923 to 1991
- Storage and small-scale manufacturing – 1992 to present
- The current owner is Western Moving and Storage

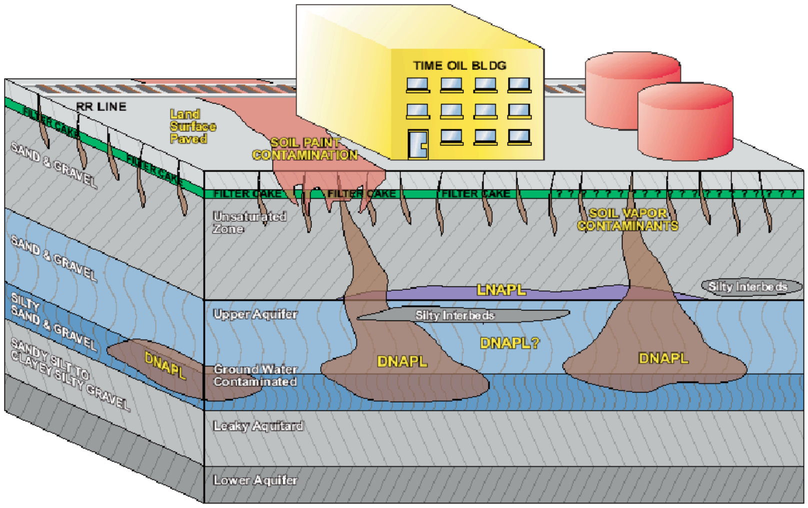
Well 12A Site Status Summary

- Record of Decisions (ROD) signed 1983
- ROD amendment 1985
- ROD modification 1987
- Five Year Reviews (FYRs) 1993, 1998, 2003, and 2008
- Remediation System Evaluation (RSE) completed December 2001
- State operating the groundwater treatment plant since October 2005

Well 12A Site Status Summary (Cont)

- Existing GETS is not providing capture of even the > 500 parts per billion (ppb) TCE plume
  - GETS designed to pump 500 gallons per minute (gpm) current < 100 gpm
- DNAPL and light non-aqueous phase liquid (LNAPL) remain on site
- Areas of potential contamination have not been fully characterized
- City of Tacoma wells continue to be impacted by the Time Oil site (Well 12A) plume

Pre-Remedial Action CSM



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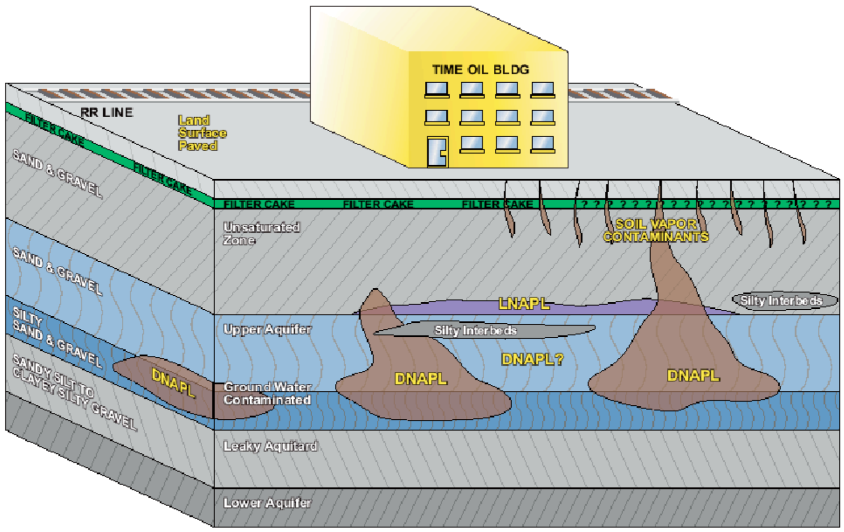
Remedial Action Summary

- Groundwater Extraction Treatment System (GETS)
  - 1988 – 2001: 550 million gallons of groundwater extracted / treated, removing 16,000 pounds VOCs
- Vapor Extraction System (VES)
  - 1993 – 1997: Removed 54,100 pounds VOCs
- Filter cake / contaminated soil removal
  - Burlington Northern Railroad excavated 1,200 cubic yards (cy) along rail line
  - VES construction / removed 5,000 cy of filter cake

CSM Update After GETS, VES, Soil / Filter Cake Removal



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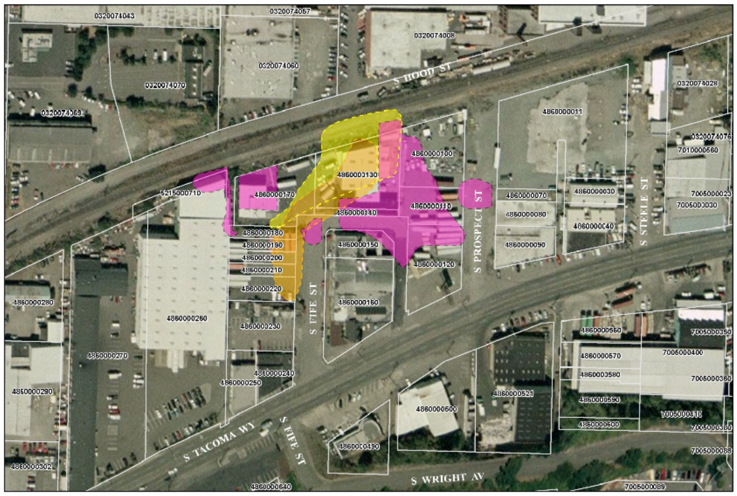

N

0 75 150 Feet

Estimated Extent of Filter Cake or Shallow Contaminated Soil

Estimated Extent of Dnapl

Estimated Extent of Lnapl

Figure
Estimated Extent of Source Areas
Time Oil Site

Extents based on observations or inferences; extent to areas of uncertainty (e.g., south and southwest of NAPL) not included here

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Desired End State

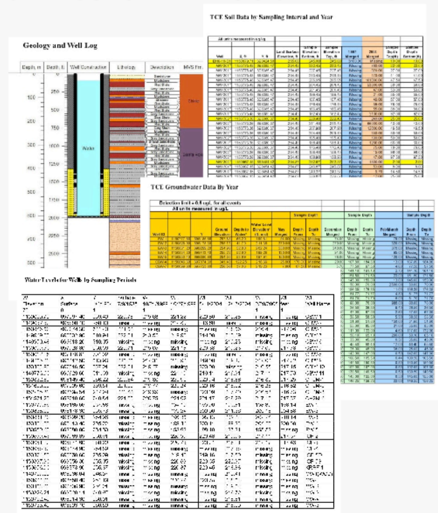
- Adequate use of robust source removal technologies
- Timely transition to cost-effective ‘polishing’ step(s)
- Reduce / eliminate need for pump and treat
- Appropriate reliance on monitored natural attenuation (MNA)
- Adaptive, flexible implementation
  - *“Sources begin to reveal themselves as remediation progresses”*

Path Forward

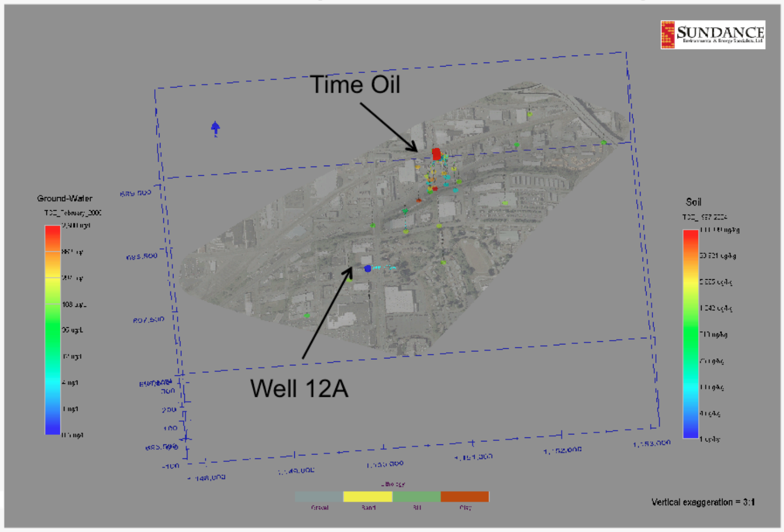
- Identify and transparently document Remedial Action Objectives
  - Realistic / measurable cleanup targets for source areas
  - Exposure Pathways
- Build the 3-D CSM for Visualization / Analysis
- Evaluate CSM and identify data gaps
- Perform field investigation to fill data gaps, if necessary
- Achieve consensus on possible remedial alternatives
- Prepare Focused Feasibility Study (FFS) / Record of Decision (ROD) Amendment

Data Set to be Incorporated into 3-D Visualization

- Over 100 geologic logs from area
- Soil sampling data
  - 1985, 1997, 2004
  - Five contaminants – TCE, PCE, PCA, trans-DCE, cis-DCE
- Groundwater data
  - 2004, 2005, 2008
  - Six contaminants – TCE, PCE, PCA, trans-DCE, cis-DCE, vinyl chloride
- Groundwater level data
  - 1984, 1985, 1999 and 2005



Location Map for Source (Time Oil) and Receptor (Tacoma Well 12A)



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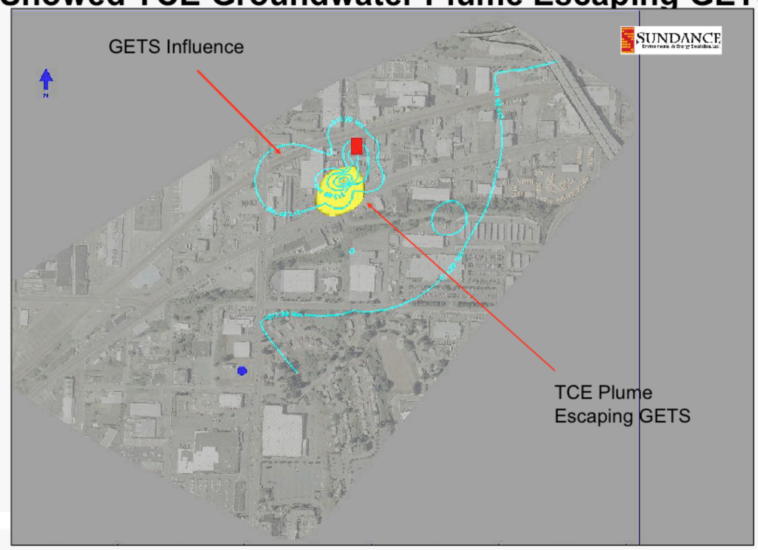
3-D Visualization of Contaminant and Water Level Data Showed TCE Groundwater Plume Escaping GETS



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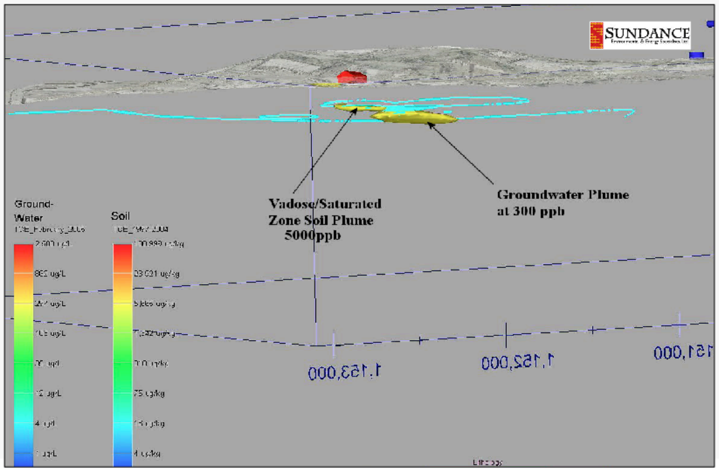
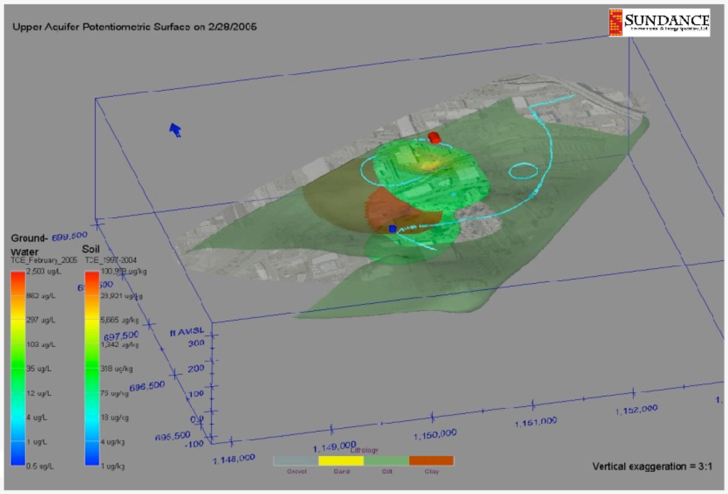
3-D Visualization of Soil, Groundwater Chemistry, and Water Levels Demonstrates Plume Actively Sourced at Vadose / Saturated Zone Interface



3-D Visualization of Soil Contaminant Data and Geology Indicate Silt Layers Affect Distribution of Contamination at Vadose / Saturated Zone Interface



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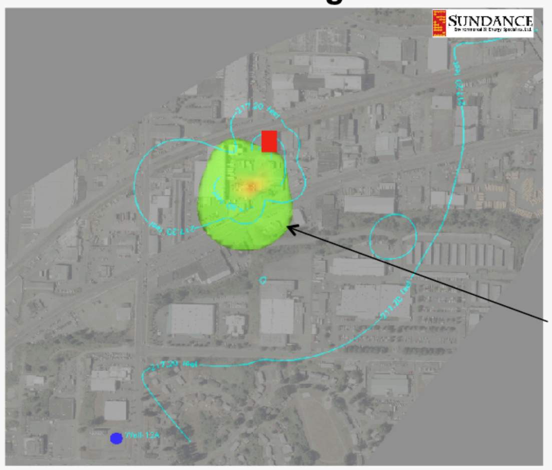
Key 3-D Visualization / Analysis Findings

Remedy-in-Place Not Controlling TCE Groundwater Plume



Plume Escaping GETS

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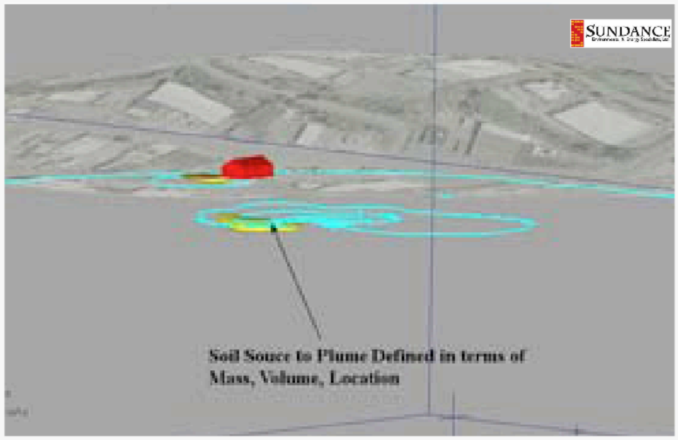
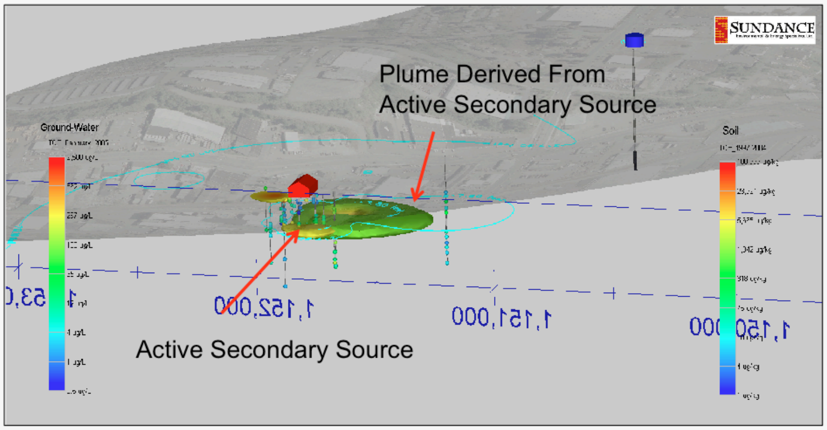
Key 3-D Visualization / Analysis Findings

Remedy-in-Place Not Controlling Migration of TCE Plume, Nor Reducing Soil Contaminant Concentrations Actively Sourcing Plumes



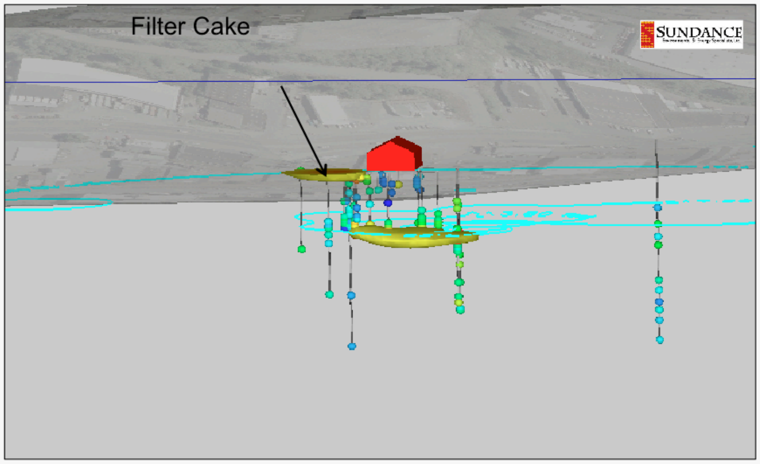
Key 3-D Visualization / Analysis Findings

Soil Source at Vadose / Saturated Interface Continuing to Source Plume



Key 3-D Visualization / Analysis Findings

Near Surface Filter Cake and DNAPL Beneath Time Oil Building



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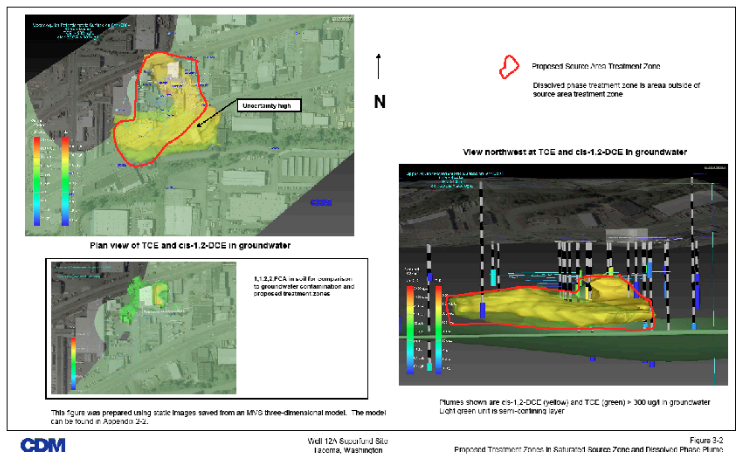
Key 3-D Visualization / Analysis Findings

Identified Initial Boundaries for Source Treatment to be Addressed in the FFS



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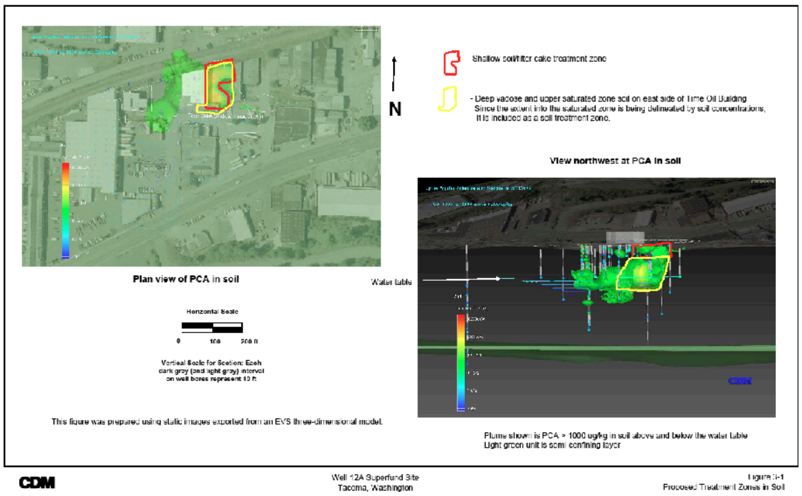
Remedy Optimization

Treatment Zones: Filter Cake and Soil



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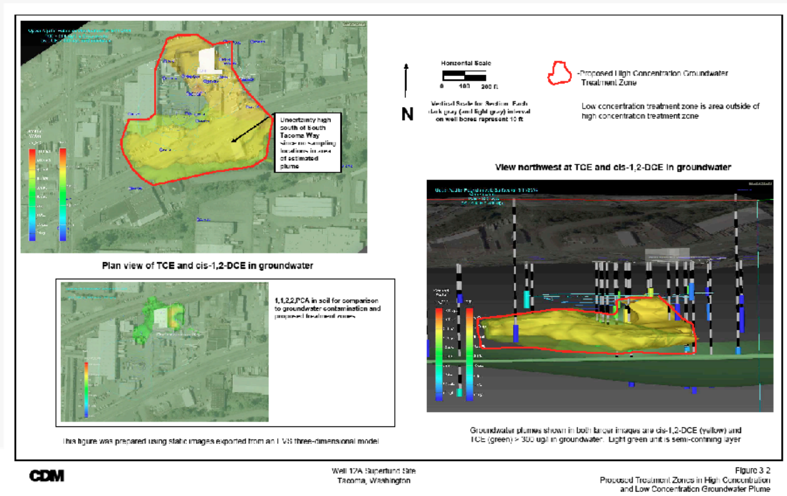
Remedy Optimization

Remedial Action Objectives: Groundwater



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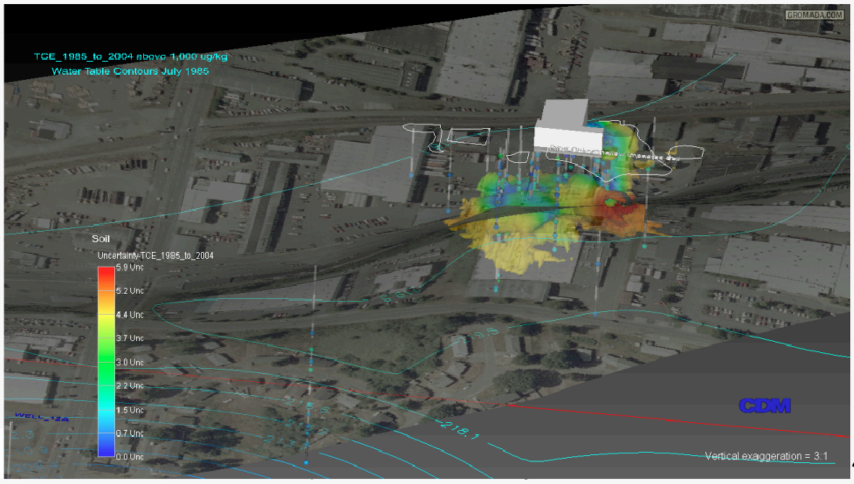
Remedy Optimization

Uncertainty in CSM Based on Existing Data Drives Targeted Sampling



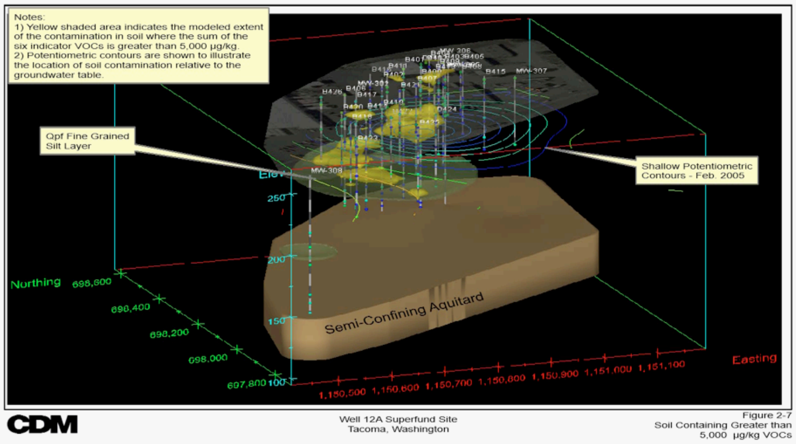
Remedy Optimization

Remedial Design Investigation (RDI) Objectives

- Delineate the soil contamination extent in the vicinity of Time Oil building to reduce uncertainty in the CSM and support delineation of treatment zones
- Assess the need for remediation beneath the former Time Oil building
- Evaluate the total organic carbon (TOC)
- Investigate previously identified geophysical anomalies and potential subsurface

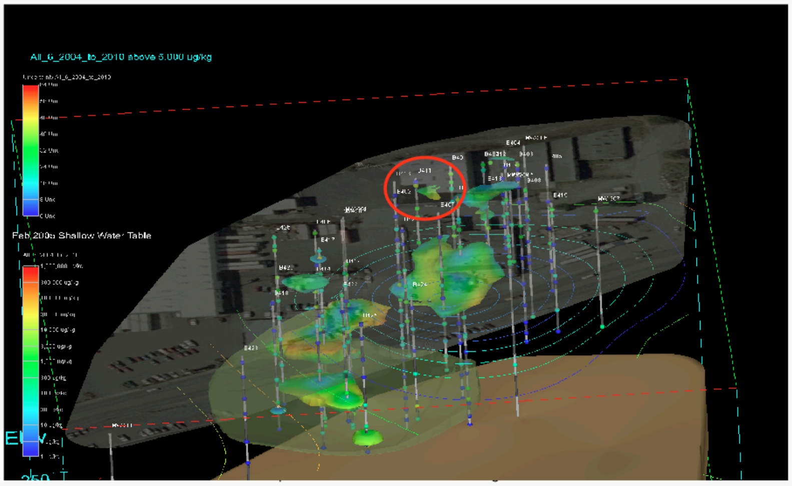
Remedy Design Optimization

Current Visualized Extent of Soil Contamination



Remedy Design Optimization

Uncertainties in Contaminant Distribution Beneath Time Oil and Near Surface Silt



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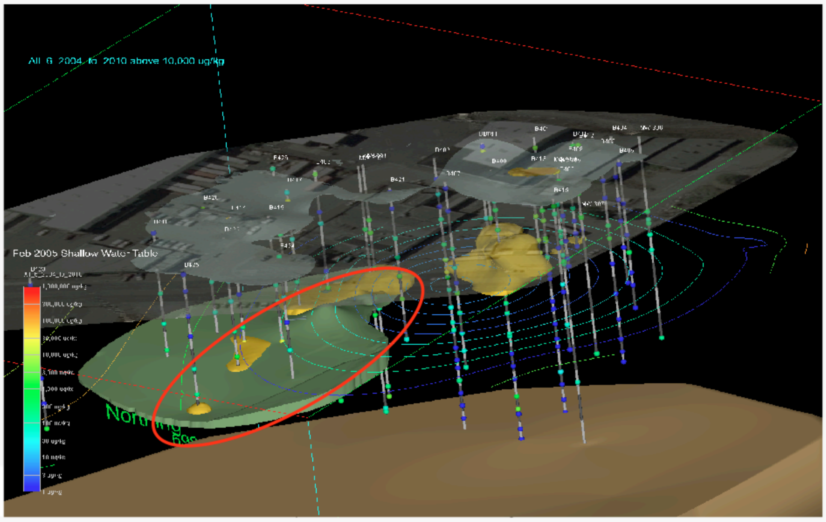
Remedy Design Optimization

DNAPL in Low Permeability Zone Approximately 50 feet bgs



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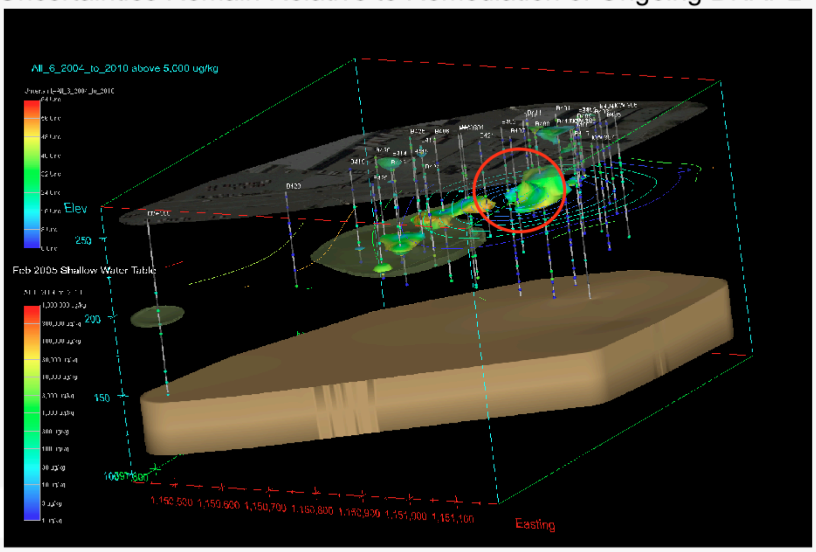
Remedy Design Optimization

Uncertainties Remain Relative to Remediation of Ongoing DNAPL



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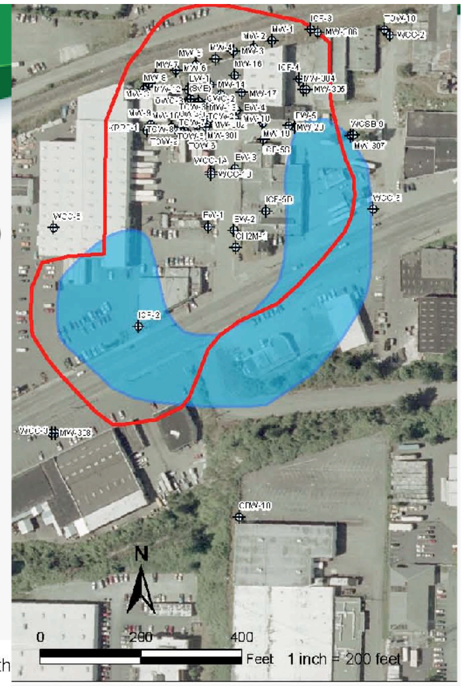
Remedy Design Optimization

Mass Discharge and
Enhanced Anaerobic Bioremediation (EAB)

- Conceptually active treatment zone and mass discharge flux line estimated within the 300 ppb VOC concentration contour
- EAB will treat contaminants within this zone and polish any remaining contaminants post-*in situ* thermal remediation (ISTR)



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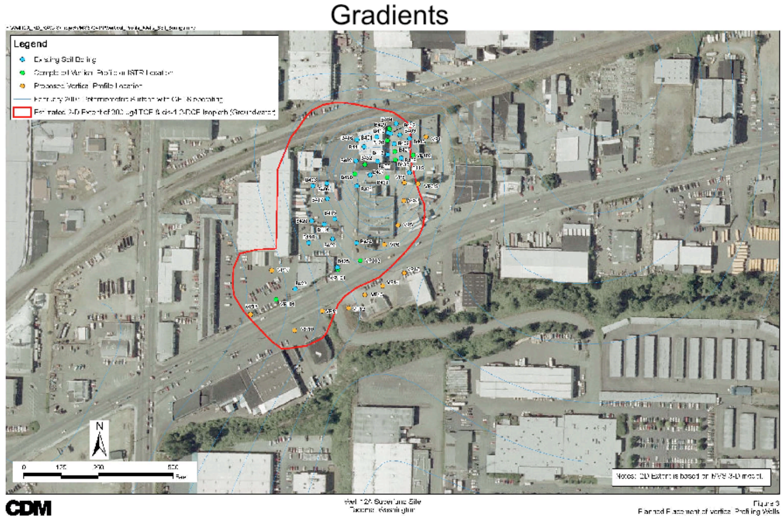
Remedy Design Optimization

Define Extent of Low Permeability Unit and Downgradient Hydraulic Gradients



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What's Next for 12A?

- Measure pre-RA baseline mass discharge for Well 12A source area
- Implement RA to achieve 90% mass discharge reduction goal
  - Excavation, ISTR, EAB
- Two post-RA mass discharge measurements planned
  - 1^{st} ~18 months post-EAB
  - 2^{nd} contingency if additional EAB needed to achieve RA objectives

Best Practices for 3-D Visualization / Analysis

- Maximize the use of existing data to produce Preliminary CSM
  - Identify data gaps for further inquiry
  - Evaluate interim or final remedy performance and opportunities for optimization
- Evolve the CSM during dynamic work strategy (DWS)-based investigations – reduce time, cost and uncertainty
- Integrated data visualizations – 'The Whole Picture'
- Build to address specific issues with room to grow
  - In our experience the biggest expense tends to be getting data into a usable format
    - Sampling reports for variable media, aquifer testing, groundwater modeling, RI/FS, RA, RD, remedy implementation, long term monitoring, etc.
  - Want hard data versus contractor interpretations

Summary of Best Practices for 3-D Visualization / Analysis

- Step 1 - Identify basic questions to answer with existing data
- Step 2 - Identify the types of hard data needed to answer questions
- Step 3 - Determine what component visualizations are needed
- Step 4 - Sort and document hard data from interpretations
- Step 5 - Import hard data into database format for building visualization components
- Step 6 - Use GIS and 3-D data analysis to evaluate sample distributions in map format
- Step 7 - Evaluate and ensure adequate distribution of geologic log data
- Step 8 - Use actual (measured) data to ensure objective 3-D visualizations

* *Note - Be aware of the principal of significant figures; not only for contaminant data; but also geology and hydrogeology*

Best Practices for 3-D Visualization / Analysis

- **<u>Step 4</u>**: Sort and document hard data from interpretations
- Create a matrix for use in documenting data types and sources for reconstructions
  - Major documents
  - Databases

		General				Media Chemistry			Geology / Hydrogeology		
Reference	Type	Site History & Past Use	Source Area Inv	Post 2007 Site Data	Nearby Site Info	Soil Gas	Surface and Subsurface Soil	Groundwater	Geology - Boring Logs/Well Construction/ Geophysical	Geology- 3D model	Hydrogeology and Groundwater Models
Innovative Technology Solutions, Inc. (ITSI), Sept. 2009, **Internal Draft, Data Evaluation to Support Remedial Investigation/Feasibility Study (RI/FS) Planning, Source Operable Unit, Newmark Superfund Site, San Bernardino, California** (DVD 1 and 2)	D	X	X			X	X				
Stantec, 2008, **Draft Newmark Groundwater Flow Model Report Appendix A, Section 4.1, Subsections - Historic Groundwater Levels, Lithologic and Well ConstructionData, and Physical Features - All compiled data**	DB, HC, S, GIS								X	X	X

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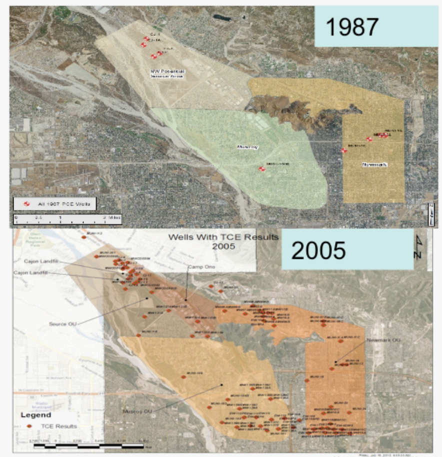
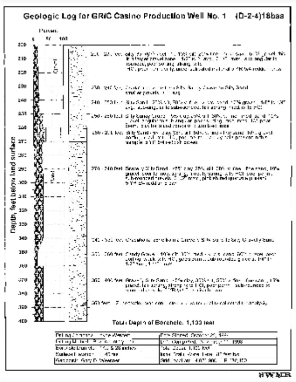
Best Practices for 3-D Visualization / Analysis

- **Step 6** - Use GIS and 3-D data analysis to evaluate sample distributions in map format
  - Distributions must be sufficient for geostatistical analyses
  - Site-specific, driven by spatial scale
  - Typically, sampling dates with most extensive distribution of chemical data are used first for visualization
    - Quality of data must be considered
    - Temporal data must be time-equivalent

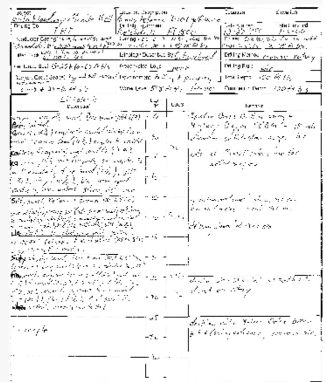


Geologic Logs Can Vary Widely in Descriptive Terminology

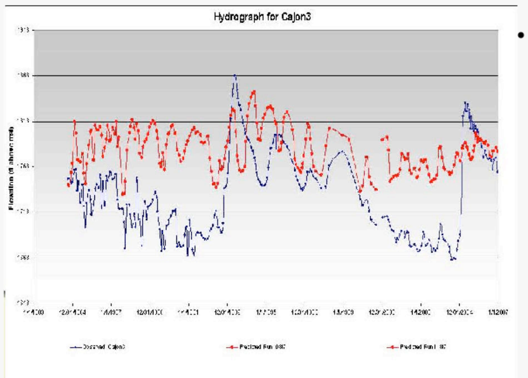
Must use least descriptive terminology in
establishing base geologic units for reconstructions



- **<u>Step 7</u>** - Evaluate and ensure adequate distribution of geologic log data in GIS
  - Use consistent lithologic classification scheme
  - Use actual basement elevations versus depth-normalized
  - Consider technology used to determine basement elevations



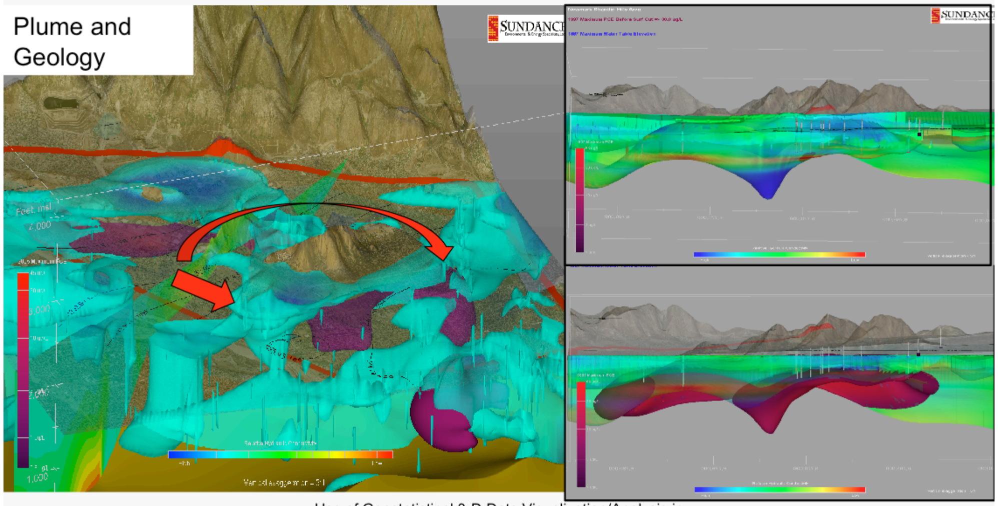
Best Practices for 3-D Visualization / Analysis



- **<u>Step 8</u>** - Use actual (measured) data to ensure objective reconstructions
  - Example - modeled groundwater level data includes interpretation and assumptions
  - Wet/dry periods should be accounted for when evaluating chemical data

Revenge of the Geologists!

Plume and Geology



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Use of Geostatistical 3-D Data Visualization/Analysis in Superfund Remedial Action Investigations

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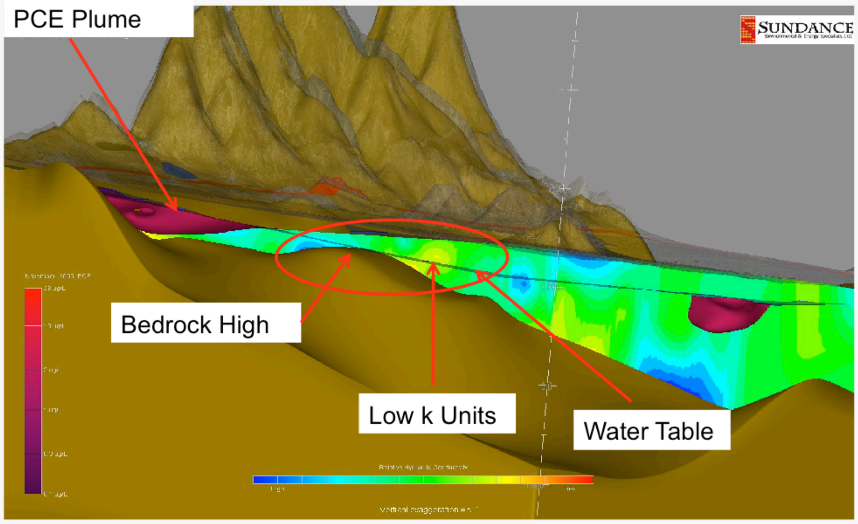
The Value of Seeing 'The Whole Picture' in 3-D



3-D Visualization / Analysis – Not Just For Existing Data

- Can be used in dynamic field investigations, when processed in real-time they support
  - Evolution of CSM during data collection efforts
  - Selection of targeted “intelligent” samples to maximize information gain / minimize cost, uncertainty
  - Contaminant type, concentration, exposure pathway, and imminent versus non-imminent exposure risk
  - Sampling density evaluations - how many is enough?
    - Reduce uncertainty / increase confidence - can set limits
    - Confidence required is determined by stakeholders based on site conditions and risk
    - Geostatistical basis also provides optimum new locations

Additional Support Considerations Planned in 2012

- Future webinars - highlighting active 3-D visualization vs. static images
- Documents / Outreach for SF RPMs
  - Continued training / presentations
  - Quality Control - best practices, considerations for procedures / guidelines
  - Contracting strategies for 3-D visualization services
    - Expectations for costs, deliverables, facilitating transfer
  - Updates to Federal Remediation Technologies Roundtable (FRTR) Decision Support Tools matrix

Summary and Benefits of 3-D Visualization / Analysis

- Move older sites to completion, facilitate transfer, illustrate Operational & Functional (O&F)
- Optimize existing remedies / new designs
- Aid consideration of performance metrics, short / medium / long-term remediation goals
- Advantages
  - Simple images backed by large understandable databases with confidence calculations
  - Multiple independent data sets (lines of evidence)
    - Agreement or divergence?

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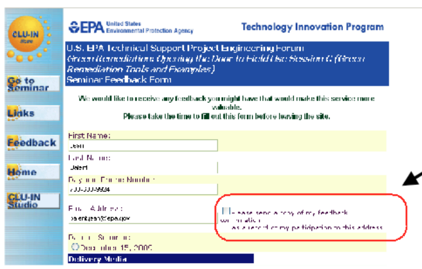
  - Sundance Environmental and Energy Specialists
    - Jackie Burton, PhD: President
    - John Shafer: Principal Scientist
  - CDM
    - Aaron Frantz: Senior Engineer
    - Adam Locke: Principal

Questions?

Resources & Feedback

- To view a complete list of resources for this seminar, please visit the **Additional Resources**
- Please complete the **Feedback Form** to help ensure events like this are offered in the future



Need confirmation of your participation today?

Fill out the feedback form and check box for confirmation email.

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