Triad Best Management Practices
Part 1 – Conceptual Site Model Case Studies

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Technical Session Objectives

- Provide case study examples of conceptual site models (CSM) used under a Triad approach
- Expose participants to the benefits of CSM development and refinement
  - » Highlight how CSMs are used to prioritize and address: data gaps, uncertainty, stakeholder concerns
  - » CSMs function as a tool to resolve competing site visions and benefit stakeholder/public presentations
- Demonstrate how a clear CSM leads to selection of appropriate tools, strategies, and remedies
- Feature some visualization tools that enhance CSMs and facilitate decision making
  - » Example SADA http://www.tiem.utk.edu/~sada/index.shtml

The CSM "Harmonizes" the Project

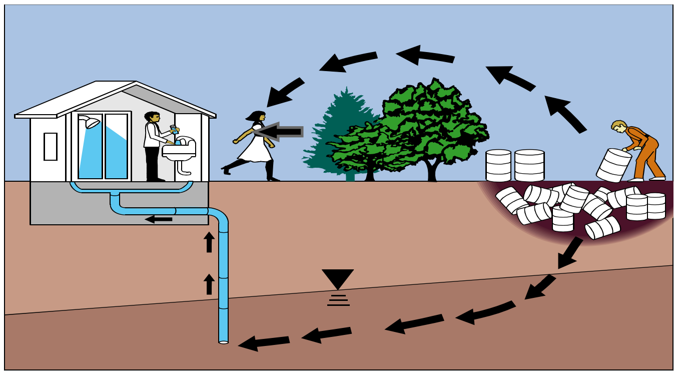
Lack of clarity here

Reuse Plans, Goals, Outcomes

Impact

…means uncertainty here

CSM



\+

Decisions:

- Exposure risk
- Cleanup goals
- Data (type, quality)
- Tolerable errors

…which means no foundation for agreement here

Determine

…or here

Approaches to:

•Assessment
•Investigation
•Cleanup Design, Implementation
•Closeout, Long-Term Operations and Maintenance

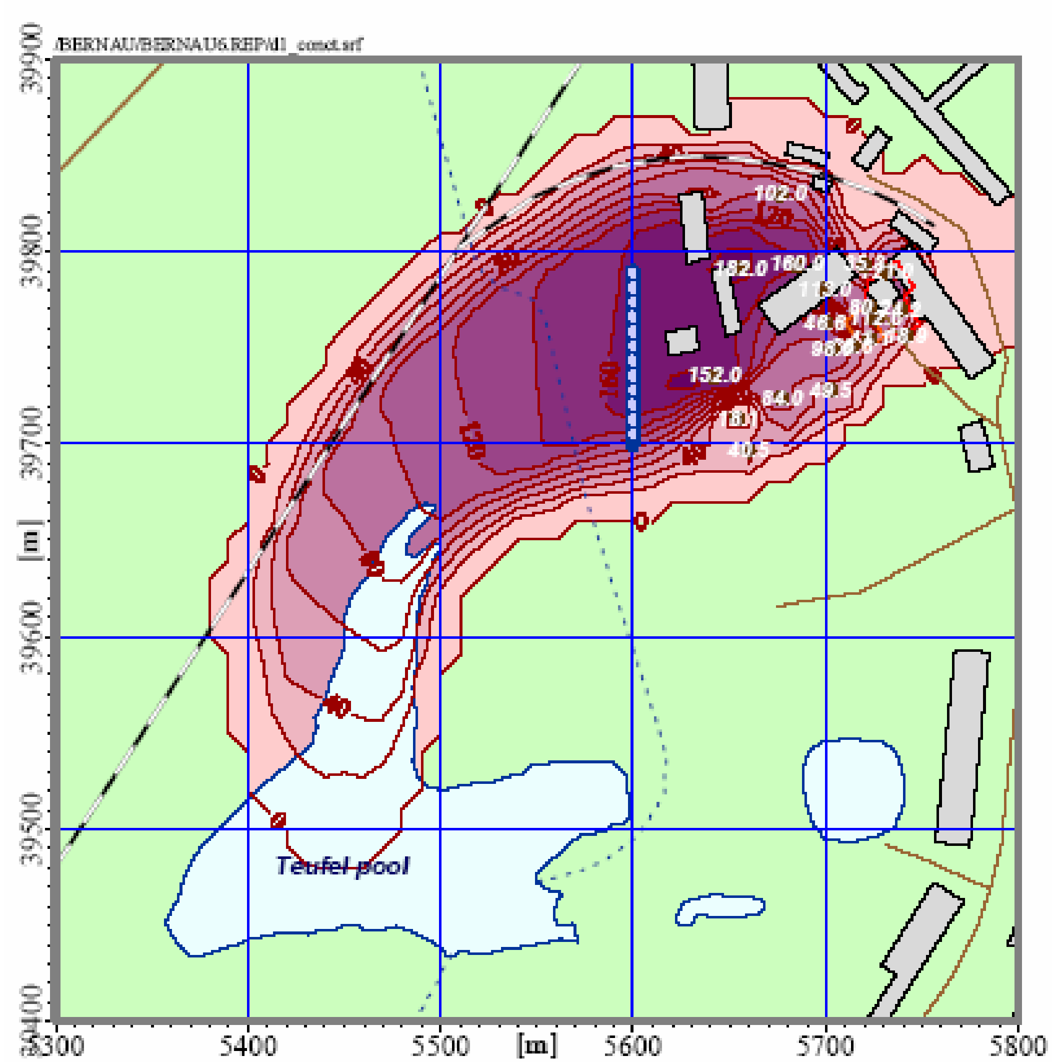
Tools for:

•Sampling, Analysis, Interpretation
•Cleanup/Remediation
  ➢Containment
  ➢Cleanup
  ➢Controls
•Monitoring, Maintenance

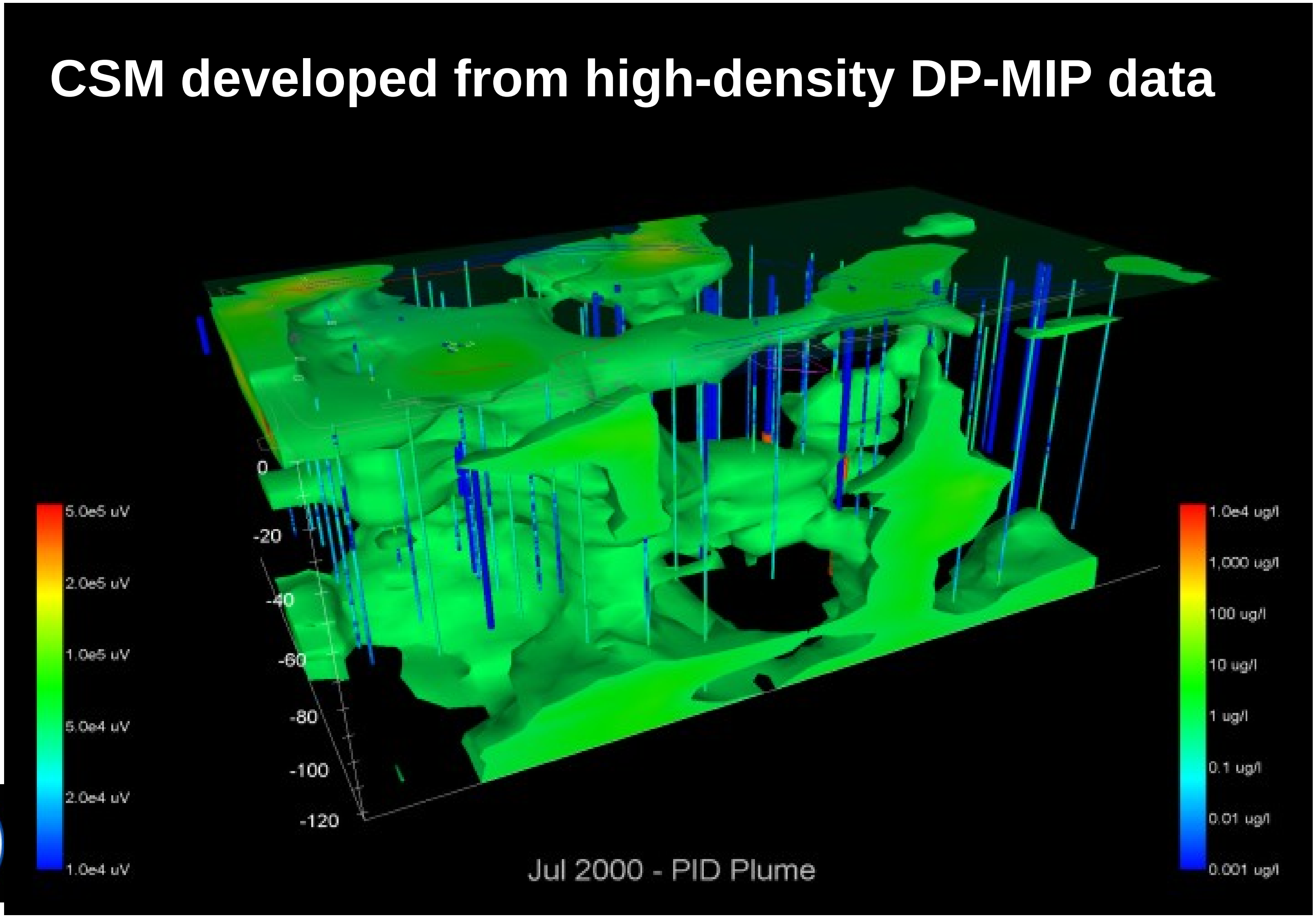
Idealized CSM Representation of a GW plume

"The usual approach of science of constructing a mathematical model cannot answer the questions of why there should be a universe for the model to describe. Why does the universe go to all the bother of existing?"

Stephen Hawking



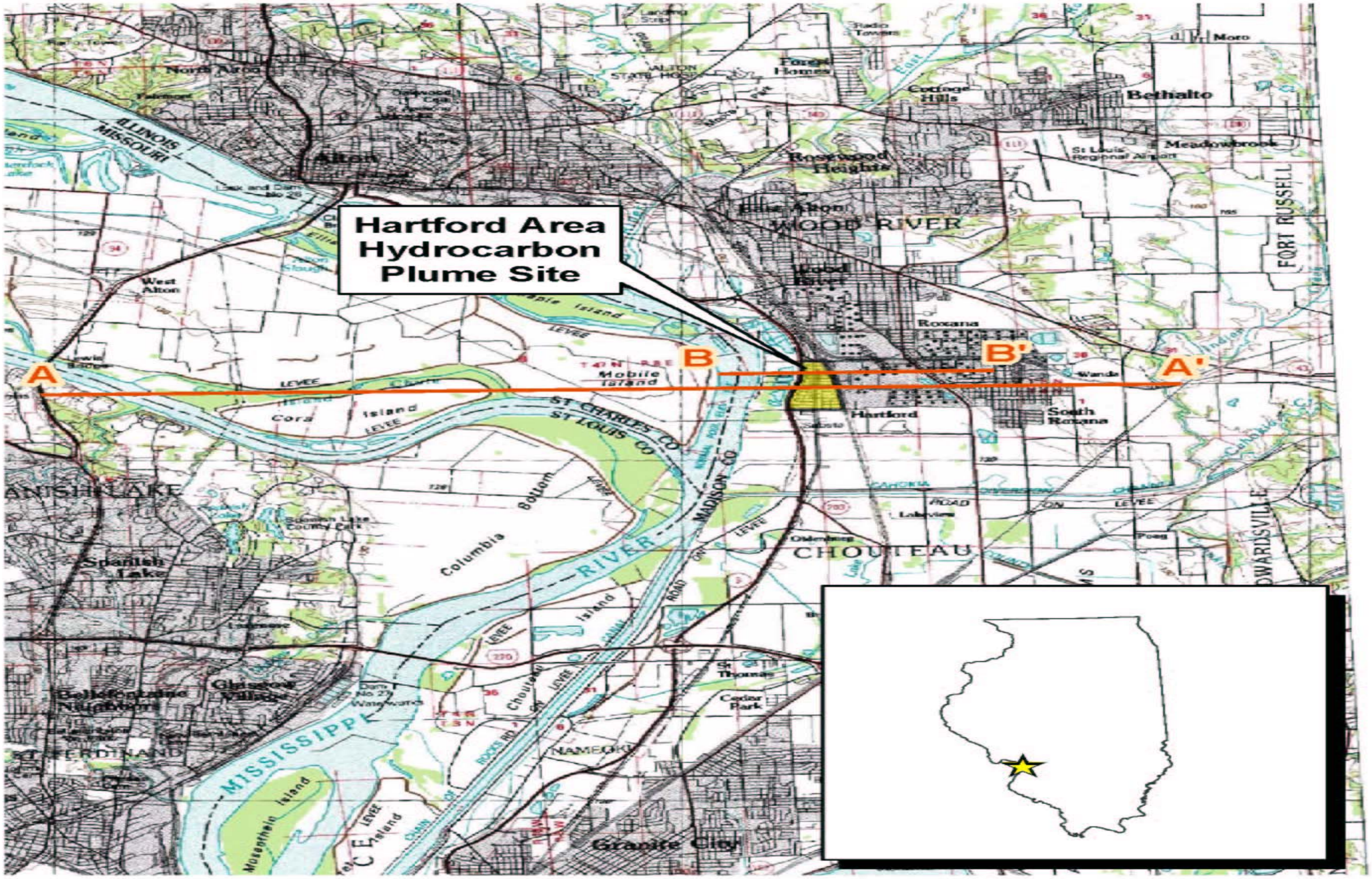
The Real World is a lot Messier than Traditional Idealized Models Portray



Adapted from Columbia Technologies, Inc.

Hartford Hydrocarbon Plume Site, Hartford, Illinois, Case Study Overview

- Site History
- Preliminary CSM for the site
- Refining the CSM using dynamic work strategies and real time measurements
- Testing the CSM using data
- The CSM for vapor intrusion
- The CSM for product removal
- Summary and lessons learned



Legend

Cross-Section Line

Site Boundary

N W E S

0 2
Miles

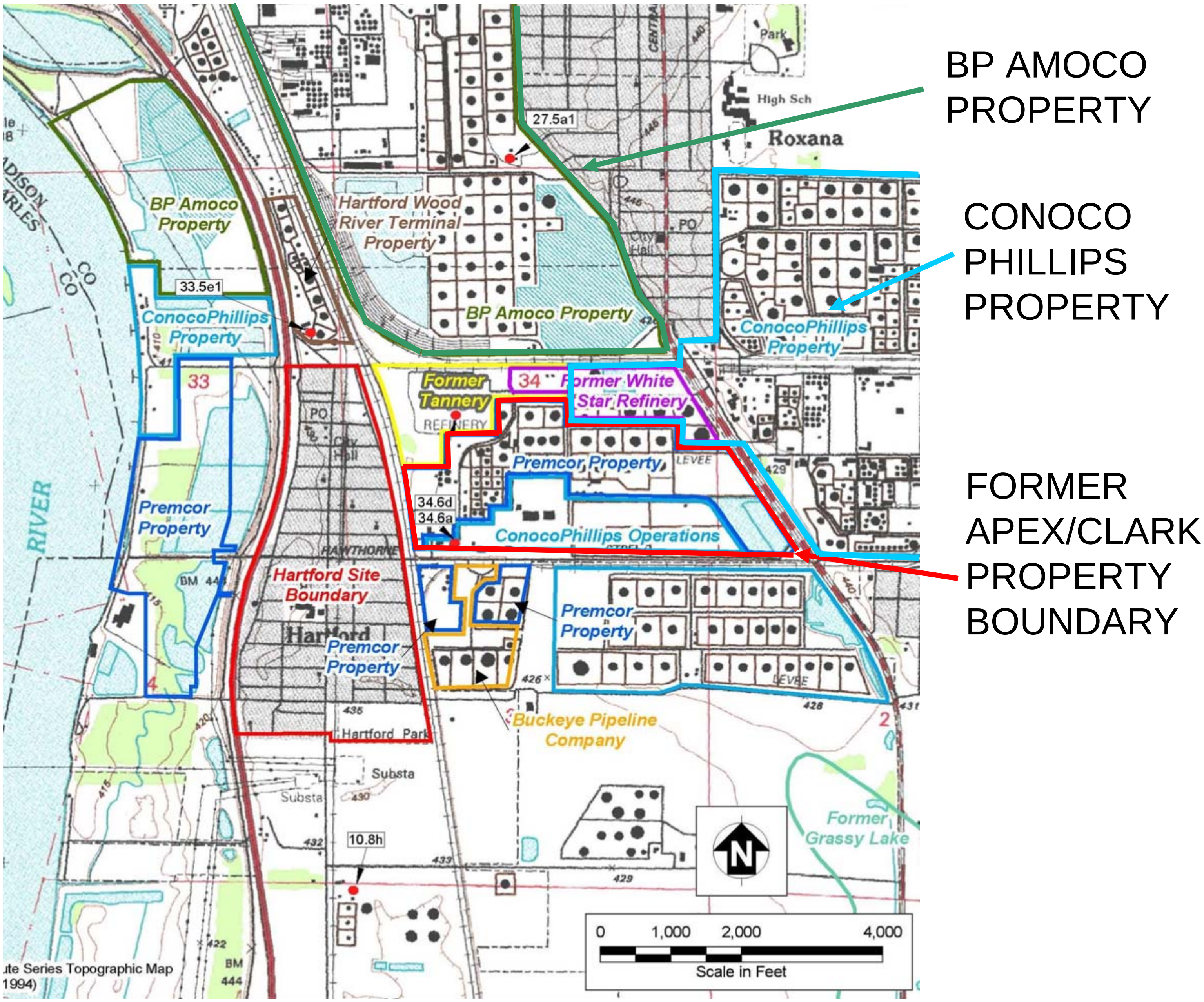
Figure 1

Location Map

Hartford Area
Hydrocarbon Plume Site
Hartford, Illinois

Tetra Tech EM Inc.

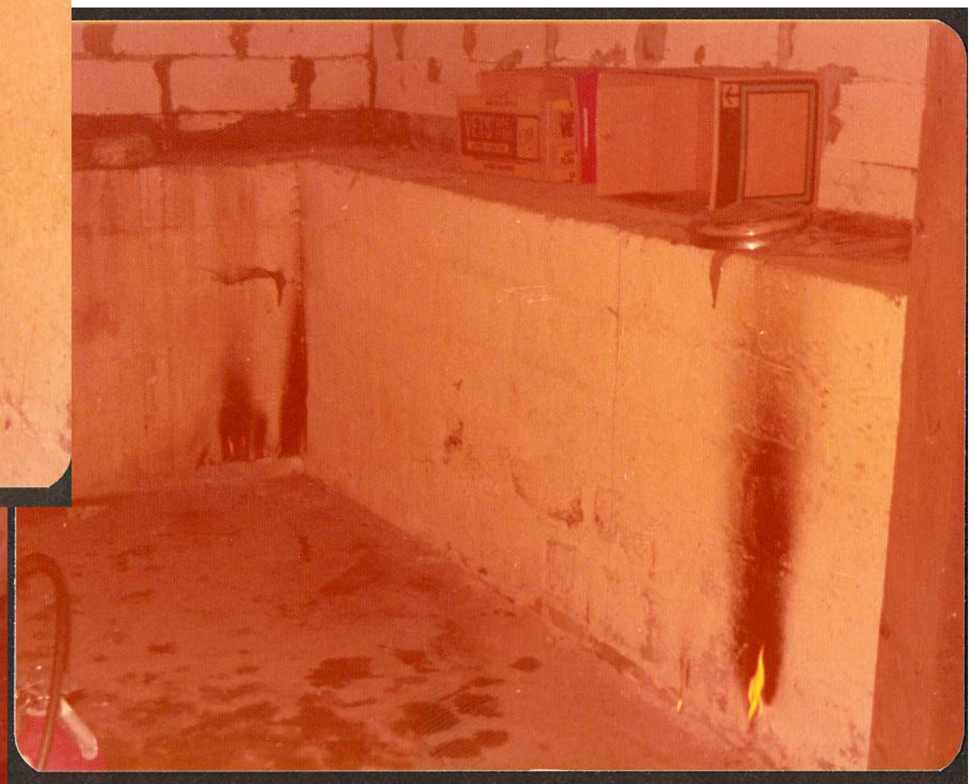
Site Location and Refineries



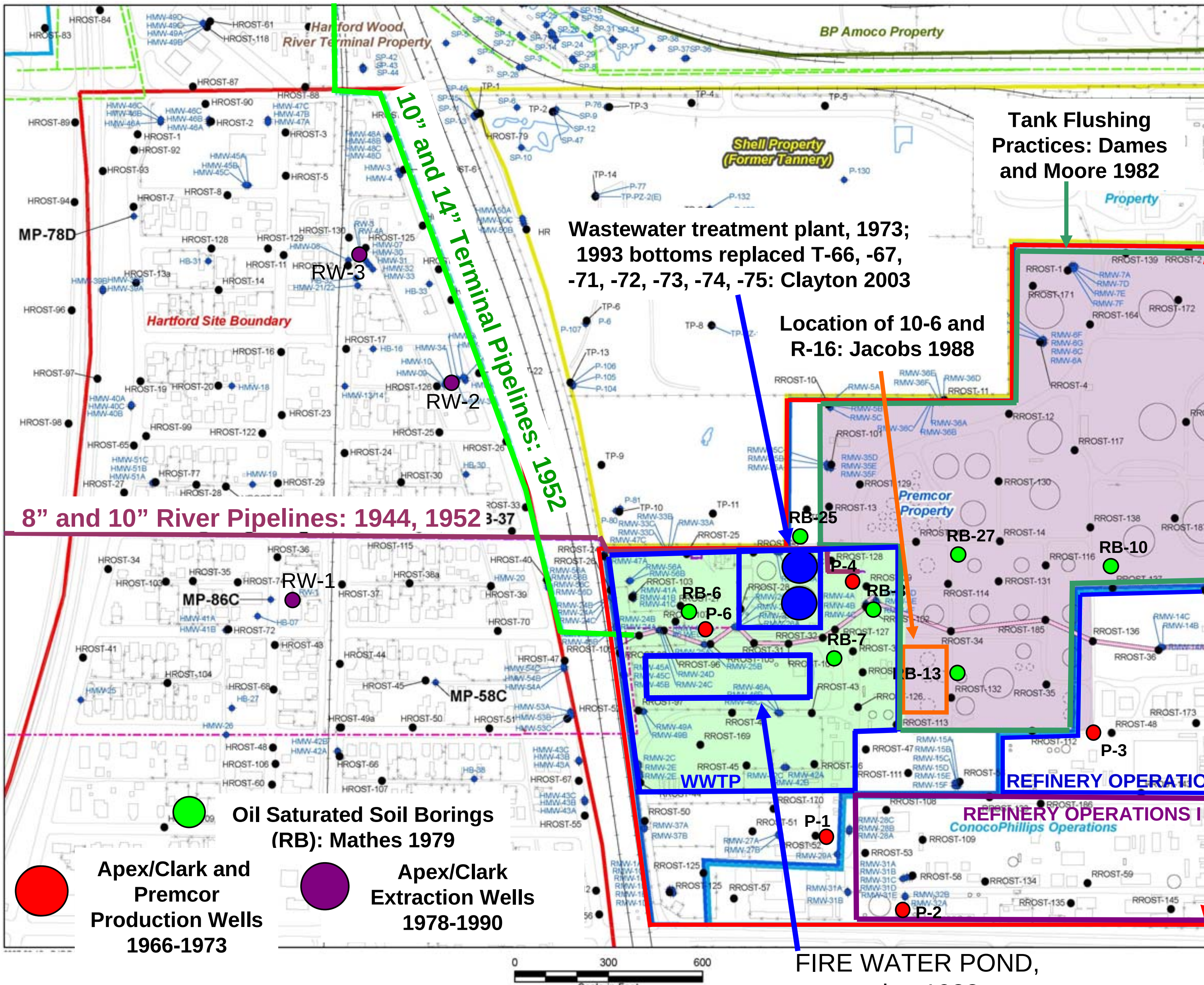
Problem Statement

- 48 historical hydrocarbon fuel spills from surrounding pipelines and storage tanks
- Fires and odors have been reported by residences particularly during spring
- Increased vapor intrusion is presumed to be caused by rising water levels carrying hydrocarbon vapors into utility corridors during high stands of the river
- Release of hydrocarbons to surface water

Circa 1972



Some Past Use Salient Features

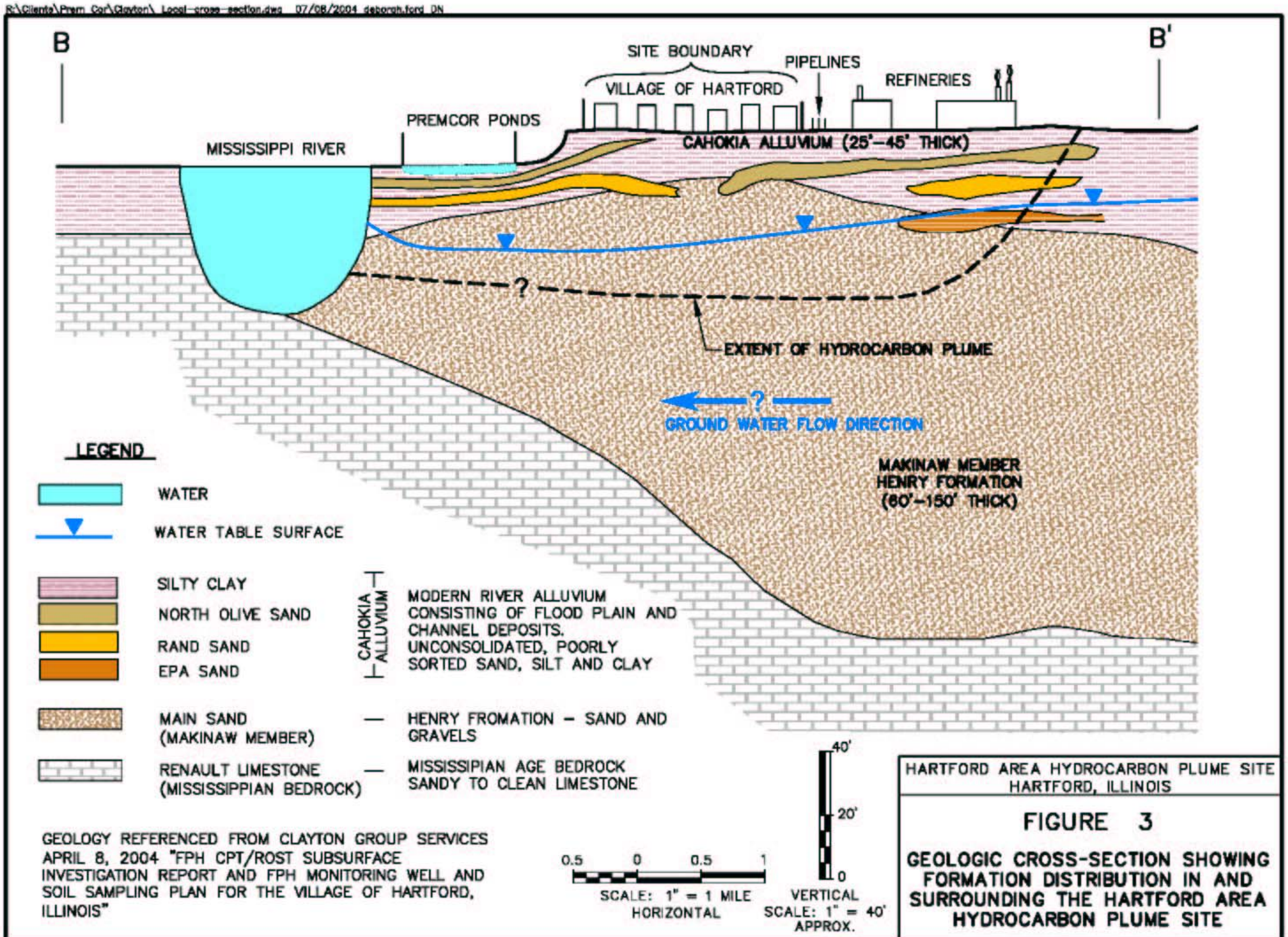


FORMER APEX/CLARK PROPERTY BOUNDARY

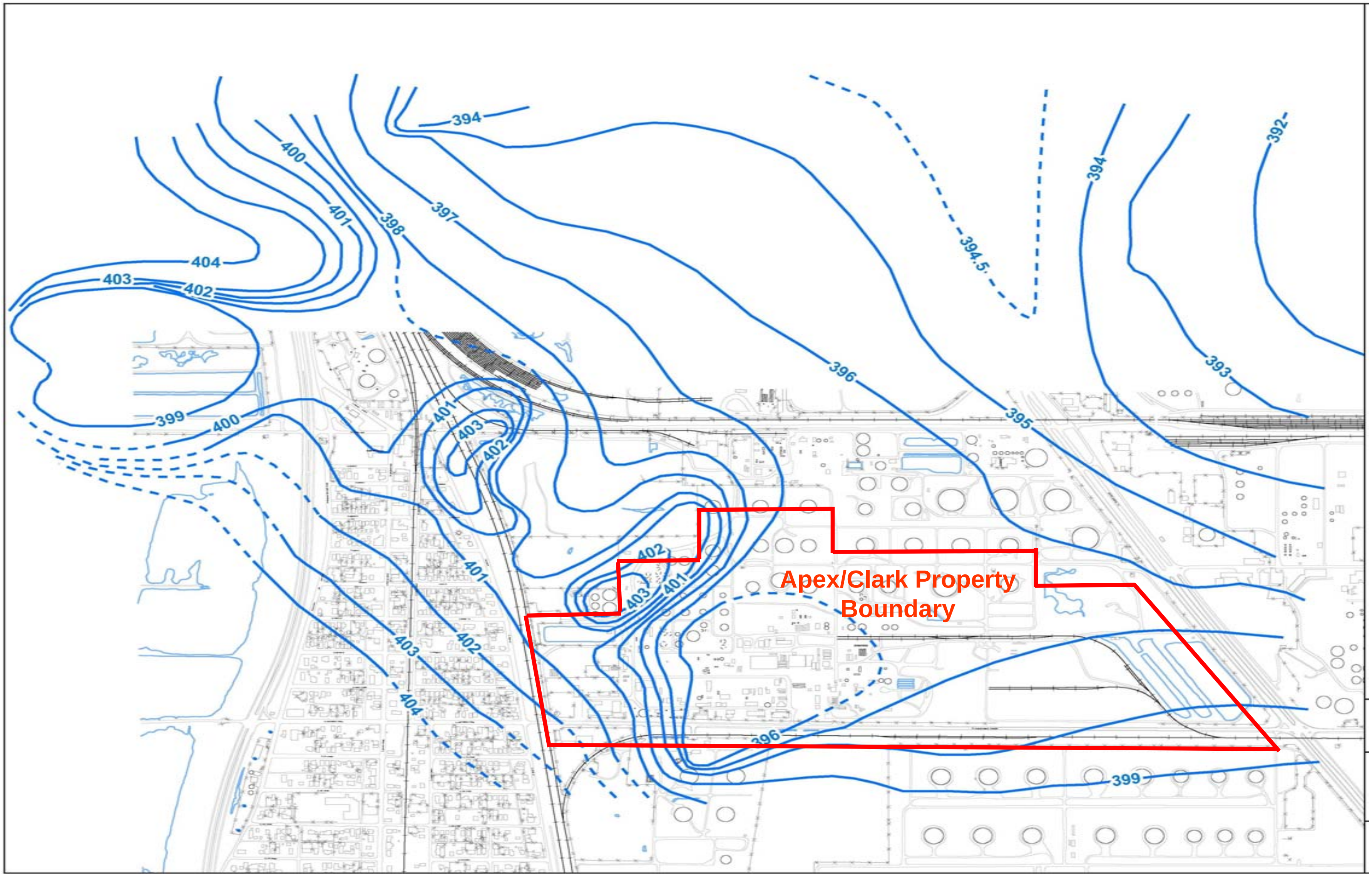
FIRE WATER POND, excavation 1988

CSM-Site Geology and Hydrogeology

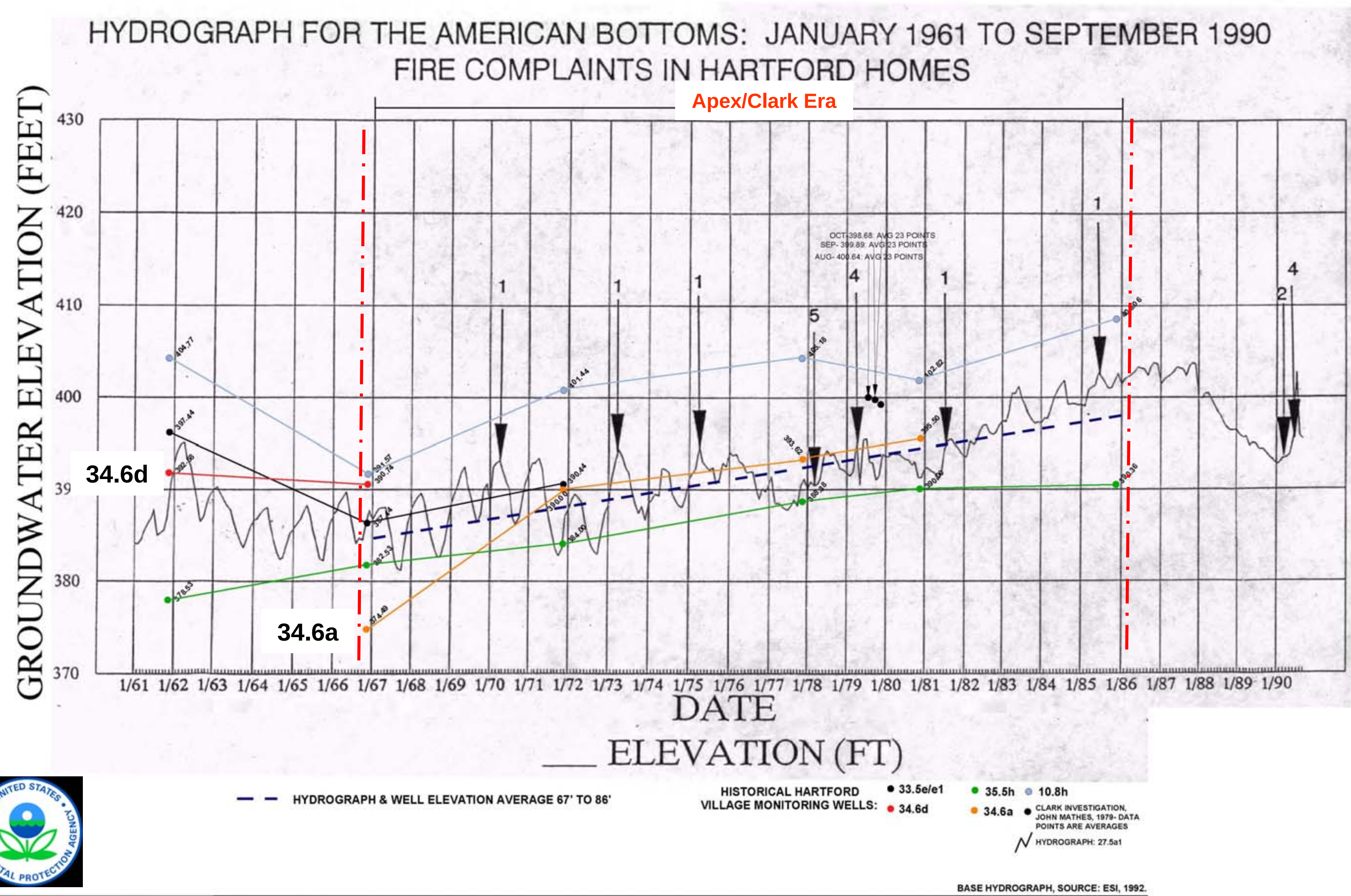
- Modern river over bank sediments underlying the site are composed of primarily silt with varying amounts of clay (10 to 40 feet thick)
- Near surface clayey silts vary in thickness across the site
- Discontinuous silts grade into highly permeable and porous glacial outwash sand (200+ feet thick)
- Pumping has reversed the natural direction of ground water flow
- The water table has been consistently rising over time and has seasonal fluctuations


R:\Clients\Prem Cor\Clayton\ Local-cross-section.dwg 07/08/2004 deborah.ford DN
B
B'
SITE BOUNDARY
VILLAGE OF HARTFORD
PIPELINES
REFINERIES
PREMCOR PONDS
MISSISSIPPI RIVER
CAHOKIA ALLUVIUM (25'-45' THICK)
EXTENT OF HYDROCARBON PLUME
GROUND WATER FLOW DIRECTION
MAKINAW MEMBER
HENRY FORMATION
(60'-150' THICK)
LEGEND
WATER
WATER TABLE SURFACE
SILTY CLAY
NORTH OLIVE SAND
RAND SAND
EPA SAND
CAHOKIA ALLUVIUM
MODERN RIVER ALLUVIUM CONSISTING OF FLOOD PLAIN AND CHANNEL DEPOSITS. UNCONSOLIDATED, POORLY SORTED SAND, SILT AND CLAY
MAIN SAND (MAKINAW MEMBER) — HENRY FROMATION – SAND AND GRAVELS
RENAULT LIMESTONE (MISSISSIPPIAN BEDROCK) — MISSISSIPIAN AGE BEDROCK SANDY TO CLEAN LIMESTONE
GEOLOGY REFERENCED FROM CLAYTON GROUP SERVICES APRIL 8, 2004 "FPH CPT/ROST SUBSURFACE INVESTIGATION REPORT AND FPH MONITORING WELL AND SOIL SAMPLING PLAN FOR THE VILLAGE OF HARTFORD, ILLINOIS"
0.5 0 0.5 1
SCALE: 1" = 1 MILE HORIZONTAL
40'
20'
0
VERTICAL SCALE: 1" = 40' APPROX.
HARTFORD AREA HYDROCARBON PLUME SITE
HARTFORD, ILLINOIS
FIGURE 3
GEOLOGIC CROSS-SECTION SHOWING FORMATION DISTRIBUTION IN AND SURROUNDING THE HARTFORD AREA HYDROCARBON PLUME SITE

Hydrogeology



Hydrograph Plot



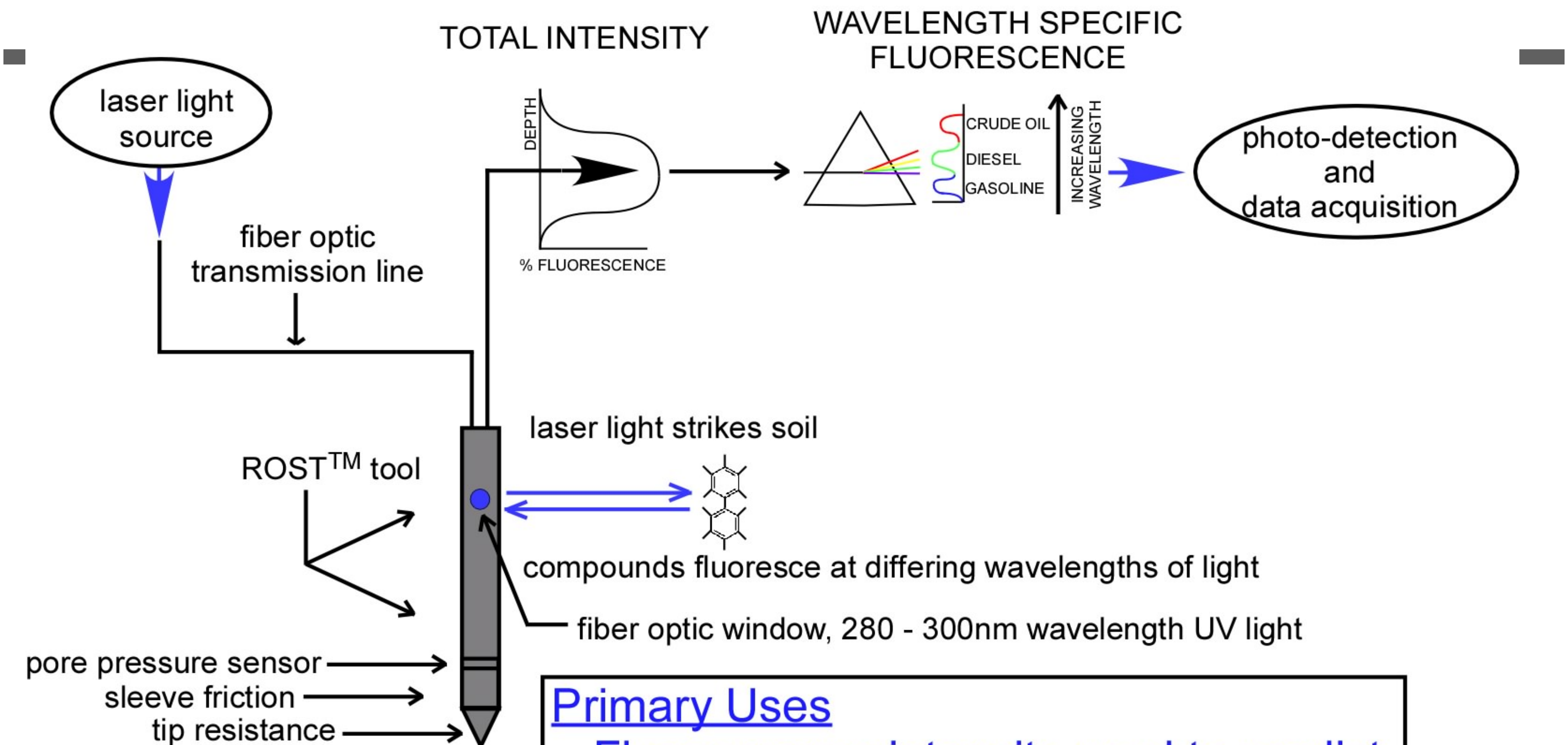
Refining the CSM using Dynamic Work Strategies and Real Time Measurements

- ROST™ used along with soil borings to define the nature and extent of product across the site
- Nested vapor probes, sub slab probes, active sewer soil gas monitoring and real time devices used to define vapor plumes based on the presence or absence of product in surface and subsurface soil
- Dissolved phase investigation conducted using direct push grab ground water sampling methods

CPT-ROST™


FUGRO
GEOTECHNICAL AND
ENVIRONMENTAL TESTING
CONE PENETROMETER SYSTEM
HOUSTON, TEXAS

How ROST™ Works



Primary Uses

- Fluorescence intensity used to predict presence of Free Product
- Wavelength specific intensity used to estimate Product Type
- Understand geology and hydrogeology

Hydrocarbons Detected Using Fluorescence Techniques

Mobility: high → low

Viscosity: low → high

Light Range Fuels

- Gasoline
- Kerosene
- Turpentine

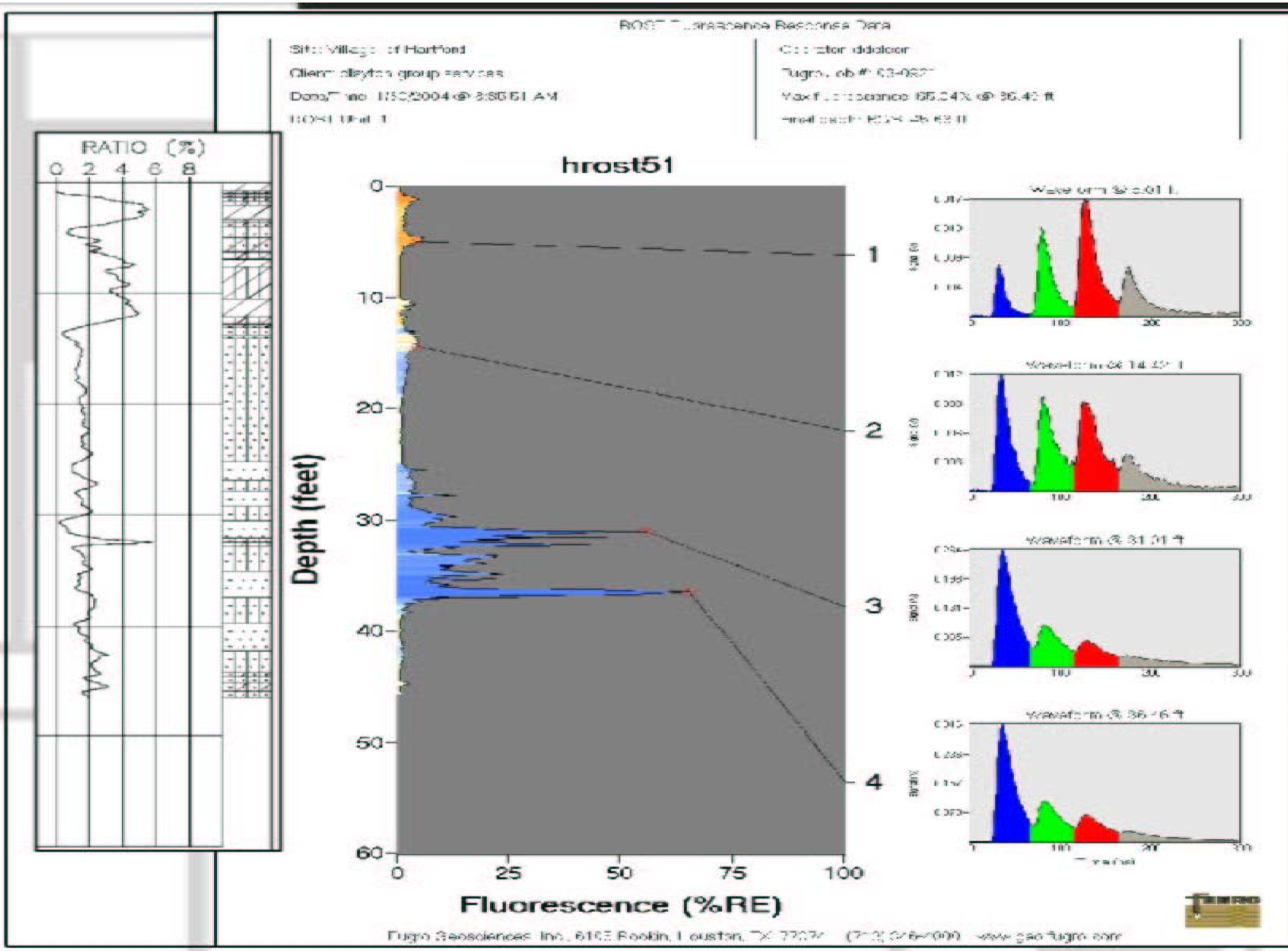
Mid-Range Fuels

- Fuel Oil
- Diesel Fuel
- Jet Fuel

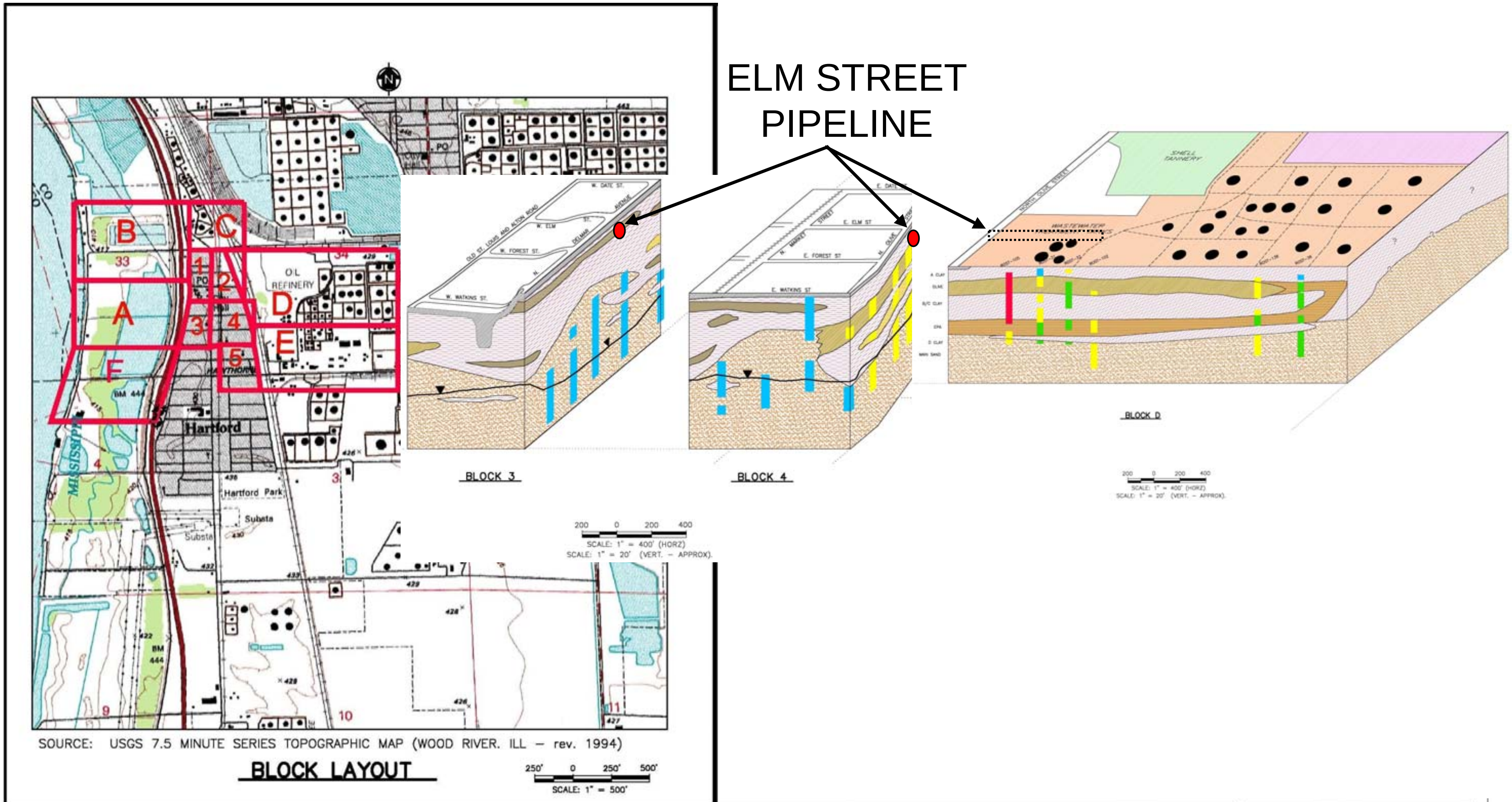
Heavy Hydrocarbons

- Motor Oil
- Crude Oil

Emitted Wavelength: 25 nano-meters (nm) → 200 nm


hrost51
RATIO (%)
0 2 4 6 8
Depth (feet)
0
10
20
30
40
50
60
1
2
3
4
0 25 50 75 100
Fluorescence (%RE)

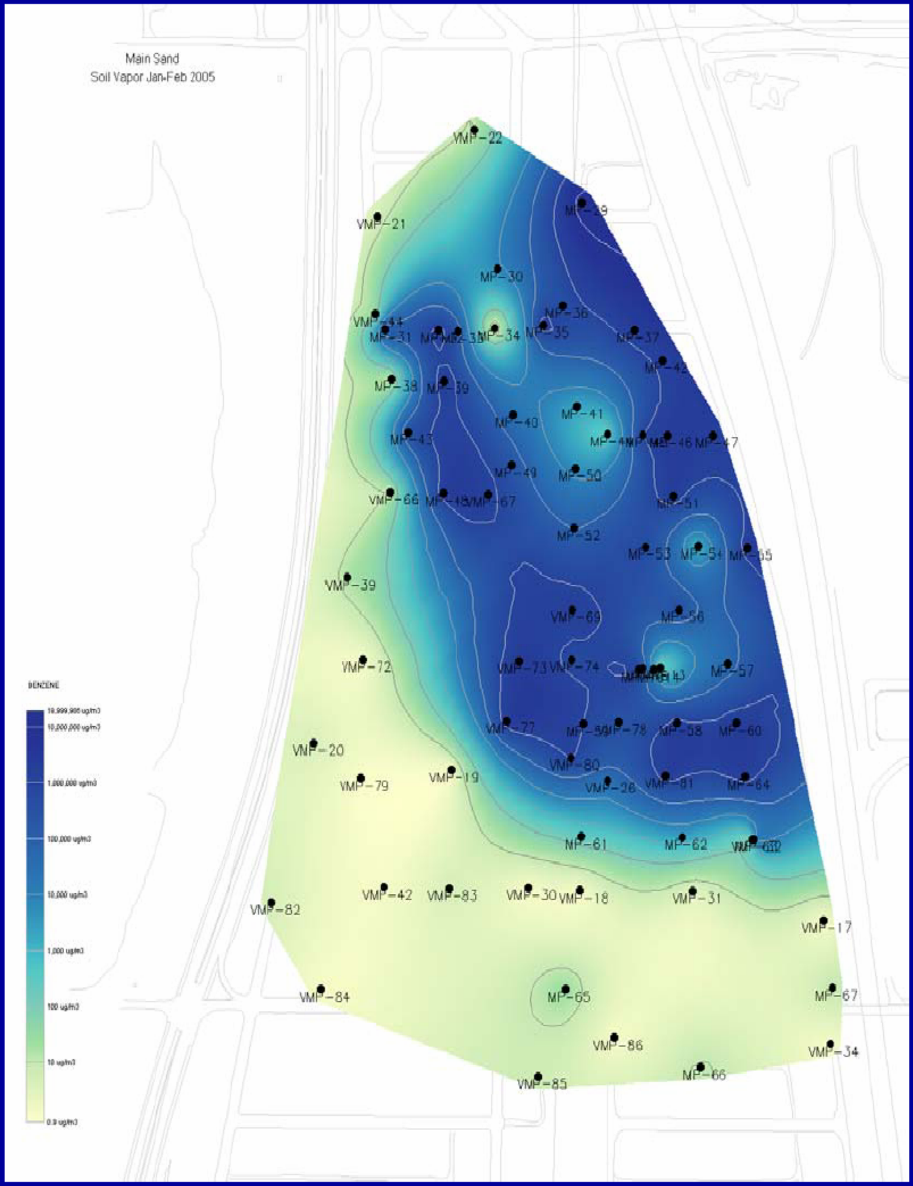
Revising the CSM – Using Visualizations



The CSM and Vapor Related Issues

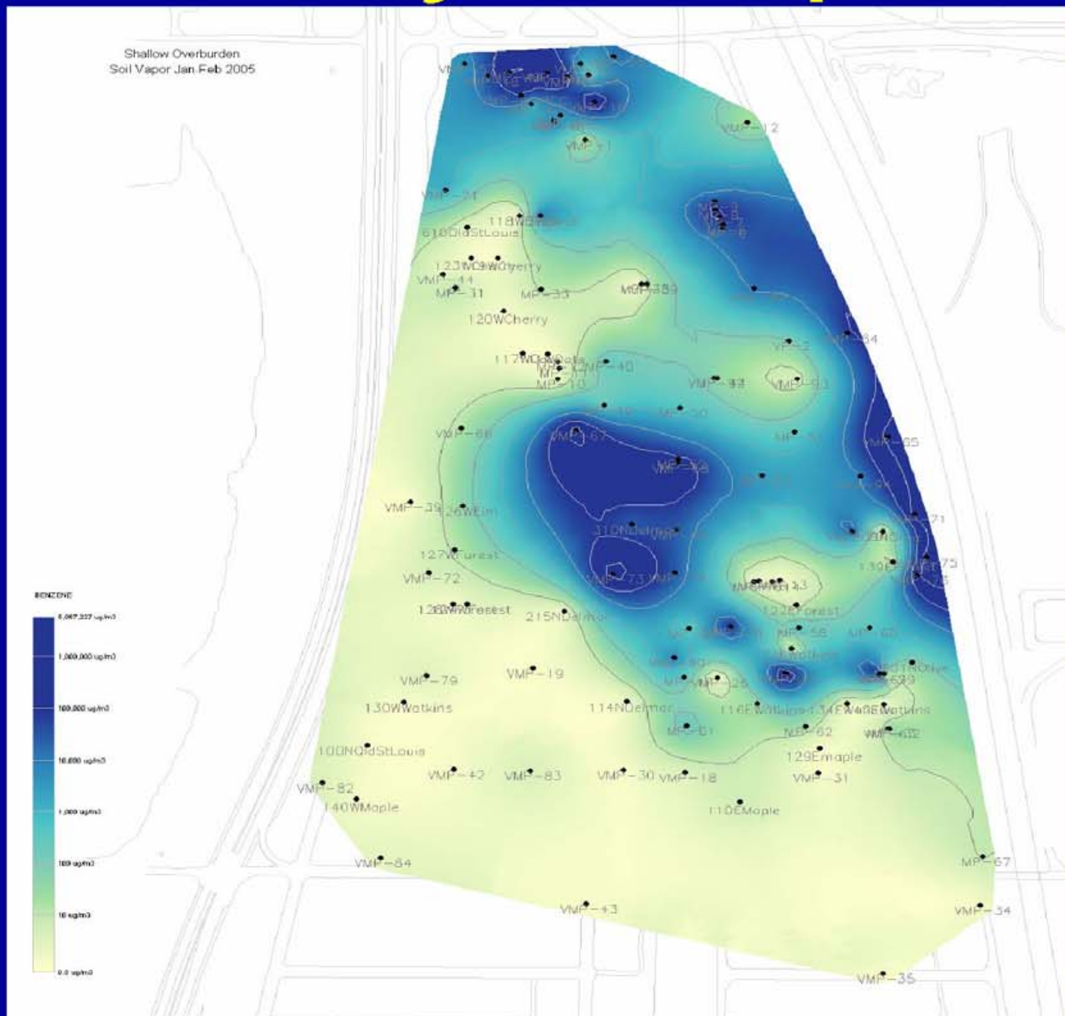
- Vapors
  - » Thinning in clays and structural highs seem to control where vapor concentrations near the surface are greatest except where a surface release has occurred
  - » Near surface releases into thicker clay zones tend to correspond with increased vapors
  - » Lateral migration of vapors possible in sand zones away from product plume in unsaturated zone
  - » Utility corridors in contact with sands a potential preferred pathway

Soil Vapor Contours in Main Stratum



- Vapor distribution correlates with LNAPL distribution in Main Stratum
- Reduced vapor concentrations observed near locations of existing SVE wells

"A" Clay Soil Vapor Distribution



- Soil vapor concentrations correlate with recent odor complaints
- Reduced vapor concentrations observed near locations of existing SVE wells

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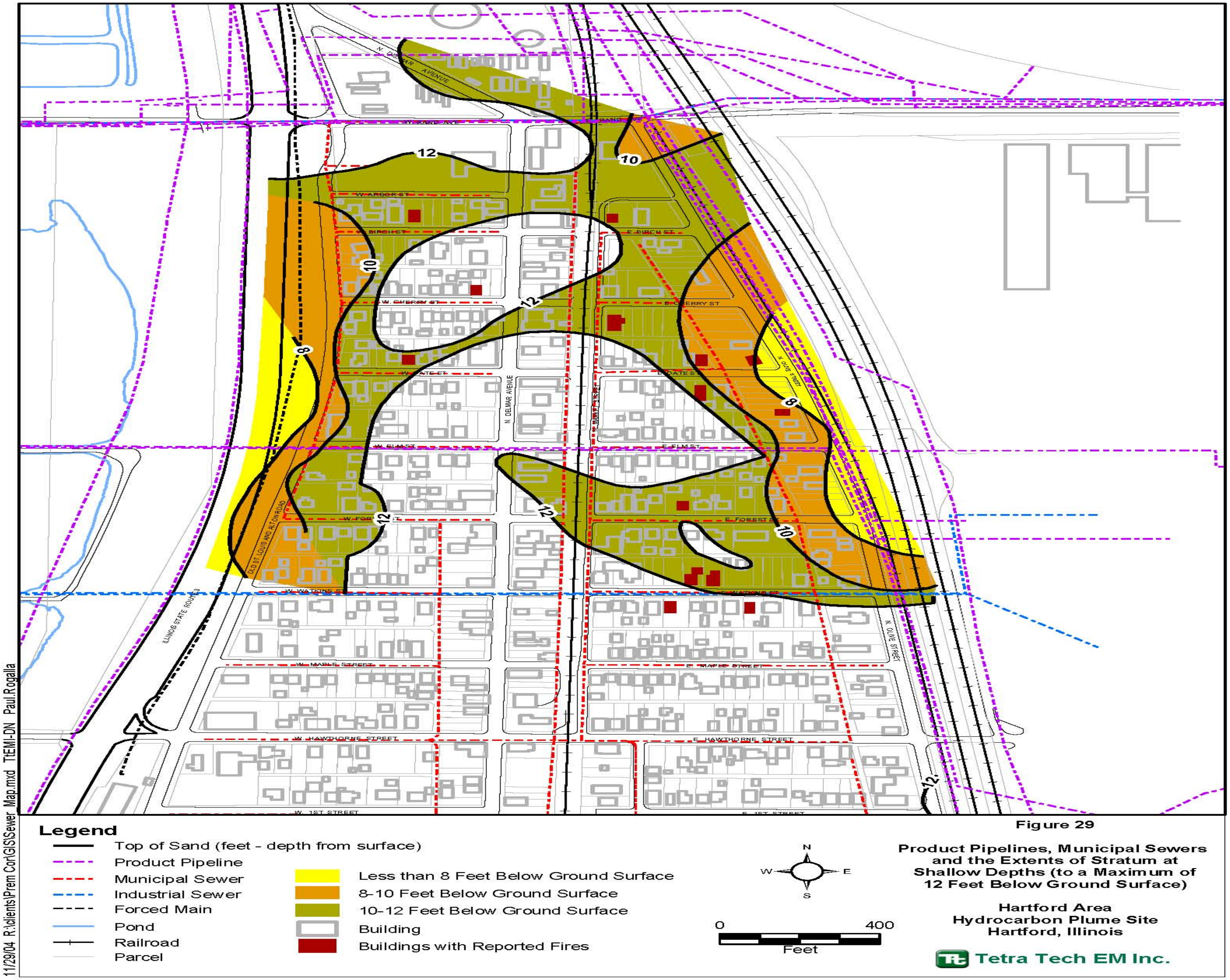


Figure 29

Product Pipelines, Municipal Sewers and the Extents of Stratum at Shallow Depths (to a Maximum of 12 Feet Below Ground Surface)

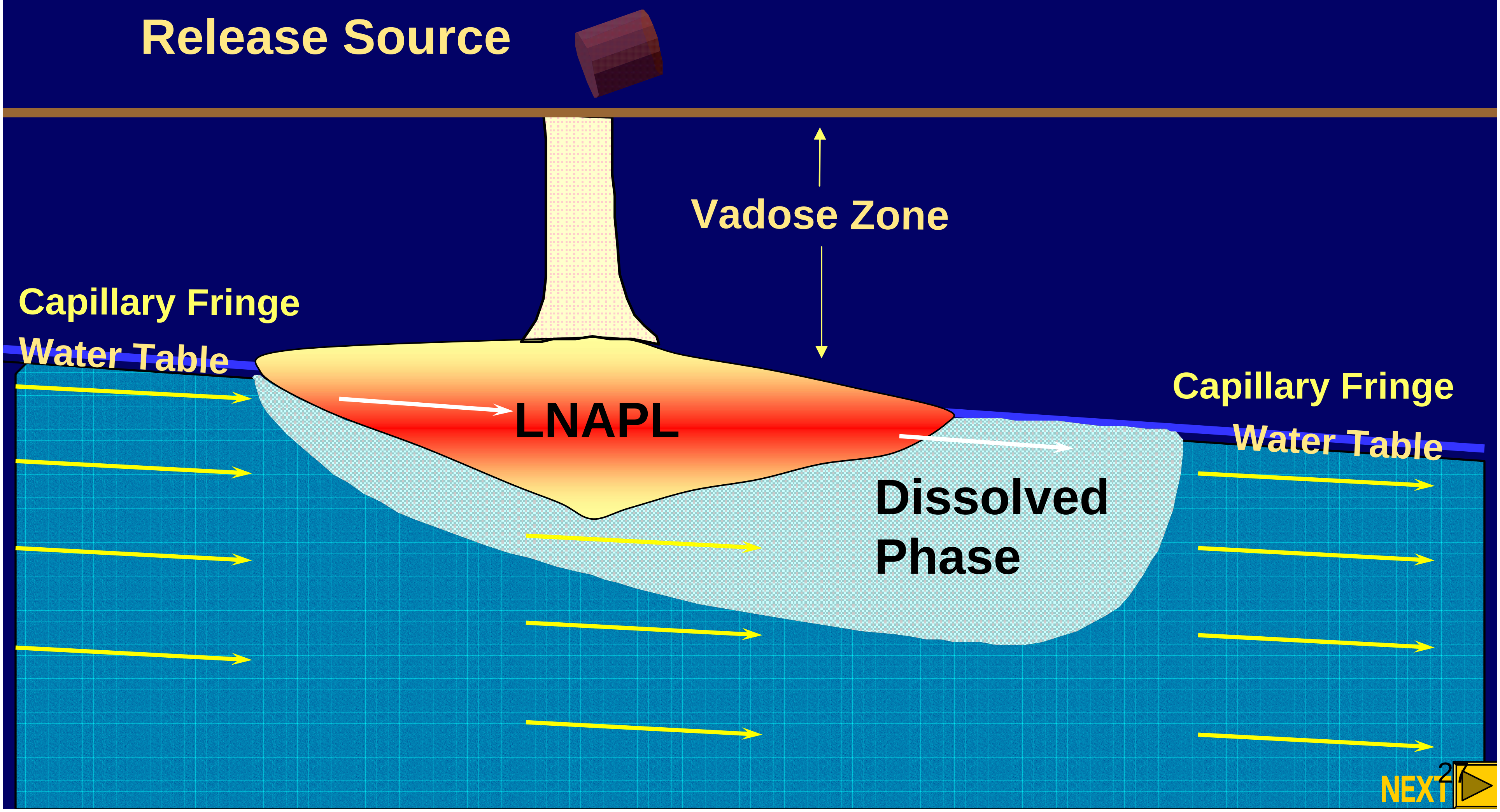
Hartford Area Hydrocarbon Plume Site
Hartford, Illinois

11/29/04 R:\clients\Prem Cor\GIS\Sewer Map.mxd TtEMI-DN Paul.Rogalla

Vapor Intrusion Mitigation System

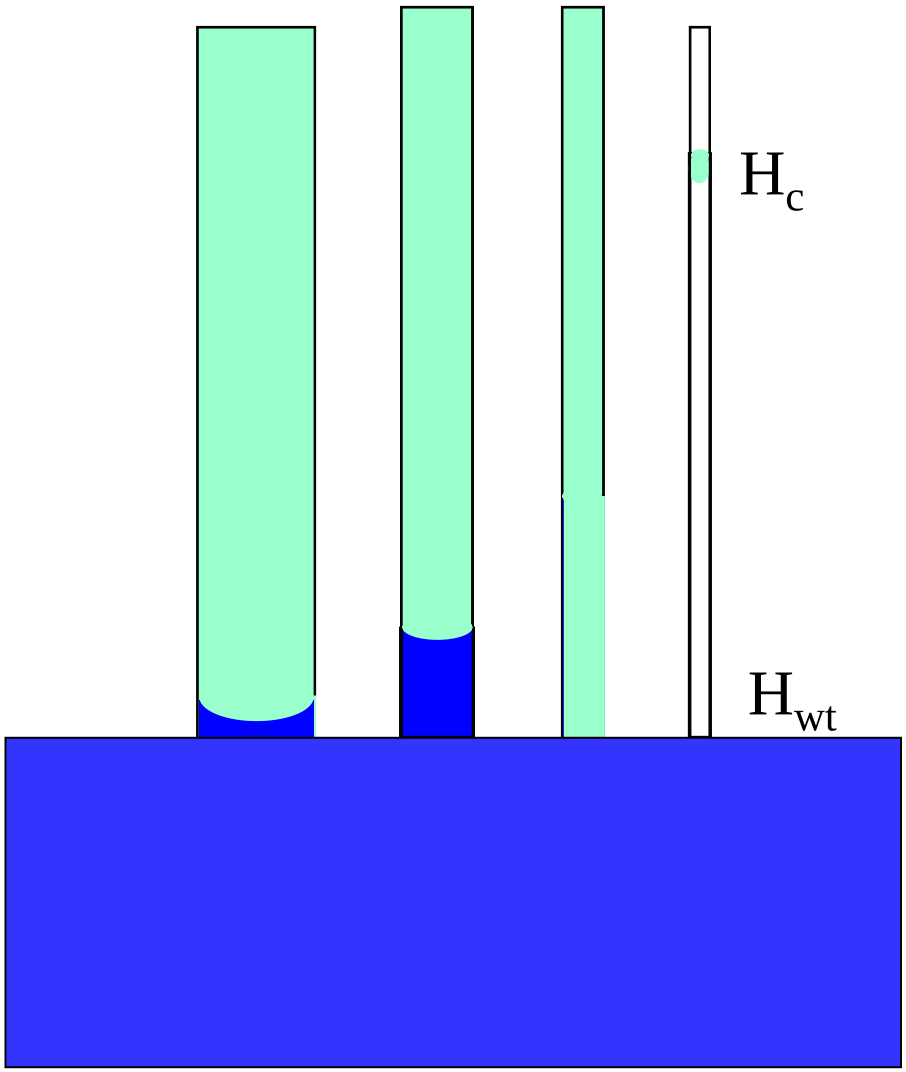
- Vapor probe data and the CSM was used to design a regional SVE system rather than a sub slab system
- System modifications are underway to compensate for the influence of utility corridors and near surface spills as evidenced by the ROST™ results
- The CSM continues to evolve as the system comes on line and monitoring data is compiled

Using a CSM to Design a Product Removal System



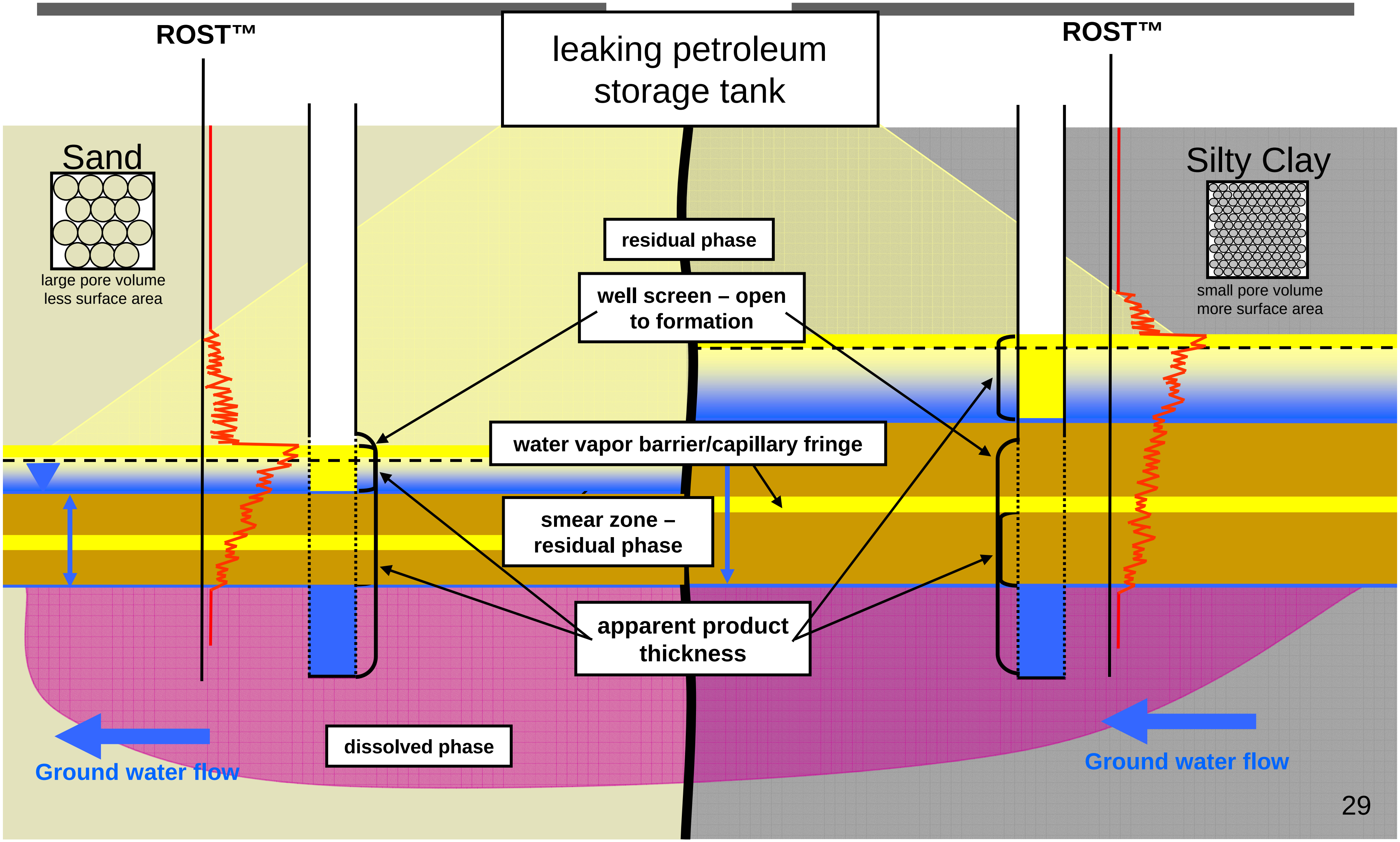
NEXT

Capillary Pressure and Apparent Product Thickness (Thickness Measured in a Well)

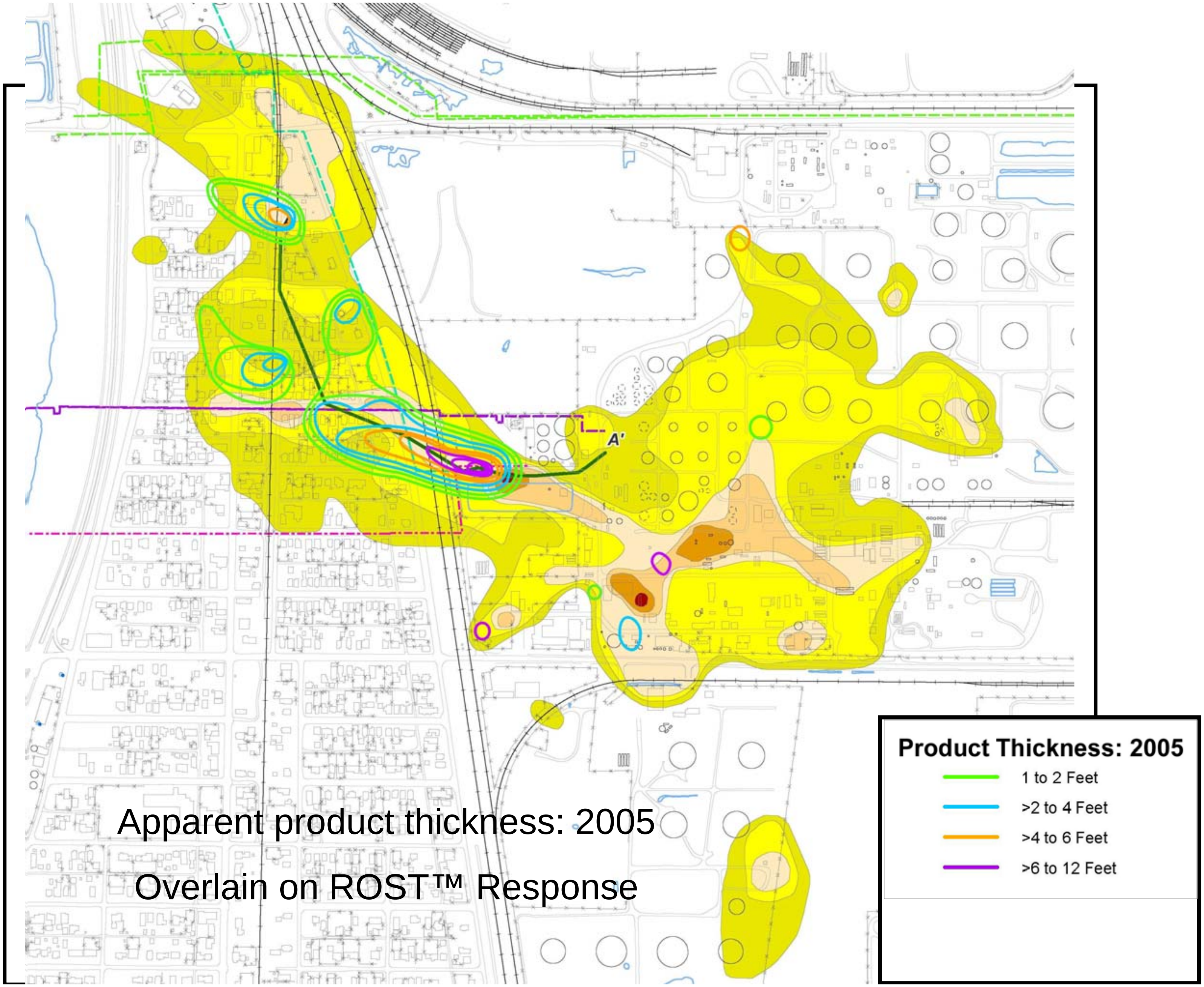


As pore size gets smaller, capillary rise gets bigger.

Understanding the Relationships Between Apparent Product Thickness, and ROST™ Response



Using the CSM to Design a Product Removal

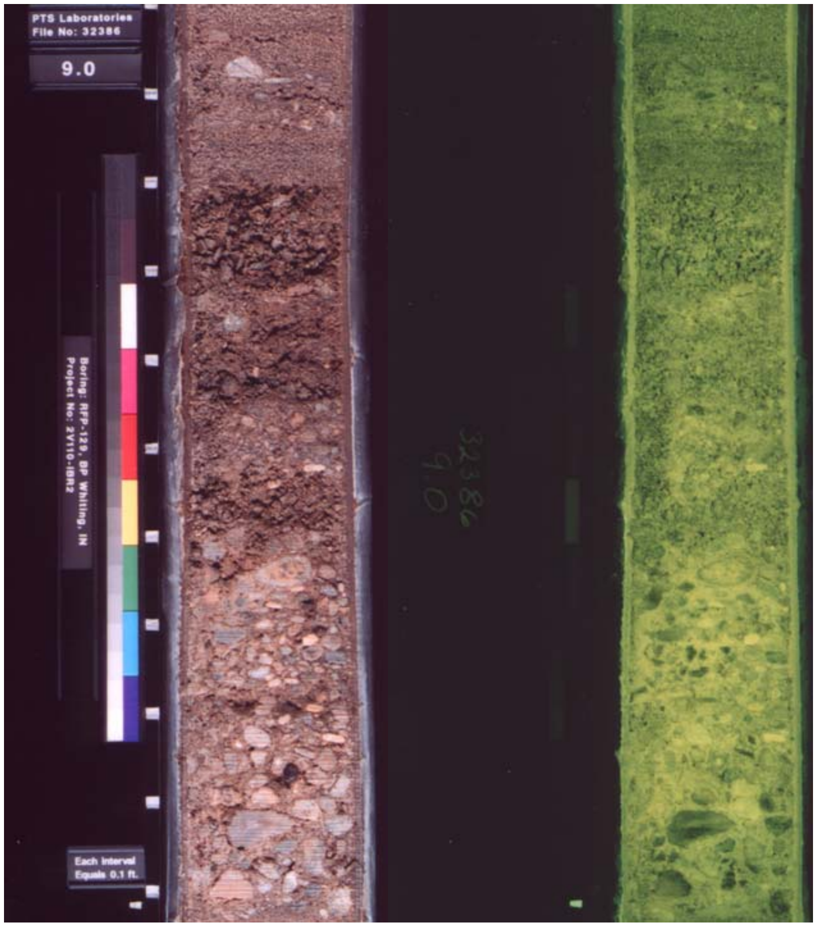


Core Testing When LNAPL Present

- Photograph cores in normal light and ultraviolet
- Perform saturation analyses where there are LNAPLs
- Perform grain size analyses and a few Atterberg limit analyses for fine-grained soils
- Obtain one or more air/water or LNAPL/water drainage capillary pressure tests (depends on your site)
- Obtain imbibition curve data and relative permeability curves (optional, based on professional judgment)

Photographs of Contaminated Cores

9 feet below ground surface



Natural

UV

Dark means no fluorescence

13 feet below ground surface

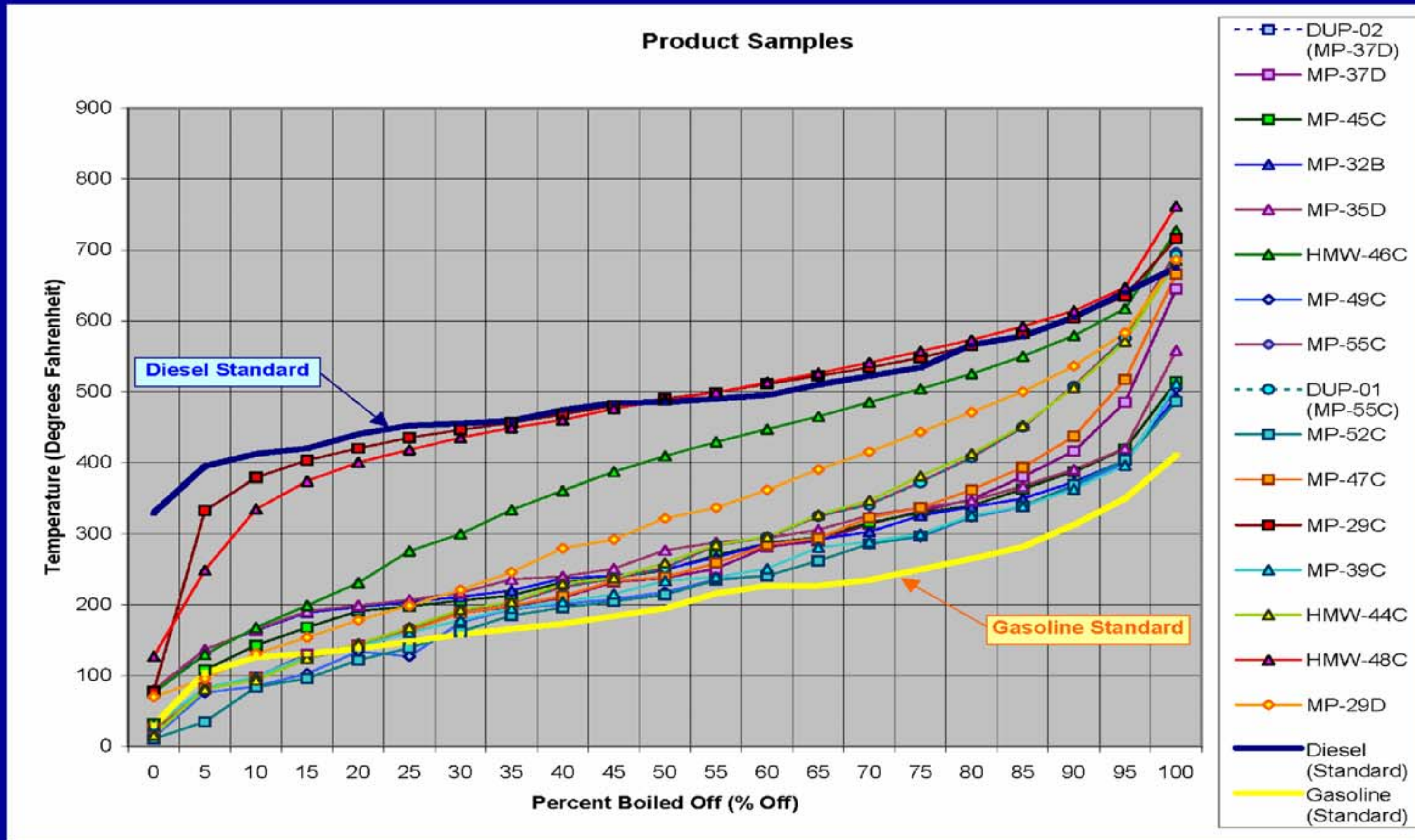
Natural

UV

Dark means no fluorescence

NEXT

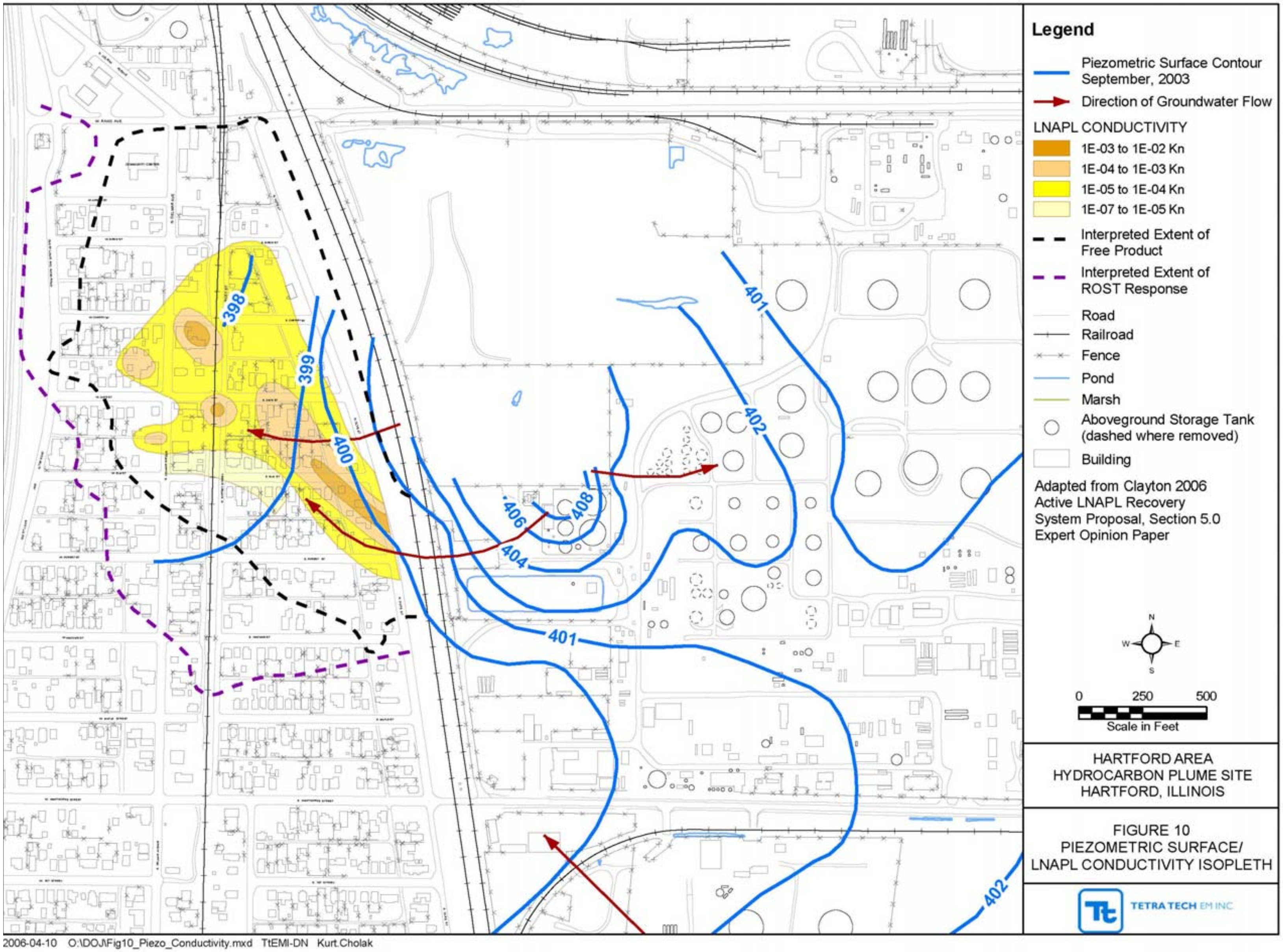
LNAPL Characteristics



- Samples fall between gasoline and diesel standard curves
- Viscosity/Density results complement simulation distribution results

HARTFORD WORKING GROUP

Permeability Corridor as Predicted by HVAC Testing



Current Product Removal Related Activities

- A mobile dual phase system is being used to evaluate removal rates
- Additional physical data is being collected to evaluate percent saturation, porosities, viscosity, and distribution to develop a clearer picture of where and if more permanent systems should be installed

Lessons Learned

- Building a comprehensive CSM lead to efficient data collection and a group consensus vision for characterization and remediation
- Use of field-based measurement technologies like ROST™ can vastly improve a project teams understanding of the geology, hydrogeology, and contaminant characteristics
- A CSM can be used to predict vapor issues and design product recovery systems more efficiently
- LNAPL sites do not always conform with our preconceived notions of how contaminants behave; “Test your CSM” and revise it continuously to get the best results

Fort Lewis, Tacoma, WA

- Two former small arms ranges and a skeet range
  - » Miller Hill active 1920-1951
  - » Evergreen Infiltration Range active 1950-1965
- Overgrown with trees and grasses

CSM

- Fixed or stationary targets and impact berms
  - » Miller Hill berm 180’ long
  - » Evergreen berm 300’ long and 40’ tall
- Lead expected to be the primary contaminant of concern (COC)
  - » 45 caliber cartridge 97% lead, 2% antimony, trace arsenic, copper, tin, and zinc
- Potential human and ecological receptors
- Bullet pockets result in significant fragmentation and ricochet
- Soil primary matrix of concern and COCs not expected to have impacted ground water

Systematic Planning

- Aerial photo review
- Develop GIS maps with range layout
- Risk pathway evaluation and identification of potential action levels
  - » 50 ppm, 250 ppm, 400 ppm, and 1,000 ppm
- Field recon to identify impact berms and firing points
  - » No vegetation on the impact zone
- Develop data management & communication strategy

Refine Project Objectives

- Confirm the presence of soil contamination
- Confirm lead is the primary COC for defining extent of contamination
- Delineate the vertical and horizontal extent of lead contamination above 50 ppm
- Manage uncertainty around contaminant volume estimates greater than 250 ppm, 400 ppm, and 1,000 ppm
- Collect data to determine if contaminated soil would be a RCRA characteristic waste

Dynamic Work Plan Strategy

- Sample location density initially driven by process knowledge and site usage
  - » 10 foot intervals lengthwise along berm face from 0-1 and 1-2 foot depth
  - » Additional sample location determined real-time to define vertical and horizontal boundaries
- Sample support driven by potential remedies
  - » Institutional controls, dig and haul, or treatment
  - » Soil sieved with number 10 (<2mm)
  - » One gallon zip-lock bag filled with soil that was archived
- Data visualization using Spatial Analysis & Decision Assistance (SADA) to maintain close communication with team members as work progressed, and evaluate statistical uncertainty

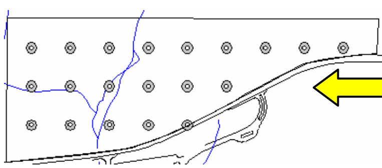
SADA General Information

- Windows-based freeware designed to integrate scientific models with decision and cost analysis frameworks in a user-friendly manner. Can be used to analyze spatially referenced analytical data or to post-process model output for risk assessment purposes.
  - » Visualization/GIS
  - » Statistical Analysis
  - » Geospatial Interpolation
  - » Geospatial Uncertainty Analysis
  - » Human Health Risk Assessment
  - » Ecological Risk Assessment
  - » Custom Analysis
  - » Area of Concern Frameworks
  - » Cost Benefit Analysis
  - » Sampling Designs
  - » Export to Arcview/Earthvision
- SADA has been supported by DOE, EPA, and the NRC. SADA through version 4 has had over 20,000 downloads. Version 5 is currently in beta release.

Sample Designs

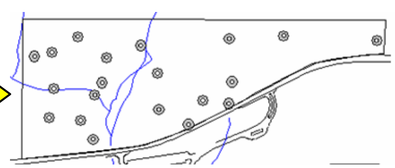
- SADA has a number of sample design strategies in Version 4. These strategies include initial and secondary designs. Some are based on data alone while others are based on modeling results. With the exception of a couple of exclusively 2d designs all are available in 3d dimensions.

Initial Designs	Secondary Designs



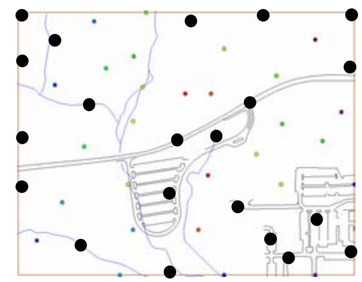
Systematic, unaligned, & hotspot search grids

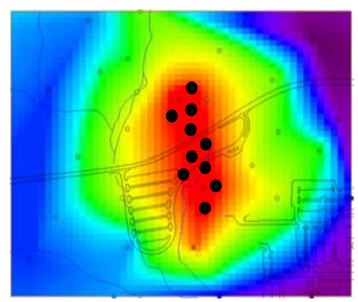
Random



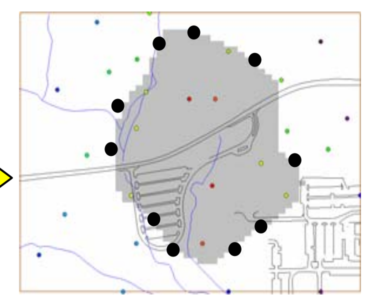
Judgmental

Adaptive Fill





AOC Boundary



Demonstration of Method Applicability (DMA)

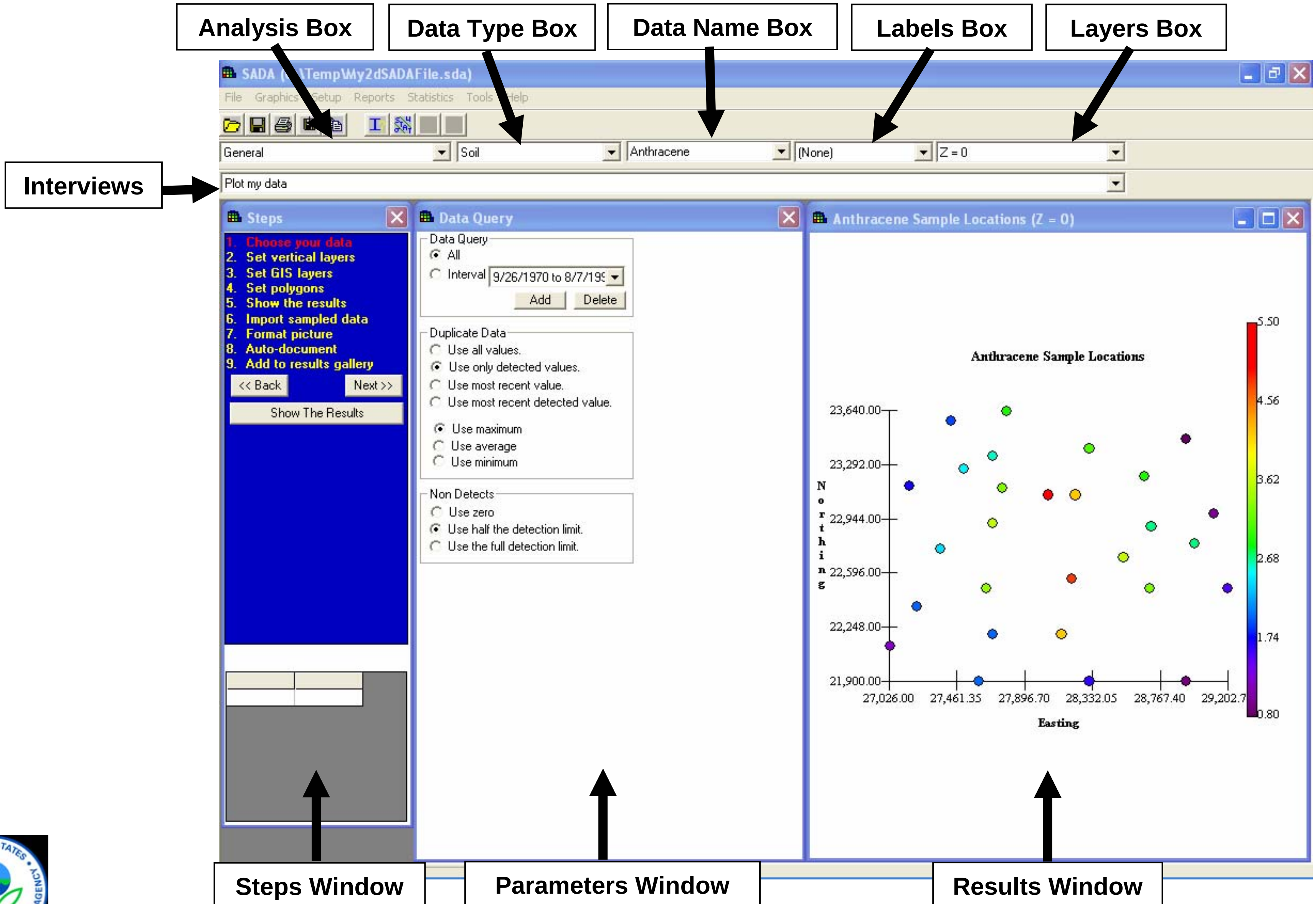
- 40 samples from impact berm at Evergreen
- Evaluate site-specific heterogeneities
  - Sampling Design (bag vs. cup)
  - Refine CSM – confirm lead primary COC
  - Evaluate XRF performance on site matrices
  - Confirm 45 ppm XRF lead detection level
- Evaluate bias of the field-based instrument technology

Data

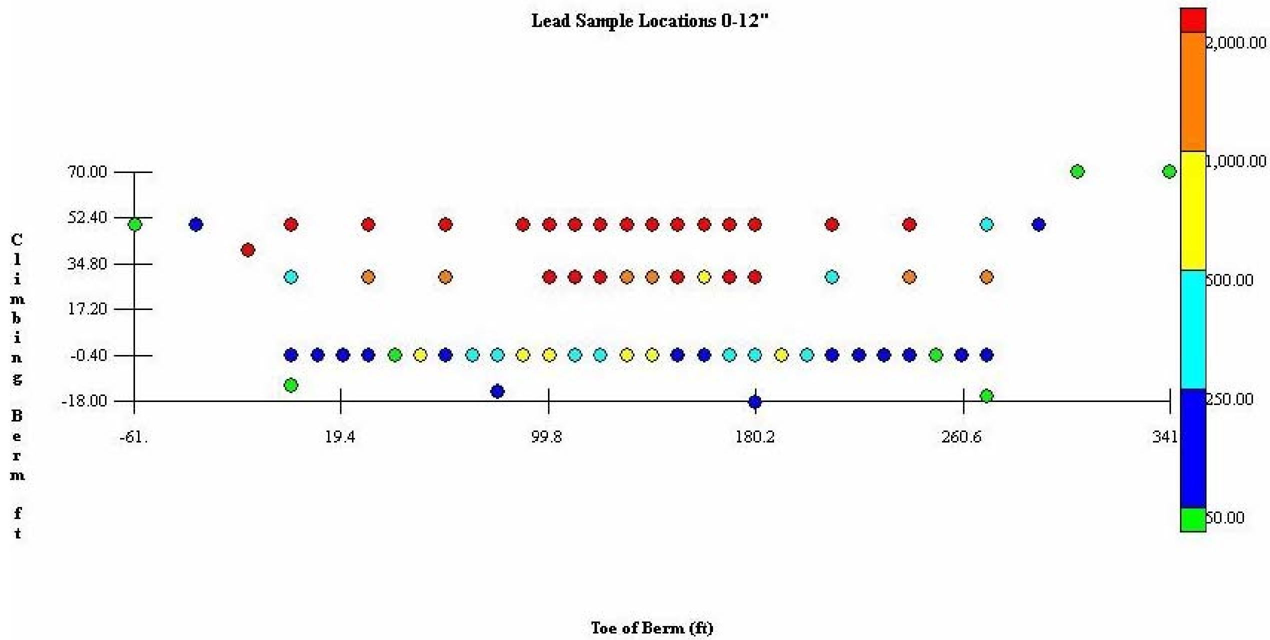
PROJECT NAME	PROJECT #	SAMPLEI	SAMPLE ID	DATE COLL	DATE RECD	ANALYZED	TAI LAB #	ANALYTE	RESULT	PQL	UNITS	METHOD
I-40/I-640 SINKHOLE	4969.013	BW/JO	HSSW1	10/1/2002	10/3/2002	10/7/2002	02-A162603	Aldrin	< 0.00005	5E-05	mg/l	8081A
I-40/I-640 SINKHOLE	4969.013	BW/JO	HSSW1	10/1/2002	10/3/2002	10/7/2002	02-A162603	a-BHC	< 0.00005	5E-05	mg/l	8081A
I-40/I-640 SINKHOLE	4969.013	BW/JO	HSSW1	10/1/2002	10/3/2002	10/7/2002	02-A162603	b-BHC	< 0.00005	5E-05	mg/l	8081A
I-40/I-640 SINKHOLE	4969.013	BW/JO	HSSW1	10/1/2002	10/3/2002	10/7/2002	02-A162603	d-BHC	< 0.00005	5E-05	mg/l	8081A
I-40/I-640 SINKHOLE	4969.013	BW/JO	HSSW1	10/1/2002	10/3/2002	10/7/2002	02-A162603	g-BHC, Lindane	< 0.00005	5E-05	mg/l	8081A
I-40/I-640 SINKHOLE	4969.013	BW/JO	HSSW1	10/1/2002	10/3/2002	10/7/2002	02-A162603	4,4'-DDD	< 0.00010	0.0001	mg/l	8081A
I-40/I-640 SINKHOLE	4969.013	BW/JO	HSSW1	10/1/2002	10/3/2002	10/7/2002	02-A162603	4,4'-DDE	< 0.00010	0.0001	mg/l	8081A
I-40/I-640 SINKHOLE	4969.013	BW/JO	HSSW1	10/1/2002	10/3/2002	10/7/2002	02-A162603	4,4'DDT	< 0.00010	0.0001	mg/l	8081A
I-40/I-640 SINKHOLE	4969.013	BW/JO	HSSW1	10/1/2002	10/3/2002	10/7/2002	02-A162603	Dieldrin	< 0.00010	0.0001	mg/l	8081A
I-40/I-640 SINKHOLE	4969.013	BW/JO	HSSW1	10/1/2002	10/3/2002	10/7/2002	02-A162603	Endosulfan I	< 0.00005	5E-05	mg/l	8081A
I-40/I-640 SINKHOLE	4969.013	BW/JO	HSSW1	10/1/2002	10/3/2002	10/7/2002	02-A162603	Endosulfan II	< 0.00010	0.0001	mg/l	8081A
I-40/I-640 SINKHOLE	4969.013	BW/JO	HSSW1	10/1/2002	10/3/2002	10/7/2002	02-A162603	Endosulfan Sulfate	< 0.00010	0.0001	mg/l	8081A
I-40/I-640 SINKHOLE	4969.013	BW/JO	HSSW1	10/1/2002	10/3/2002	10/7/2002	02-A162603	Endrin	< 0.00010	0.0001	mg/l	8081A
I-40/I-640 SINKHOLE	4969.013	BW/JO	HSSW1	10/1/2002	10/3/2002	10/7/2002	02-A162603	Endrin Aldehyde	< 0.00010	0.0001	mg/l	8081A
I-40/I-640 SINKHOLE	4969.013	BW/JO	HSSW1	10/1/2002	10/3/2002	10/7/2002	02-A162603	Endrin Ketone	< 0.00010	0.0001	mg/l	8081A
I-40/I-640 SINKHOLE	4969.013	BW/JO	HSSW1	10/1/2002	10/3/2002	10/7/2002	02-A162603	Heptachlor	< 0.00005	5E-05	mg/l	8081A
I-40/I-640 SINKHOLE	4969.013	BW/JO	HSSW1	10/1/2002	10/3/2002	10/7/2002	02-A162603	Heptachlor Epoxide	< 0.00005	5E-05	mg/l	8081A
I-40/I-640 SINKHOLE	4969.013	BW/JO	HSSW1	10/1/2002	10/3/2002	10/7/2002	02-A162603	Methoxychlor	< 0.00010	0.0001	mg/l	8081A
I-40/I-640 SINKHOLE	4969.013	BW/JO	HSSW1	10/1/2002	10/3/2002	10/7/2002	02-A162603	Toxaphene	< 0.00500	0.005	mg/l	8081A
I-40/I-640 SINKHOLE	4969.013	BW/JO	HSSW1	10/1/2002	10/3/2002	10/7/2002	02-A162603	alpha-Chlordane	< 0.00005	5E-05	mg/l	8081A
I-40/I-640 SINKHOLE	4969.013	BW/JO	HSSW1	10/1/2002	10/3/2002	10/7/2002	02-A162603	gamma-Chlordane	< 0.00005	5E-05	mg/l	8081A
I-40/I-640 SINKHOLE	4969.013	BW/JO	HSSW1	10/1/2002	10/3/2002	10/6/2002	02-A162603	Aroclor 1016	< 0.00050	0.0005	mg/l	8082
I-40/I-640 SINKHOLE	4969.013	BW/JO	HSSW1	10/1/2002	10/3/2002	10/6/2002	02-A162603	Aroclor 1221	< 0.00100	0.001	mg/l	8082
I-40/I-640 SINKHOLE	4969.013	BW/JO	HSSW1	10/1/2002	10/3/2002	10/6/2002	02-A162603	Aroclor 1232	< 0.00050	0.0005	mg/l	8082
I-40/I-640 SINKHOLE	4969.013	BW/JO	HSSW1	10/1/2002	10/3/2002	10/6/2002	02-A162603	Aroclor 1242	< 0.00050	0.0005	mg/l	8082
I-40/I-640 SINKHOLE	4969.013	BW/JO	HSSW1	10/1/2002	10/3/2002	10/6/2002	02-A162603	Aroclor 1248	< 0.00050	0.0005	mg/l	8082
I-40/I-640 SINKHOLE	4969.013	BW/JO	HSSW1	10/1/2002	10/3/2002	10/6/2002	02-A162603	Aroclor 1254	< 0.00050	0.0005	mg/l	8082
I-40/I-640 SINKHOLE	4969.013	BW/JO	HSSW1	10/1/2002	10/3/2002	10/6/2002	02-A162603	Aroclor 1260	< 0.00050	0.0005	mg/l	8082
I-40/I-640 SINKHOLE	4969.013	BW/JO	HSSW1	10/1/2002	10/3/2002	10/5/2002	02-A162603	Arsenic	< 0.0050	0.005	mg/l	6010B
I-40/I-640 SINKHOLE	4969.013	BW/JO	HSSW1	10/1/2002	10/3/2002	10/5/2002	02-A162603	Barium	0.08	0.01	mg/l	6010B

- SADA imports comma delimited files (csv) and Microsoft Access
- Requires the presence of certain fields in the data set
  - » Easting, Northing, Depth, Value, Name
- Can use other forms of information as well
  - » Media, Detection, Date, CAS Number
- Other metadata can be displayed
- Some analyses are media-dependent

Scaleable Interface

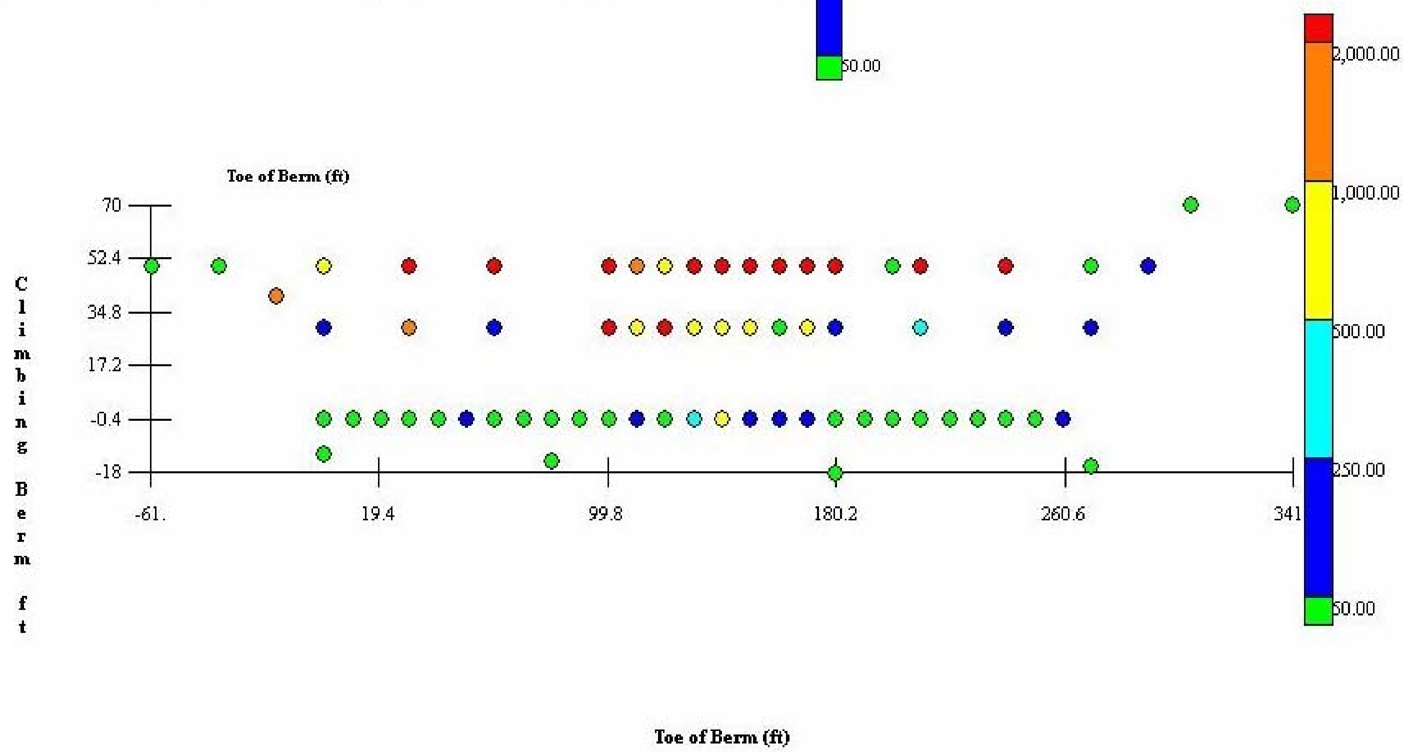


0-12”



Lead Sample Locations 0-12"
Climbing Berm ft
70.00
52.40
34.80
17.20
-0.40
-18.00
-61.
19.4
99.8
180.2
260.6
341
2,000.00
1,000.00
500.00
250.00
50.00
Toe of Berm (ft)

12-24”



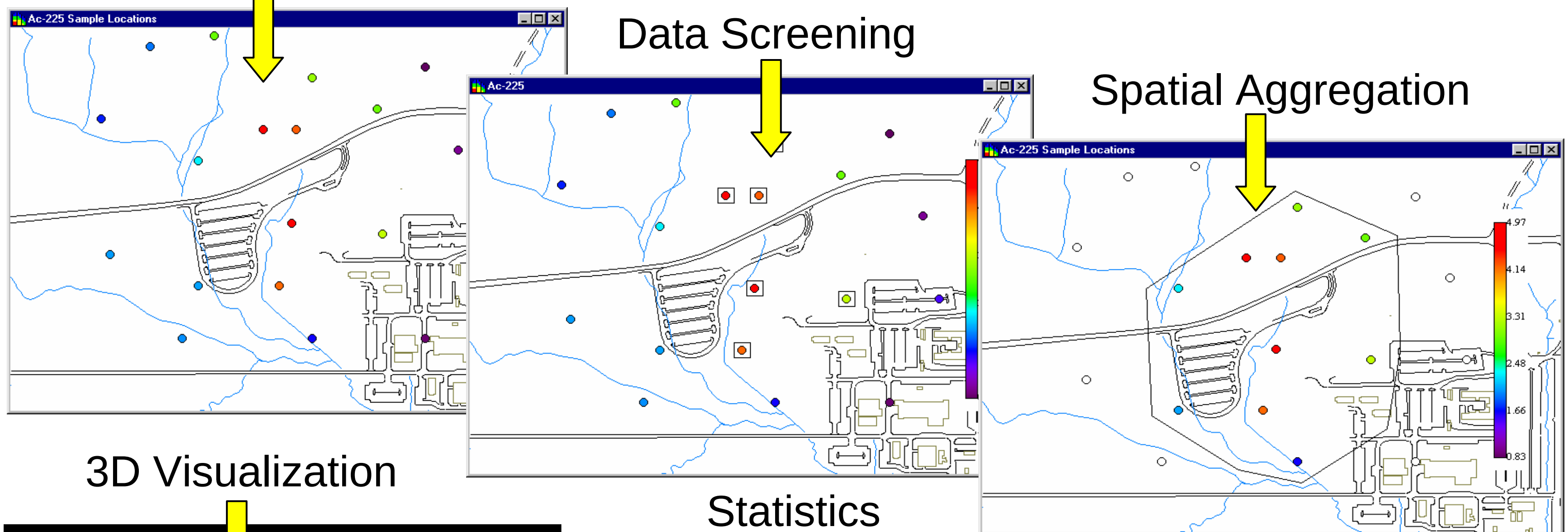
Climbing Berm ft
70
52.4
34.8
17.2
-0.4
-18
-61.
19.4
99.8
180.2
260.6
341
2,000.00
1,000.00
500.00
250.00
50.00
Toe of Berm (ft)

Basic Data Exploration

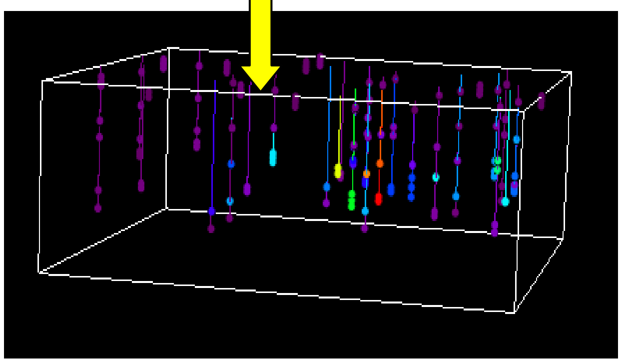
Data/GIS Visualization

Data Screening

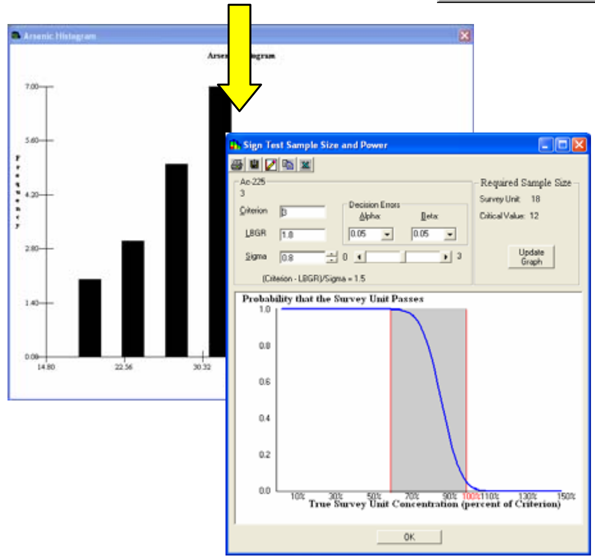
Spatial Aggregation



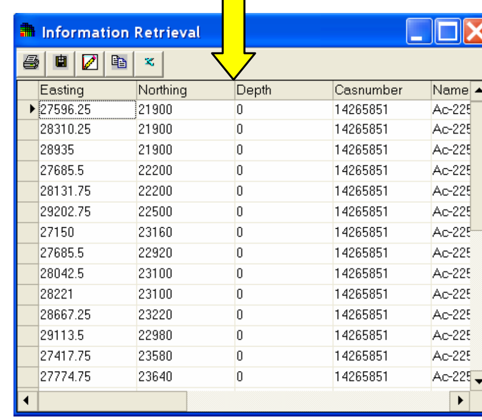
3D Visualization



Statistics



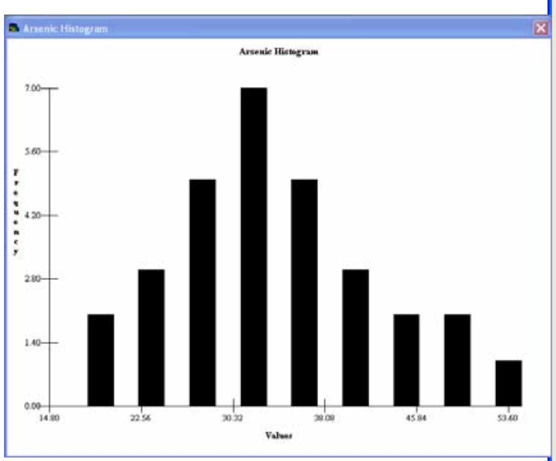
Spatial Data Query

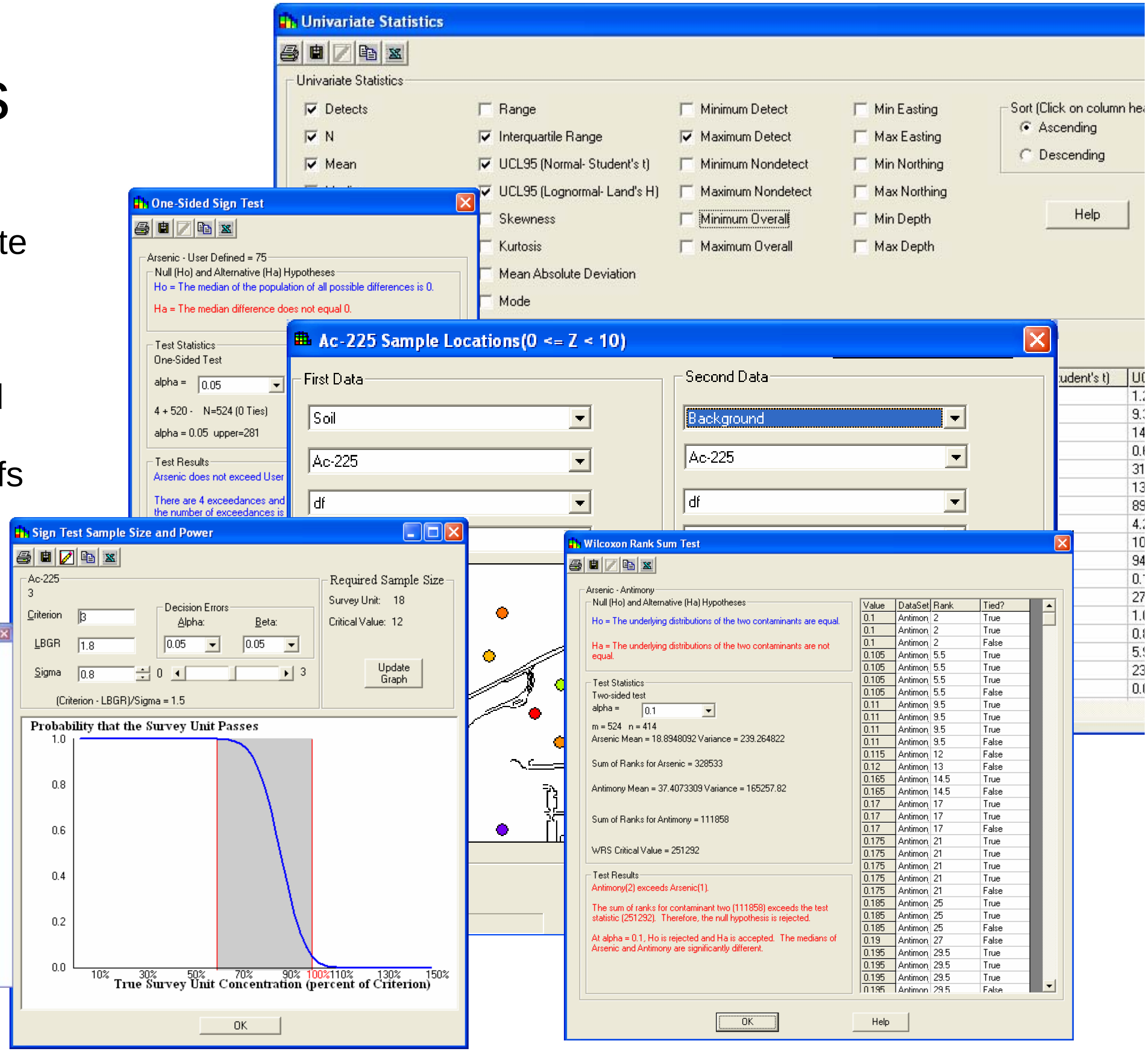


Easting	Northing	Depth	Casnumber	Name
27596.25	21900	0	14265851	Ac-225
28310.25	21900	0	14265851	Ac-225
28935	21900	0	14265851	Ac-225
27685.5	22200	0	14265851	Ac-225
28131.75	22200	0	14265851	Ac-225
29202.75	22500	0	14265851	Ac-225
27150	23160	0	14265851	Ac-225
27685.5	22920	0	14265851	Ac-225
28042.5	23100	0	14265851	Ac-225
28221	23100	0	14265851	Ac-225
28667.25	23220	0	14265851	Ac-225
29113.5	22980	0	14265851	Ac-225
27417.75	23580	0	14265851	Ac-225
27774.75	23640	0	14265851	Ac-225

Classical Statistics

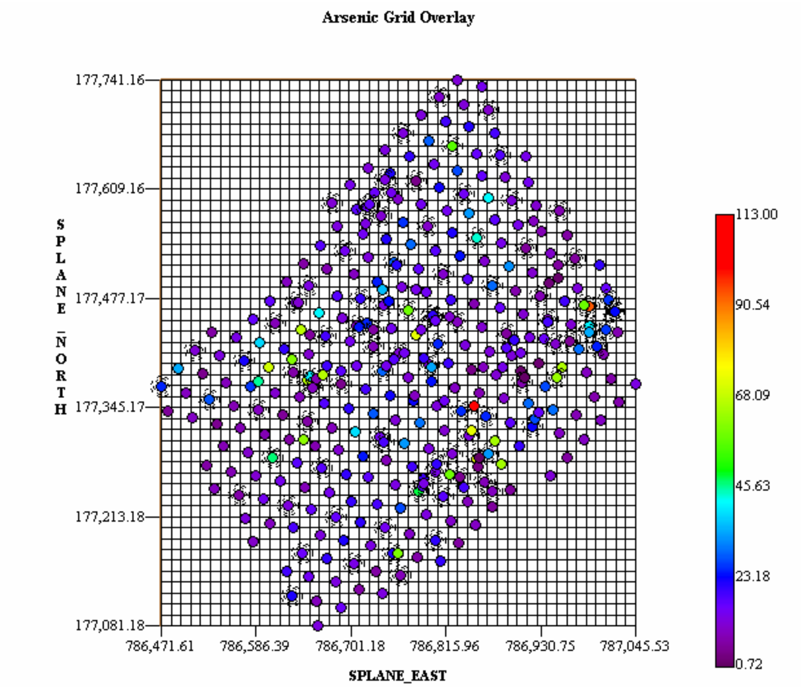
- EPA DQO/DQA
- Numerous univariate statistics
- Non-parametric hypothesis testing
- Power curve based sample sizes
- Histograms and cdfs

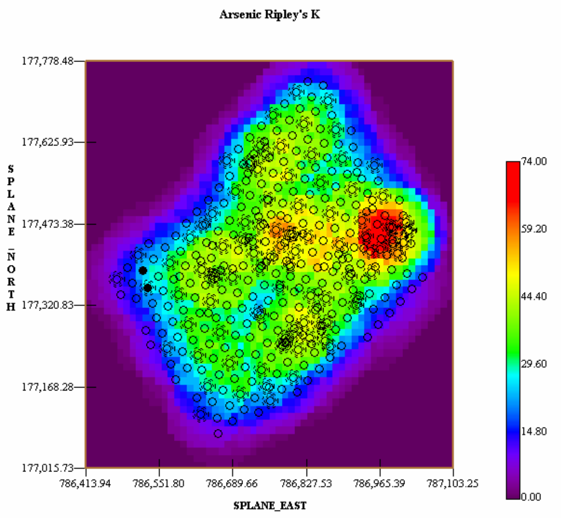




Spatial Statistics

- Local Index of Spatial Association (LISA) displays show maps of moving window statistics, these statistics are calculated at each grid node and the results displayed
- Ripley's K- sampling intensity with each window
- Moran's I- measure of correlation between all points in each window
- Geary's C- semivariance calculation (average dissimilarity) between points within each window

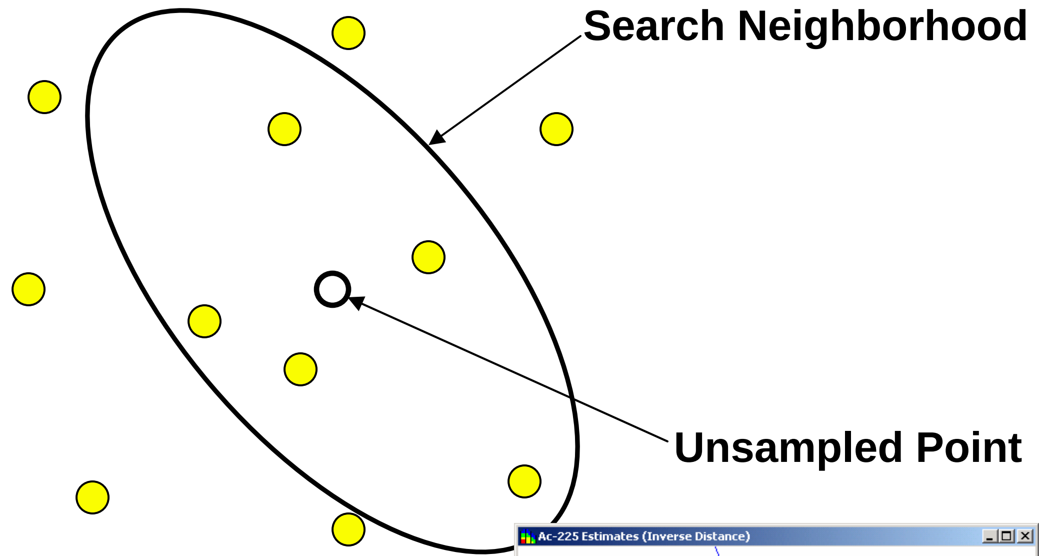




Spatial Estimation

The estimated value V_o at an unsampled location is estimated as the weighted average of nearby values.

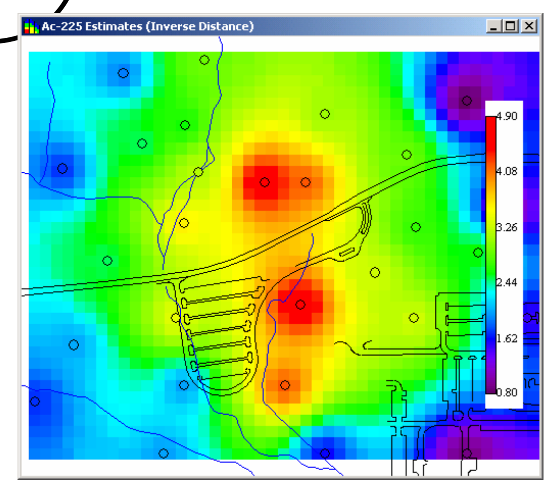
$$V_0 = \sum_{i=1}^{N} w_i V_i$$



Inverse Distance

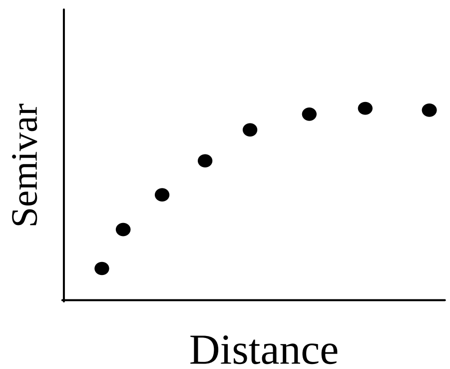
$$w_i = \frac{1}{d_i^p \sum_{j=1}^{N} d_j^{-p}}$$

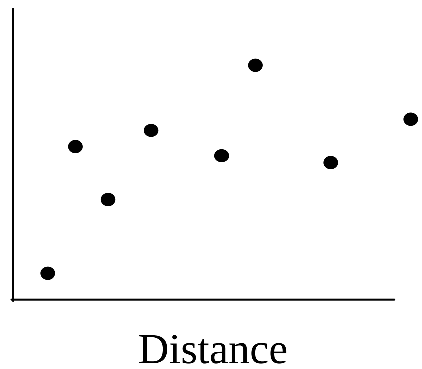
w_i is the weight for the ith neighbor
d_i is the distance of the ith neighbor
p is the power
N is the number of neighbors within the search neighborhood

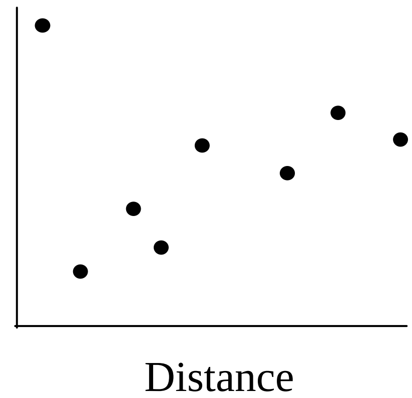


Modeling Spatial Auto-correlation

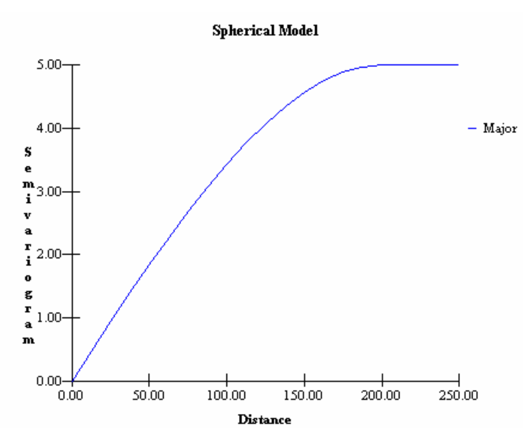
Semi-variograms often do not conform to the well behaved monotonic increasing variogram structures seen in text book examples.

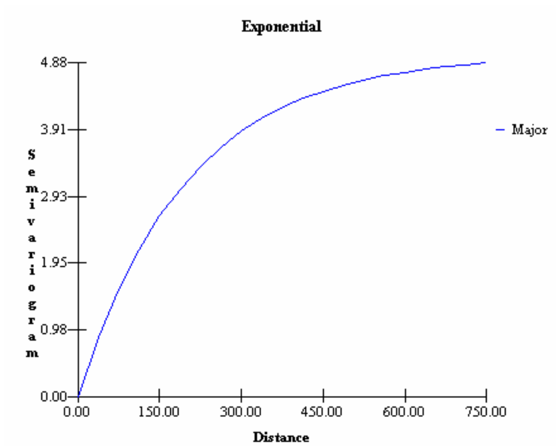


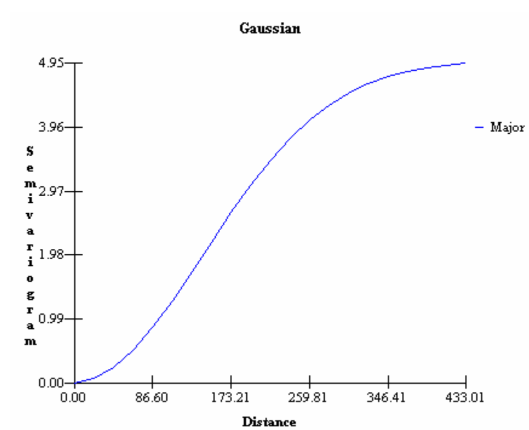




SADA provides 3 standard correlation models that provide flexibility in semi-variogram data: Spherical, Exponential, and Gaussian.

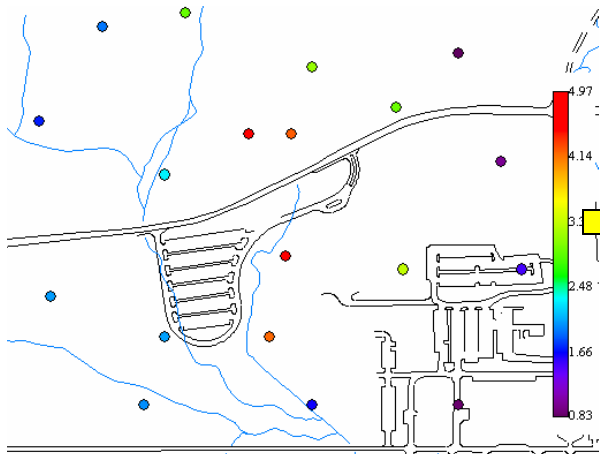




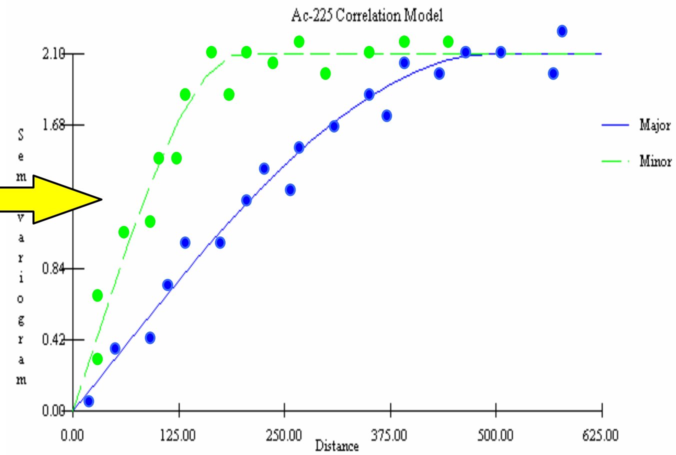


Autofit routines are available to assist in fitting correlation models. These models are then used to generate kriging maps.

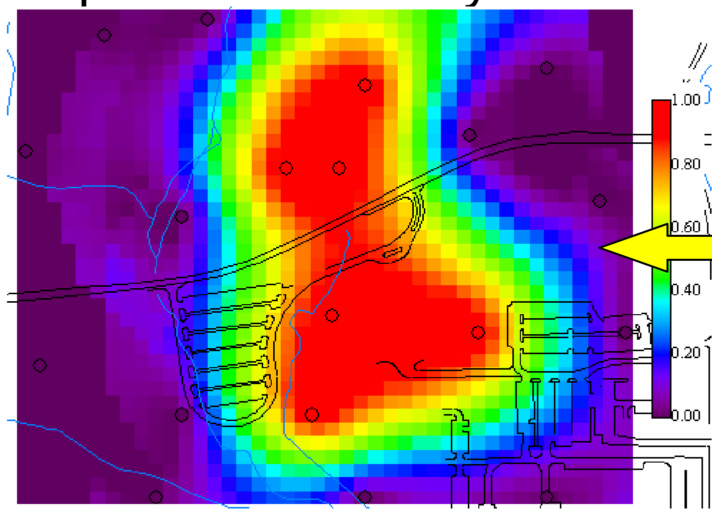
Spatial Analysis



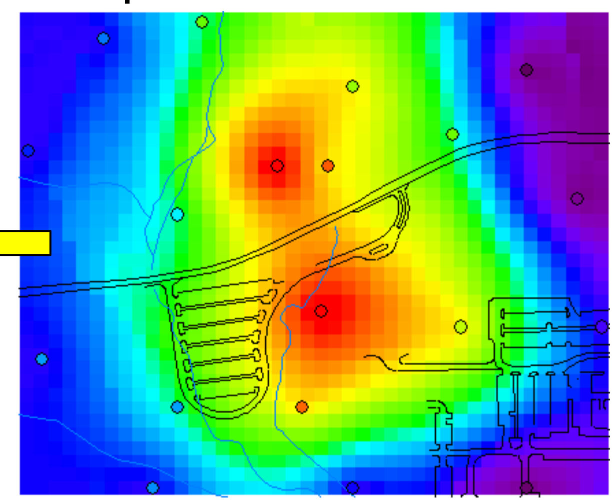
Model Spatial Correlation

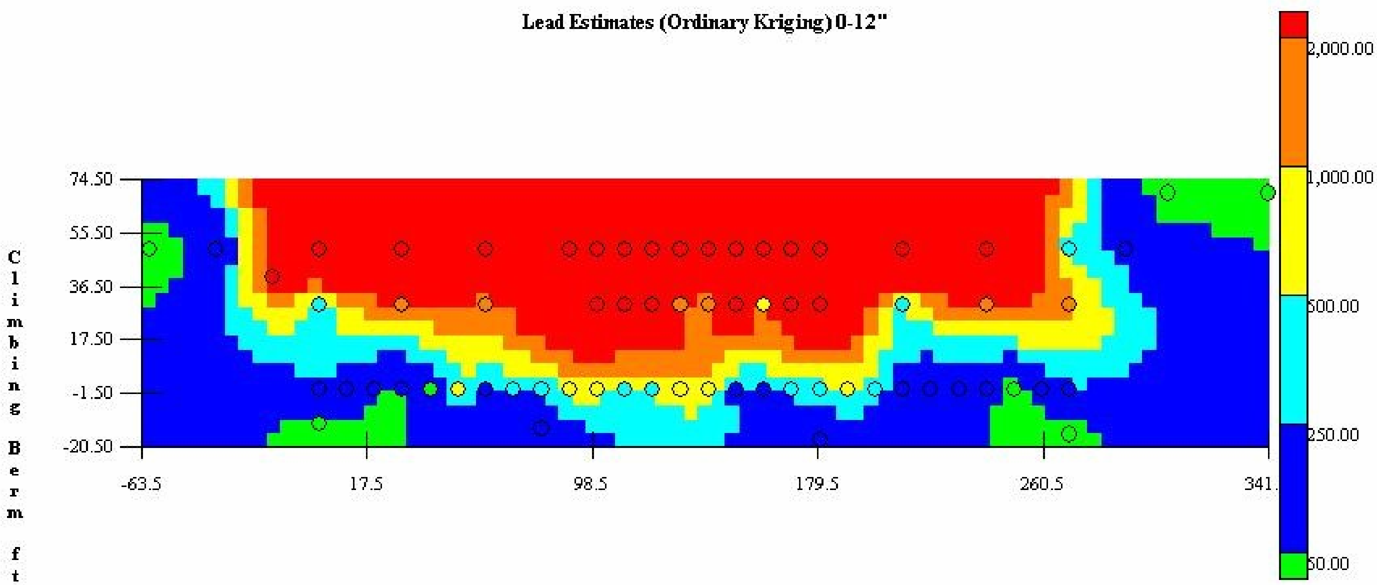


Spatial Uncertainty

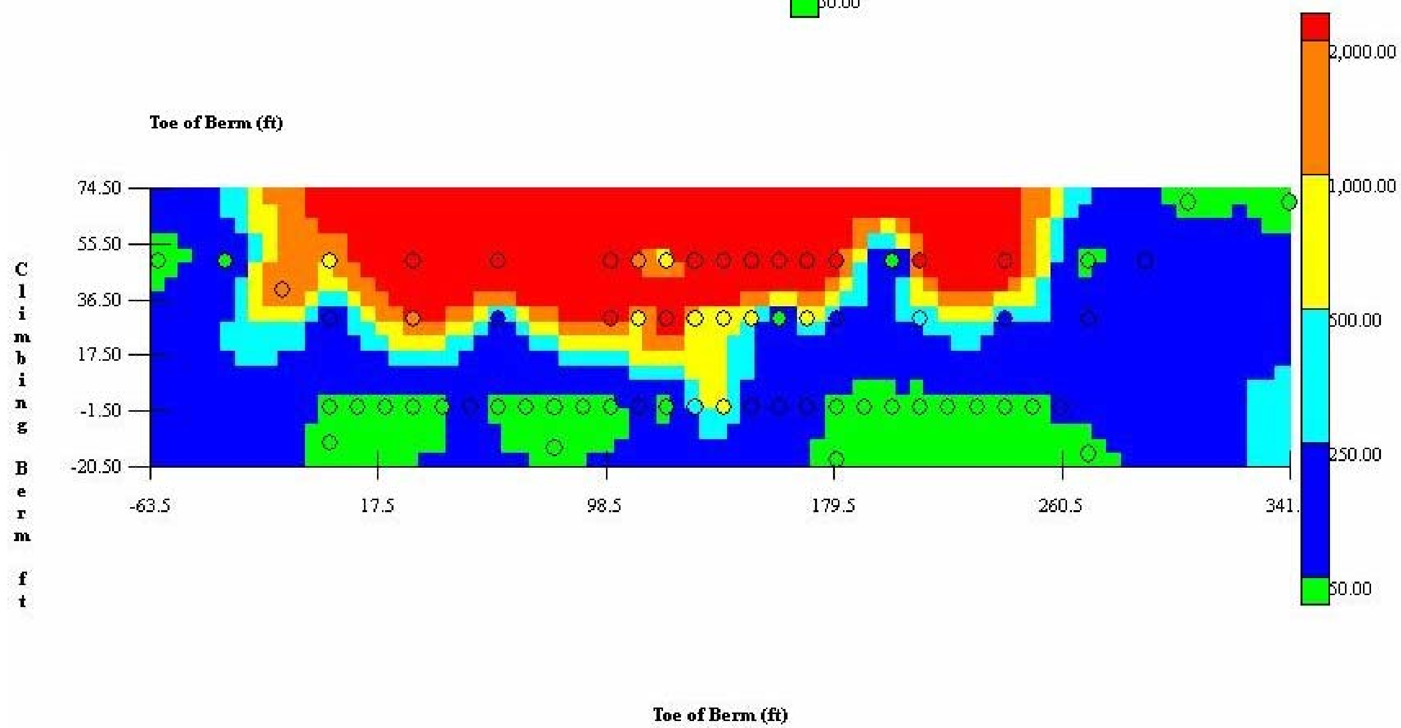


Spatial Estimation




Lead Estimates (Ordinary Kriging) 0-12"
Climbing Berm ft
74.50
55.50
36.50
17.50
-1.50
-20.50
-63.5
17.5
98.5
179.5
260.5
341.
2,000.00
1,000.00
500.00
250.00
50.00
Toe of Berm (ft)

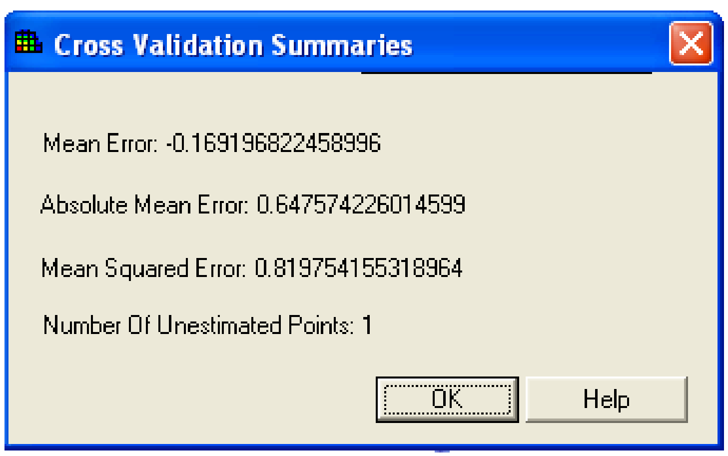
0-12”

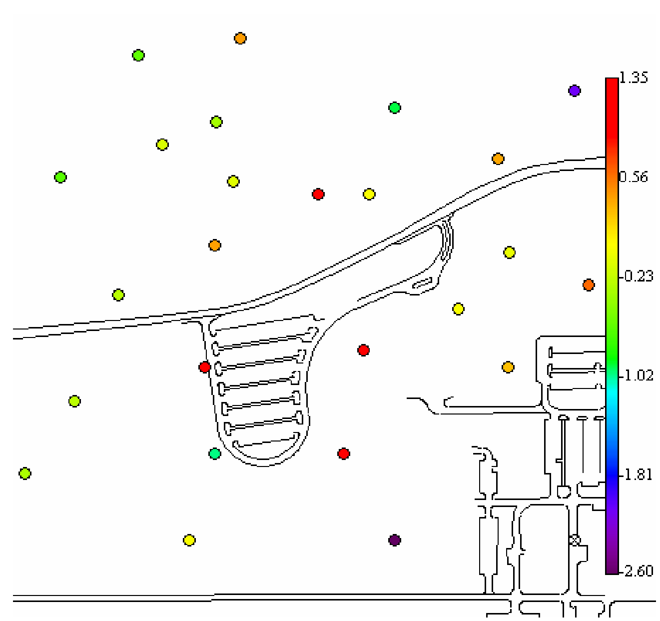

Climbing Berm ft
74.50
55.50
36.50
17.50
-1.50
-20.50
-63.5
17.5
98.5
179.5
260.5
341.
2,000.00
1,000.00
500.00
250.00
50.00
Toe of Berm (ft)

12-24”

Comparing Spatial Models (Cross Validation)

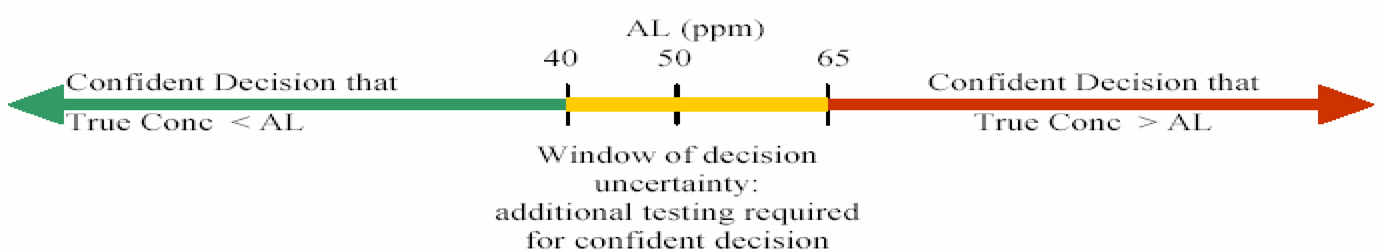
- Cross validation provides estimates of model error based on existing data
- Process of removing one sample at a time and predicting the concentration at that location, and measuring the error
- Statistic generated for all samples that can be used to make comparative statements between different spatial models:
  - » Mean of errors
  - » Absolute mean error
  - » Mean squared error





DMA

- Develop uncertainty intervals where it is judged that data can be confidently trusted to declare areas as
  - » "Clean" – No further investigation
  - » "Dirty" – Remedial action needed
  - » "Ambiguous" – Further data required

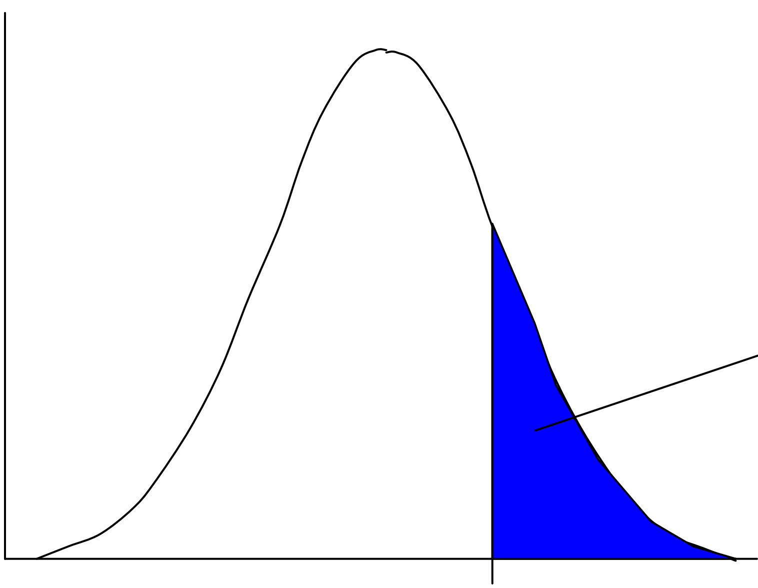


Source: TIO - Considerations for Developing a Methods Applicability Study, March 2003

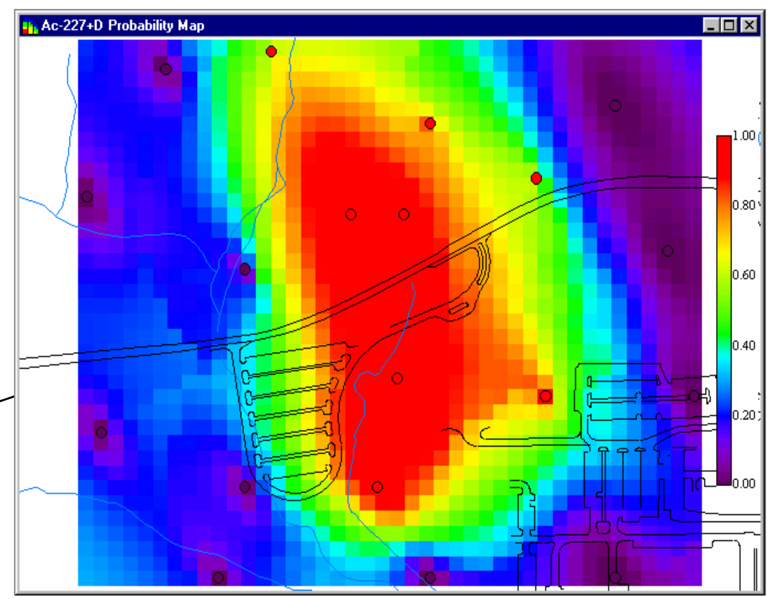
Probability Maps

- A probability map spatially delineates the probability of exceeding a specified threshold.
- The probability of the center of each block exceeding the threshold value is calculated.
- Probability maps can only be created with ordinary or indicator kriging.

Probability > 3.0 pCi/G

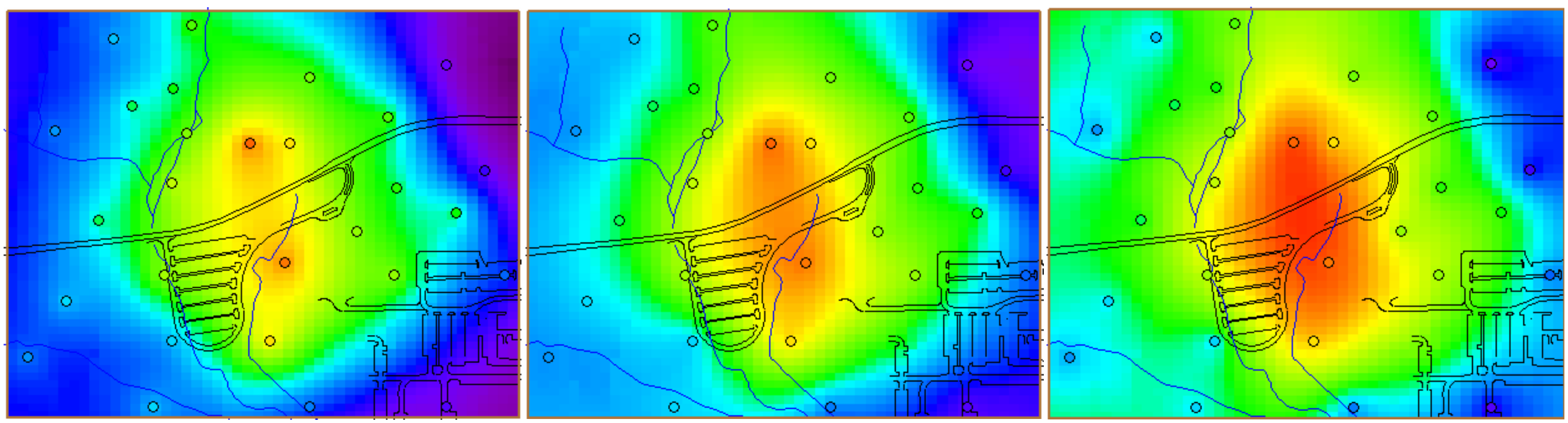


Probability > 3.0 pCi/G



Kriging Maps

- Kriging provides an estimate with an associated kriging variance at each grid node.
- Allows one to be conservative (e.g., percentiles > .5)
- Allows one to spatially ascertain the difference between an “optimistic, realistic, and pessimistic” (e.g., 25th, 50th, and 75th) maps.

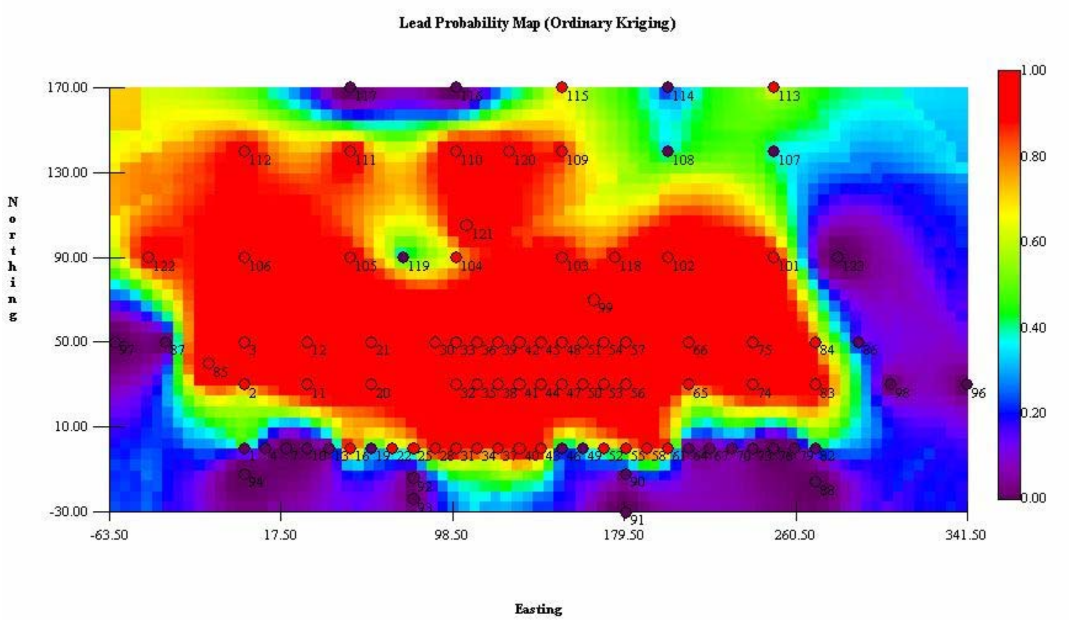


“optimistic” p=0.25

“realistic” p=0.5

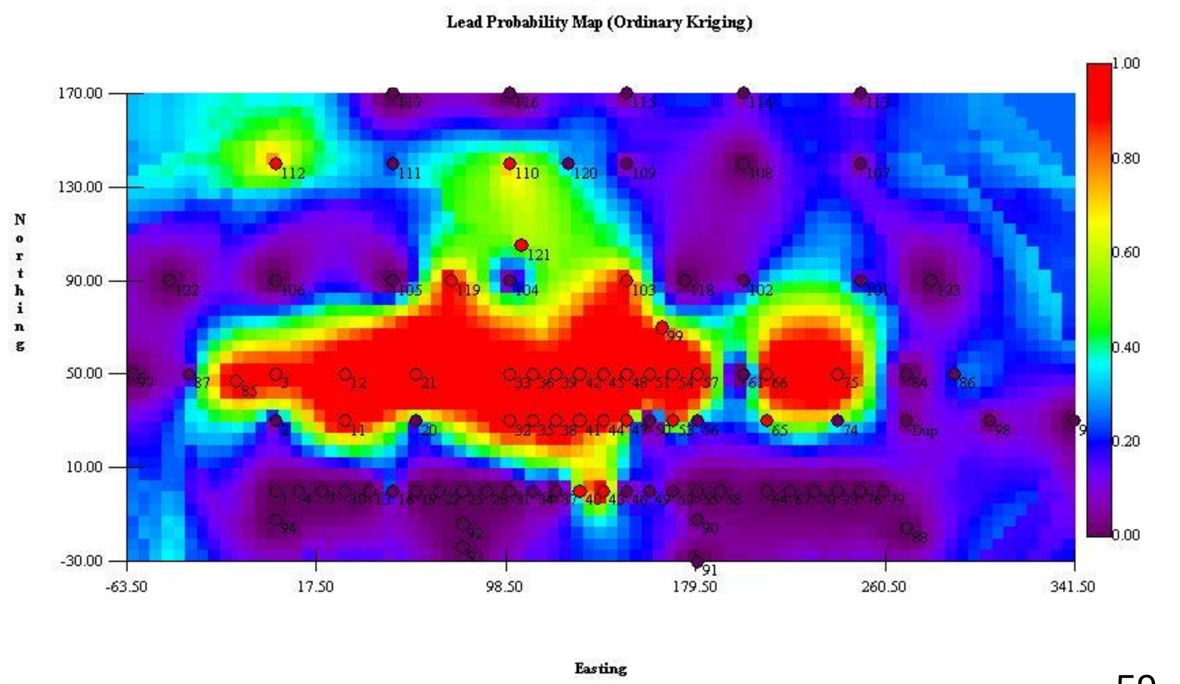
“pessimistic” p=0.75

Evergreen Berm, Plan View Probability > 250 ppm

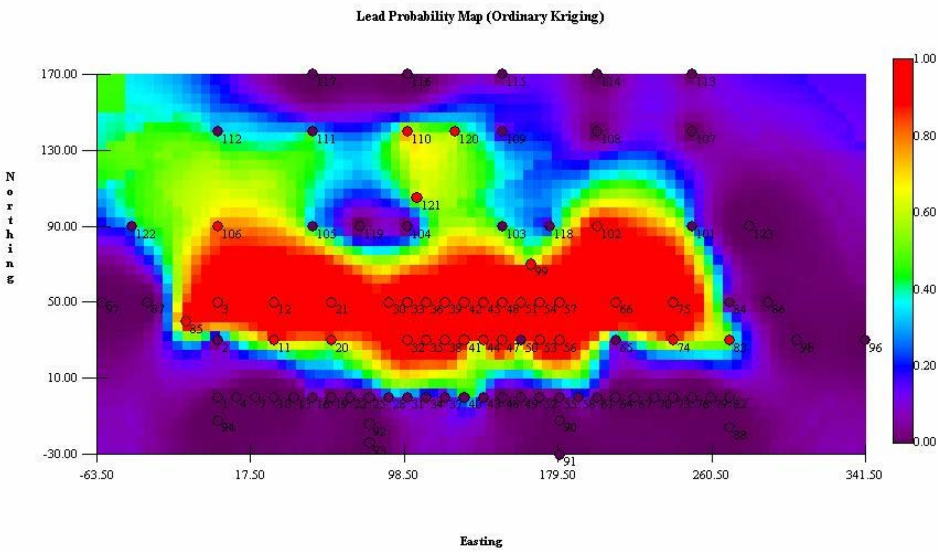


0-12”

12-24”

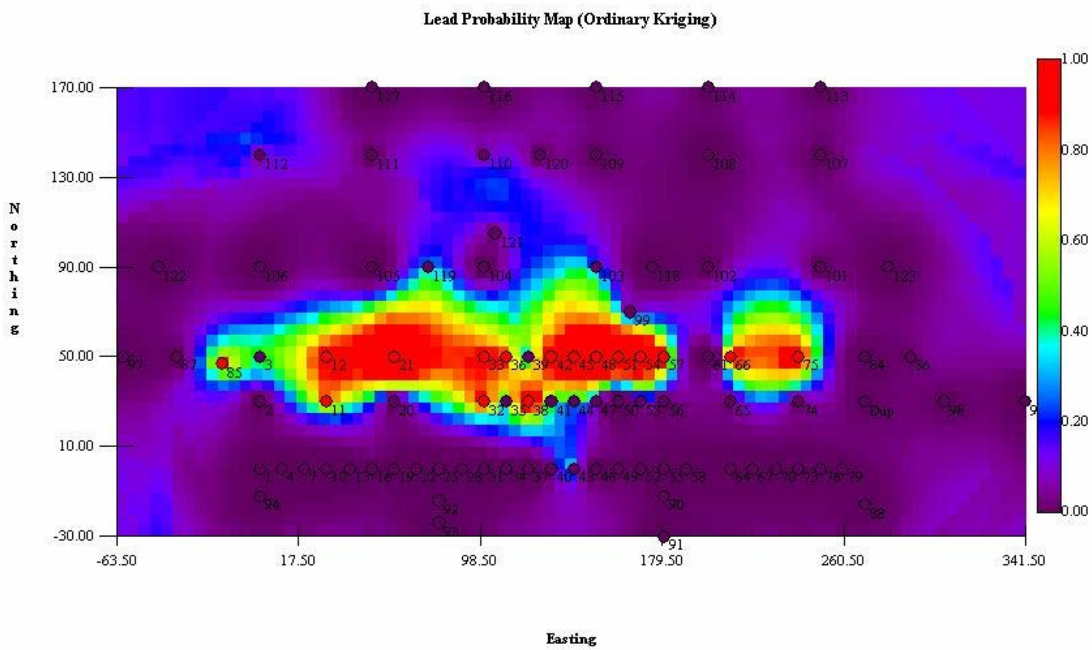


Evergreen Berm, Plan View Probability > 1,000 ppm



0-12”

12-24”

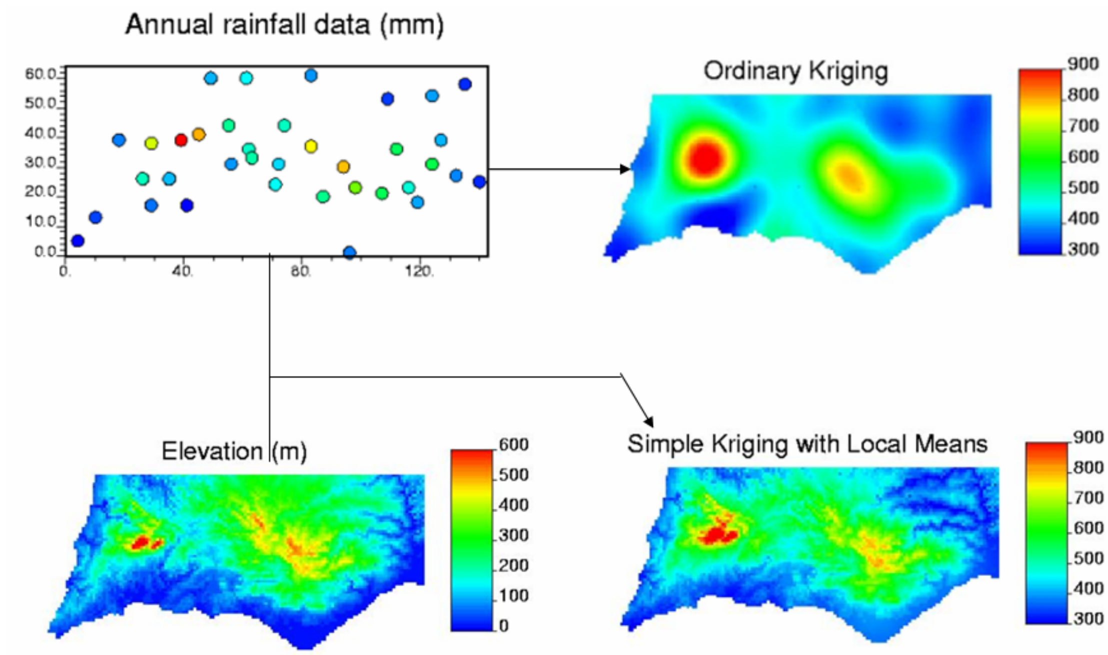


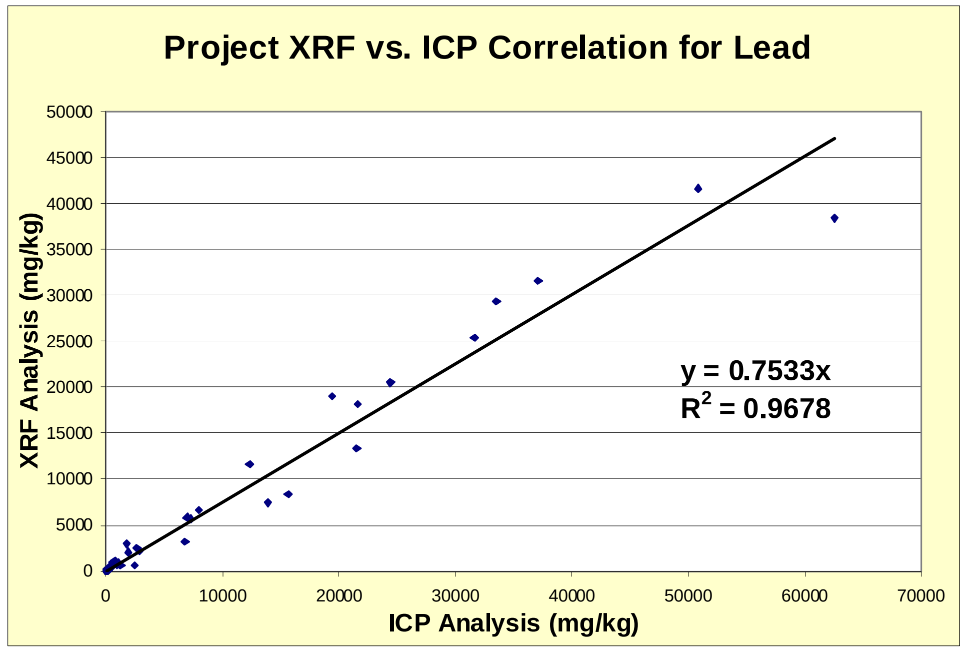
Uncertainty Reduction

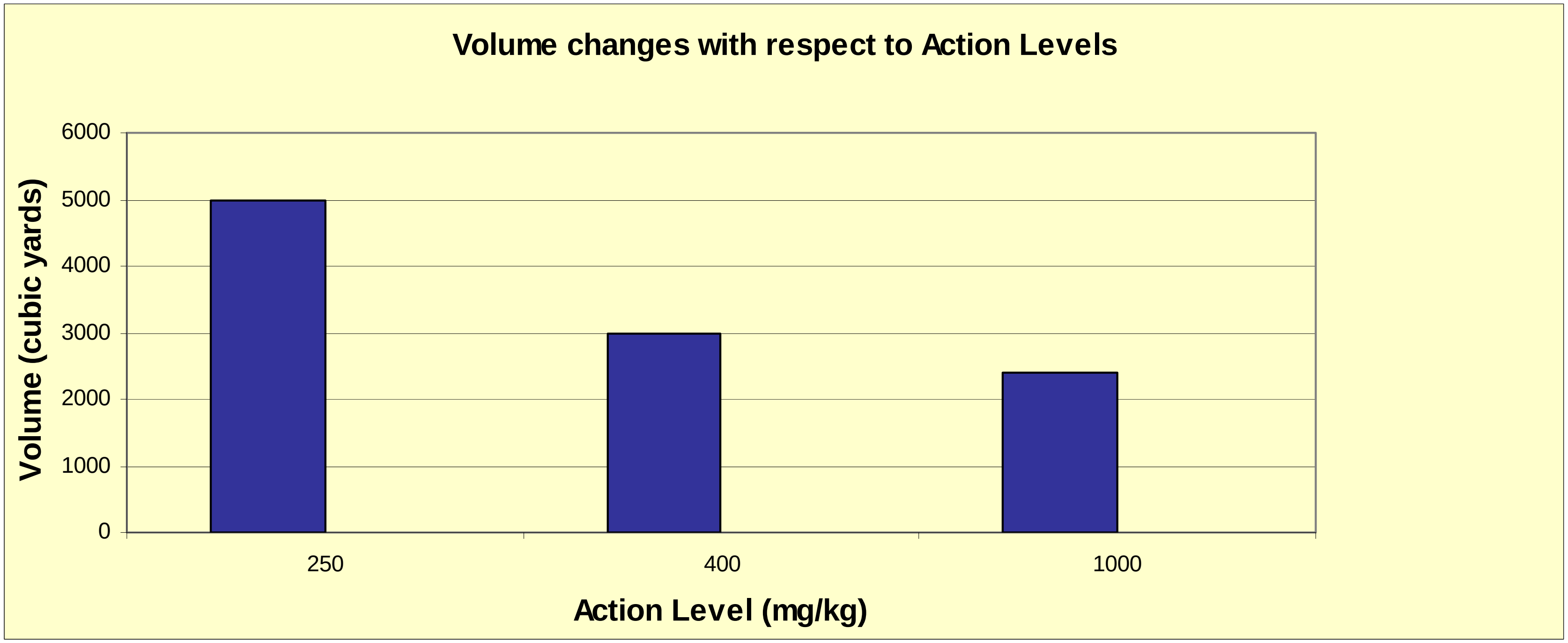
- Collaborative samples were collected within the ambiguous “window of uncertainty”
- Co-located field duplicate sites to assess impact of site heterogeneity
- Precision samples to assess impact of within sample heterogeneity
- Collection of additional samples by immediate step-out

Using Secondary Information

- Incorporation of related secondary information and/or “soft data” can improve spatial analysis by providing some indication of what hard data values might look like at unsampled locations.
- SADA V5 focuses on using soft info as covariates for multivariate kriging and as priors in geobayesian applications.



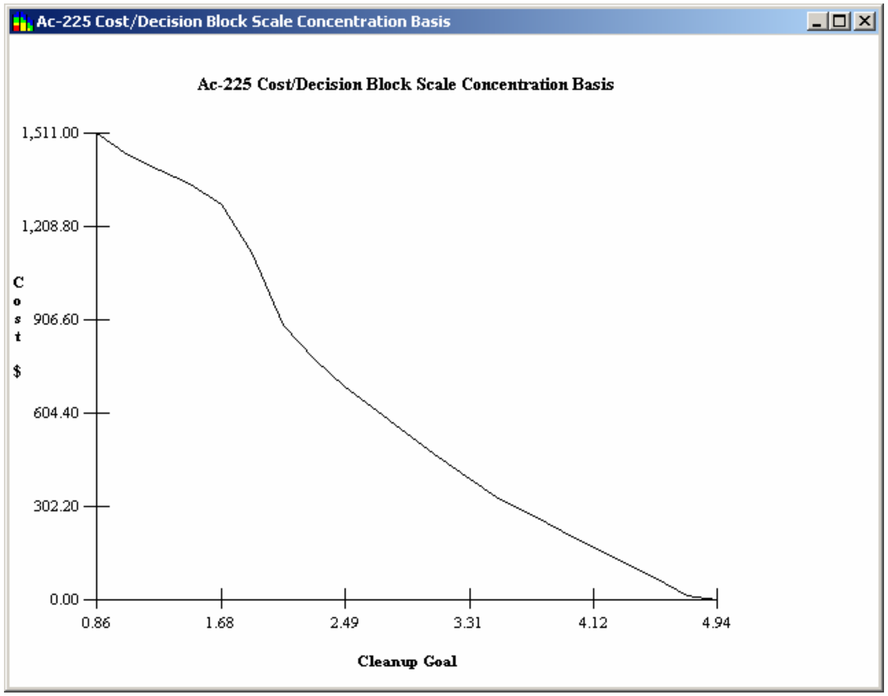




Action Level (mg/kg)	Volume (Yards^3)	Excavation Effort
250	5000	Maximum
400	3000	Moderate
1000	2400	Minimal

Cost vs. Risk Reduction in Remediation

- Calculate and visualize associated cost for a range of cleanup goals.
- Cost is calculated by determining the area of concern (or volume for 3d) for a threshold value, then multiplying the number of blocks in this area by the remedial cost per block.
- After the threshold value range is calculated, cost is calculated for each incremental value in this range.



Conclusions

- Dynamic work plan strategies and field measurement technologies can guide sampling locations based on an evolving CSM allowing for rapid delineation of extent of contamination
- Reductions in analytical per sample costs result in increased data density allowing for management of decision uncertainty
- Statistically valid conclusions require both sampling and analytical uncertainties to be managed
- Sufficient data was generated to proceed with feasibility study with reliable contaminated soil estimates