Autopsy of a Small UST Site in Bedrock: Implications for Remedial Effectiveness

Case Study, Devens, MA

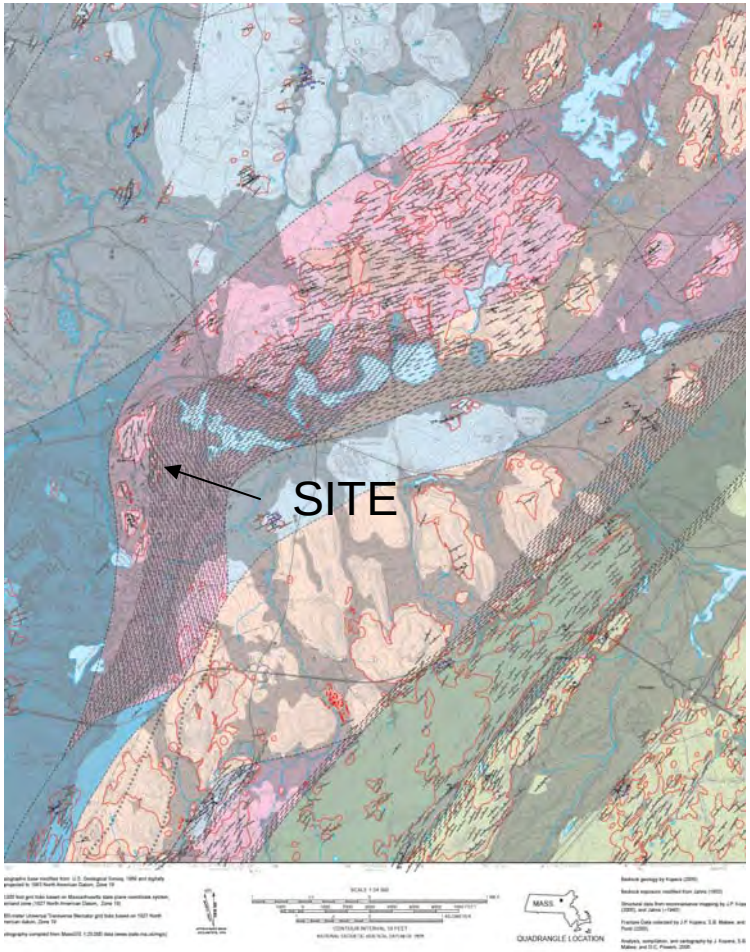
William C. Brandon, Hydrogeologist, US EPA Region 1

Federal Remediation Technology Roundtable Meeting
Characterization and Remediation of Sites with Fractured Bedrock
Washington, DC
November 9, 2010

Acknowledgements

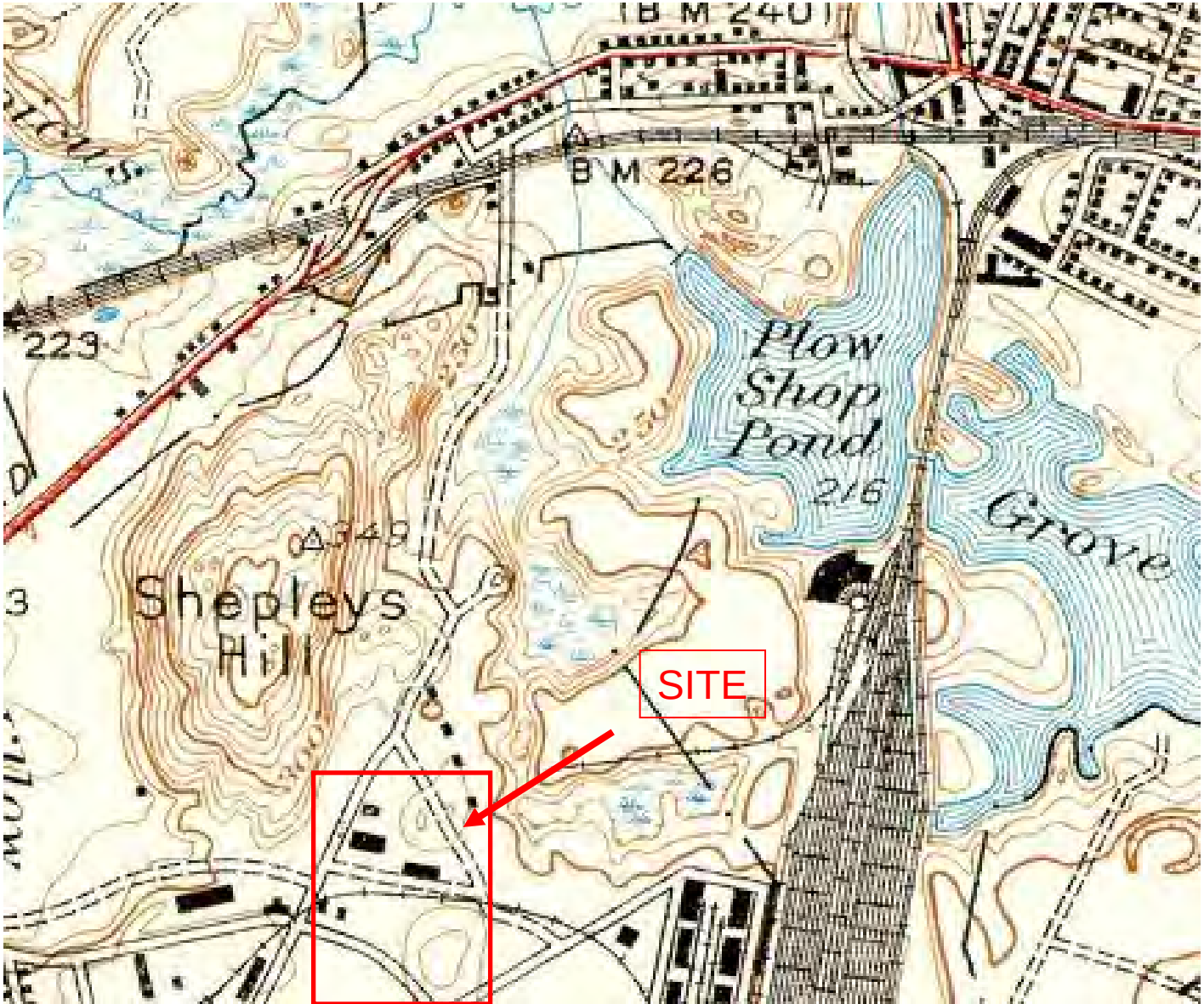
- Gannet Fleming Inc.
- Army BRAC Office
- HGL Inc.
- EPA Region 1 Federal Facilities
- EPA Region 1 OEME
- Mass Development

Geologic Setting

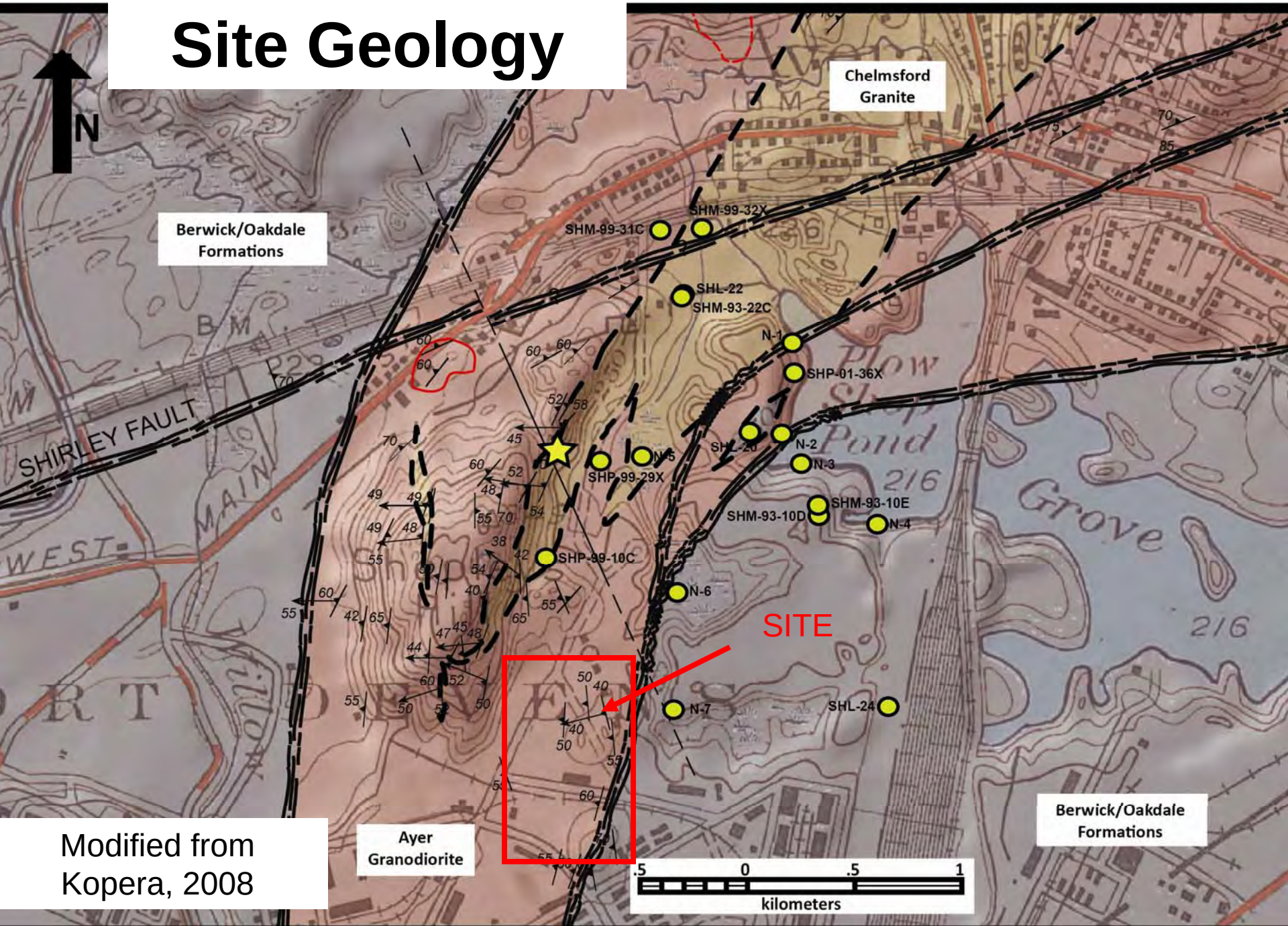


PRELIMINARY BEDROCK GEOLOGIC MAP
AYER QUADRANGLE, MASSACHUSETTS
M.O.S.G. OPEN FILE REPORT 06-03
SHEET 1 OF 4

Site Location



Site Geology

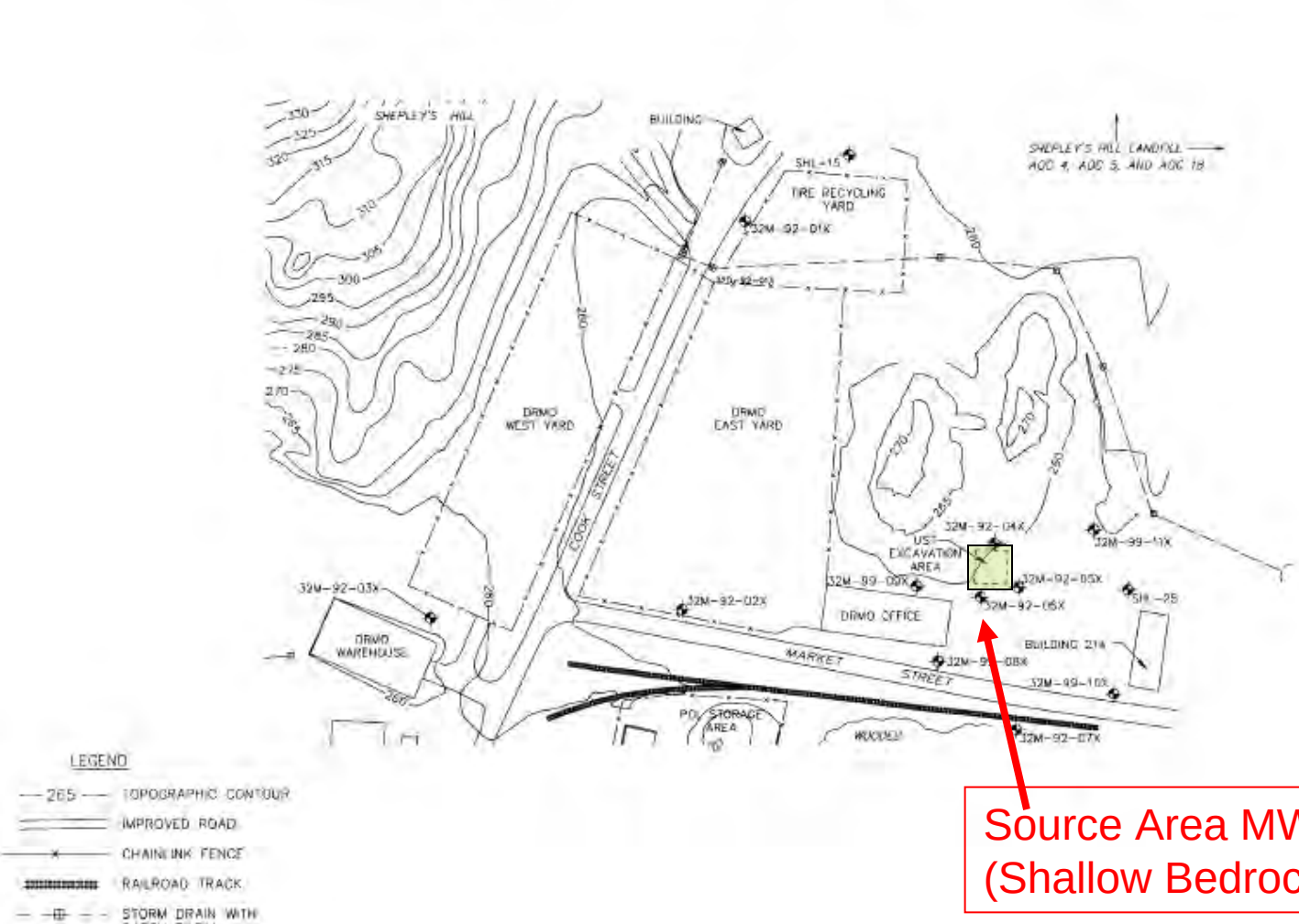


Modified from Kopera, 2008

Geologic History

- Silurian metasediments
- Intrusion of Ayer Granodiorite (Devonian)
- Intrusion of Chelmsford Granite (later Devonian)
- Deformation, faulting, metamorphism
- Quaternary glaciation and de-glaciation
  - Unloading, development of sheeting fractures
  - Deposition of outwash sand, gravel

DRMO Site Plan

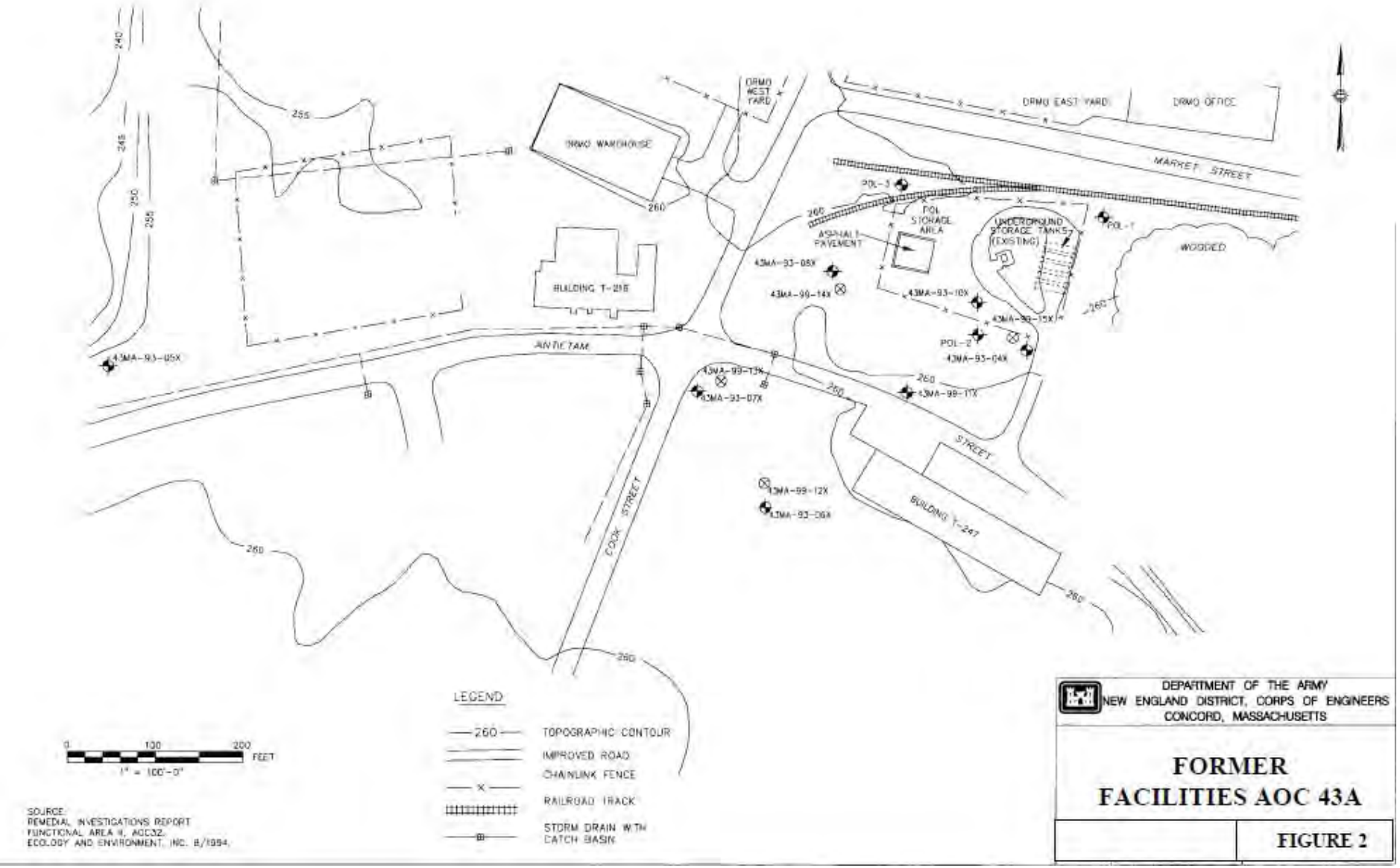


Source Area MW
(Shallow Bedrock)

DEPARTMENT OF THE ARMY
NEW ENGLAND DISTRICT, CORPS OF ENGINEERS
CONCORD, MASSACHUSETTS

FORMER FACILITIES AOC 32

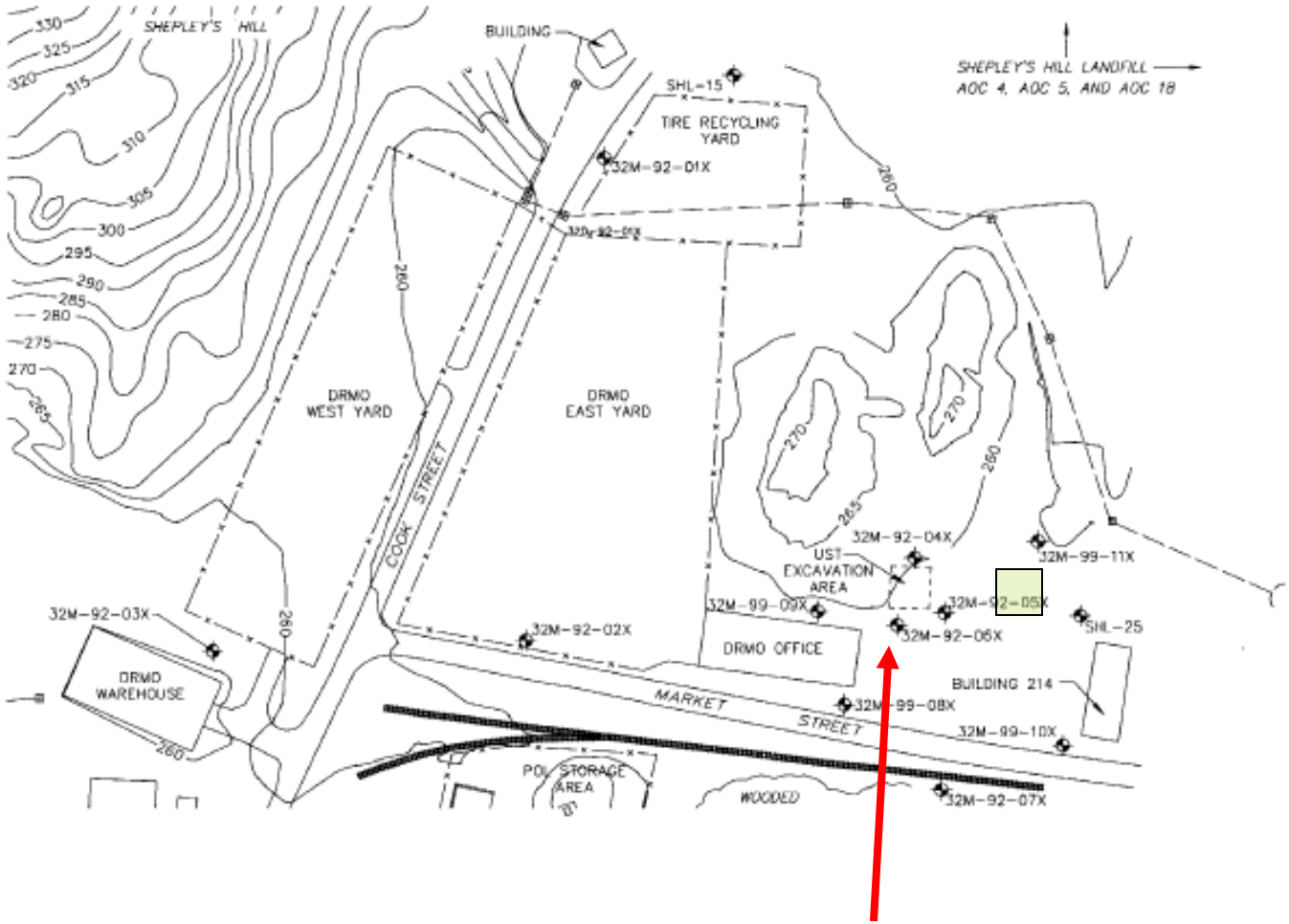
POL Site Plan



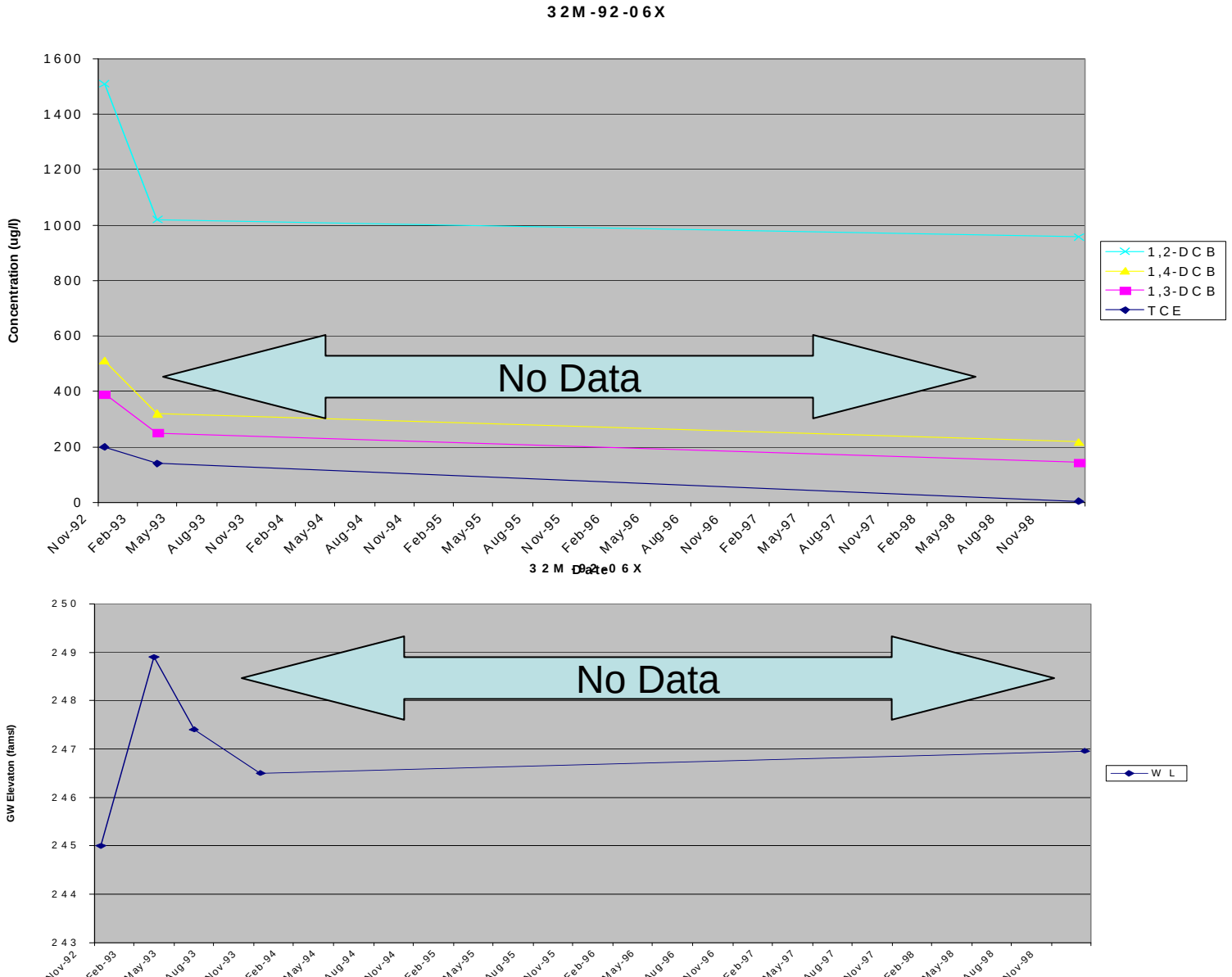
DRMO Site History

- Defense Reutilization and Marketing Office (DRMO)
  - Equipment Recycling ~ 1964-1995
  - 5000 gal Waste Oil UST
    - UST removed 1992
    - Limited soil removal (tank grave partially in BR)
    - COCs: TCE, DCB, VPH, As, Mn
- 1998-1999; LTMP (V_1.0) Initiated

DRMO LTM Network
Pre-2000



COC Trends (Pre-2000)



Site History (Part II)

- Warehouse Construction Results in large-scale site alterations (2000-2001)
  - Bedrock Blasting/Cut-and-fill
  - Engineered Drainage (Storm sewers, Detention Basin)
  - Extensive area of impervious surface (Building, Parking lots)

- Site Hydrology Profoundly Altered

- 2001-2002; LTMP Revised (v.2),
  - Numerous new monitoring wells installed.
  - New baseline
  - Ongoing LTM and data evaluation (2002-2006)

Site: Pre-construction (March 2000)

Pre-Blast Bedrock Exposures at SE Corner of Building Area

Fill Emplacement
SW of Building Footprint

Storm Drain Installation

Subsurface Utilities

LTM/CSM Issues (2002-2006)

- “Moving Target” - Site Hydrology Slowly Evolving Post-Construction
- Few COCs identified at POL after 2002, but
- “Down-gradient” directions uncertain
- Persistent Contamination in UST-13 Area
- Bedrock Affected, but Fracture Network not evaluated
- Adequacy of LTM network called into question

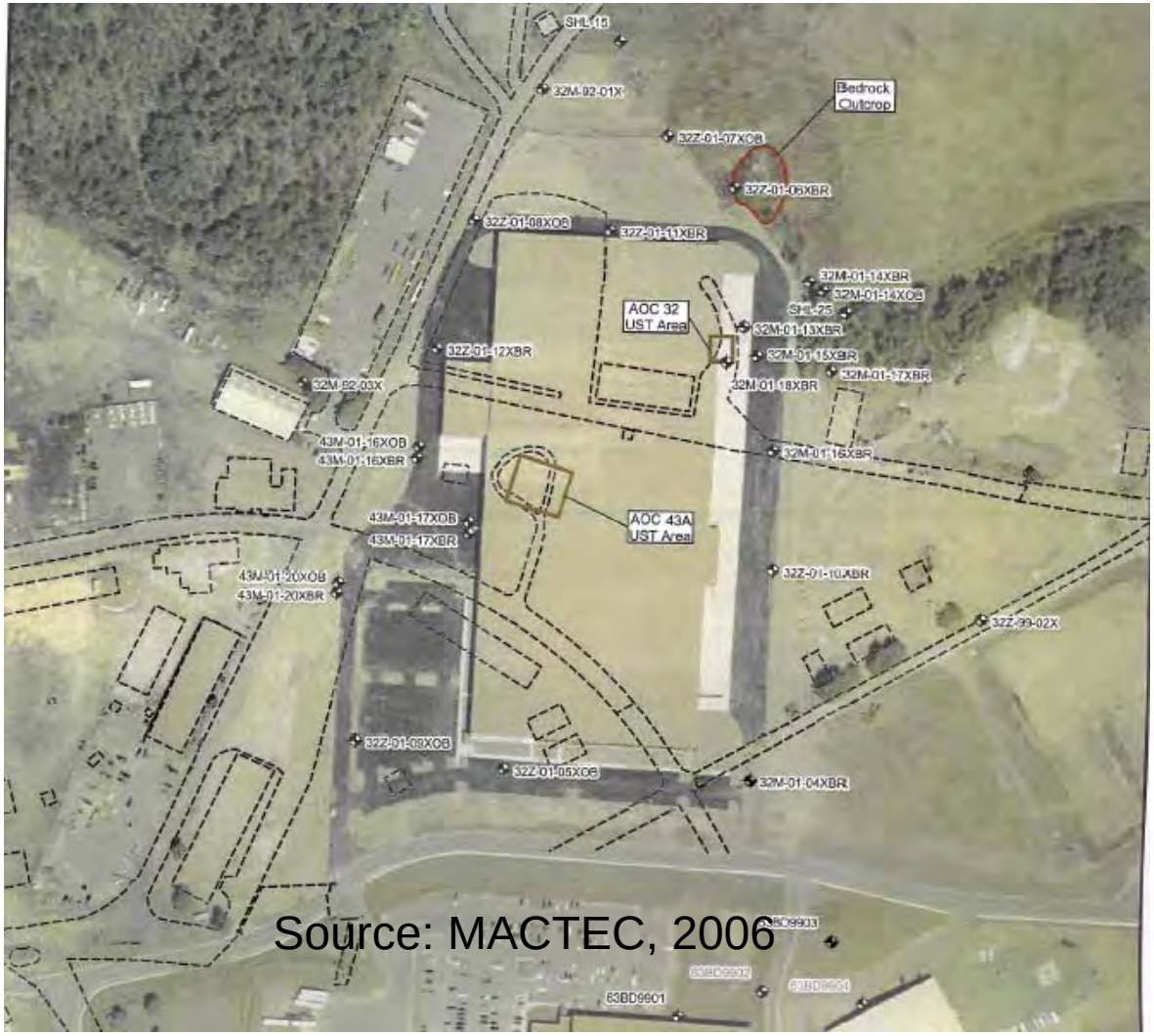
Near-Term Objectives

- Detailed evaluation of bedrock structural data from outcrop mapping
- Update CSM (Consensus)
  - Bedrock Surface Map
  - Bedrock Fracture Data
  - Ground Water Flow Gradients
    - Lateral/vertical
    - Source Areas/Downgradient of Source Areas
    - Long-term water level trends
  - Configuration of Subsurface Hydrostratigraphic Units (2D/3D)
  - Detailed cross sections through each source area normal and parallel to hydraulic gradient
- Identify Data Gaps
- Recommend Adjustments to GW Monitoring Network

Longer-term Objectives

- Install New Monitoring Wells
- Decommission Unnecessary Wells
- New Baseline; Re-initiate Long-term Monitoring
- Evaluate time-series contaminant trends
- Determine whether additional remedial measures are needed
- **Site Closeout**

Site Plan with Existing Monitoring Well Locations



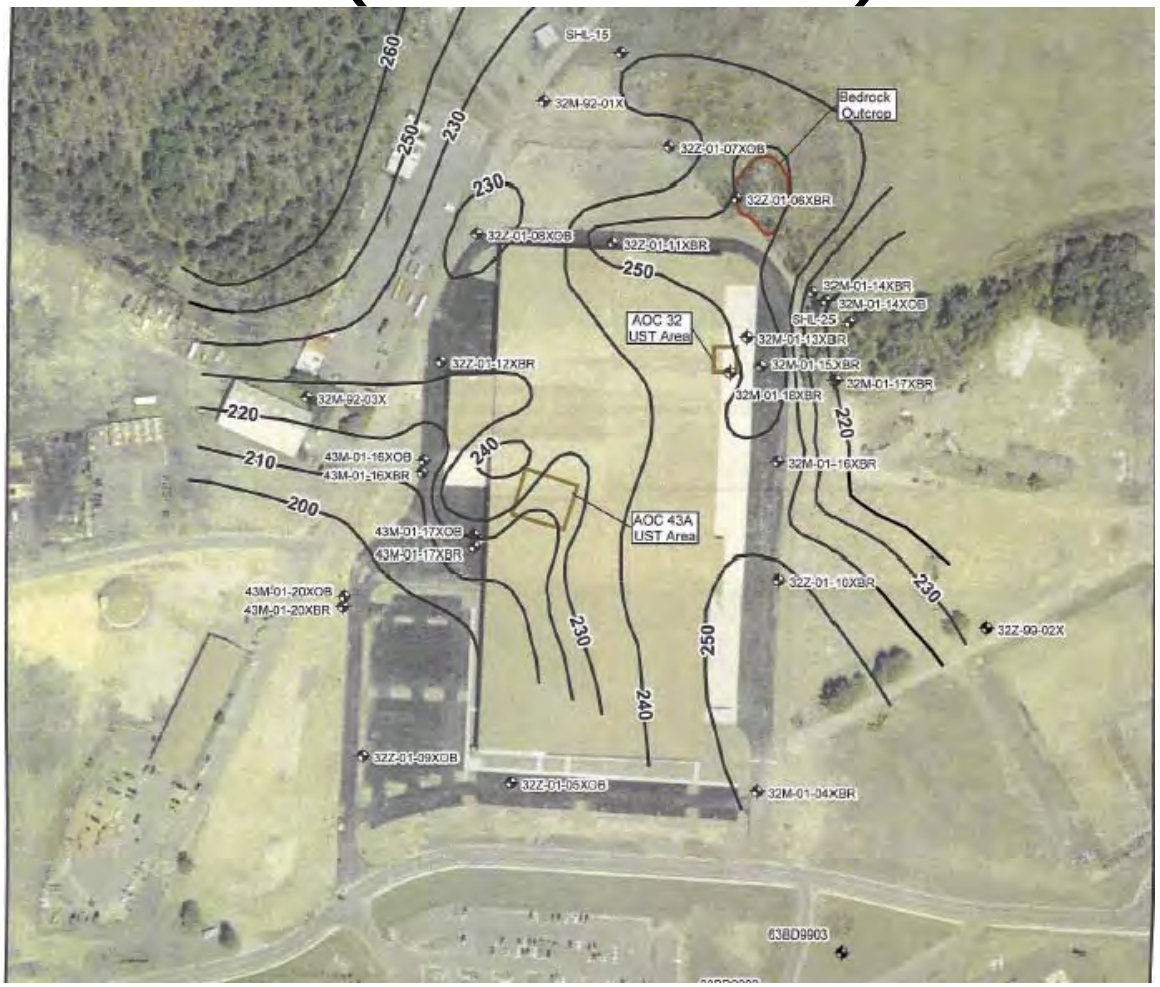
Source: MACTEC, 2006

Elements of Bedrock Evaluation

- Configuration of top-of-bedrock surface
- Geologic Mapping
- Rock Type Identification
- Foliation orientation Data
- Joint Orientation Data
- Structural Analysis
  - Stereo-net analysis
  - Joint/Fracture Mapping

Bedrock Elevation (Pre-Blast)

Elevation of Bedrock Surface (Post-Blast)

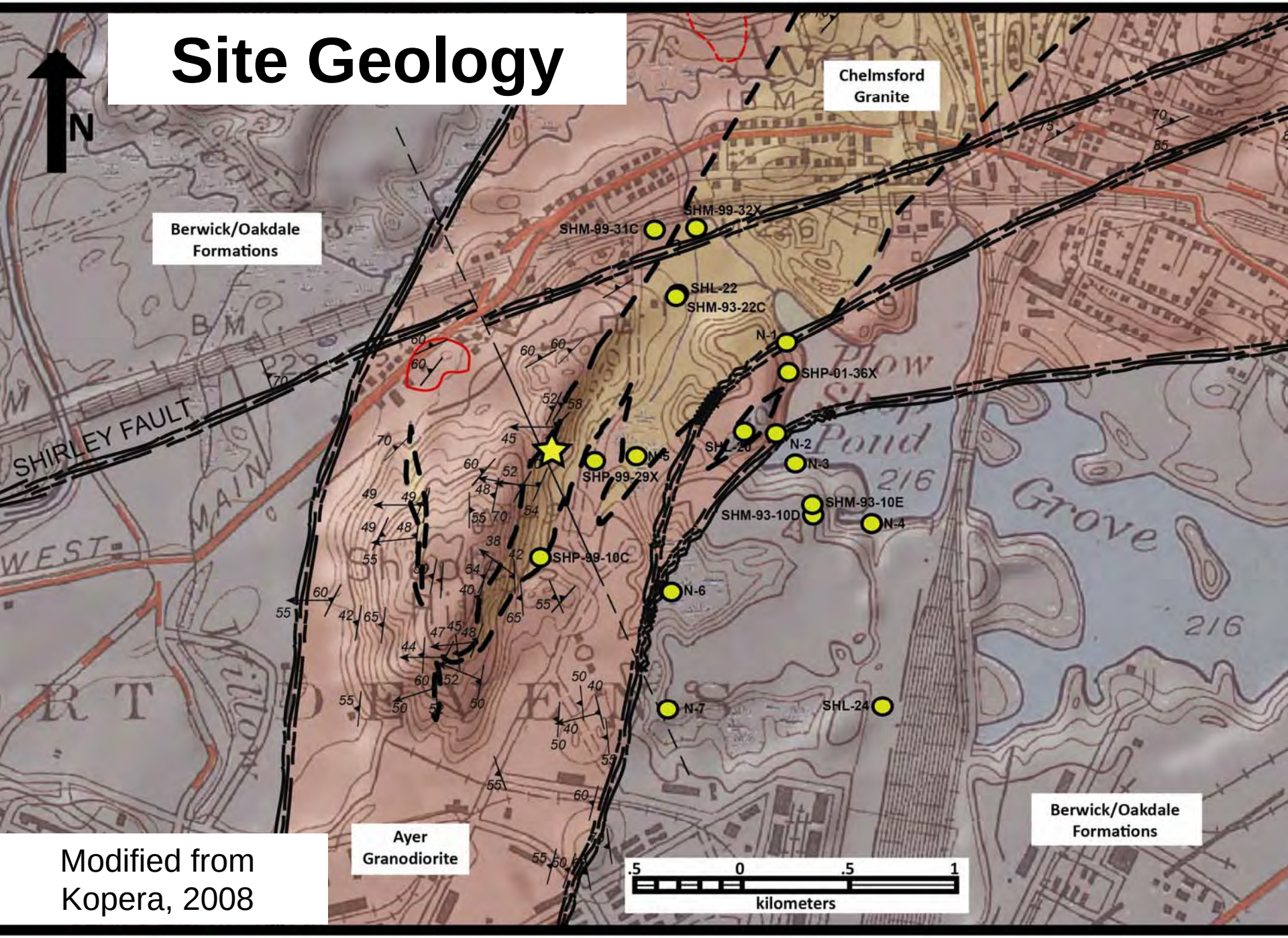


Source: MACTEC, 2006

Major Rock Types

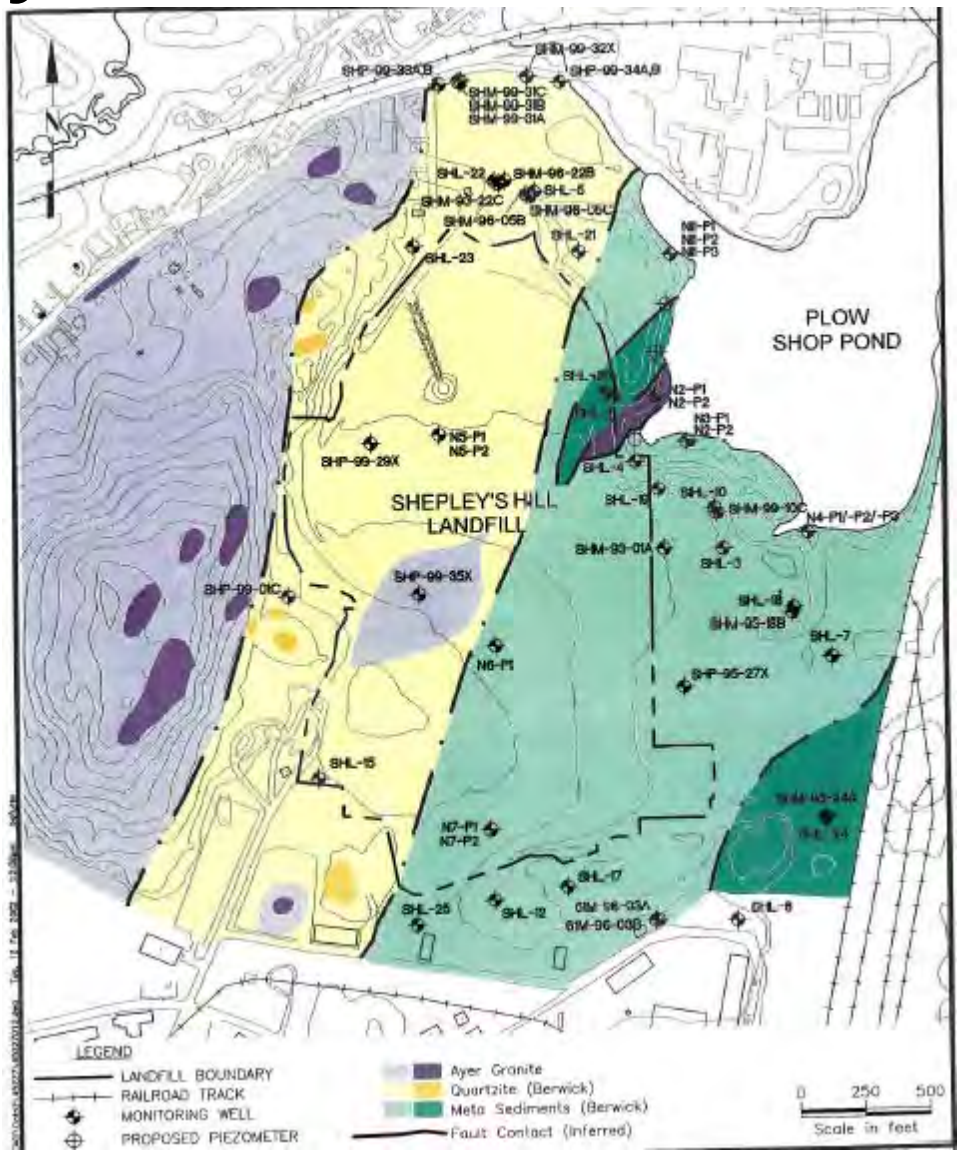
- Berwick Formation (S-O)
  - Thick-bedded to massive Metaconglomerates, cg conglomeratic quartzite, fg feldspathic biotitic quartzite
  - Thinly bedded to massive dark gray to brown calcareous and phyllitic siltstones and mg feldspar-qz-biotite schist
- Ayer Granite
  - Devens Long-Pond Facies
  - Massive gneissic equigranular to porphyroblastic biotite granite and granodiorite

Site Geology



Modified from Kopera, 2008

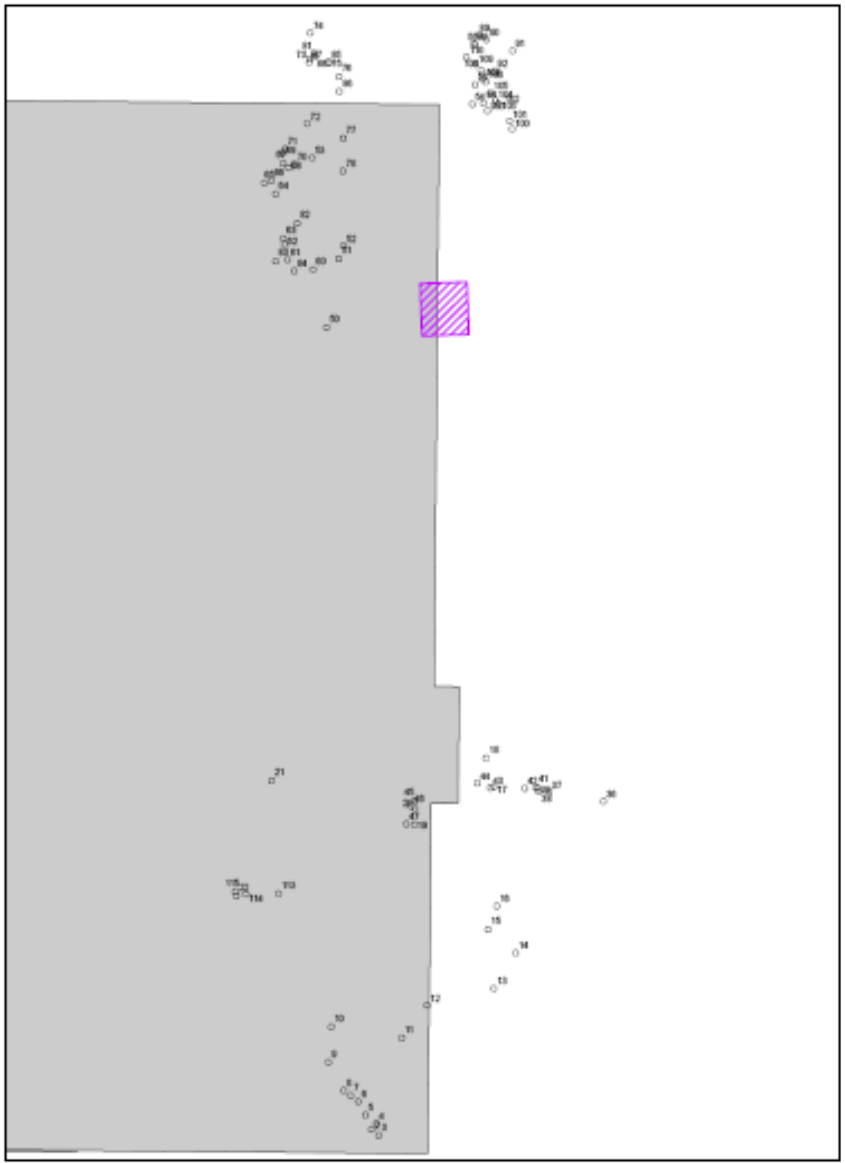
Bedrock Geologic Map of the Shepley's Hill Landfill Area



Source Harding ESE, 2003

Blasting Presents Fresh Exposures

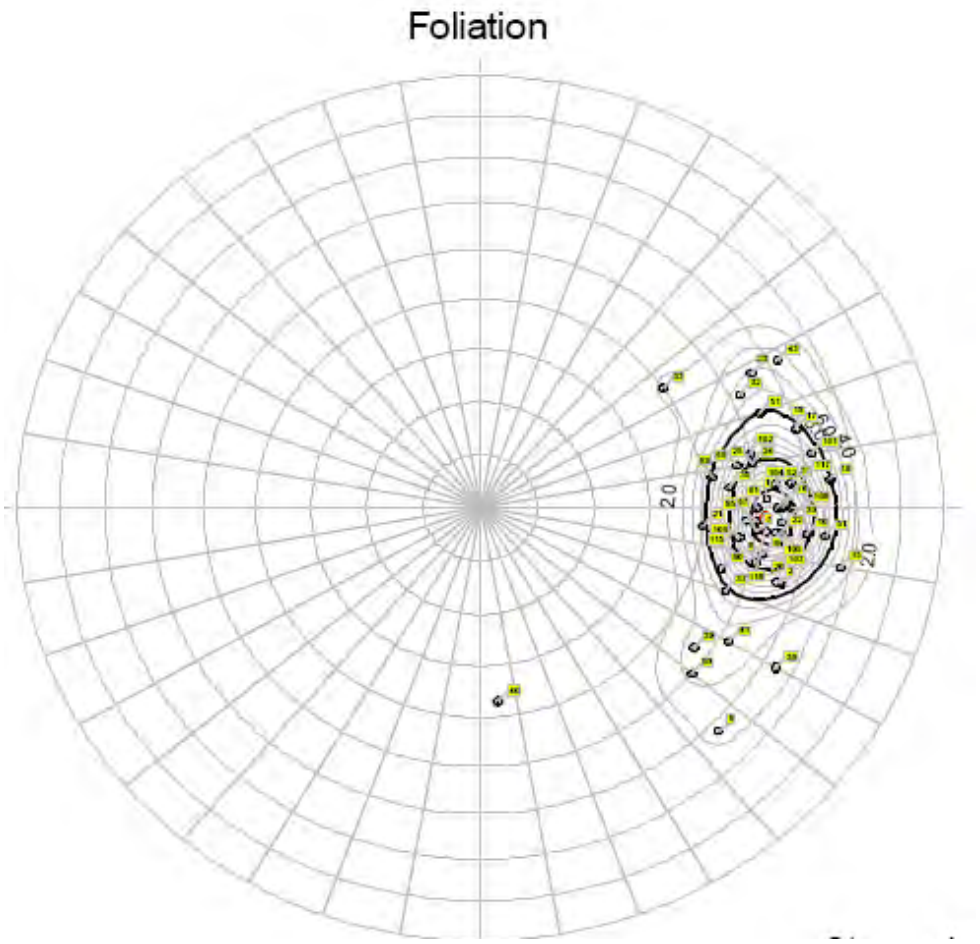
Overview of Locations Where Structural Data Was Collected



Foliation

- Primary layering in metamorphic rocks
- Generally follows compositional layering
- Consistent orientation at site-scale
- Local evidence of minor folding

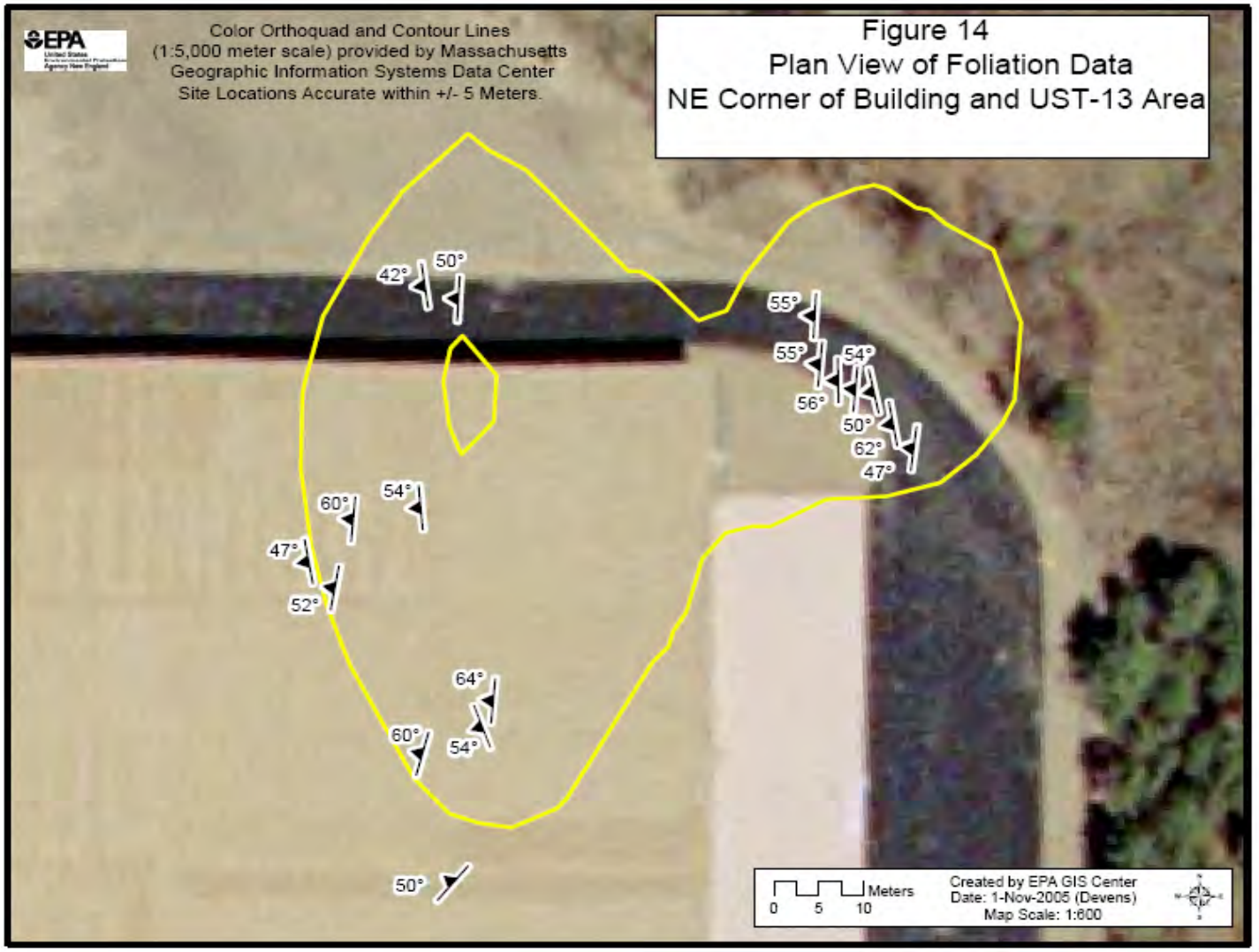
Stereoplot of Foliation Orientations



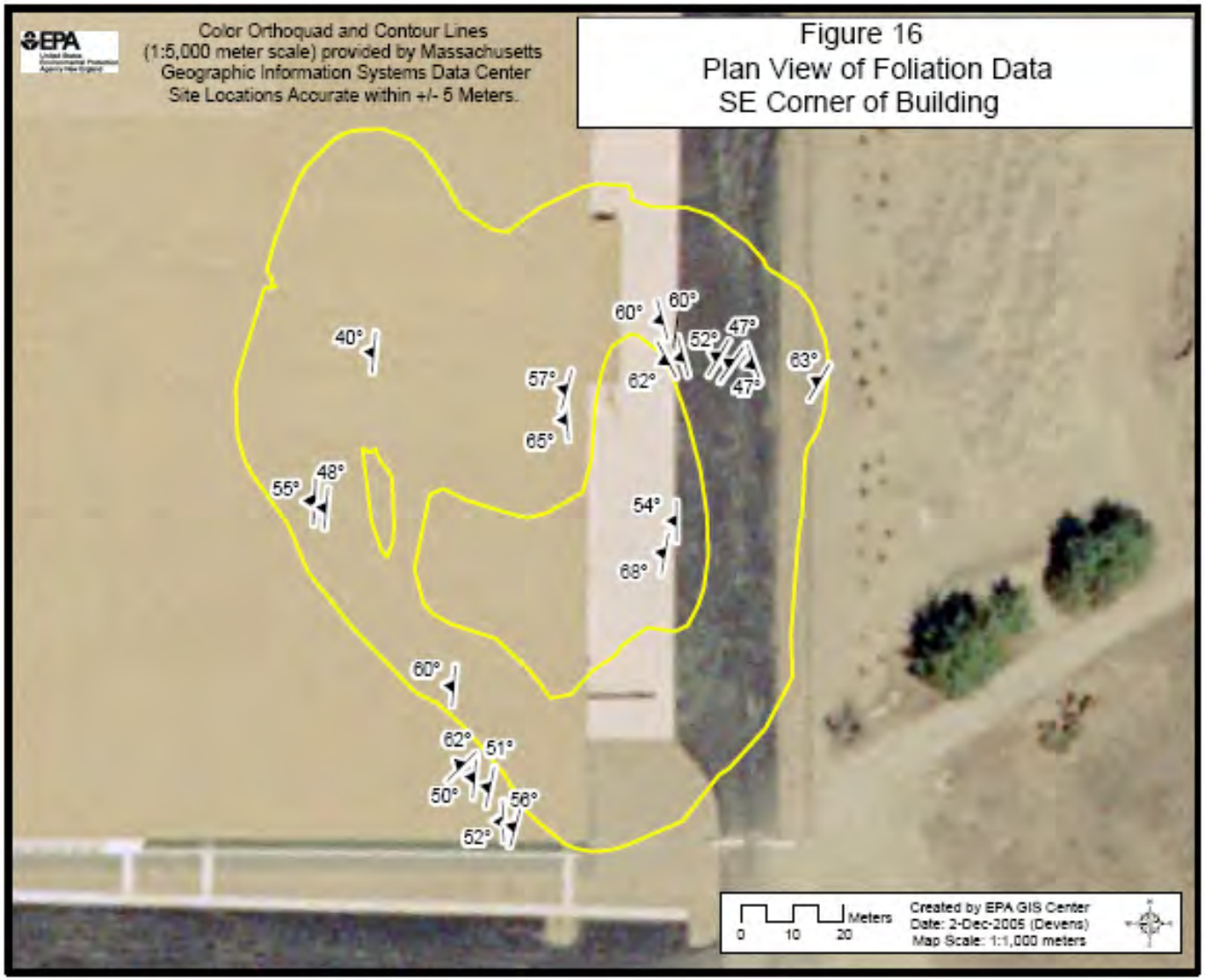
N=49
Strike ~ N3
Dip ~ 52 W

Statistical Summary	
Projection:	Schmidt (Equal Area)
Number of Sample Points:	49
Mean Lineation Azimuth:	92.2
Mean Lineation Plunge:	38.2
Great Circle Azimuth:	20.8
Great Circle Plunge:	39.7
1st Eigenvalue:	0.926
2nd Eigenvalue:	0.057
3rd Eigenvalue:	0.017
LN (E1 / E2):	2.794
LN (E2 / E3):	1.181
(LN(E1/E2)) / (LN(E2/E3)):	2.366
Spherical Variance:	0.0404
Rbar:	0.9596

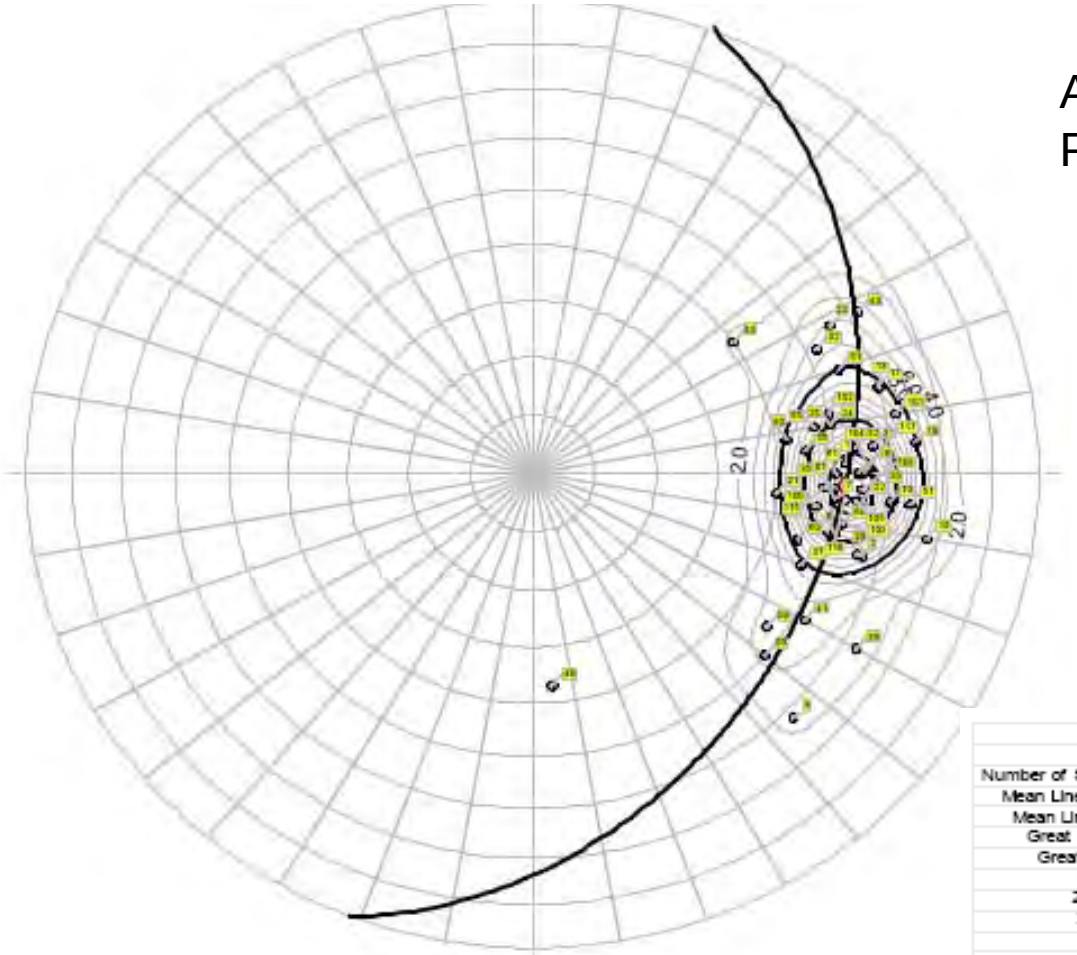
Plan View of Foliation Data NE Corner of Building



Plan View of Foliation Data SE Corner of Building



Stereoplot of Foliation indicating Fold Axis



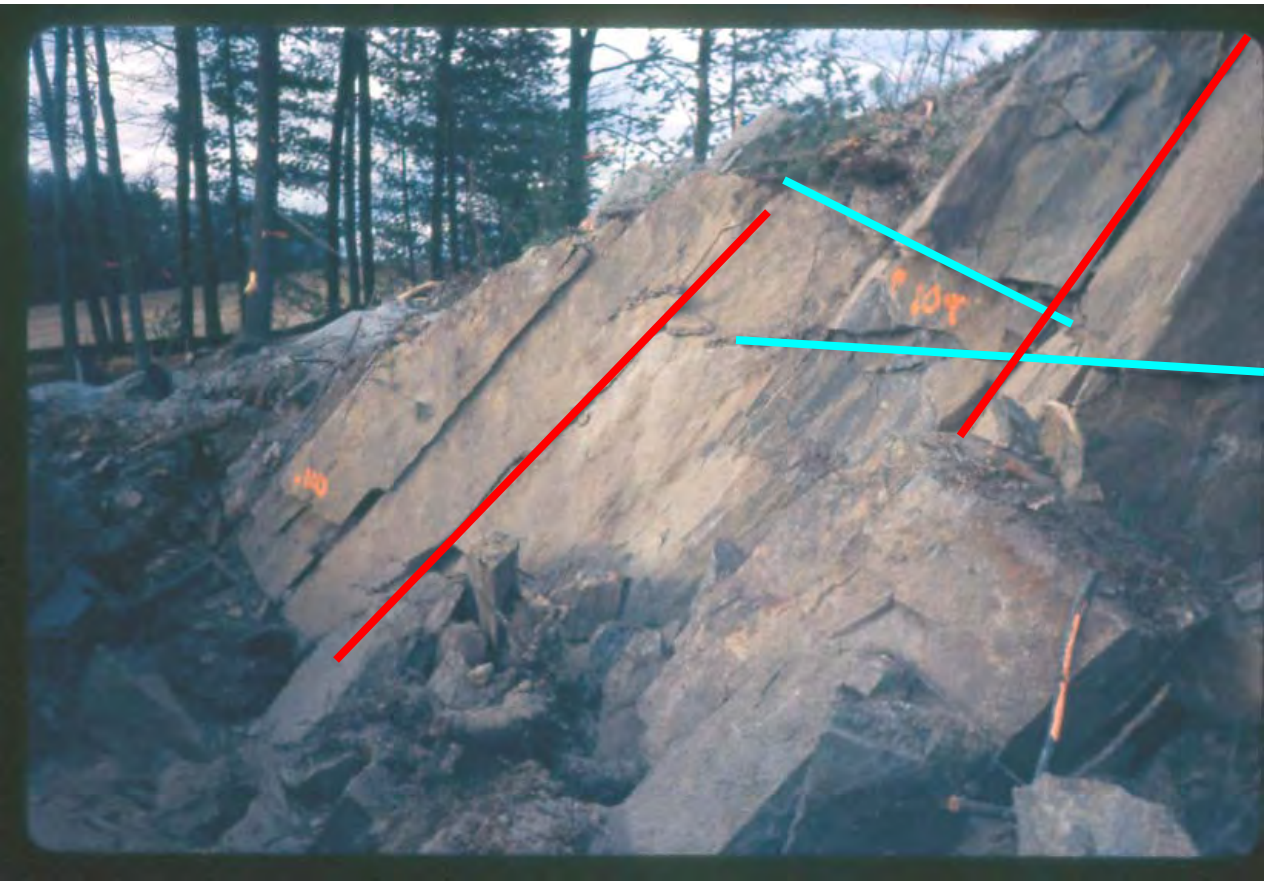
Azimuth ~ N21E
Plunge ~ 40

Statistical Summary	
Projection:	Schmidt (Equal Area)
Number of Sample Points:	49
Mean Lineation Azimuth:	92.2
Mean Lineation Plunge:	38.2
Great Circle Azimuth:	20.8
Great Circle Plunge:	39.7
1st Eigenvalue:	0.926
2nd Eigenvalue:	0.057
3rd Eigenvalue:	0.017
LN (E1 / E2):	2.794
LN (E2 / E3):	1.181
(LN(E1/E2)) / (LN(E2/E3)):	2.366
Spherical Variance:	0.0404
Rbar:	0.9596

Joints

- Generic Term for Planar discontinuity in Rock Mass (e.g., crack)
- Open joints may transmit water (oxidation)
- Greater Variability than Foliation

Intersecting Joint Sets



Stereo-plot of Joint Orientations

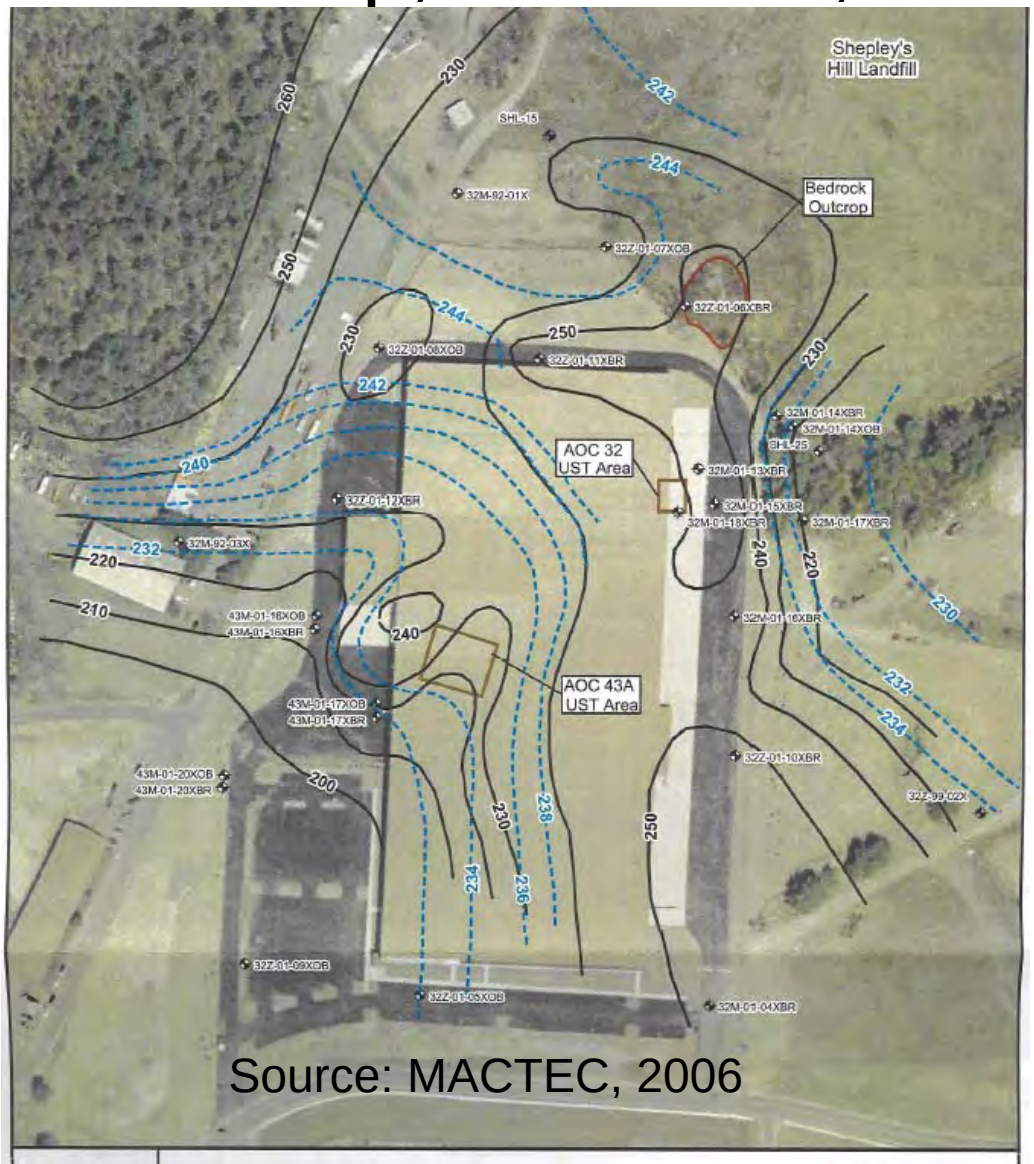
N=156
66 stations

Statistical Summary	
Projection:	Schmidt (Equal Area)
Number of Sample Points:	156
Mean Lineation Azimuth:	87.8
Mean Lineation Plunge:	4.2
Great Circle Azimuth:	65.3
Great Circle Plunge:	11.1
1st Eigenvalue:	0.452
2nd Eigenvalue:	0.321
3rd Eigenvalue:	0.226
LN (E1 / E2):	0.341
LN (E2 / E3):	0.351
(LN(E1/E2)) / (LN(E2/E3)):	0.973
Spherical Variance:	0.5849
Rbar:	0.4151

Major and Minor Joint Sets

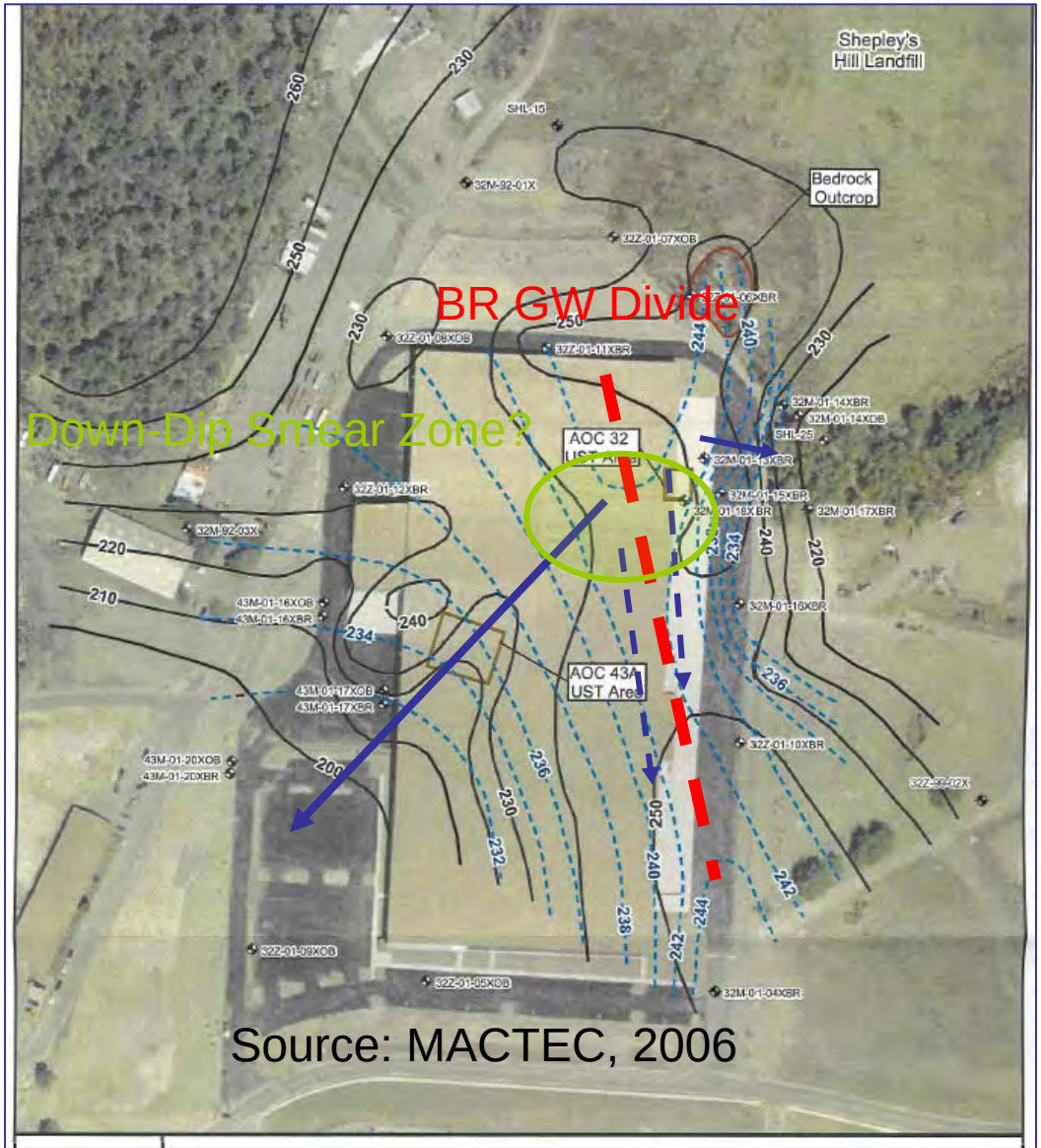
- N3E +/-, 50-60 W (parallel to foliation)
- N45E +/-, 65-85 SE
- Near-surface sheeting joints at various orientations, Sub-parallel to former topography
- ~ N70W, Subvertical (weak)
- ~ N30W, > 70-80 SE or SW Dips (weak)

Interpretive Overburden Groundwater Surface Map, October 7, 2004



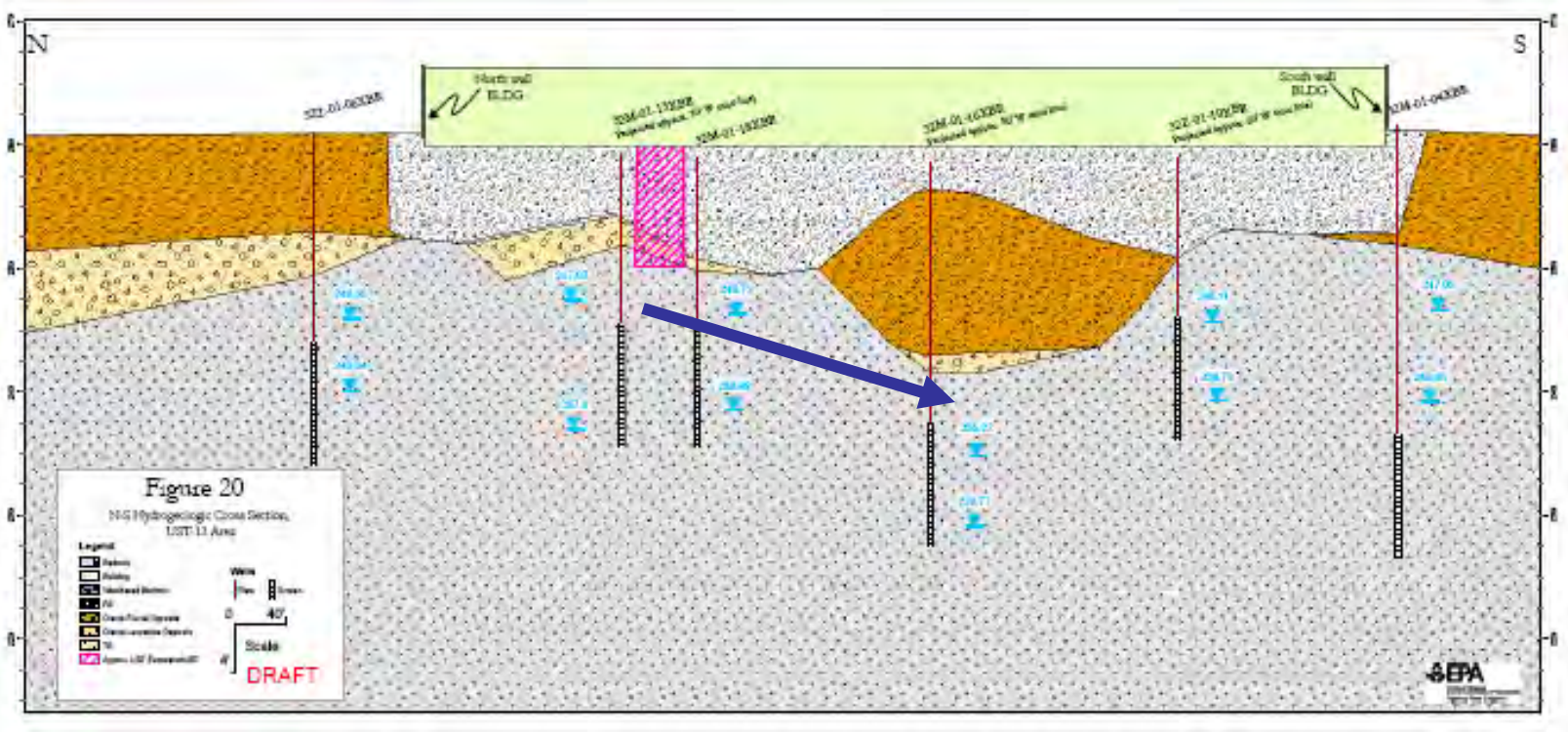
Source: MACTEC, 2006

Interpretive Bedrock Groundwater Surface Map, October 7, 2004

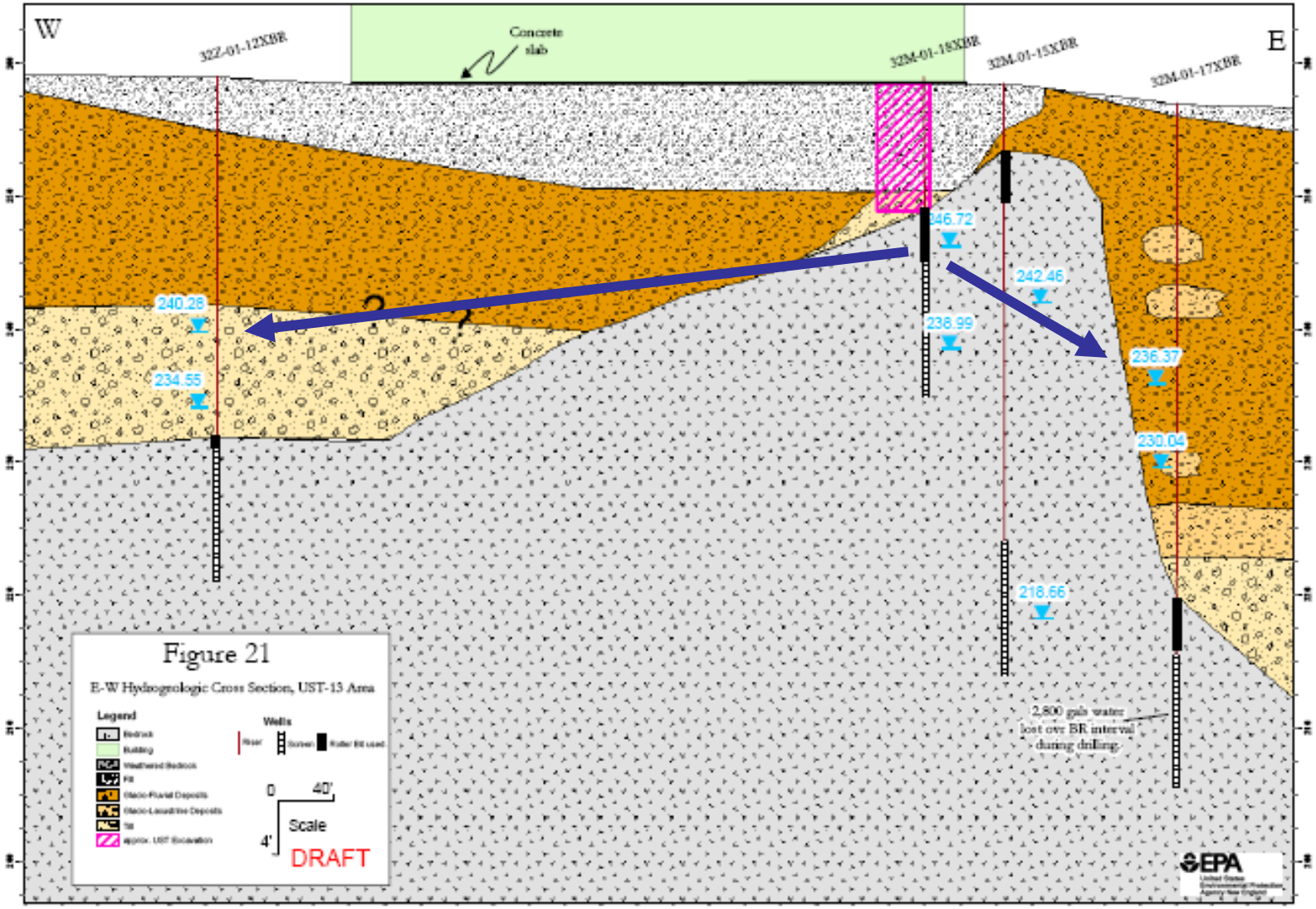


Source: MACTEC, 2006

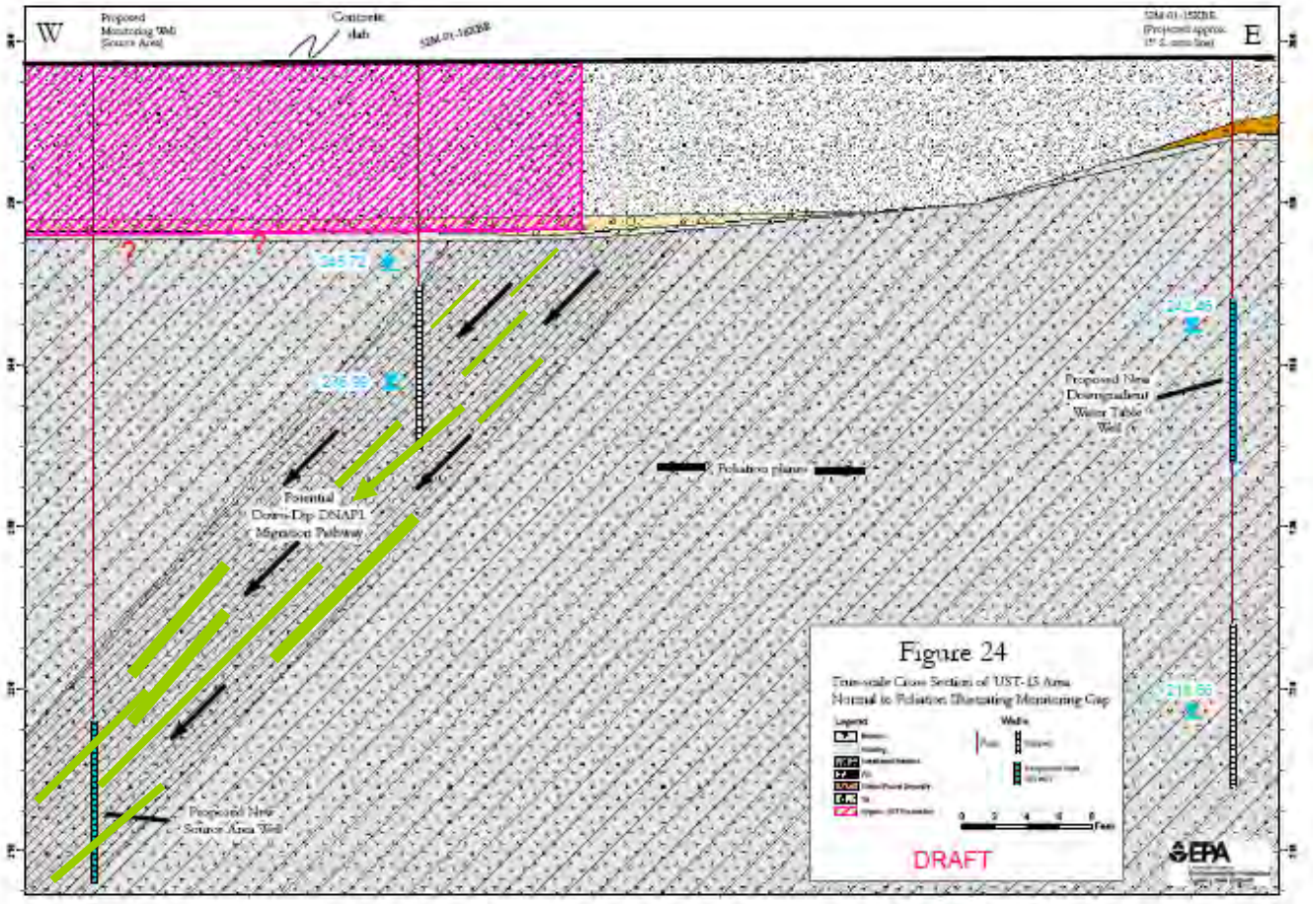
N-S Hydrogeologic Cross Section – UST 13



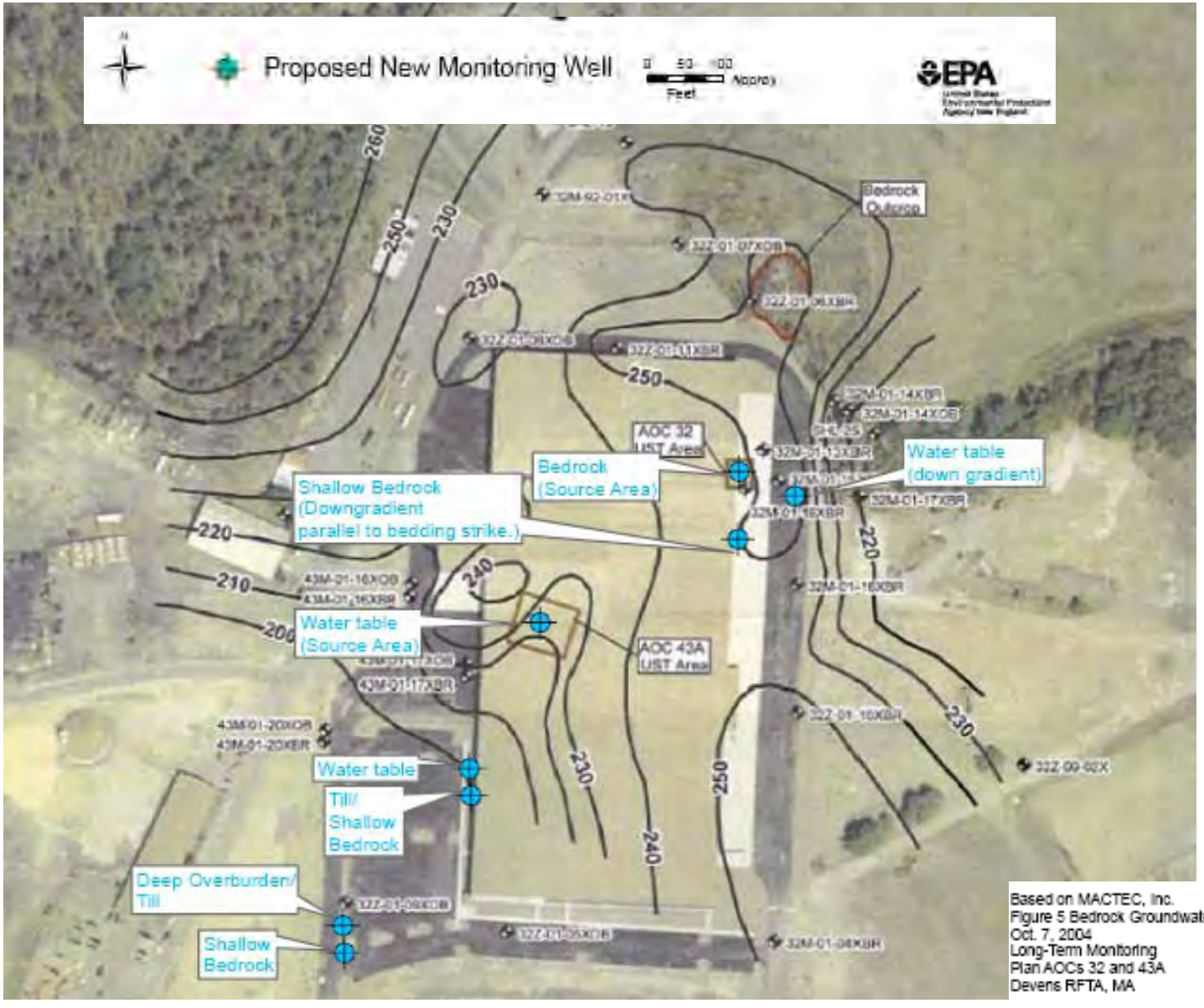
W-E Hydrogeologic Cross-Section
UST 13 Area



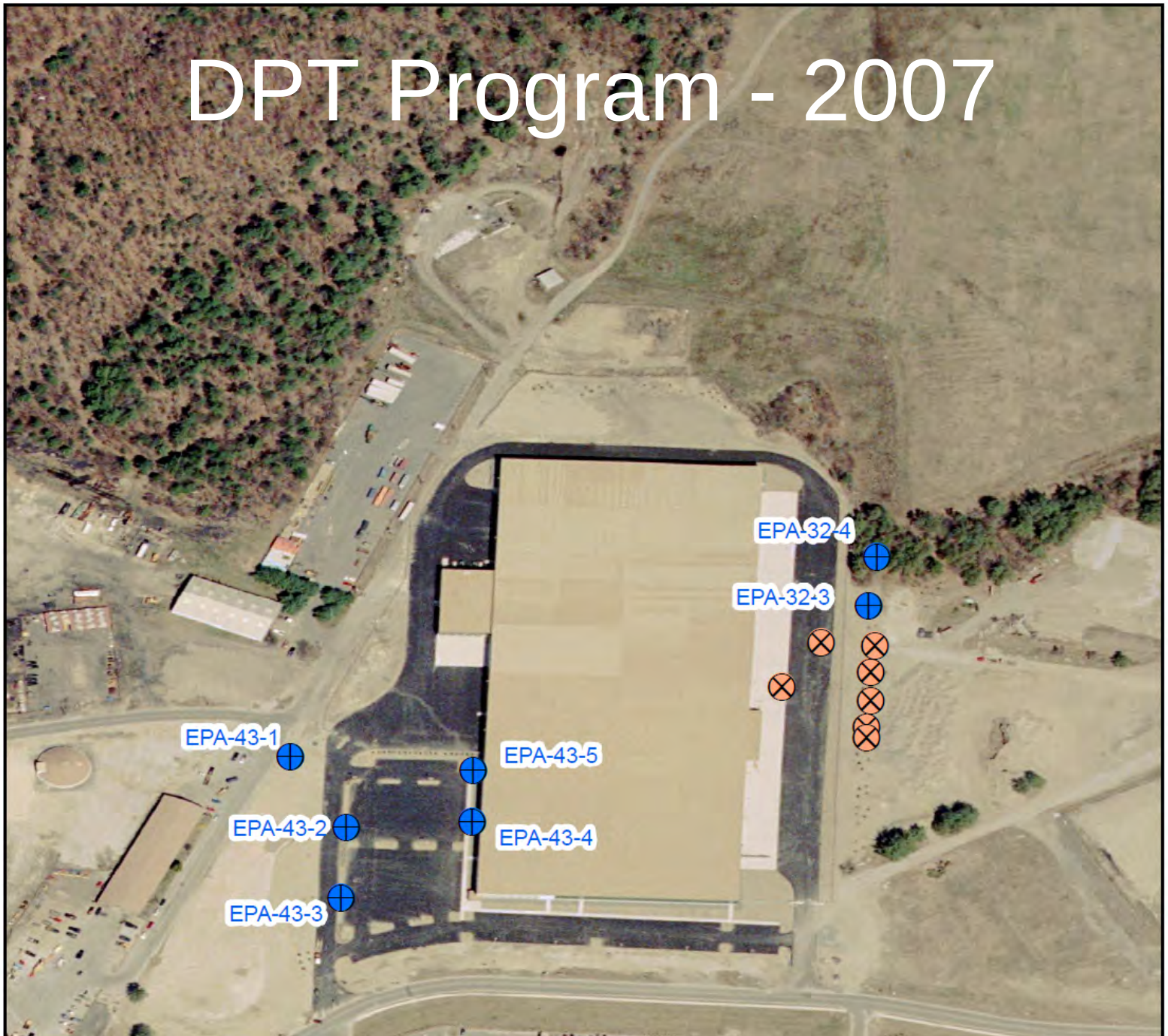
True-Scale Cross Section of UST-13 Area Normal to Foliation, Illustrating Monitoring Gap

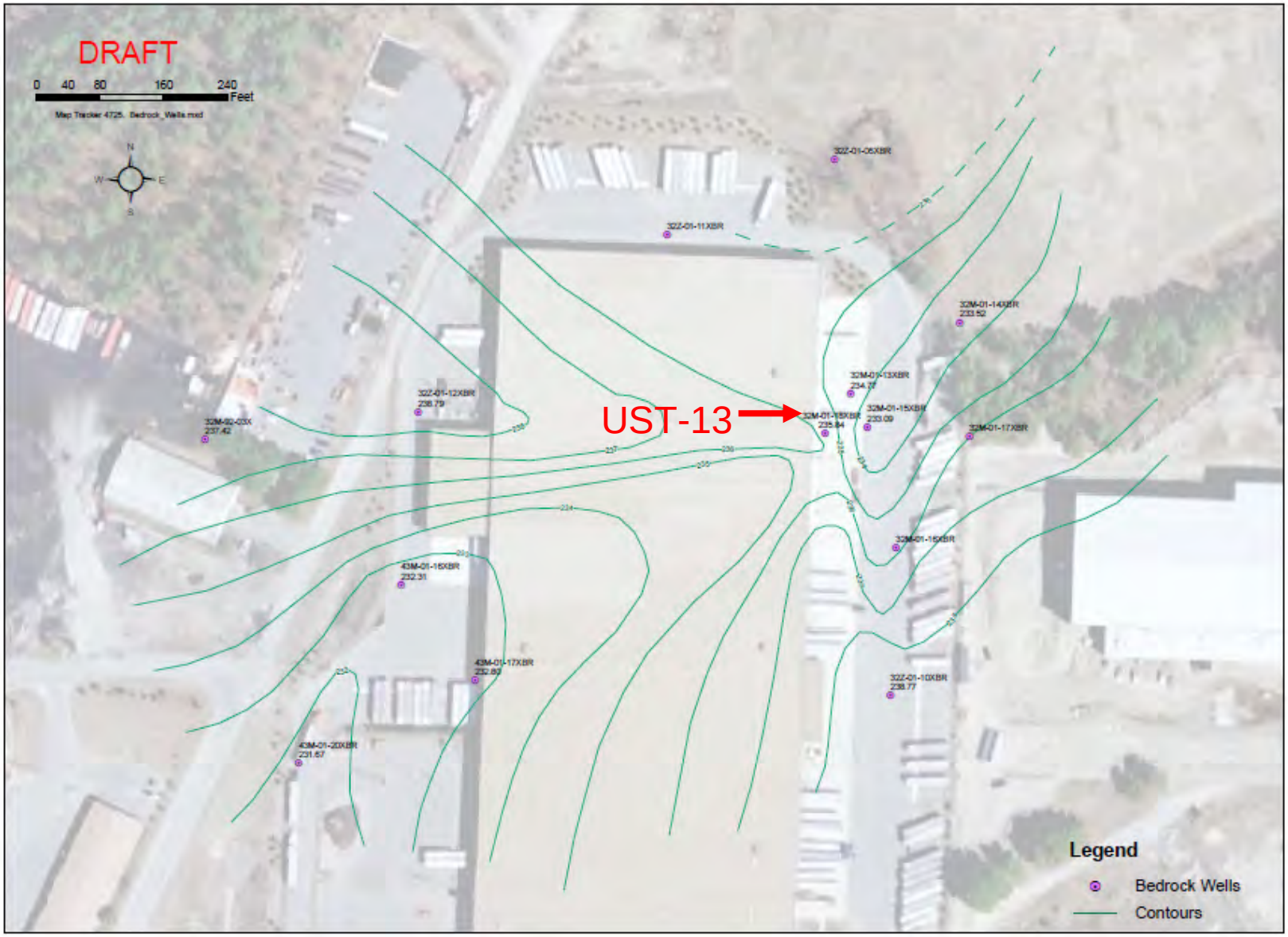


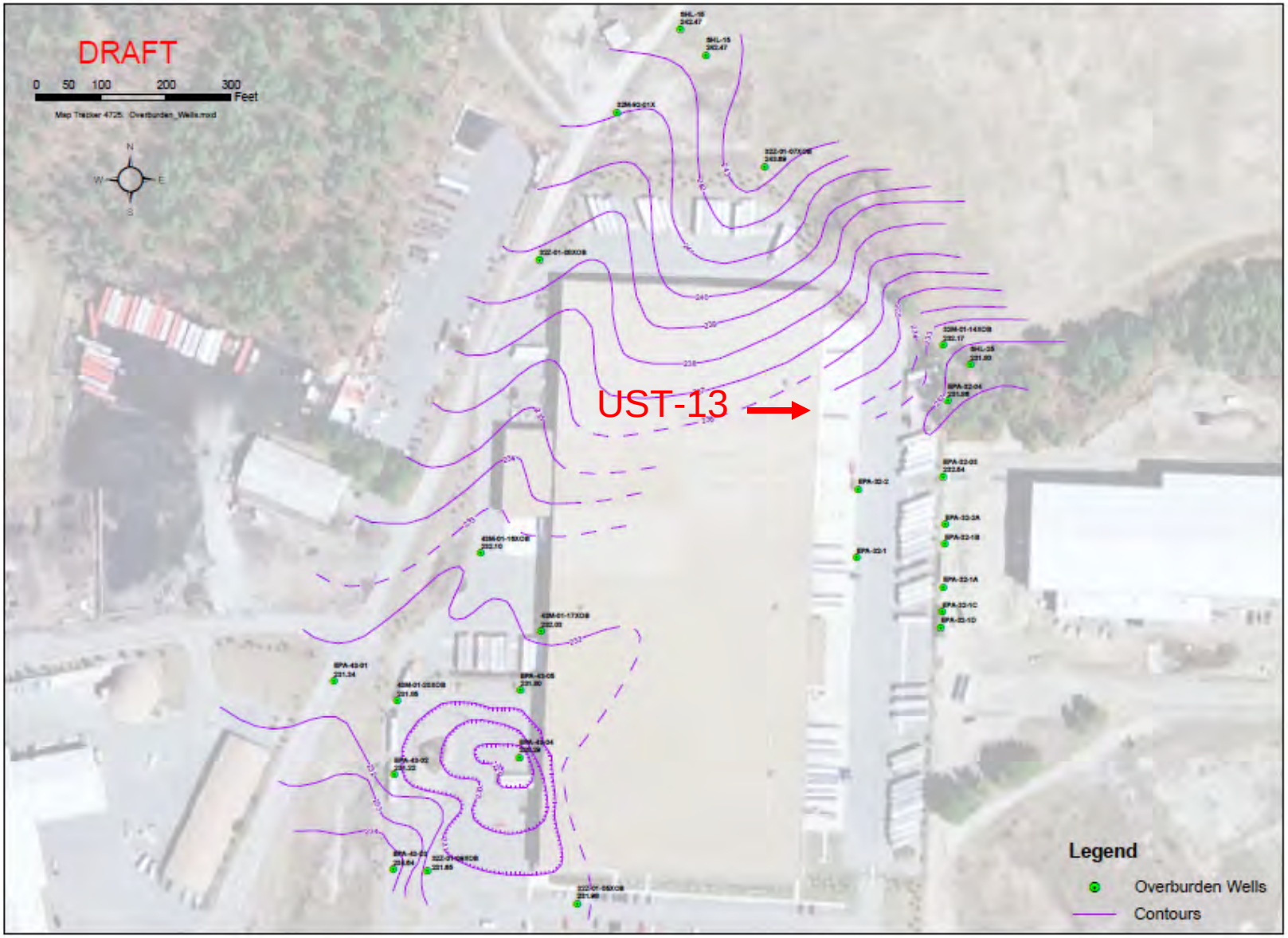
Plan View of Site 32-43A Indicating Proposed Locations for New Monitoring Wells



Based on MACTEC, Inc.
Figure 5 Bedrock Groundwater Surface
Oct. 7, 2004
Long-Term Monitoring
Plan AOCs 32 and 43A
Devens RFTA, MA


DPT Program - 2007
EPA-32-4
EPA-32-3
EPA-43-1
EPA-43-5
EPA-43-2
EPA-43-4
EPA-43-3


DRAFT
0 40 80 160 240
Feet
Map Tracker 4725_Bedrock_Wells.mxd
N
W
E
S
UST-13
32Z-01-06XBR
32Z-01-11XBR
32M-01-14XBR
233.52
32M-01-13XBR
234.37
32M-01-15XBR
233.09
32M-01-17XBR
32M-01-18XBR
235.84
32Z-01-12XBR
238.79
32M-02-03X
237.42
43M-01-16XBR
232.31
43M-01-17XBR
232.80
43M-01-20XBR
231.67
32Z-01-10XBR
238.77
Legend
Bedrock Wells
Contours


DRAFT
0 50 100 200 300
Feet
Map Tracker 4725: Overburden_Wells.mxd
N
W
E
S
UST-13
Legend
Overburden Wells
Contours

Summary and Conclusions

- Basic Geologic Analysis points to numerous opportunities for LTM Improvements
- Many existing MWs are no longer useful and should be eliminated from the program
- UST-13 Area Requires several new MWs
  - Source area
  - True down-gradient directions
  - Water-table (BR/OB)
- Joints parallel to foliation may play a significant role in contaminant migration
  - Down-dip migration of NAPL (W/SW)
  - Dissolved COC migration along strike (S)

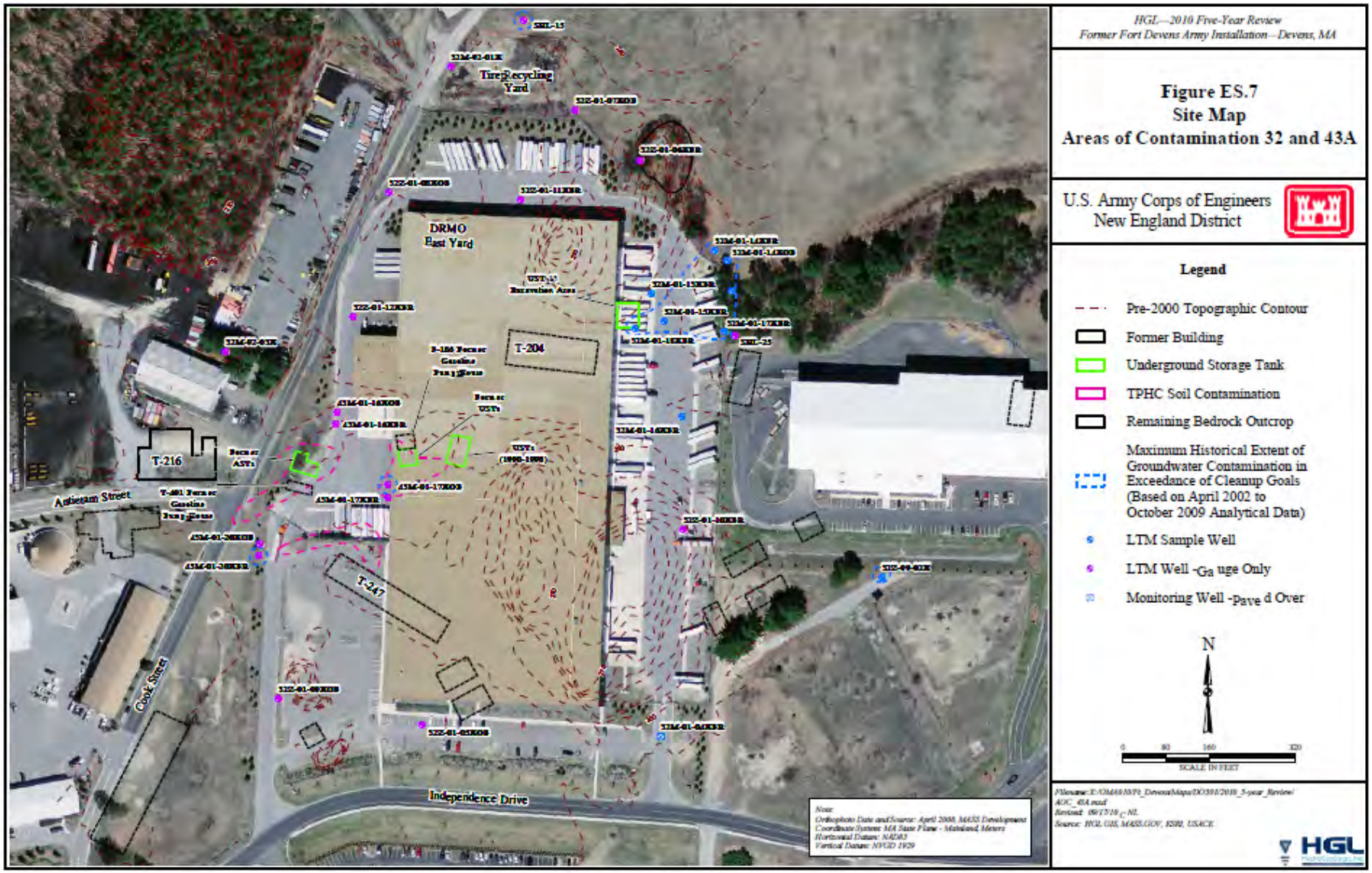
Summary and Conclusions (Cont.)

- Systematic water table rise in the POL area
- Many existing MWs no longer screened optimally for water table monitoring
- Source area MWs needed
- Several MWs needed to SW of source area along primary flow pathways (SOB/DOB)
- Target SW-striking Bedrock Structure

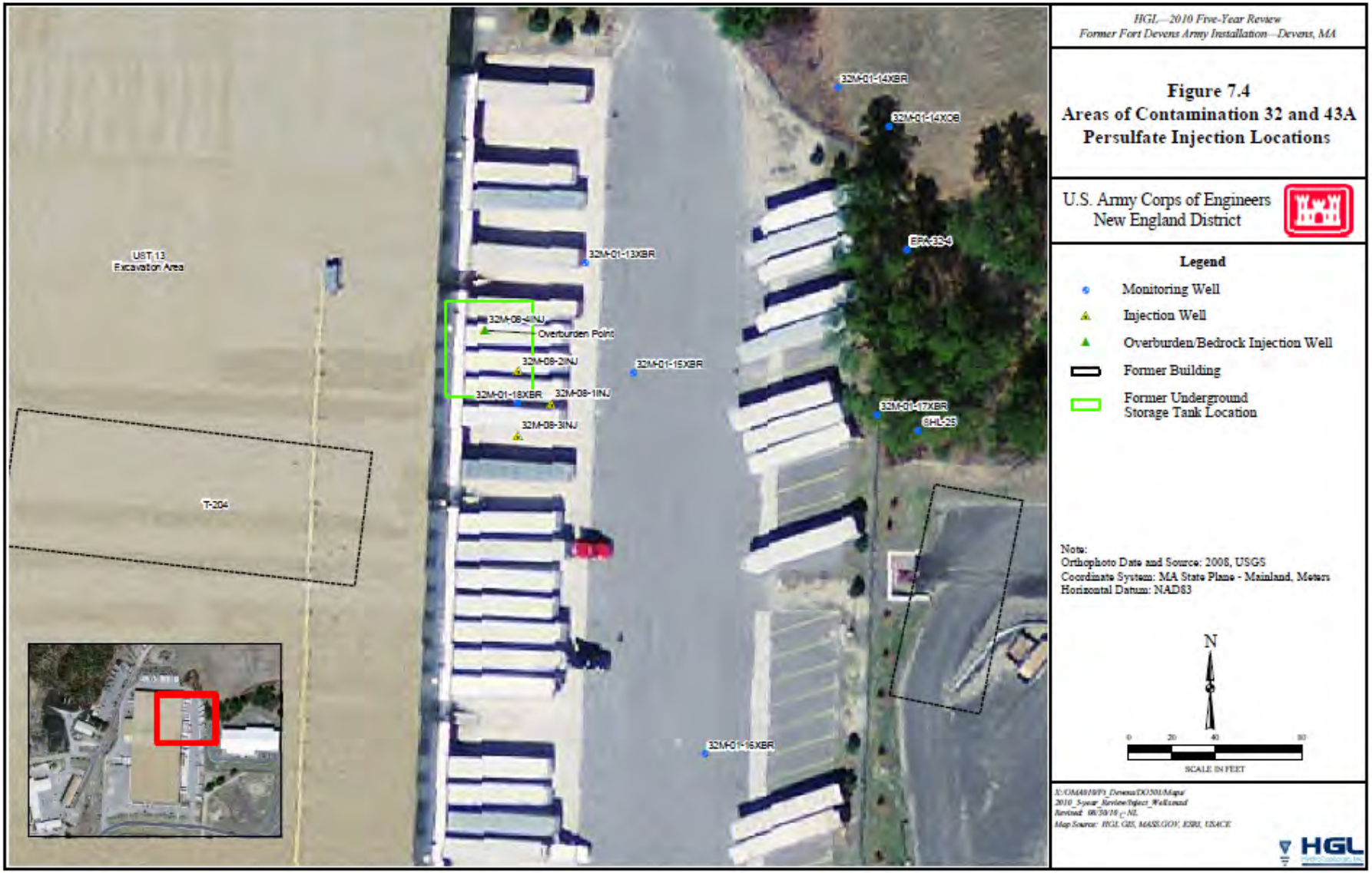
Recommendations and Outstanding Issues

- CSM Consensus
- Install New Monitoring Wells
- Decommission Unnecessary Wells
- New Baseline; Re-initiate Long-term Monitoring
- Evaluate time-series contaminant trends
- Evaluate Perchlorate (Blasting)
- Install Transducers to evaluate long-term water level trends
- Determine whether additional remedial measures are needed

2009 Persulfate Injection



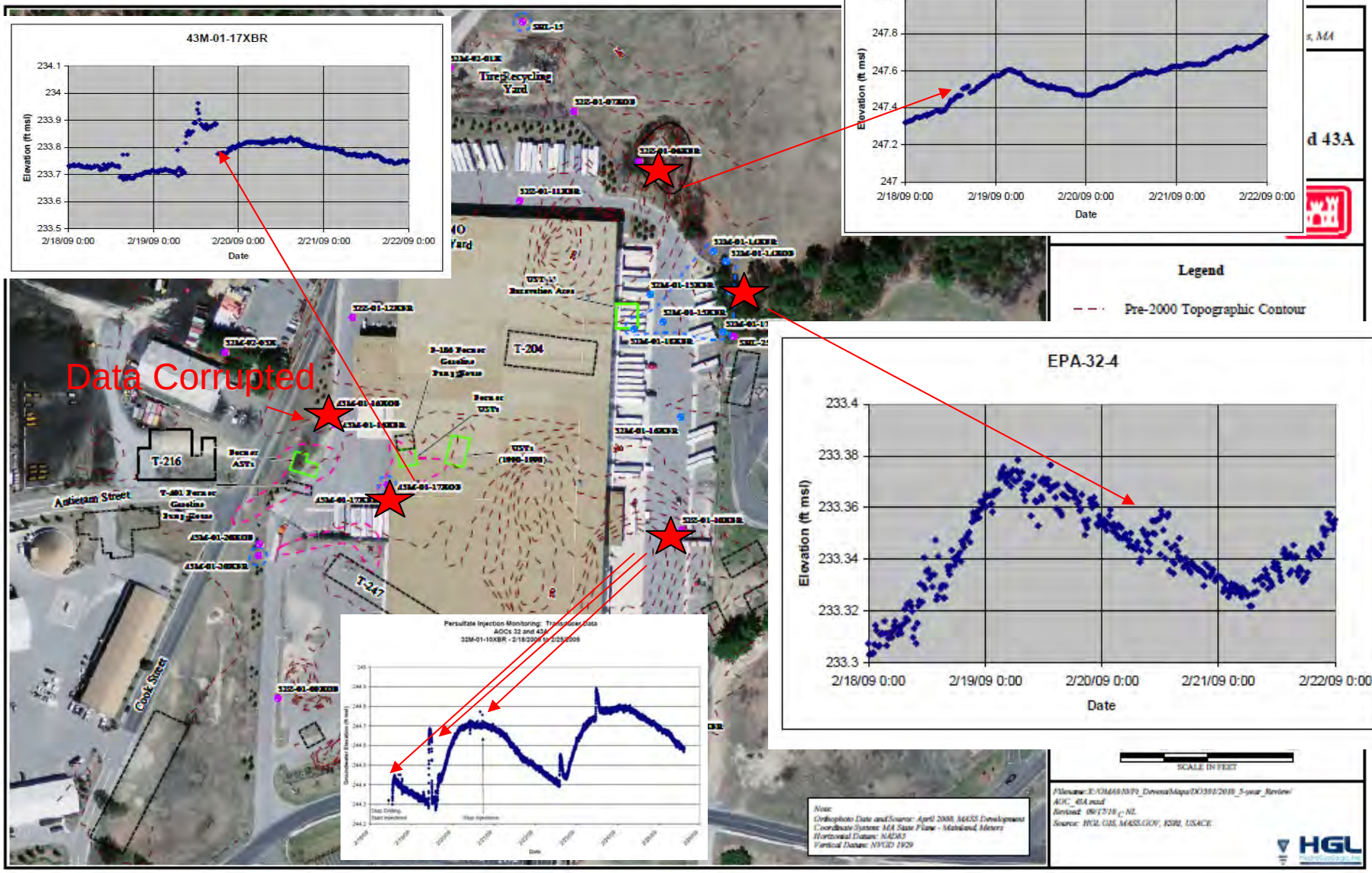
2009 Persulfate Injection



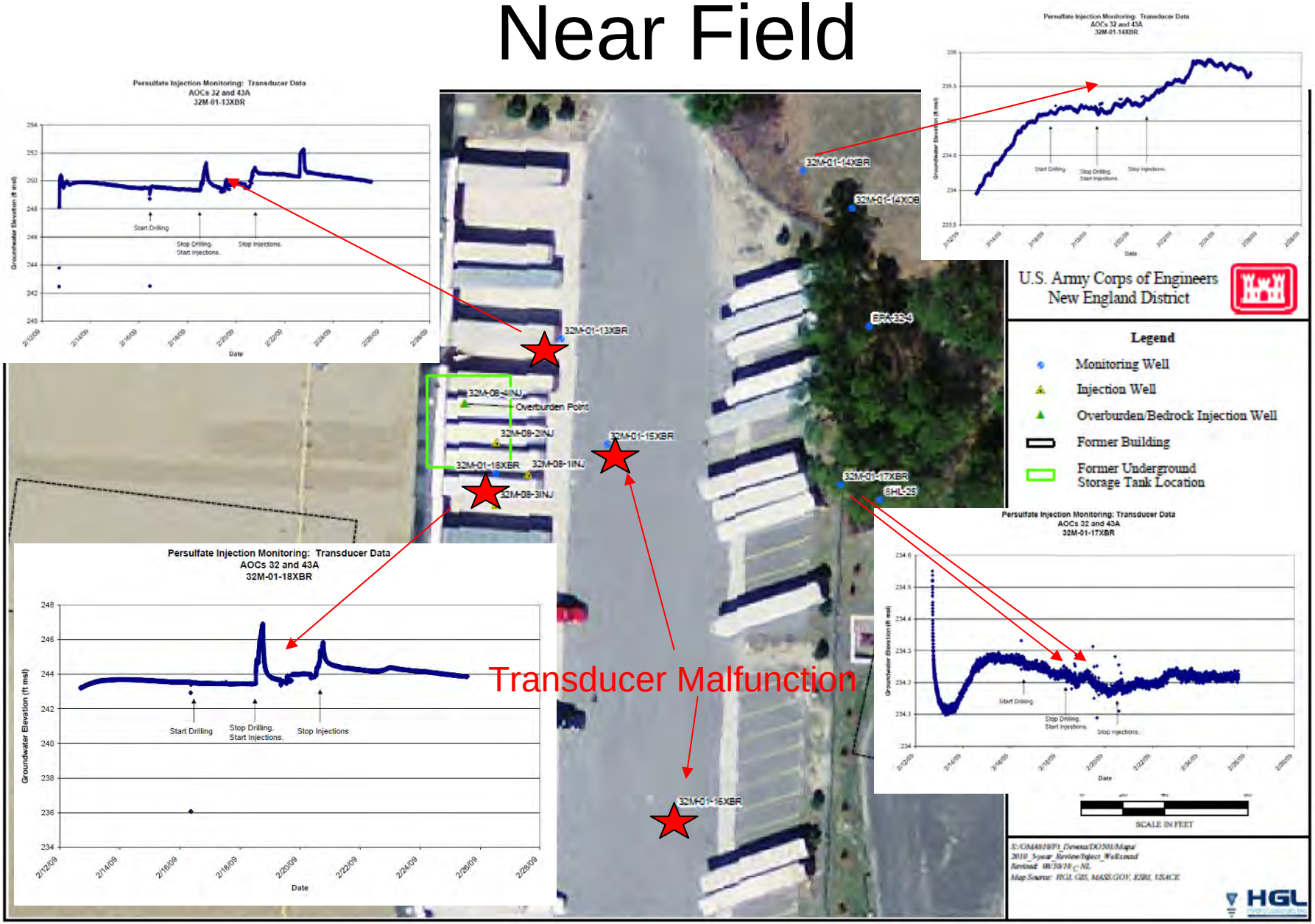
2009 Persulfate Injection

- Focus on “hotspot” near 32M-01-18XBR
- 3 shallow bedrock injection wells installed around 32M-01-18XBR
- Overburden injection well installed on Top-of-bedrock in former tank grave
- 1800 gallons of water/sodium persulfate solution injected February 2009
- sodium hydroxide used as catalyst

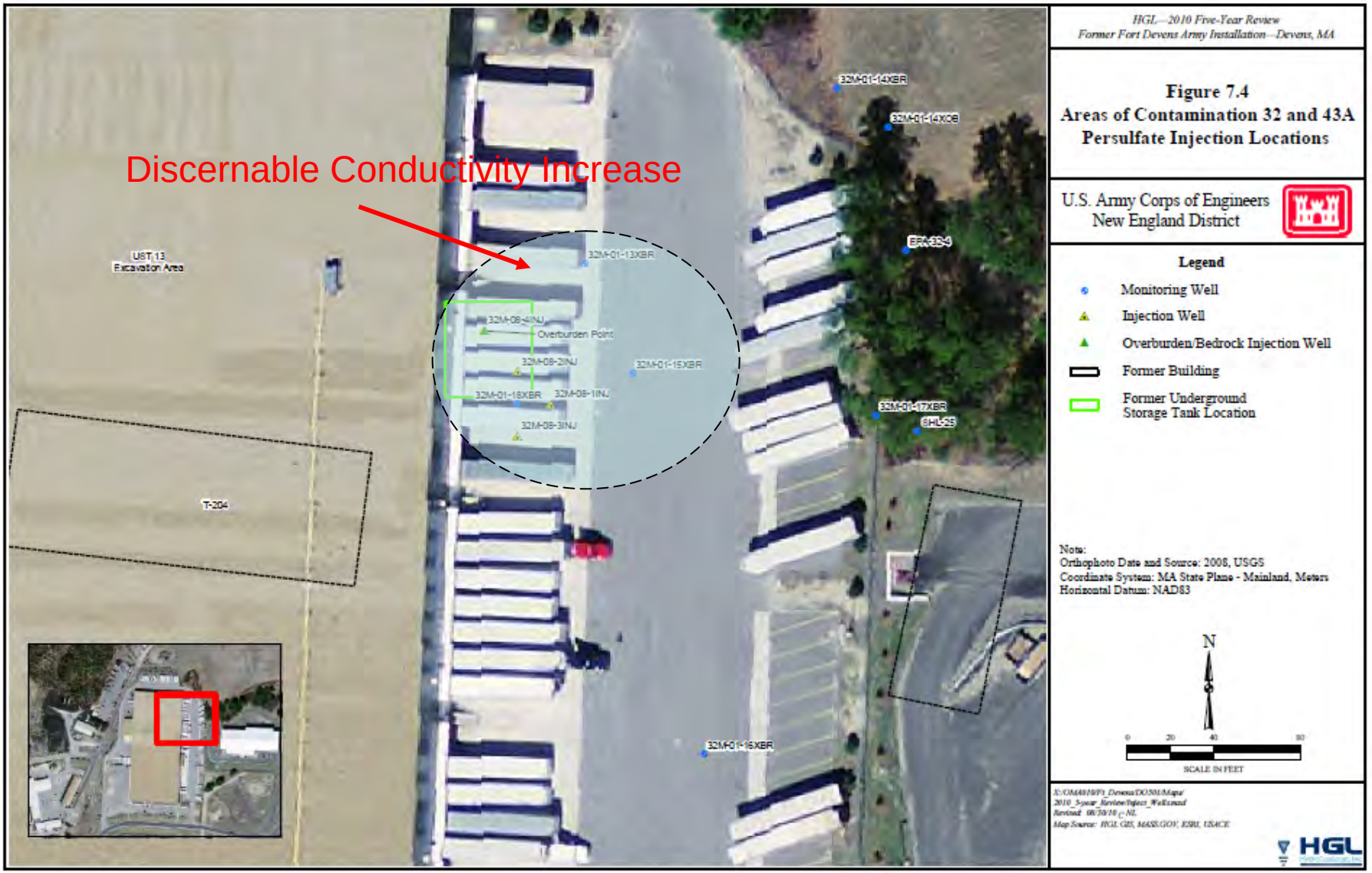
Injection Pressure Response Far Field

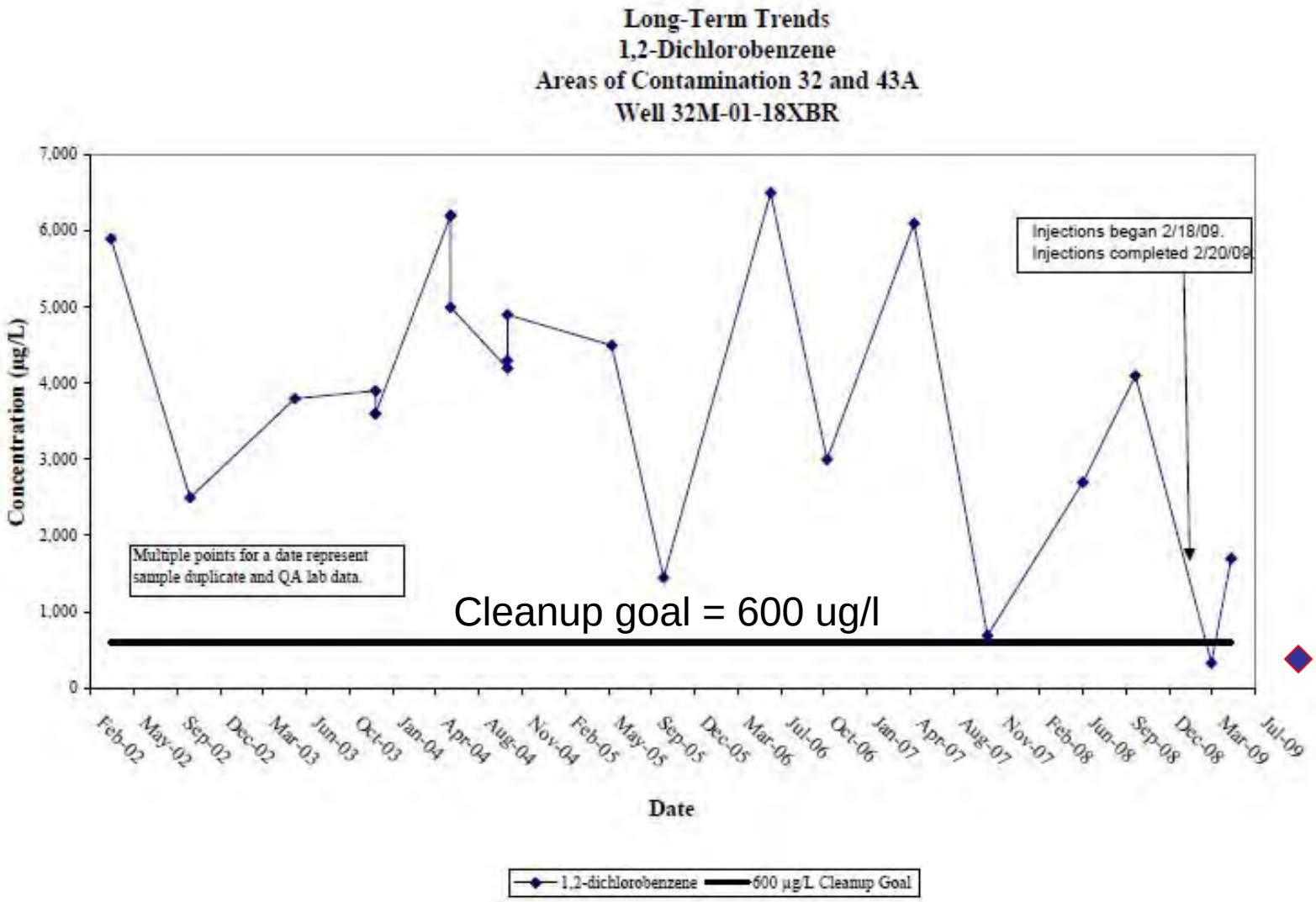


Injection Pressure Response Near Field

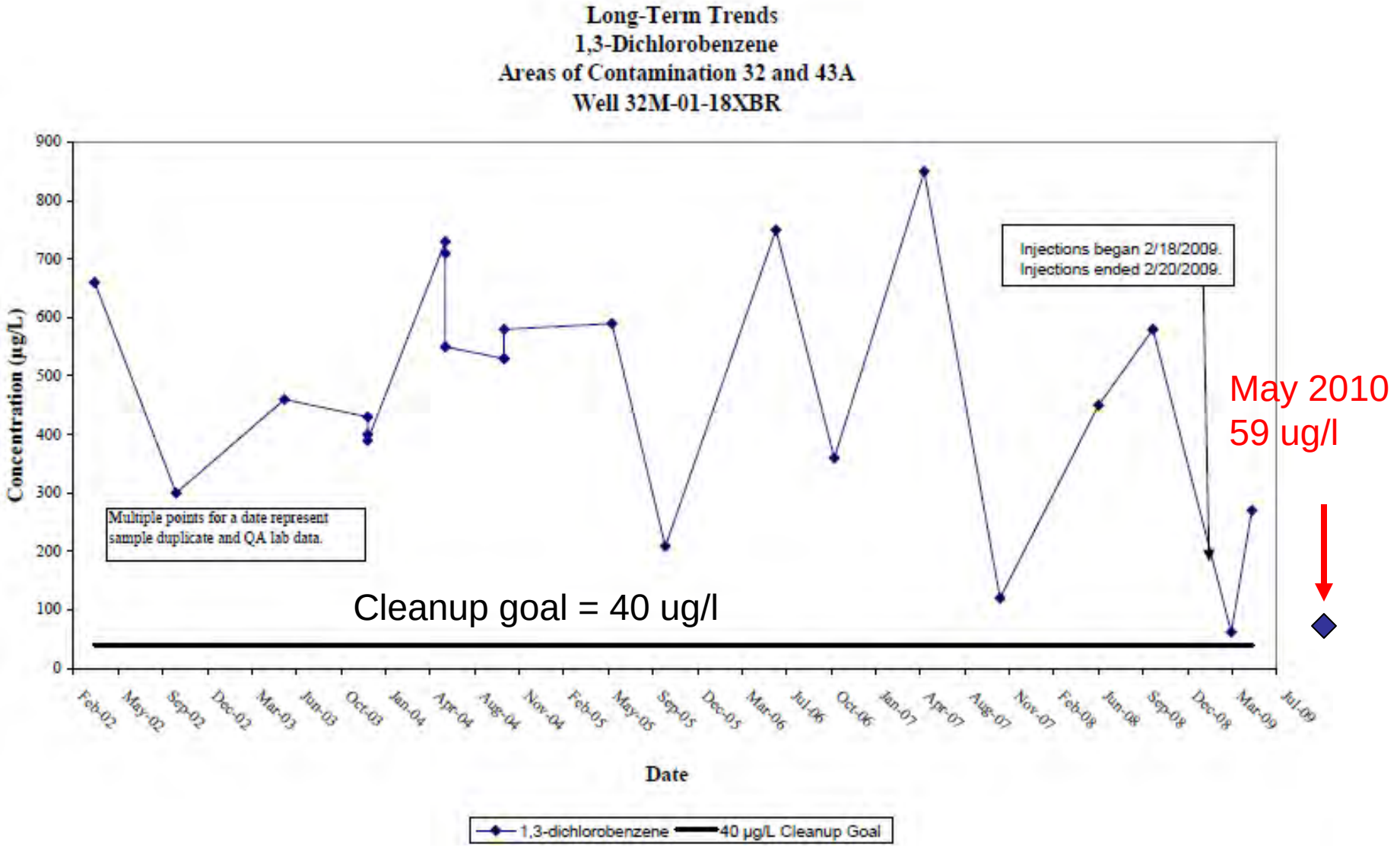


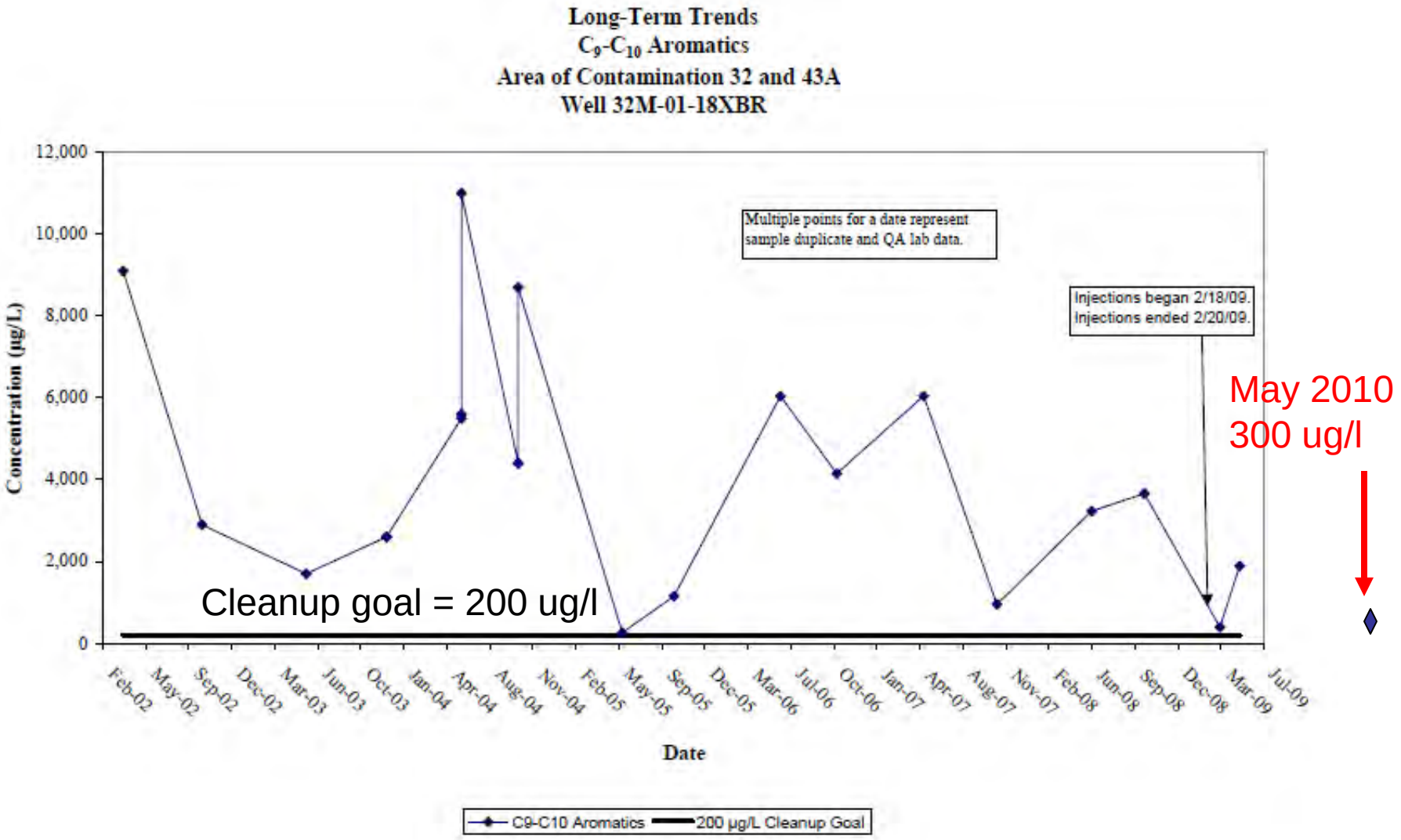
Injection Conductivity Response Near Field





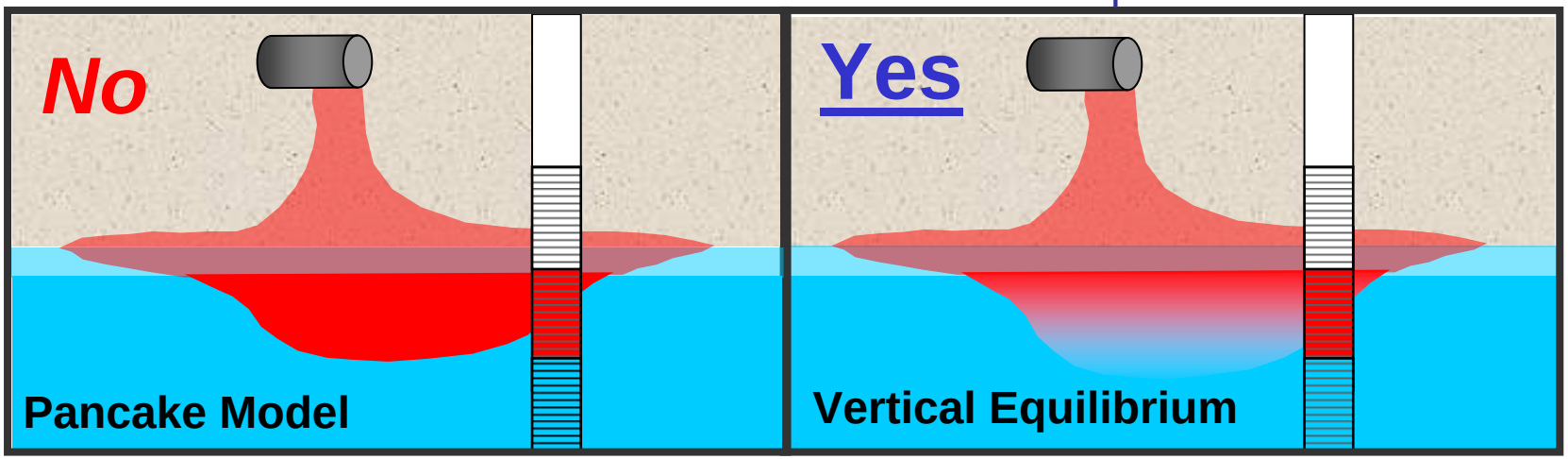
May 2010
300 ug/l


Long-Term Trends
1,3-Dichlorobenzene
Areas of Contamination 32 and 43A
Well 32M-01-18XBR
Concentration (µg/L)
900
800
700
600
500
400
300
200
100
0
Injections began 2/18/2009.
Injections ended 2/20/2009.
Multiple points for a date represent sample duplicate and QA lab data.
Cleanup goal = 40 ug/l
May 2010
59 ug/l
Feb-02
May-02
Sep-02
Dec-02
Mar-03
Jun-03
Oct-03
Jan-04
Apr-04
Aug-04
Nov-04
Feb-05
May-05
Sep-05
Dec-05
Mar-06
Jul-06
Oct-06
Jan-07
Apr-07
Aug-07
Nov-07
Feb-08
Jun-08
Sep-08
Dec-08
Mar-09
Jul-09
Date
1,3-dichlorobenzene
40 µg/L Cleanup Goal

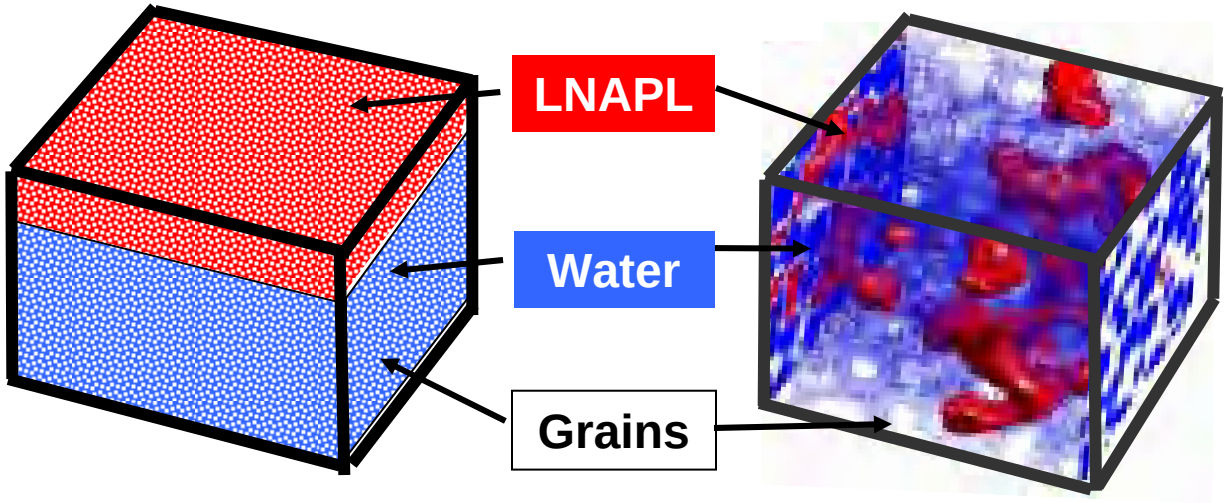

Long-Term Trends
C9-C10 Aromatics
Area of Contamination 32 and 43A
Well 32M-01-18XBR
Concentration (µg/L)
12,000
10,000
8,000
6,000
4,000
2,000
0
Multiple points for a date represent sample duplicate and QA lab data.
Injections began 2/18/09.
Injections ended 2/20/09.
Cleanup goal = 200 ug/l
May 2010
300 ug/l
Feb-02
May-02
Sep-02
Dec-02
Mar-03
Jun-03
Oct-03
Jan-04
Apr-04
Aug-04
Nov-04
Feb-05
May-05
Sep-05
Dec-05
Mar-06
Jul-06
Oct-06
Jan-07
Apr-07
Aug-07
Nov-07
Feb-08
Jun-08
Sep-08
Dec-08
Mar-09
Jul-09
Date
C9-C10 Aromatics
200 µg/L Cleanup Goal

Vertical LNAPL Distribution

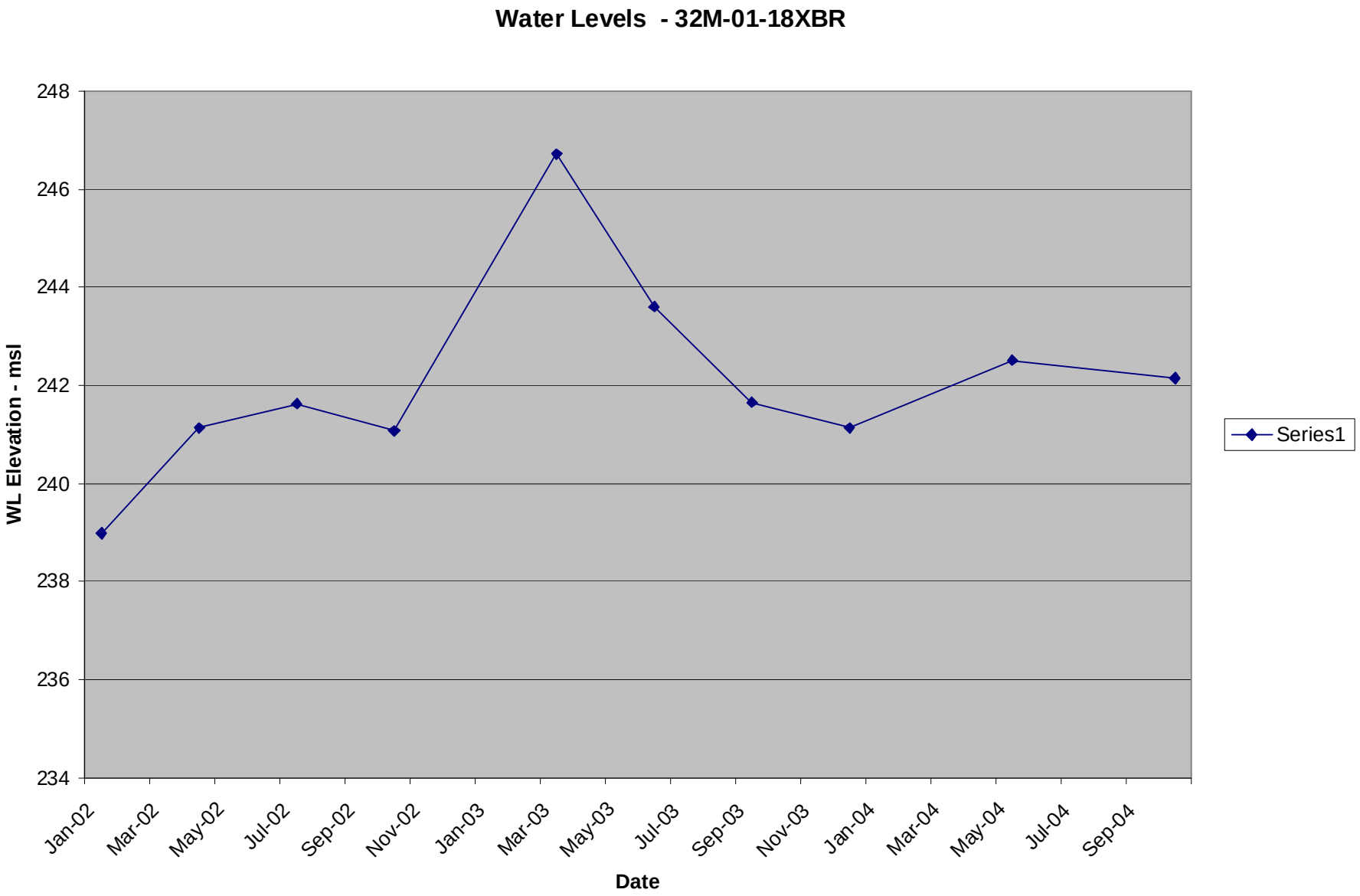
Pancake Model vs. Vertical Equilibrium Model



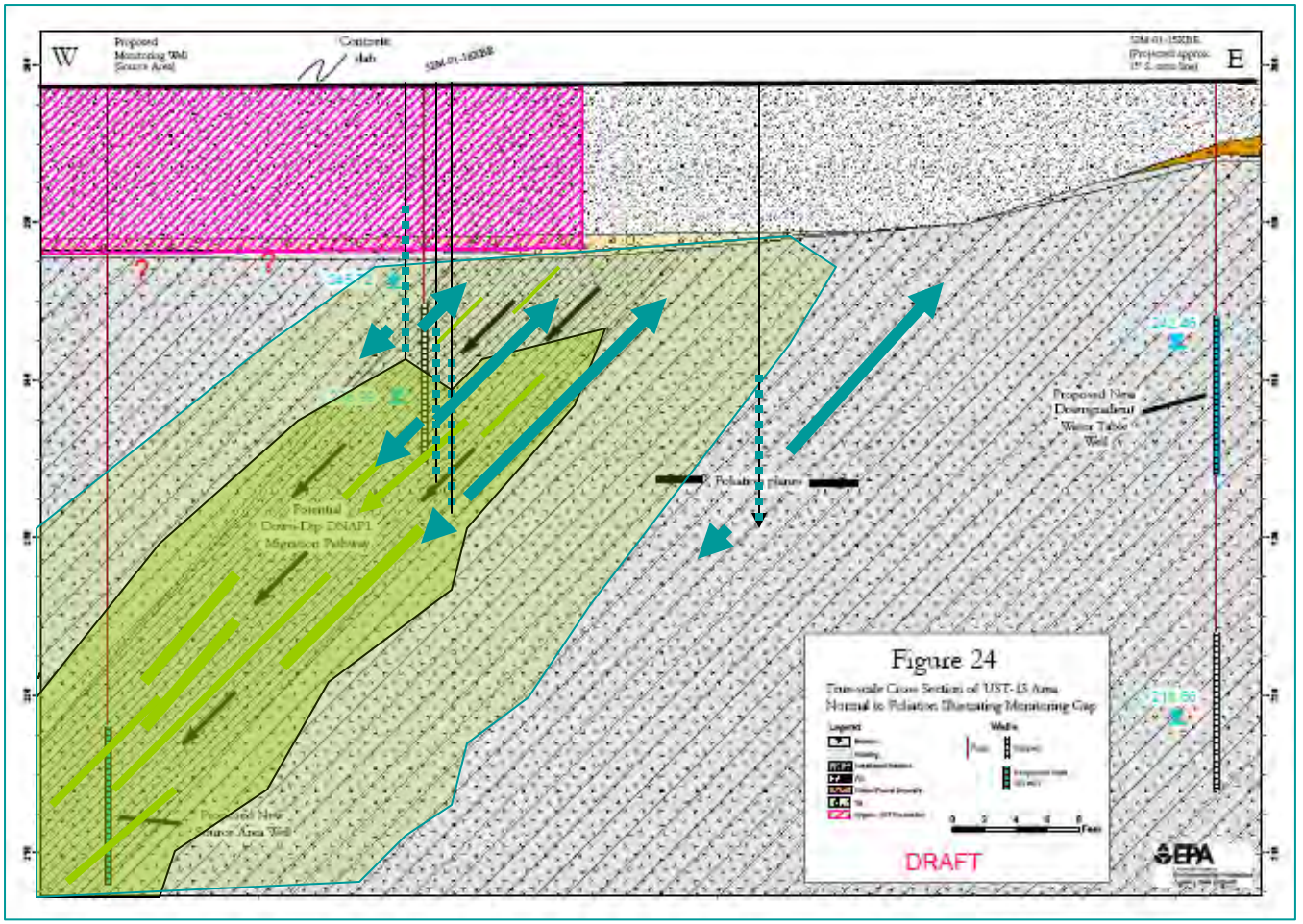
- Assumes LNAPL floats on water table
- Uniform LNAPL saturation



- LNAPL penetrates below water table
- LNAPL and water coexist in pores


Water Levels - 32M-01-18XBR
WL Elevation - msl
248
246
244
242
240
238
236
234
Jan-02
Mar-02
May-02
Jul-02
Sep-02
Nov-02
Jan-03
Mar-03
May-03
Jul-03
Sep-03
Nov-03
Jan-04
Mar-04
May-04
Jul-04
Sep-04
Date
Series1

True-Scale Cross Section of UST-13 Area Normal to Foliation, Illustrating Monitoring Gap



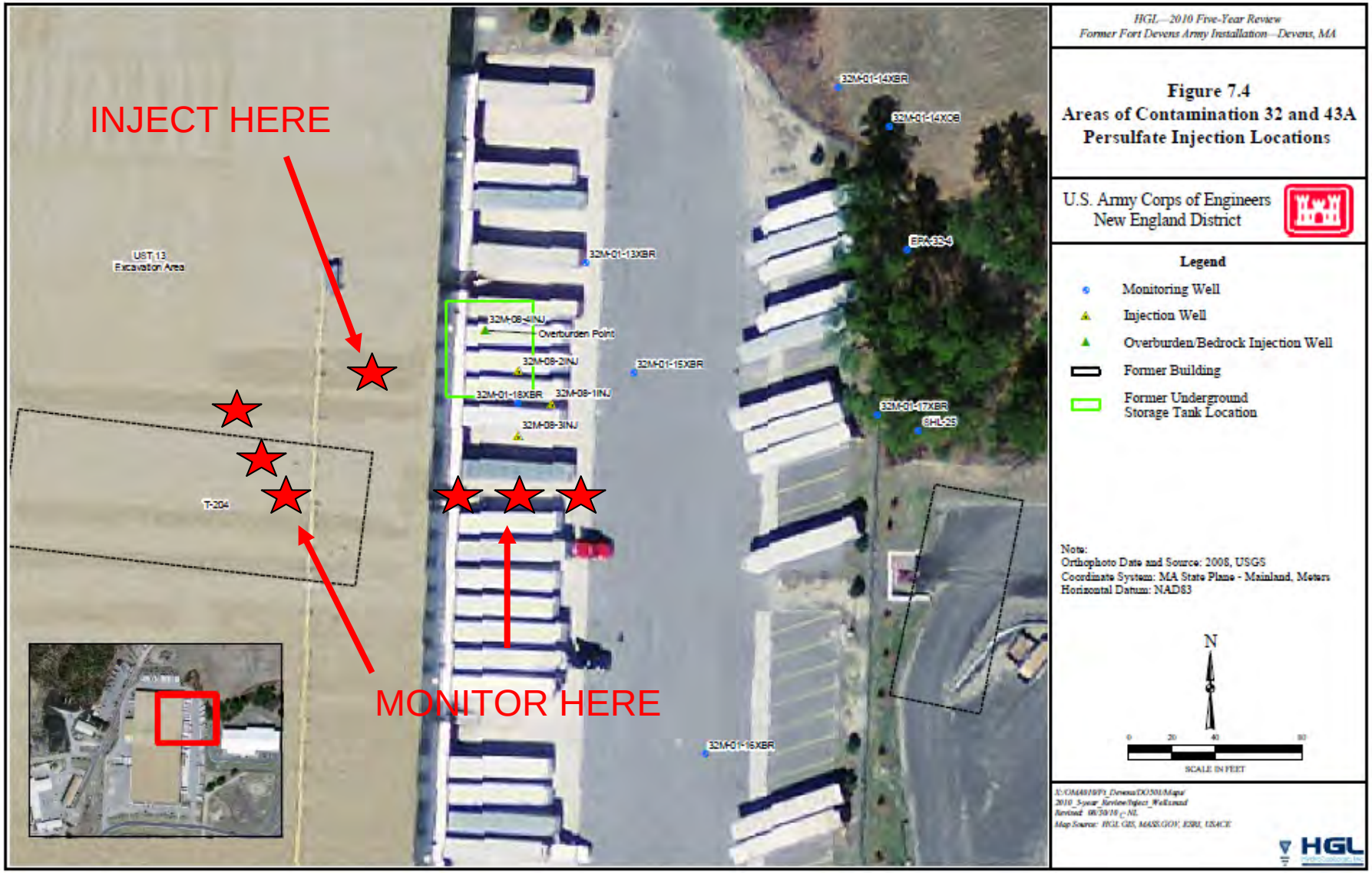
Questions for Ongoing LTM

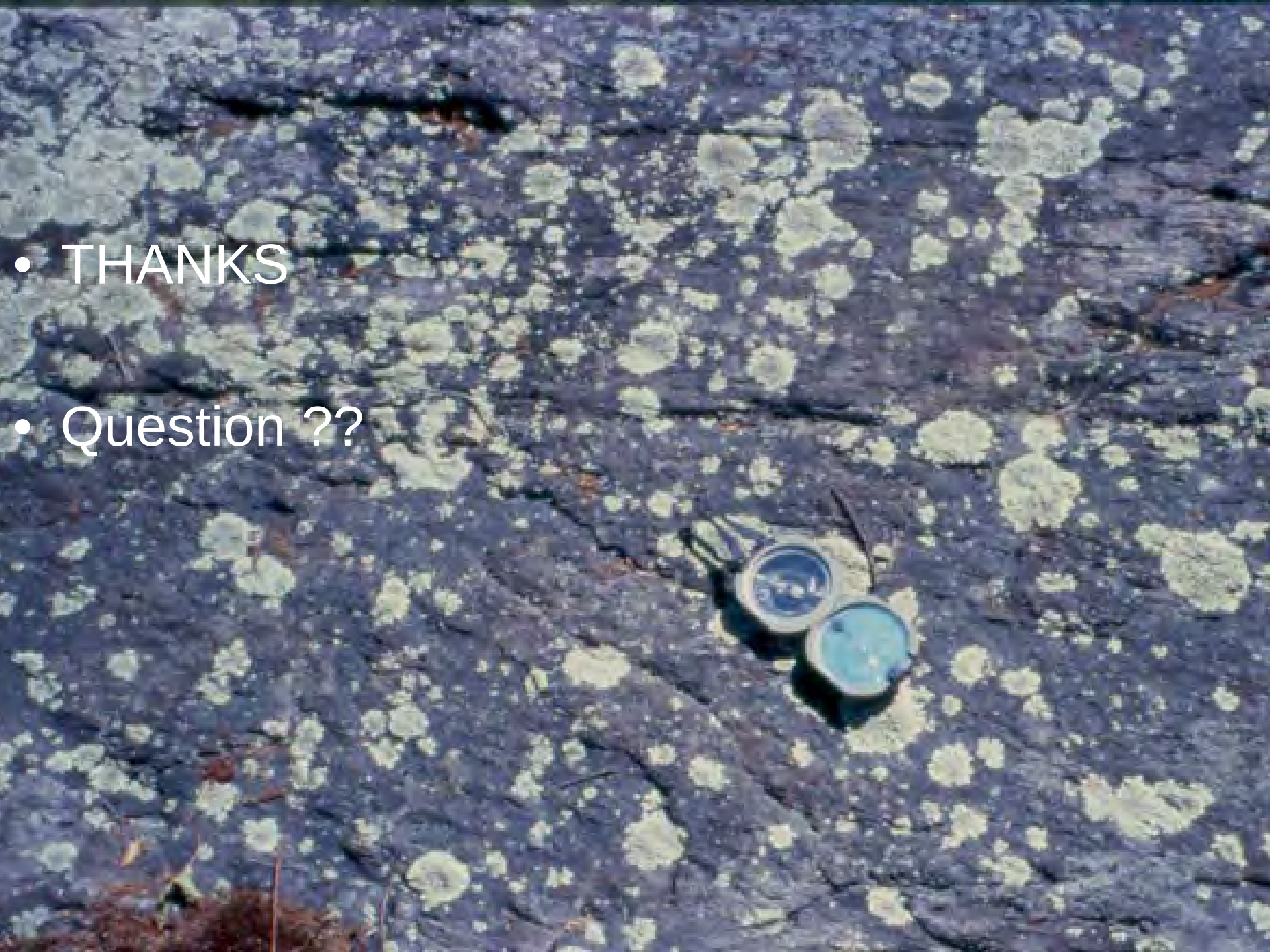
- Is the apparent COC attenuation real?
- Or will the Oscillatory longer-term trends resume
- Does the site behave as a typical “drowned smear zone”?
- Delivery: Will future remedial efforts need to more carefully consider the bedrock fracture system?
- *Deliverance*: How might one increase the oxidant contact with residual contaminants?

Next Steps

- Install Transducers to evaluate long-term water level trends
- Determine whether additional remedial measures are needed
- Consider Injecting in down-dip directions
- Monitor in down gradient areas in consideration of bedrock ground water gradients and bedrock fabric

2009 Persulfate Injection





- THANKS
- Question ??