Coupled Use of Instrumentation and Geologic History to Assess Movement, Performance, and Stabilization of Large Landslide in Western Pennsylvania

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Geohazards Impacting Transportation in Appalachia
Chattanooga, TN
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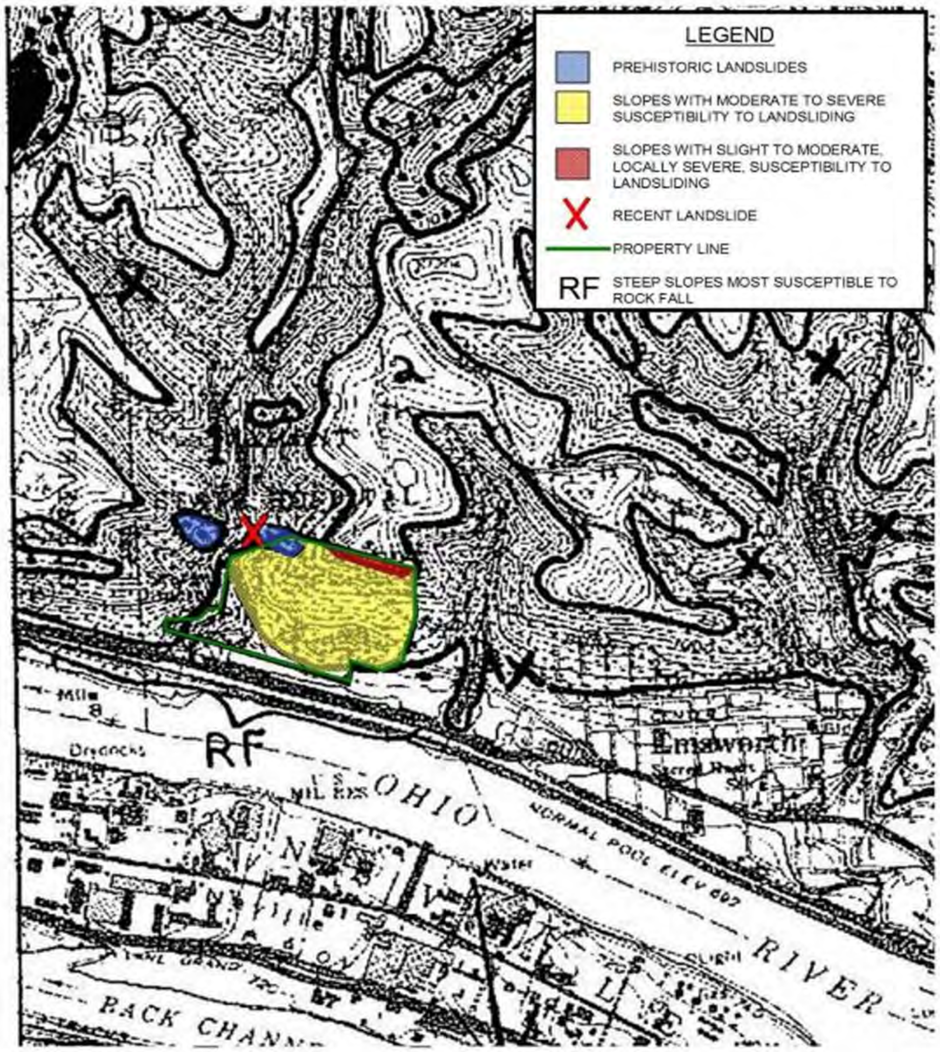
The Project and Problem

- Confidential site in Western Pennsylvania
- Slopes at 4H:1V in colluvium exist in area recognized (by many) to be "Landslide Prone"
- Slope failed during balanced cut-fill construction operation while placing fill at 2H:1V slopes
- Rehabilitation strategy considered a minimum of off-site disposal of soil

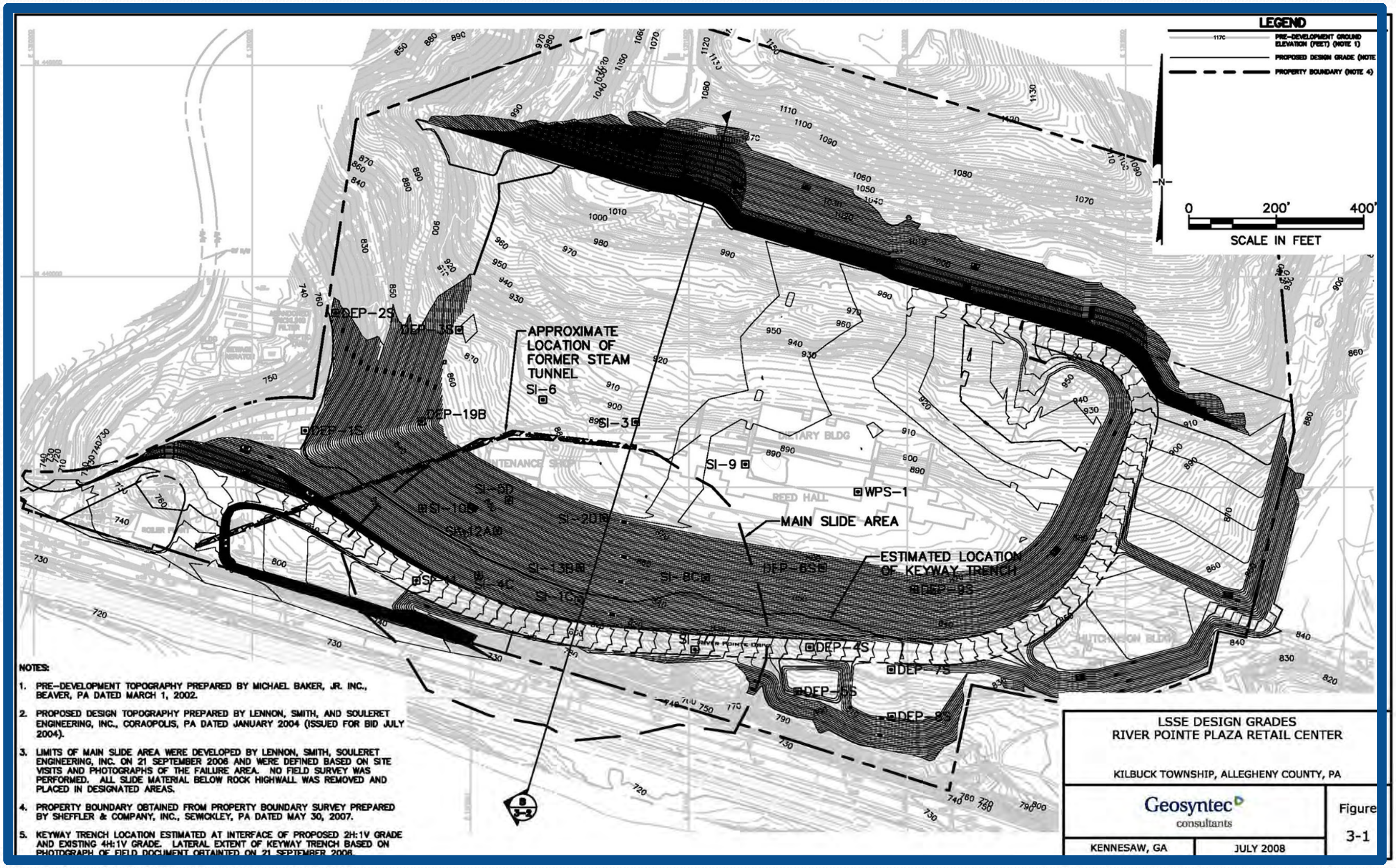
2005 Aerial Image of Site in Western Pennsylvania

USGS Landslide Susceptibility Map

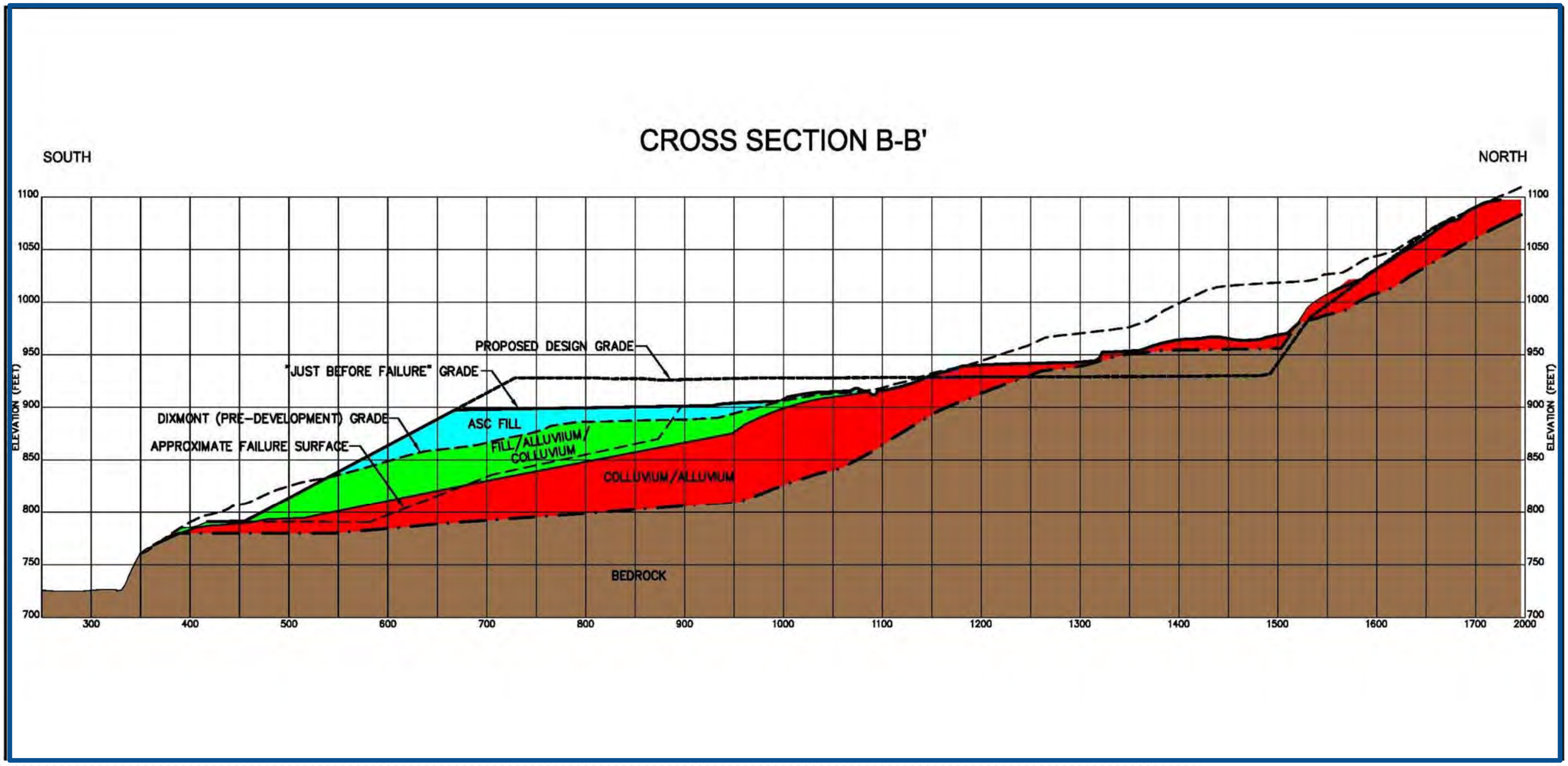


(after: USGS Map of Susceptibility to Landsliding, Allegheny County, Pennsylvania, J.S. Pomeroy and W.E. Davis, 1975)

Location of Analysis Section B-B’



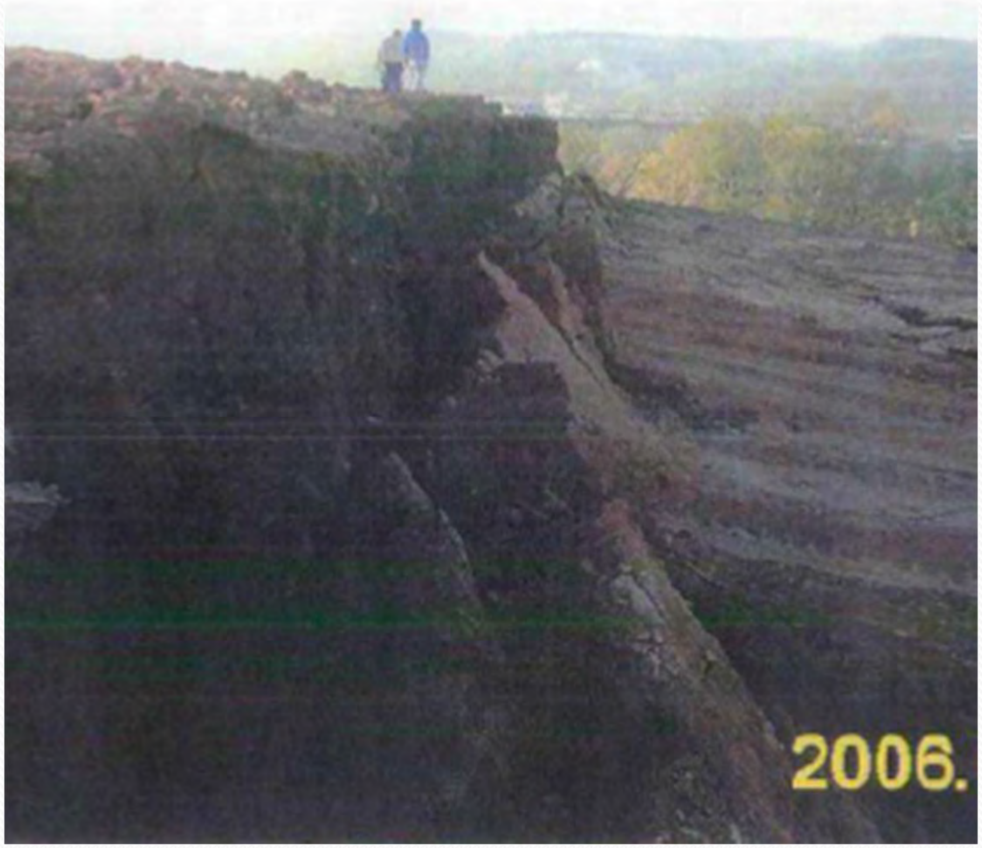
Analysis Section B-B’



Net Result!

Net Result!

Lessons Learned??

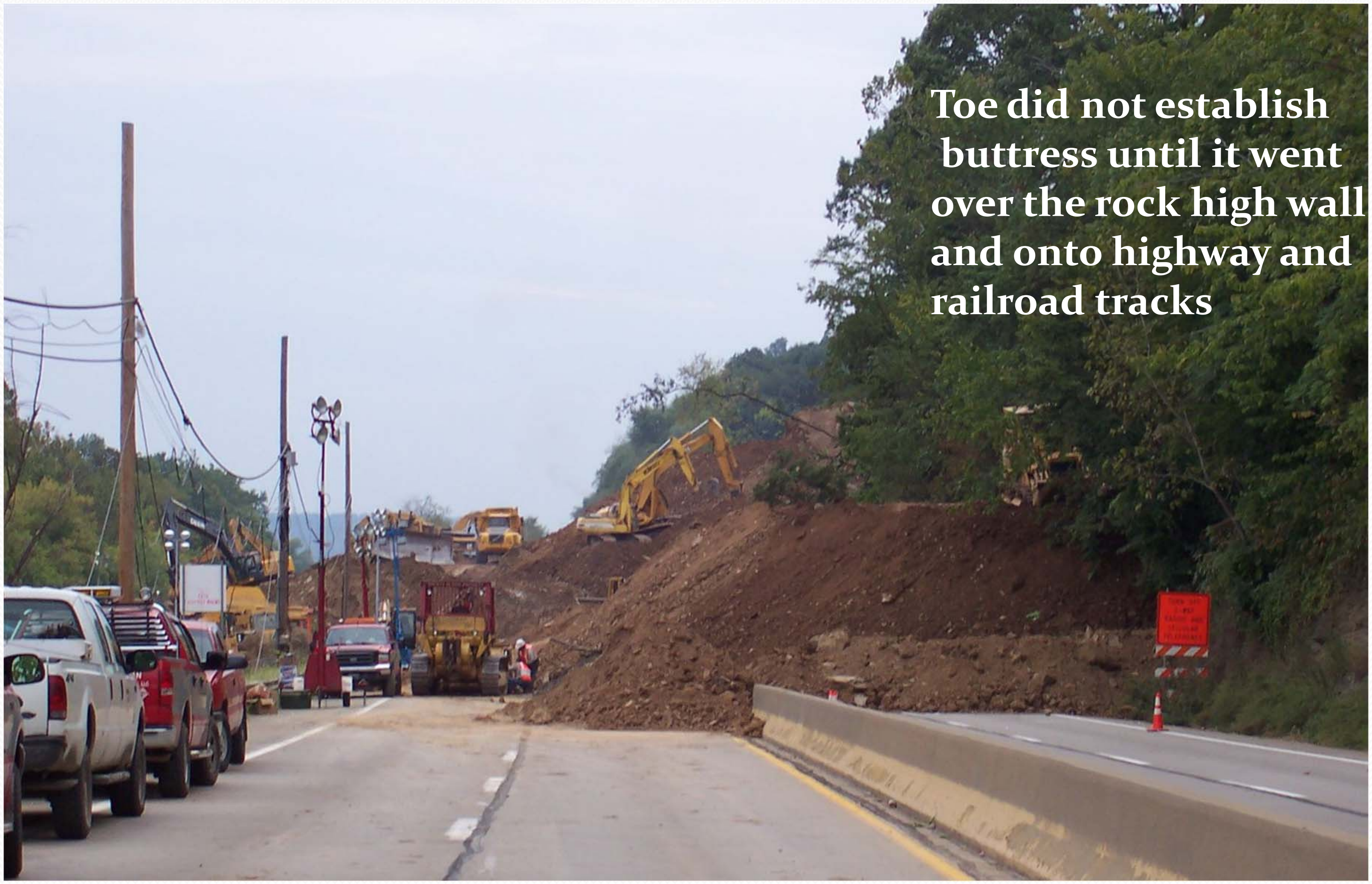


May 1, 2006

September 22, 2006

Emergency Earthwork to Reopen Highway and Rail Lines

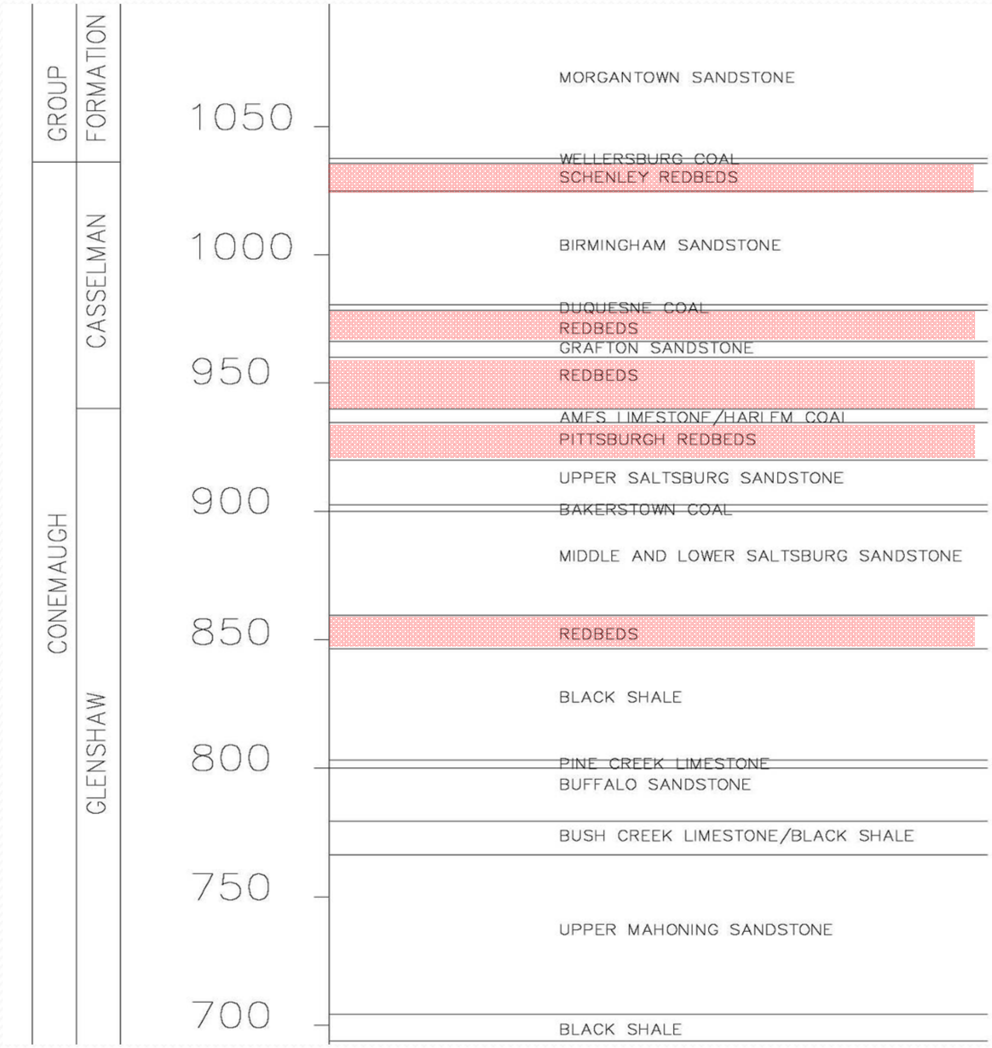
Mechanism of Failure



Role of Geology

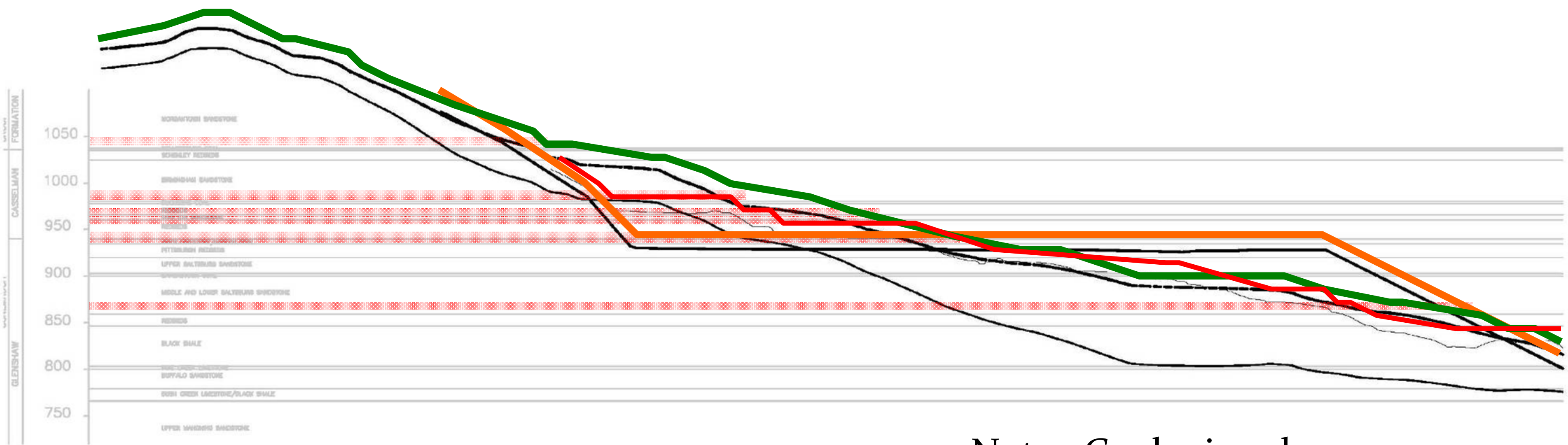
- Geologic Setting
- Site History
- Lessons from Geologic Setting
- Site-specific Considerations

Geologic Section



Redbed units represent chronic stability problems in Western PA

Geologic Cross-section



Note: Geologic column extended to graded surface for location purposes only

Pre-Development Grade

Design Grade

Post-failure Grades

Bedrock Elevation

Redbeds

Claystone and Colluvium as Geohazards

- Characteristics of claystone comprising redbed units
  - low strength
  - rapid degradation when exposed to weathering
  - formation of low strength clayey colluvial soils on slopes
  - predisposed planes of weakness in the form of slickensides and nonsystematic joints
  - most published case histories focus on cut slopes into the claystone/redbed units

Landslides in Colluvium

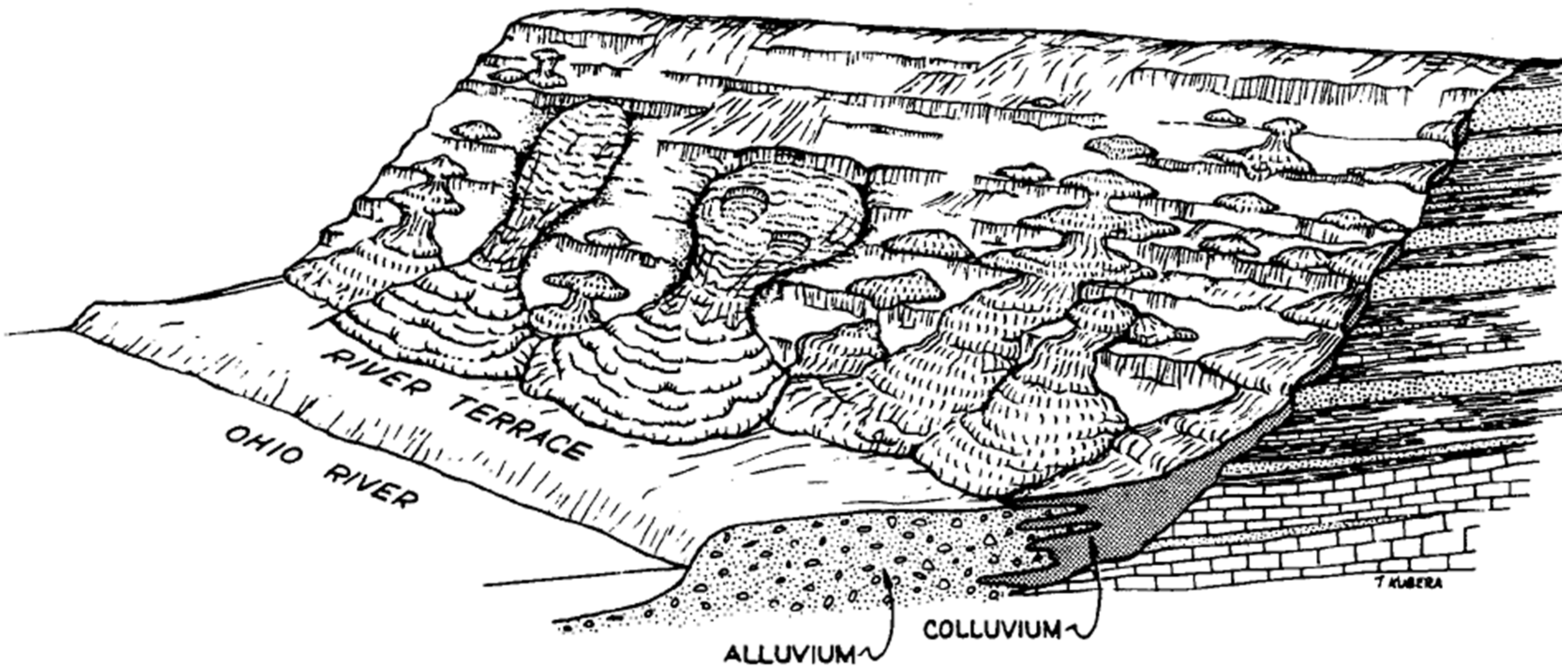
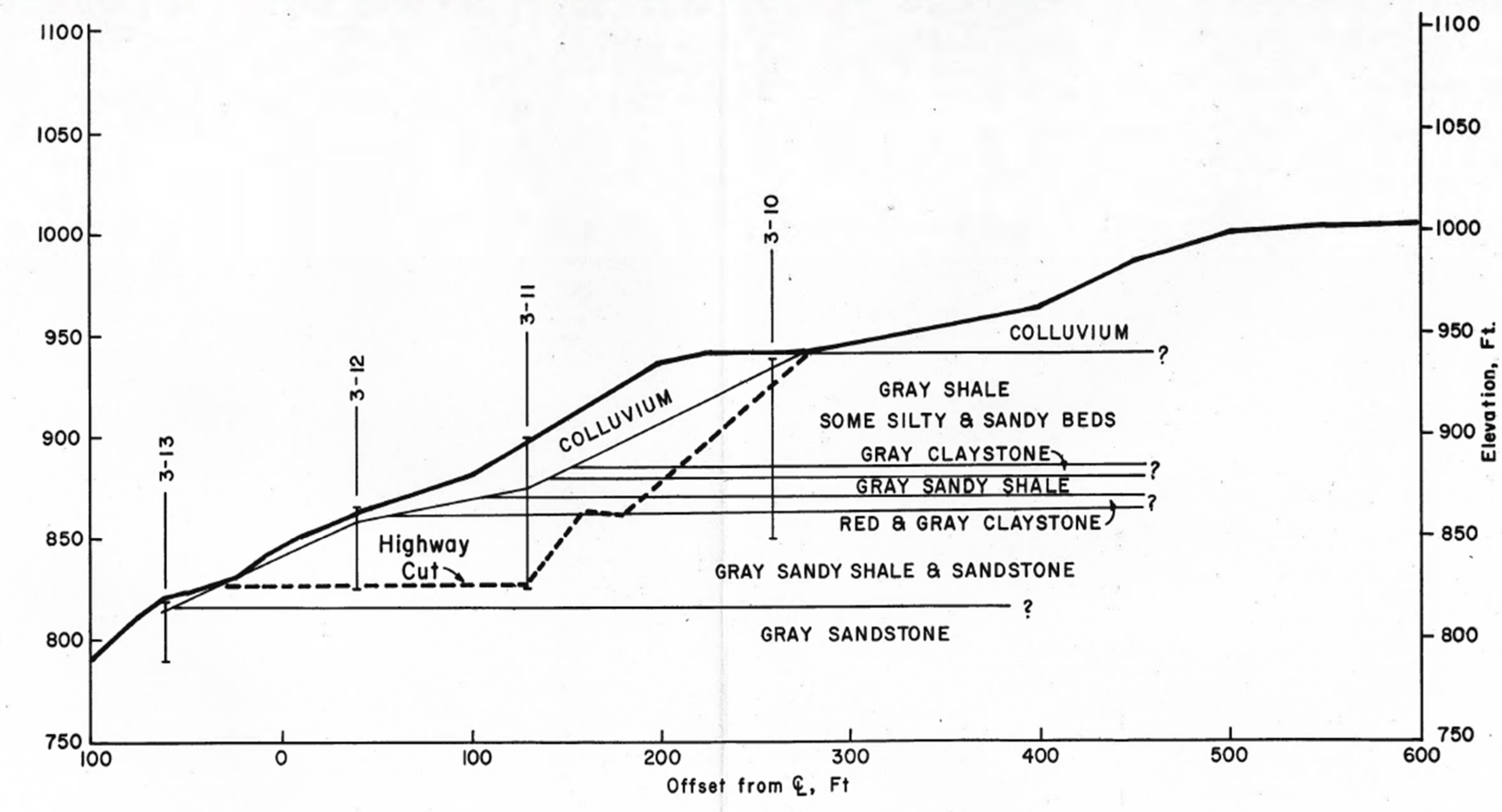


Fig. 2 : Idealized diagram of colluvial slope development

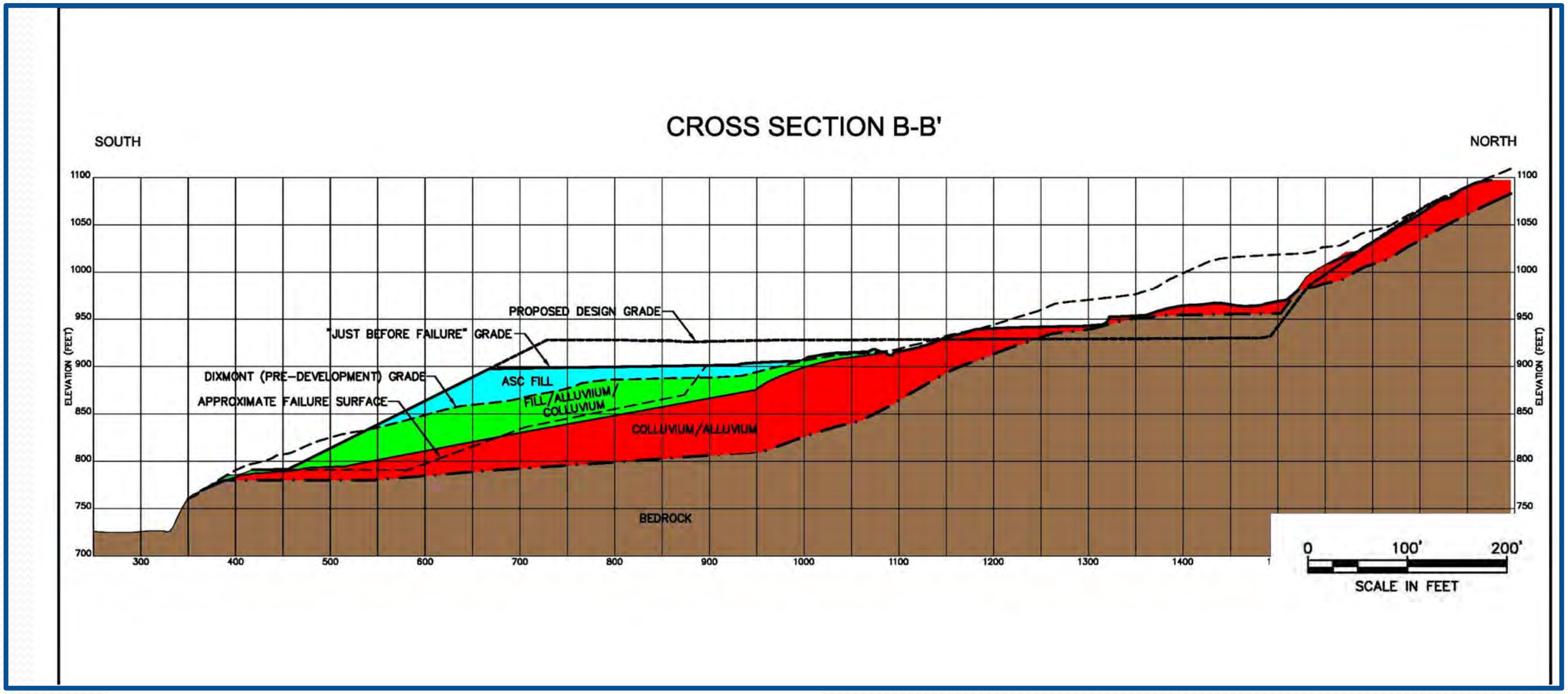
(after Gray and Gardner, 1977)

Landslides in Colluvium



(after Hamel and Flint, 1969)

Analysis Section B-B’



Note the thickness of colluvium
over the bedrock surface

Potential Influence of Glaciers??

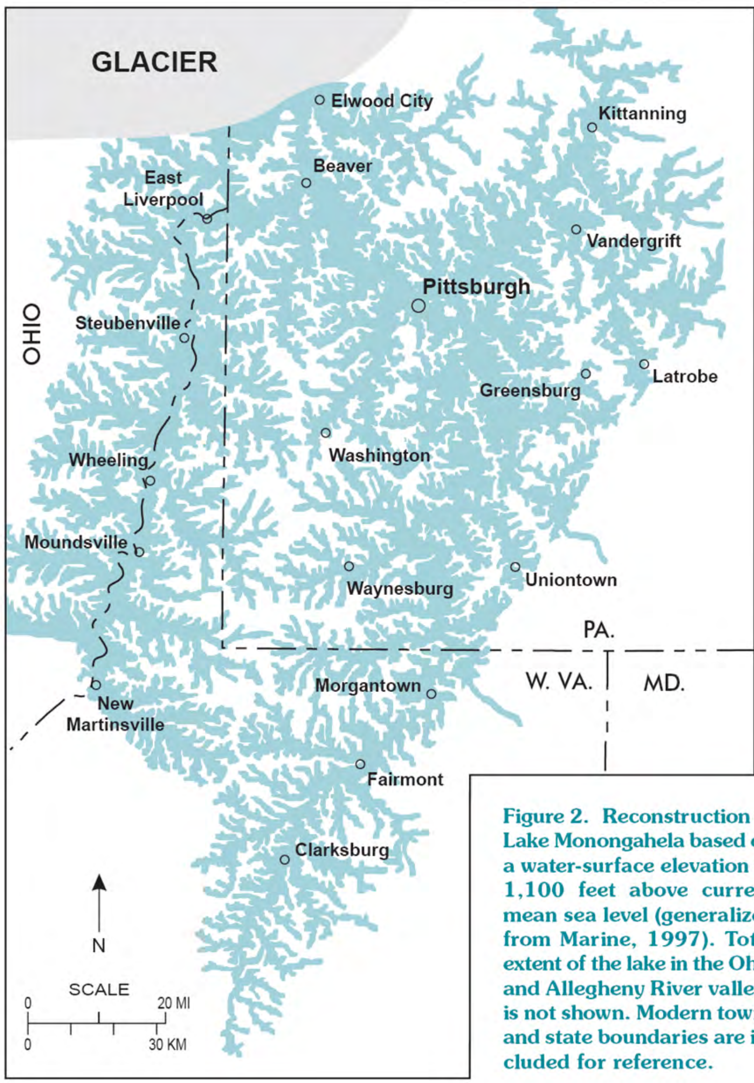


Figure 2. Reconstruction of Lake Monongahela based on a water-surface elevation of 1,100 feet above current mean sea level (generalized from Marine, 1997). Total extent of the lake in the Ohio and Allegheny River valleys is not shown. Modern towns and state boundaries are included for reference.

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(after Harper, 2002)

Potential Influence of Lake Terraces

Table 1. ***Levels of Terraces Above the Three Rivers in the Pittsburgh Area***
(from Marine, 1997)

Terrace	Distance above river level (feet)[1]	Distance above mean sea level (feet)
First	30	740
Second	160	900
Third	220	960
Fourth	260	1,000
Fifth	330	1,040

[1]Normal pool level.

(after Harper, 2002)

Colluvium Shear Surfaces and Alluvial Clay

Lessons from Geologic Setting

- Lake Monongahela did not cut terraces in bedrock but "drowned" the existing topography with lacustrine sediment (Harper, 2002)
- Ancient landslides in colluvium are common and manifested as "slump benches"
- Exposed claystone in redbed units weather rapidly when exposed
- Slickensided claystone and colluvium materials may be at residual strength
- Shear strength values ranging from 11° to 16° are not uncommon which would result in slopes of 3.5H:1V to 5H:1V for a FS=1.0
- Expanding lattice clay minerals are commonly found in the claystone along major highway roadcuts
- Water seepage often contributes to problems
- Sliding block analyses found to be potentially most critical
- Major unknowns include shear strength and water levels
- Site-specific assessment is critical as "no general rules can be given" (after Hamel and Flint, 1969)

Site-specific Considerations

- Very thick colluvium unit(s) exist at the site
- Back-calculation results suggest shear strengths on the order of 16° to 18° are appropriate
- "Groundwater levels" may be a misnomer in this type of environment
- Geotechnical/geologic logging suggests presence of alluvial/lacustrine clay with the claystone
- Two distinct episodes of colluvium formation may explain the conditions at the site
- Just when you think you understand the geology, another factor seems to raise its head

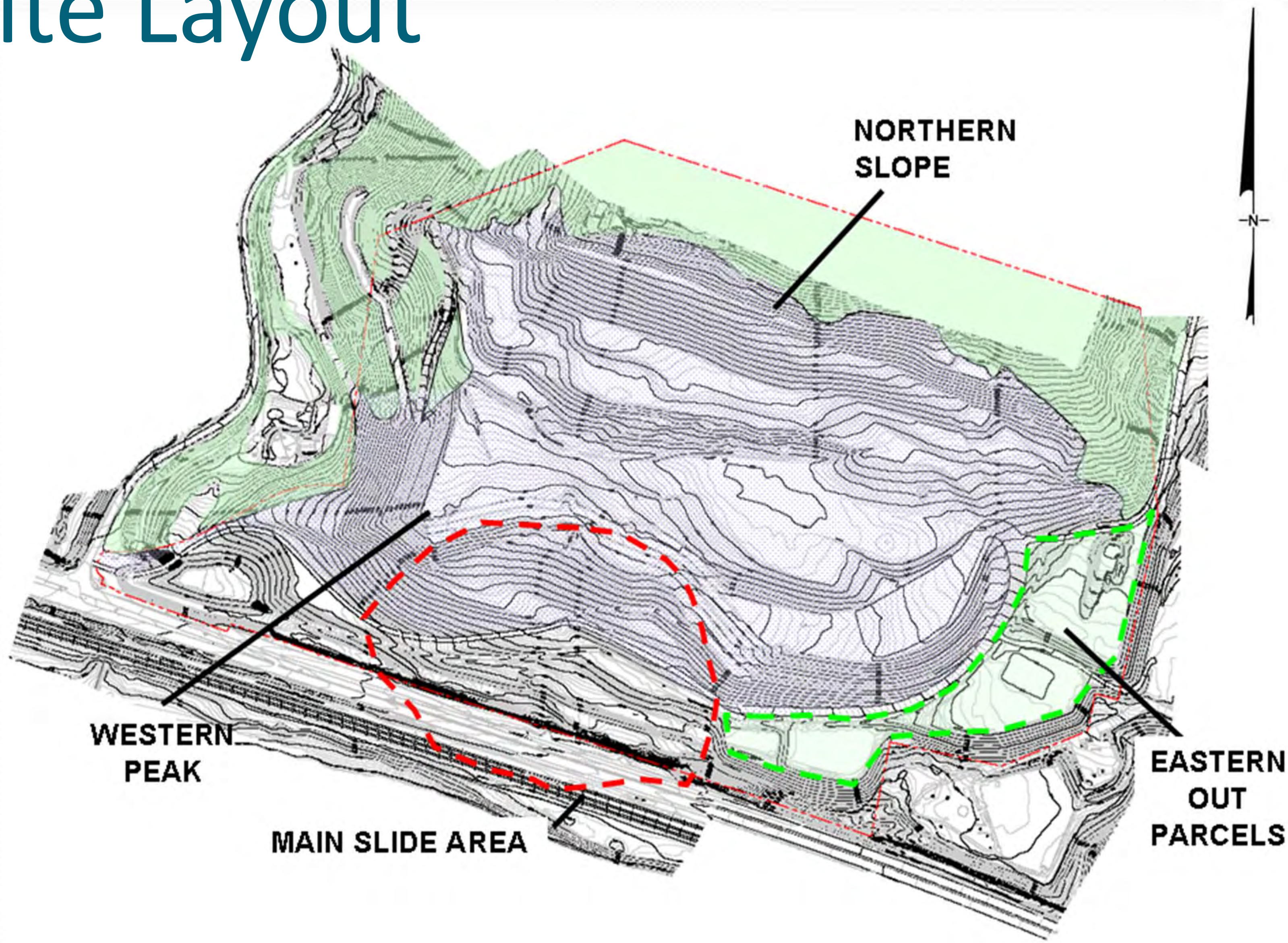
Role of Instrumentation

- Types of Instruments
- Strategic Use of Instrumentation
- Results of Instrumentation Monitoring
- Lessons from Instrumentation and Monitoring

Types of Instrumentation

- Surface Monitoring Points – survey readings
- Slope Inclinometers – manual readings
- Piezometers – manual and data logger
  - water levels
  - response to pumping
- Construction Control Points – survey readings

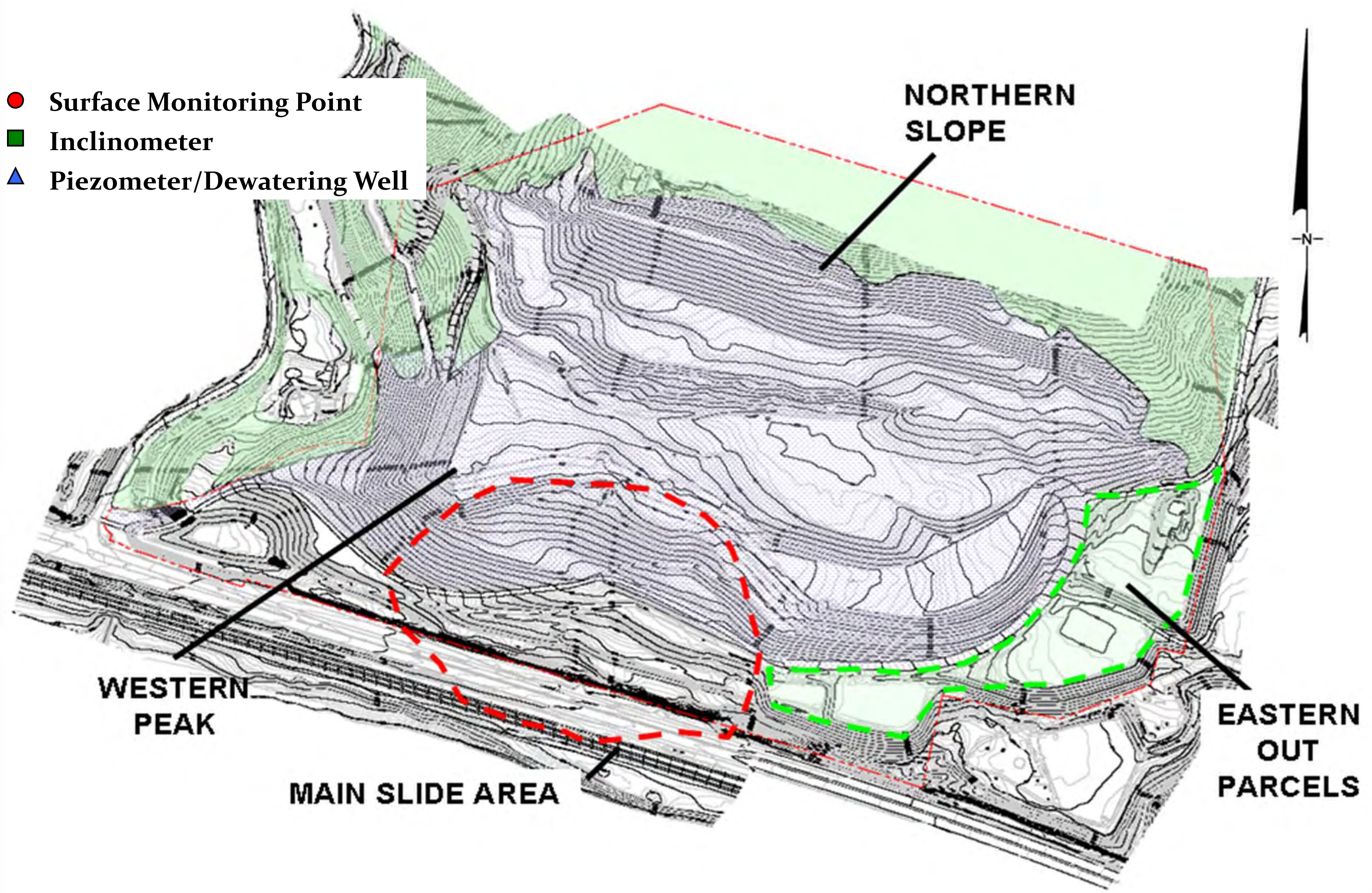
Site Layout


NORTHERN SLOPE
N
WESTERN PEAK
MAIN SLIDE AREA
EASTERN OUT PARCELS

Strategic Use of Instrumentation

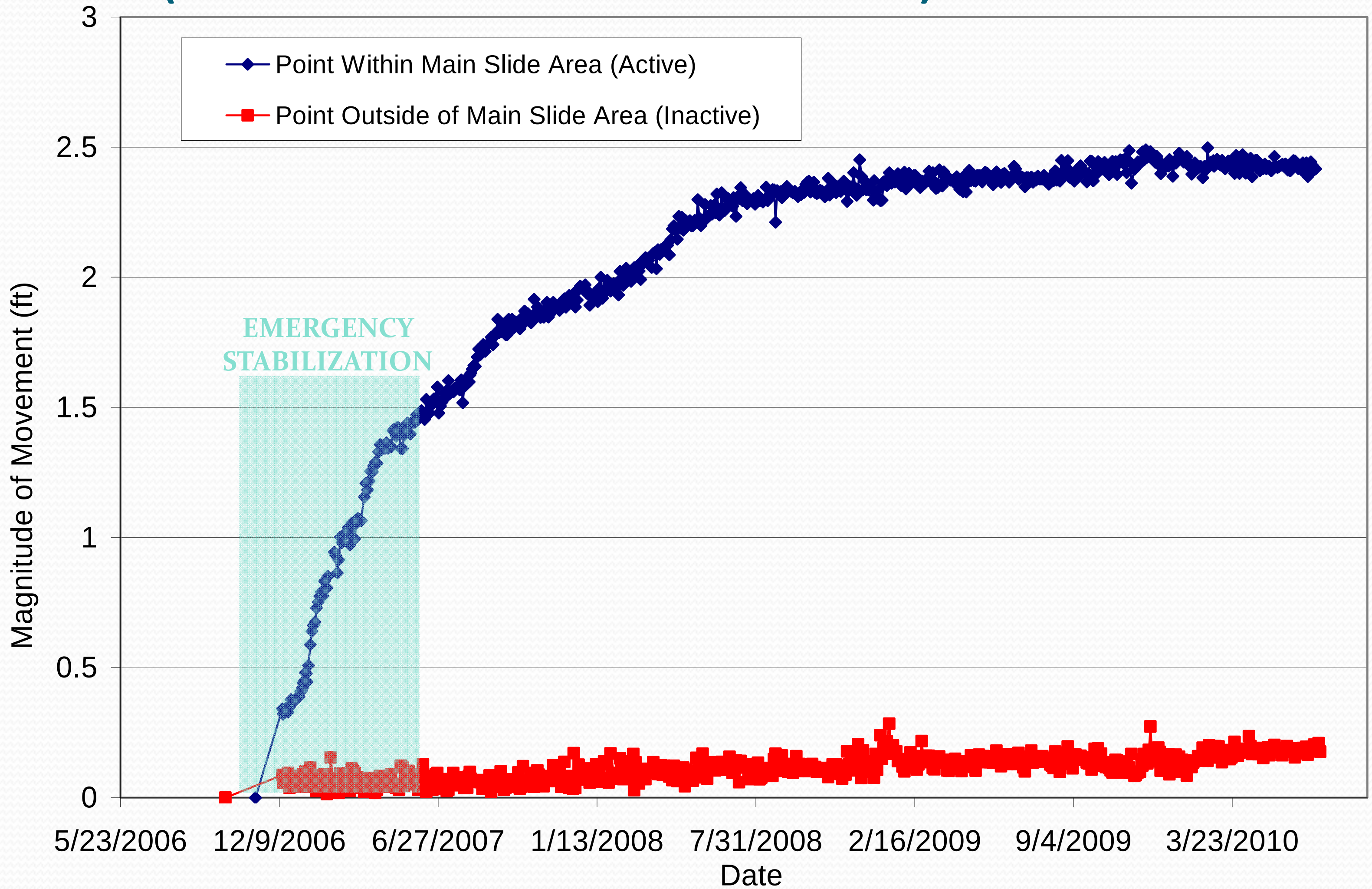
- Goals
  - •Identify site groundwater levels and perched water zones
  - •Confirm location and extent of failure surface
  - •Monitor performance of stabilization measures
  - •Provide information to optimize stabilization design
- Inclinometers
  - •Over twenty (20) installed to bedrock – occasionally "replaced"
  - •Monitored on "every-other-day" basis
- Piezometers
  - •Over forty (40) installed to varying depths
  - •Monitored every day
- Surface Monitoring Points (including temporary and construction)
  - •Over 170 installed
  - •Monitored in two groups — "every other day" and "every other week"
  - •Pre- and post-rehabilitation installations

Instrumentation Network at Site

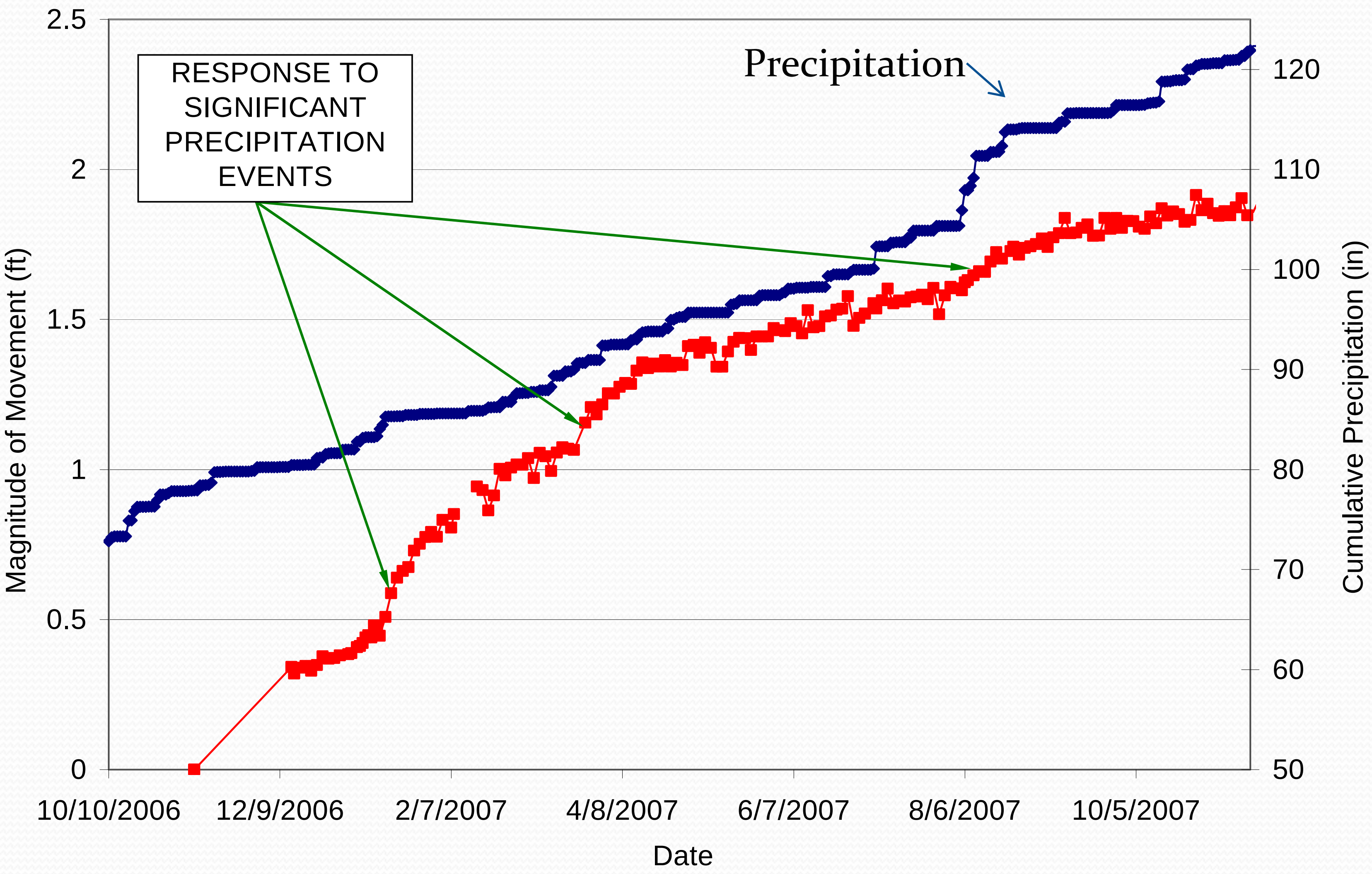


Surface Monitoring Points

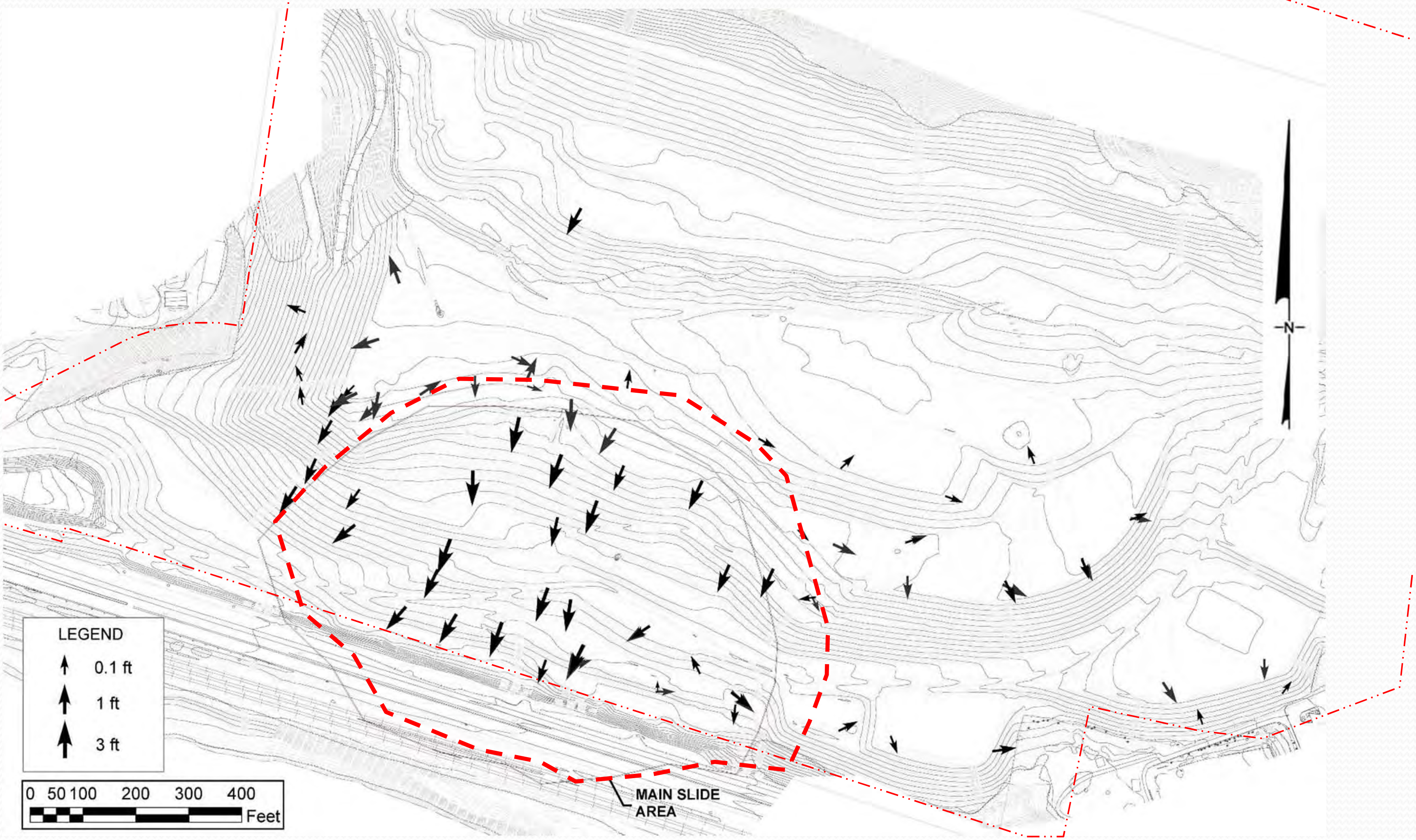
(active and inactive areas)



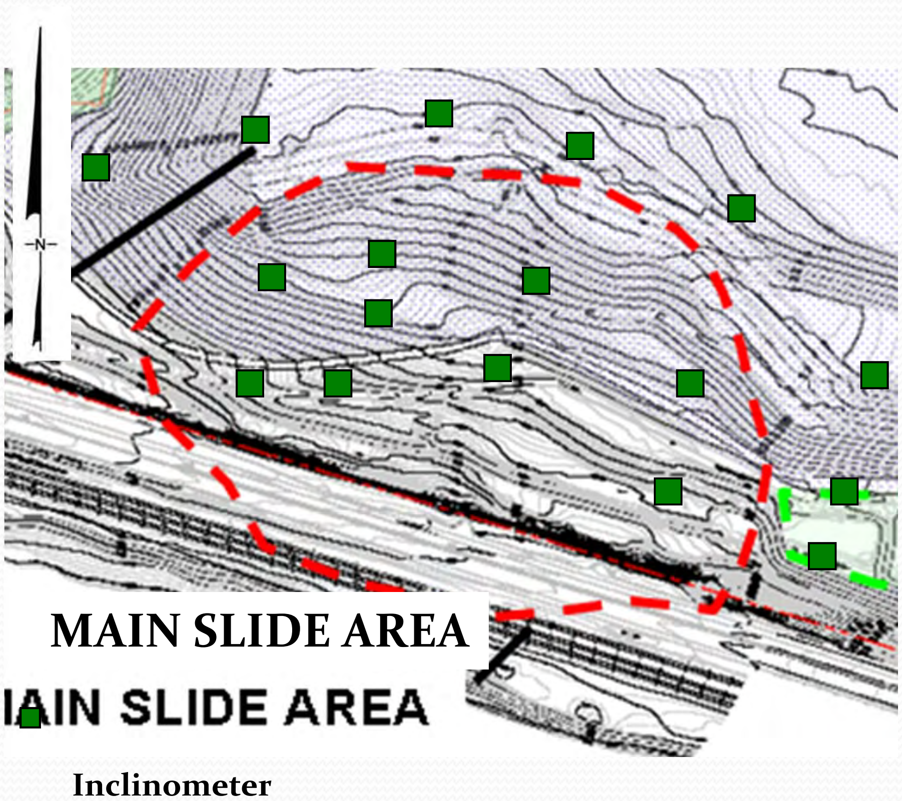
Surface Monitoring Points - Precipitation

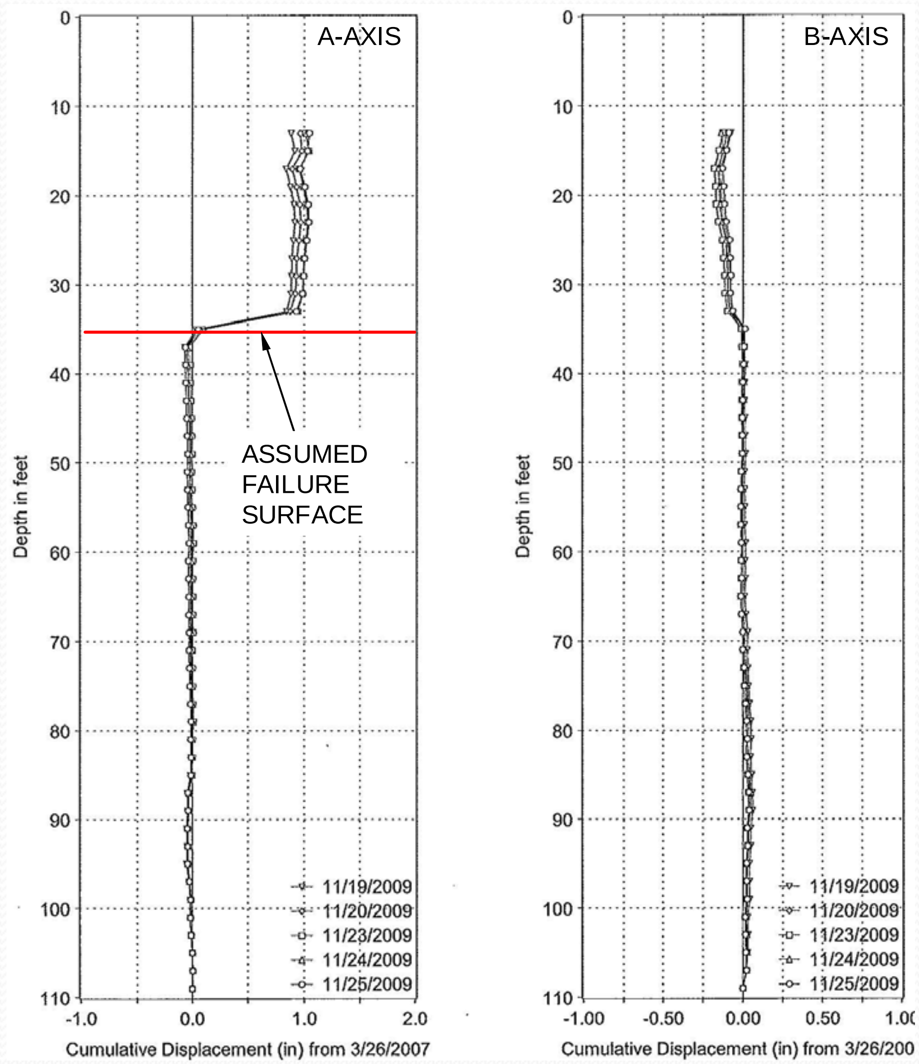


Vector Map to Visualize Surface Monitoring Points



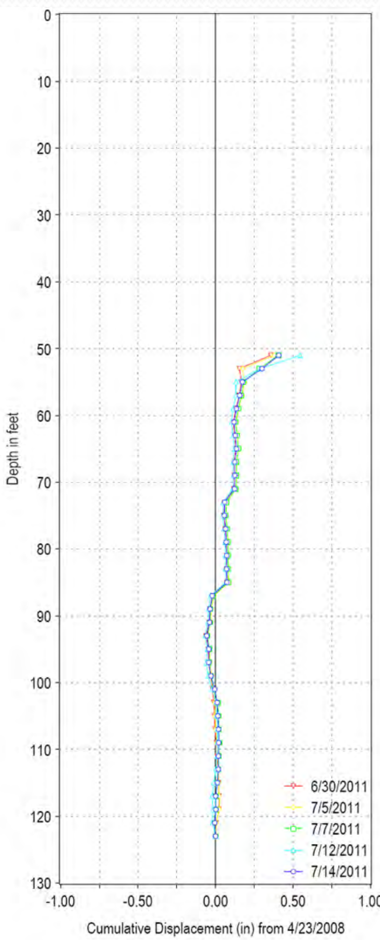
Role of Slope Inclinometers

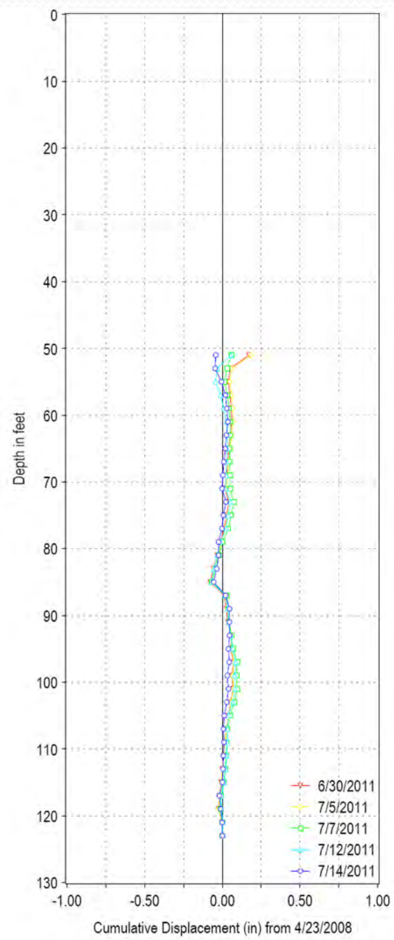




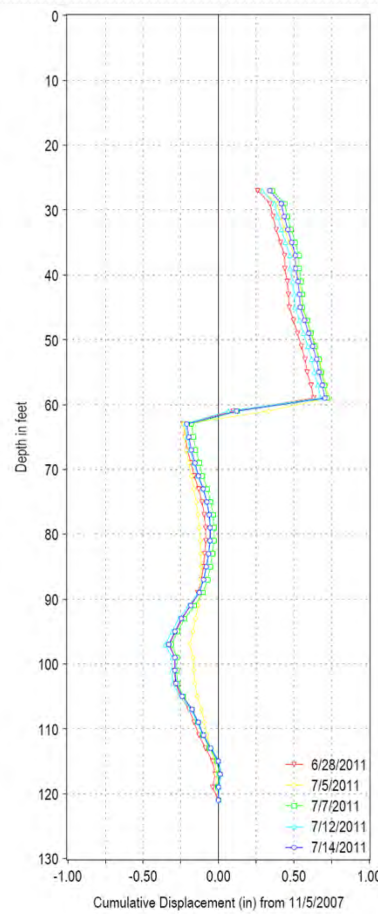
“Typical” Inclinometer Response

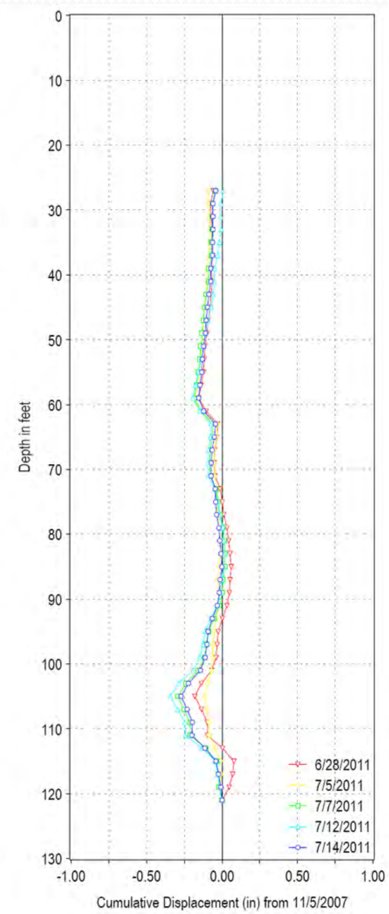
Location DEP 19B



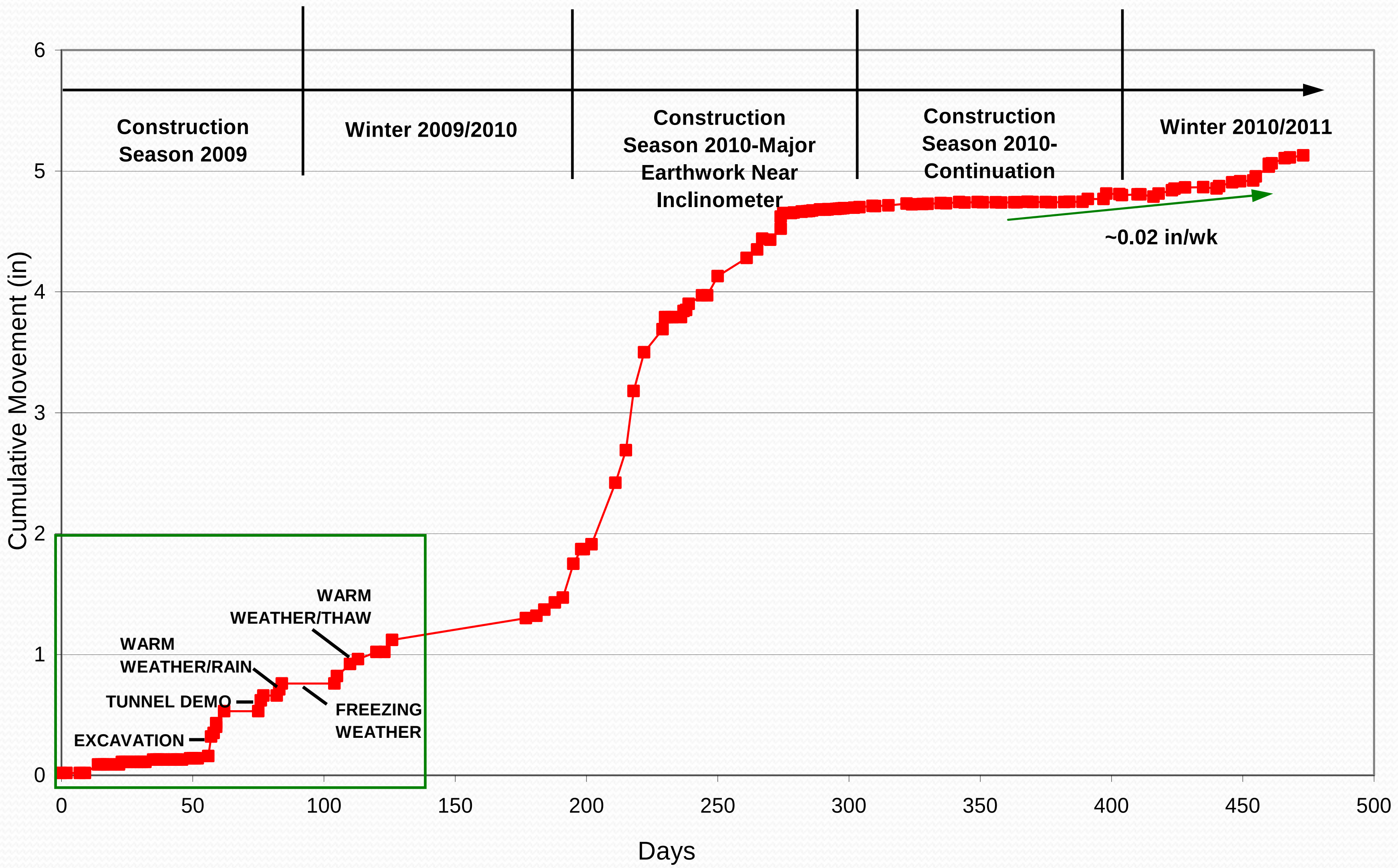


Location WPS-1

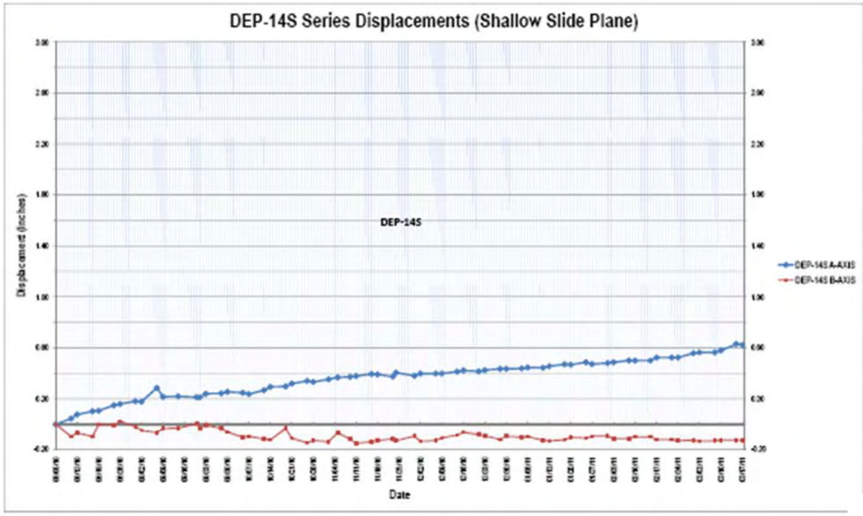




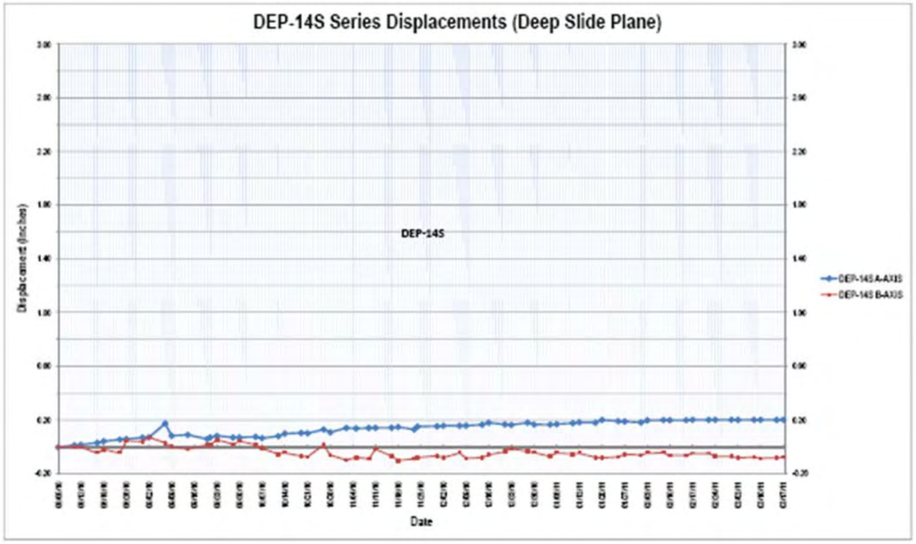
Slope Inclinometer Response to Construction



Slope Inclinometer Response

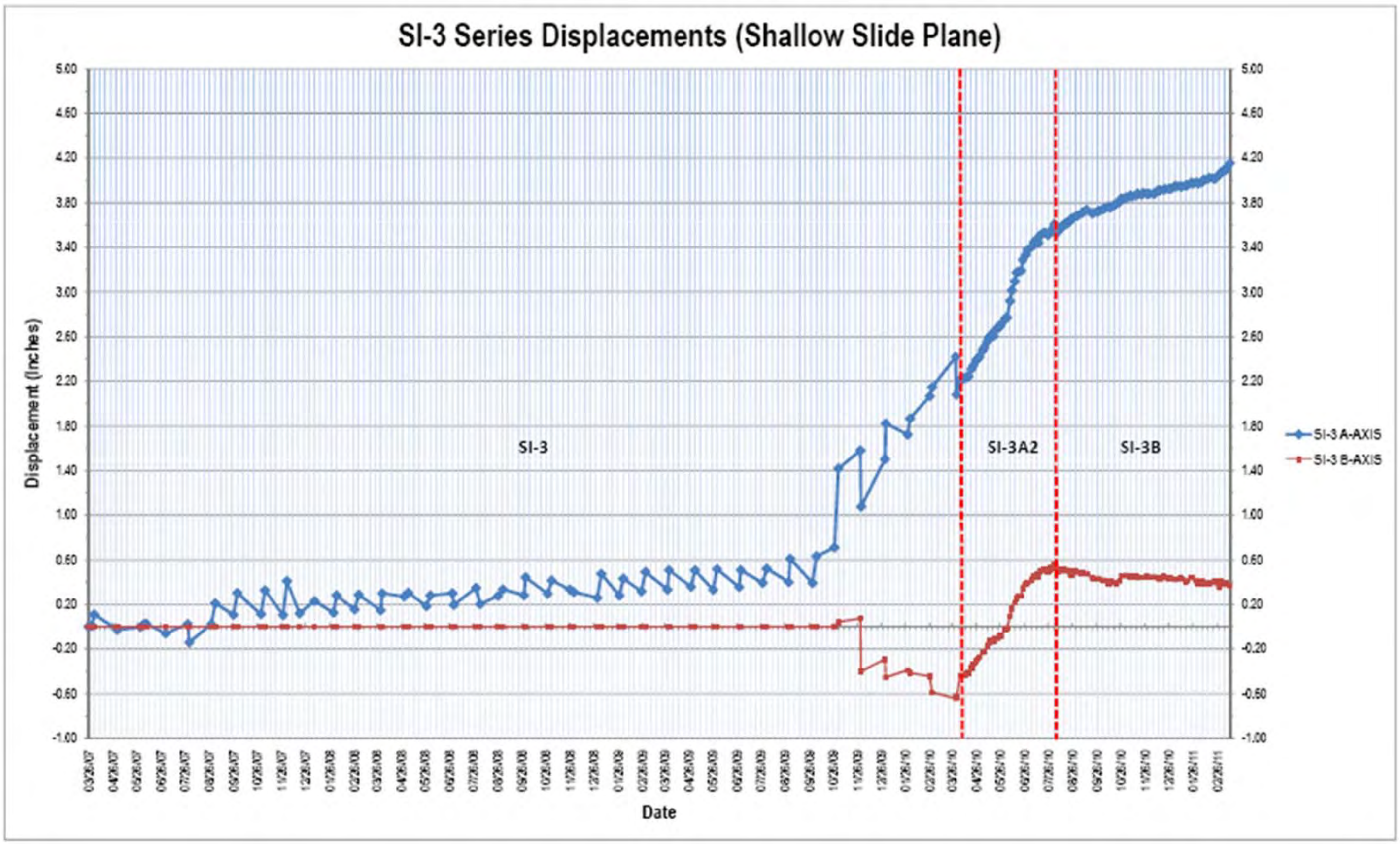


Shallow Movements
(0.4 inches/major division)



Deep Movements
(0.4 inches/major division)

Reactivation During Construction



Inclinometer During Construction

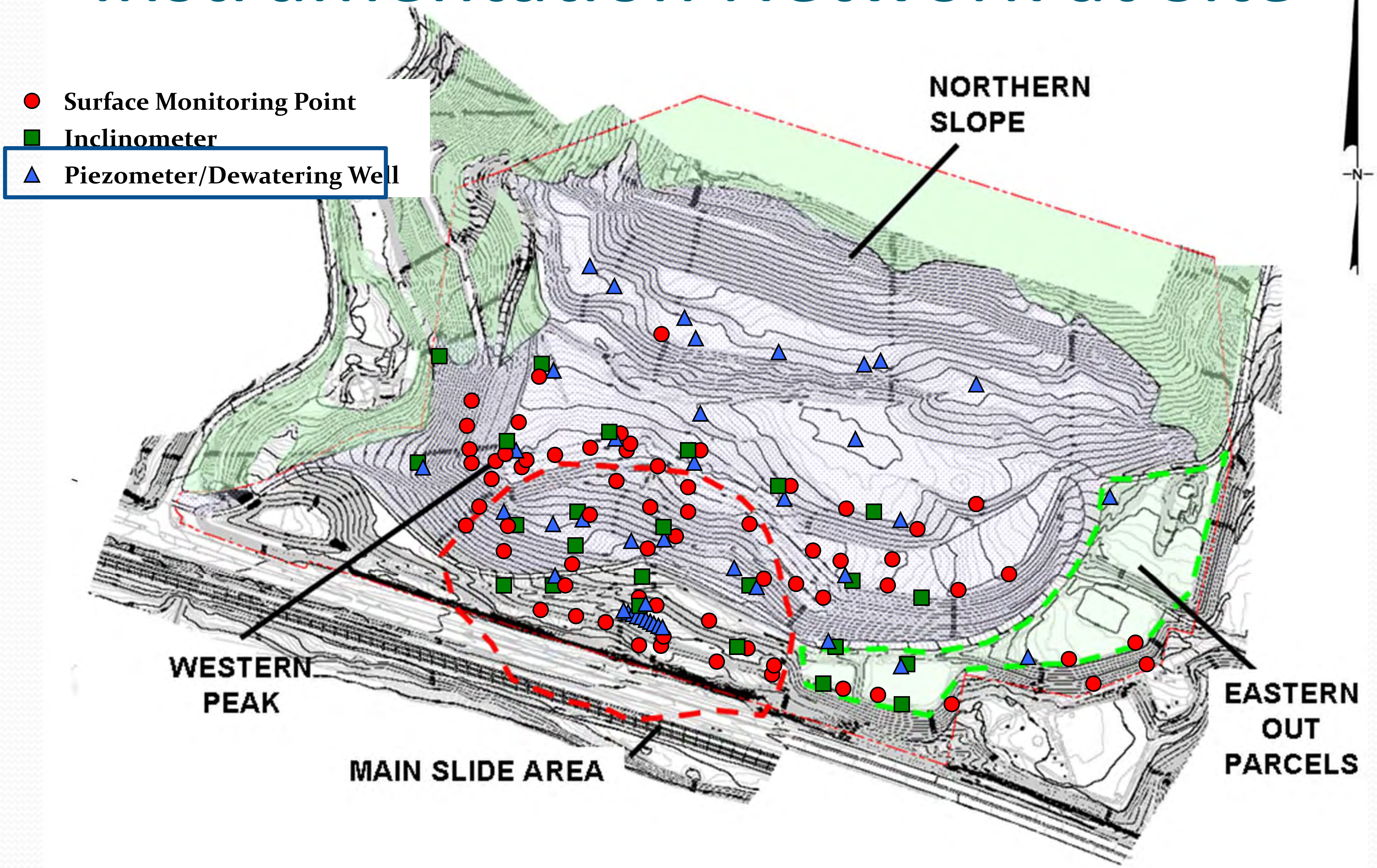
(excavation)

Inclinometer During Construction
(exposing slip plane)

Inclinometer During Construction

(exposed material interface)

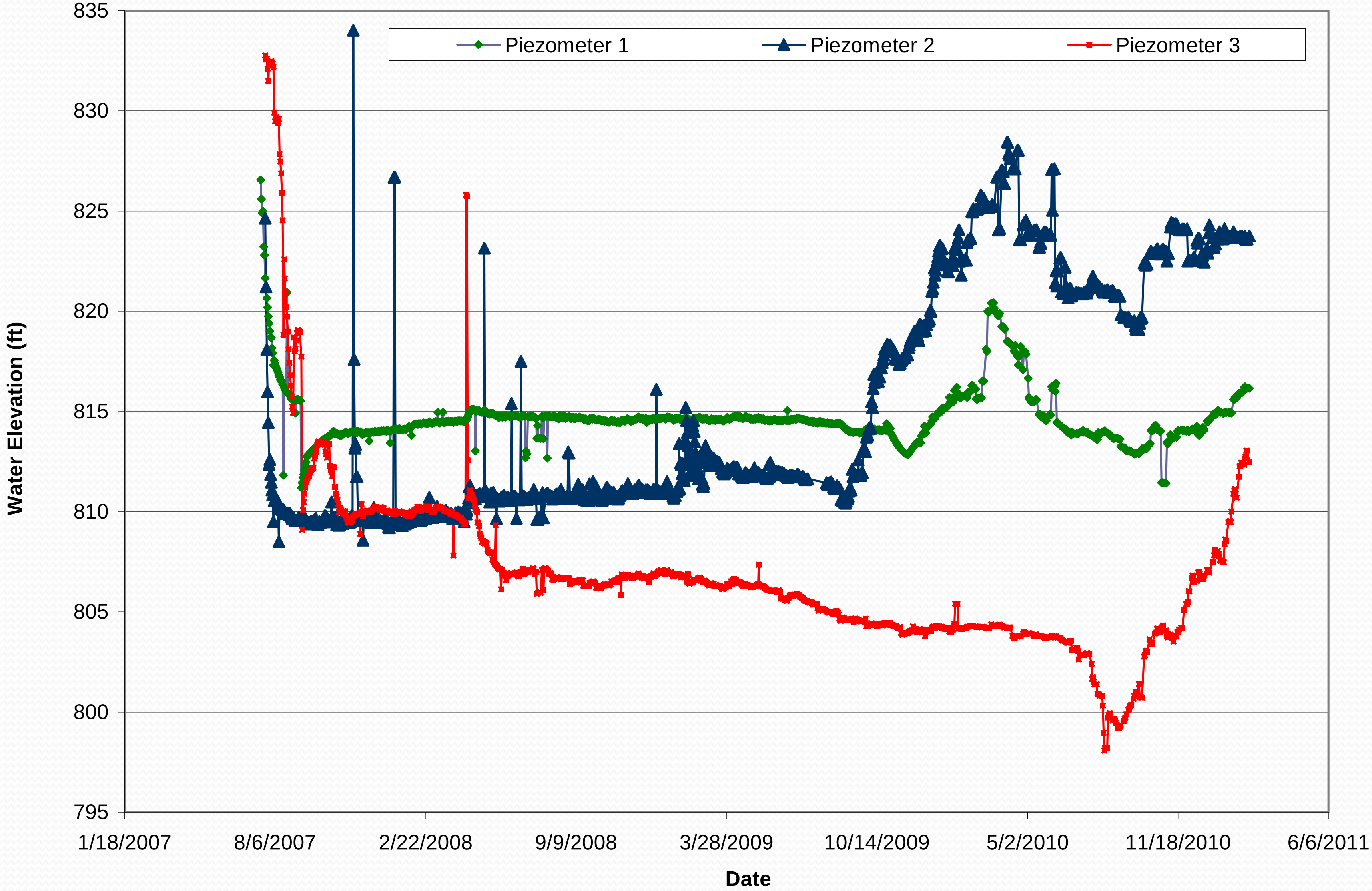
Instrumentation Network at Site



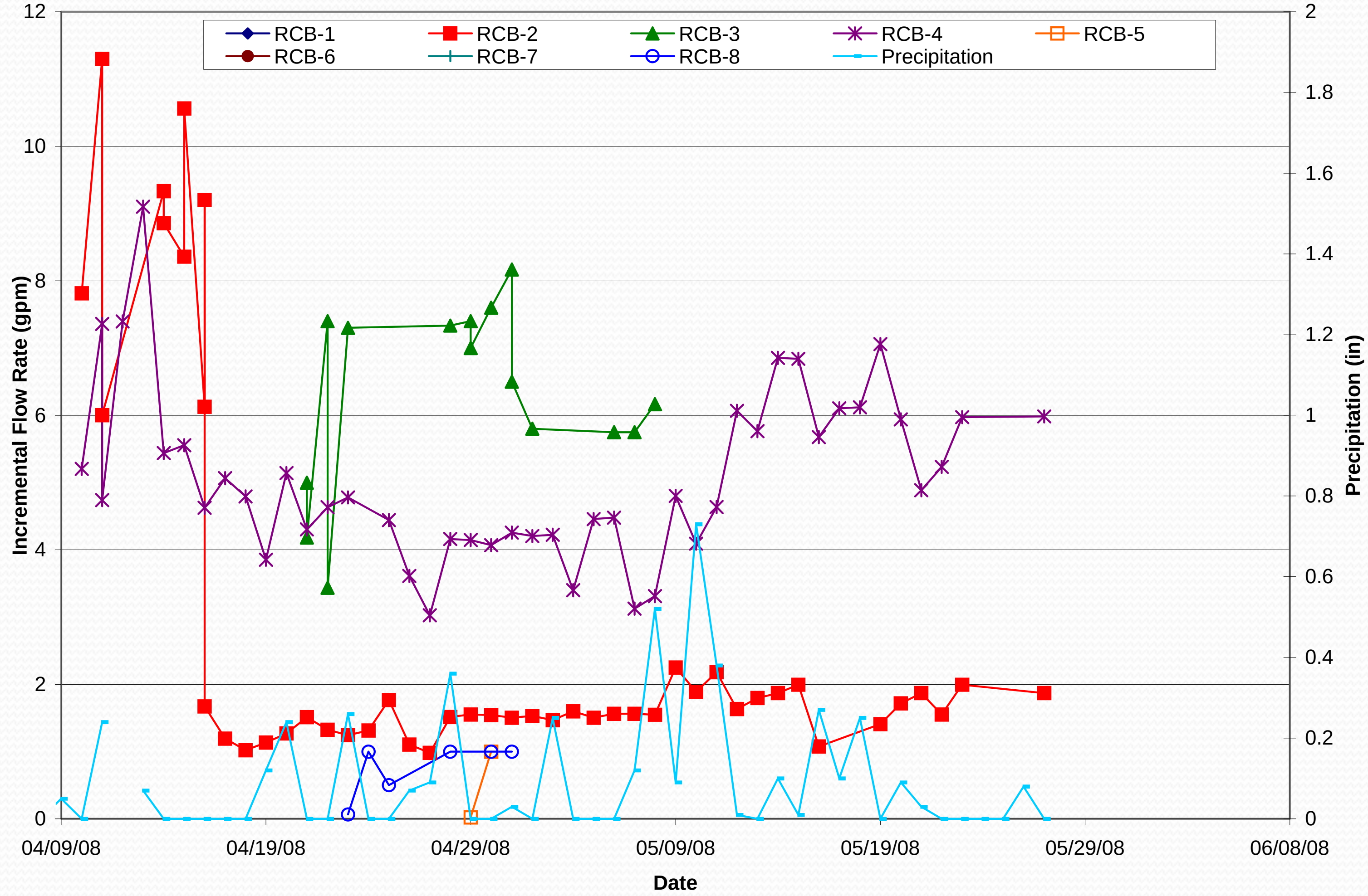
Piezometers

- Assess “groundwater” levels
- Impact of precipitation
- Cause-effect on movements
- Impact of pumping

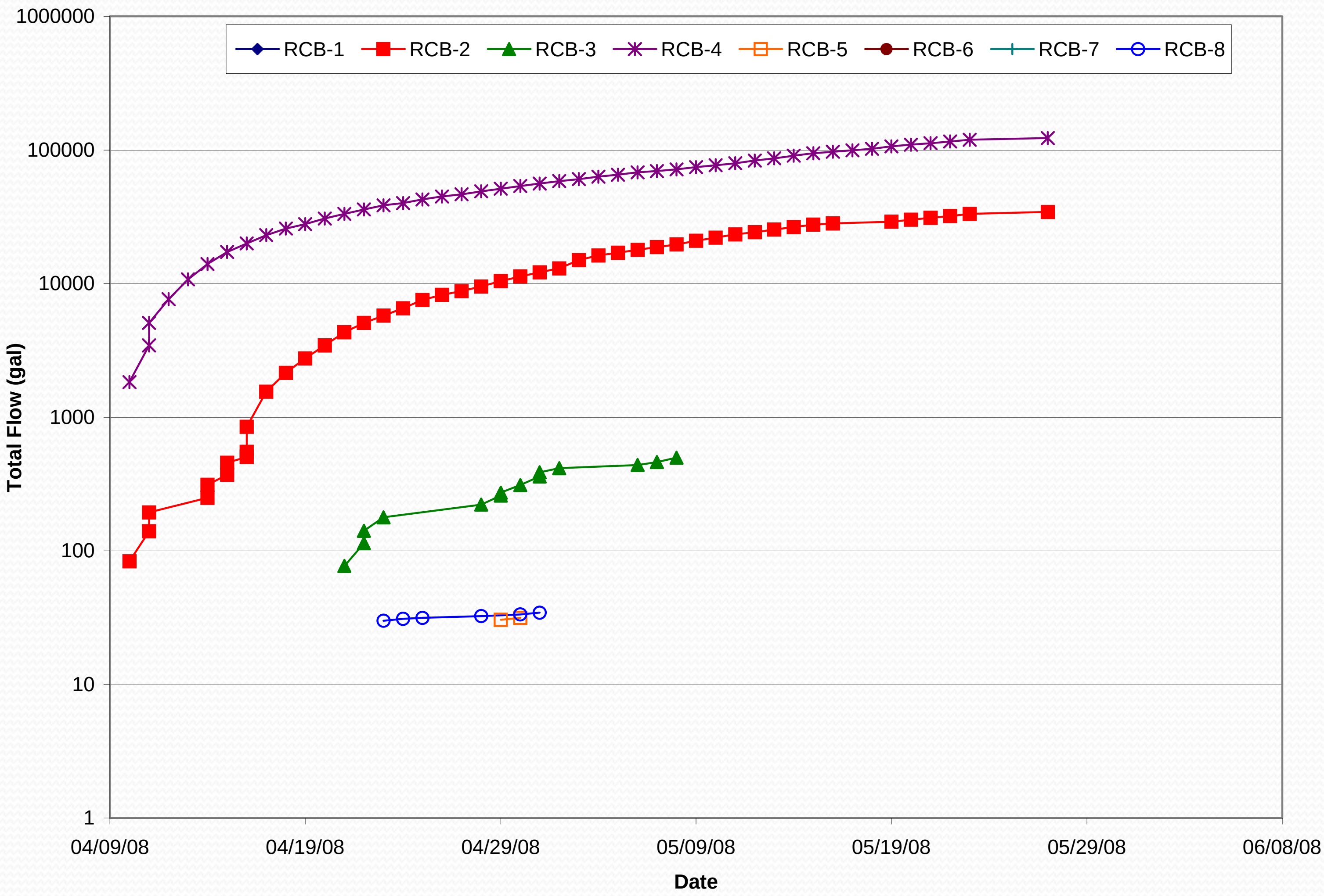
Piezometer Response to Construction



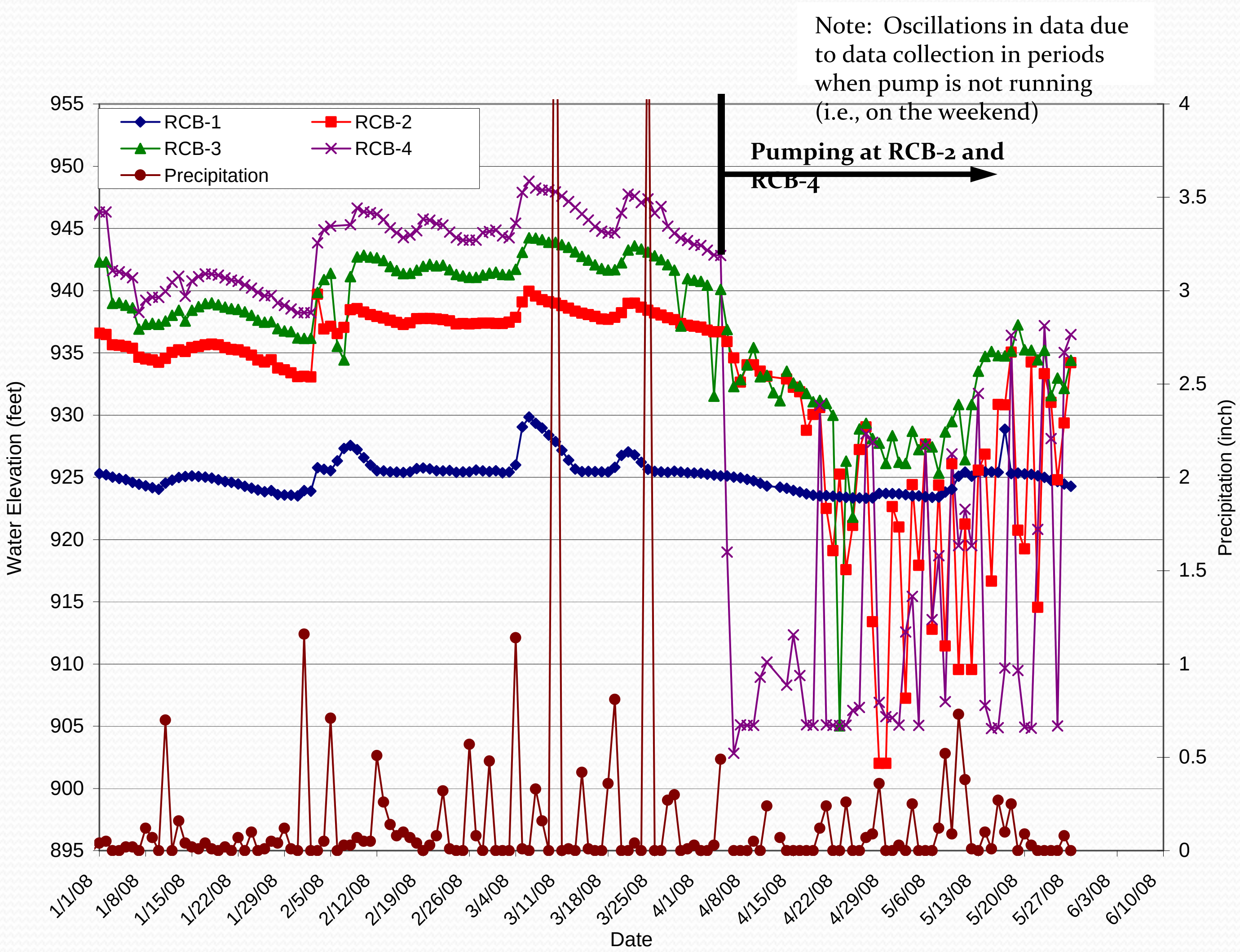
Impact of Precipitation on Pumping



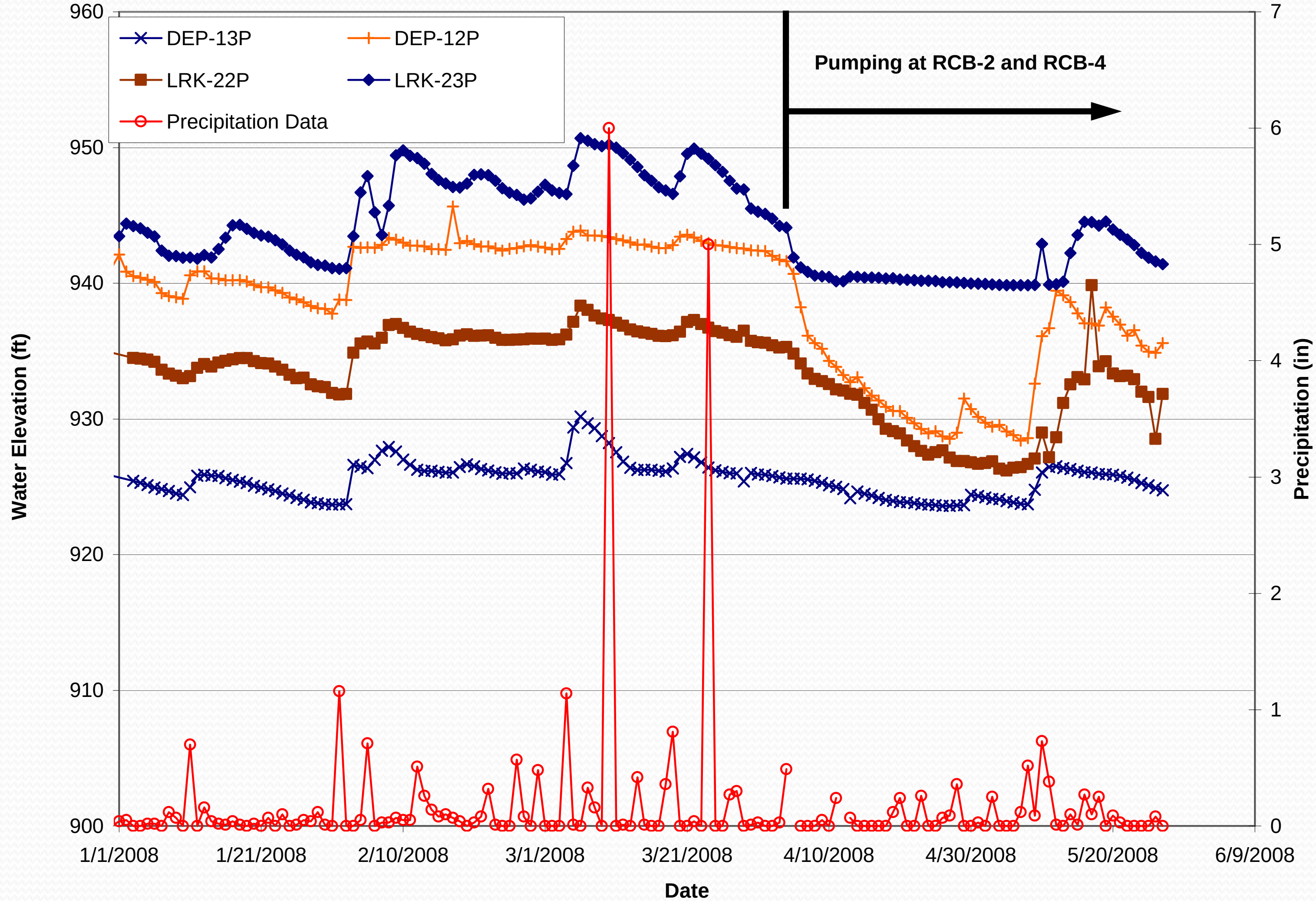
Pumping Efficiency



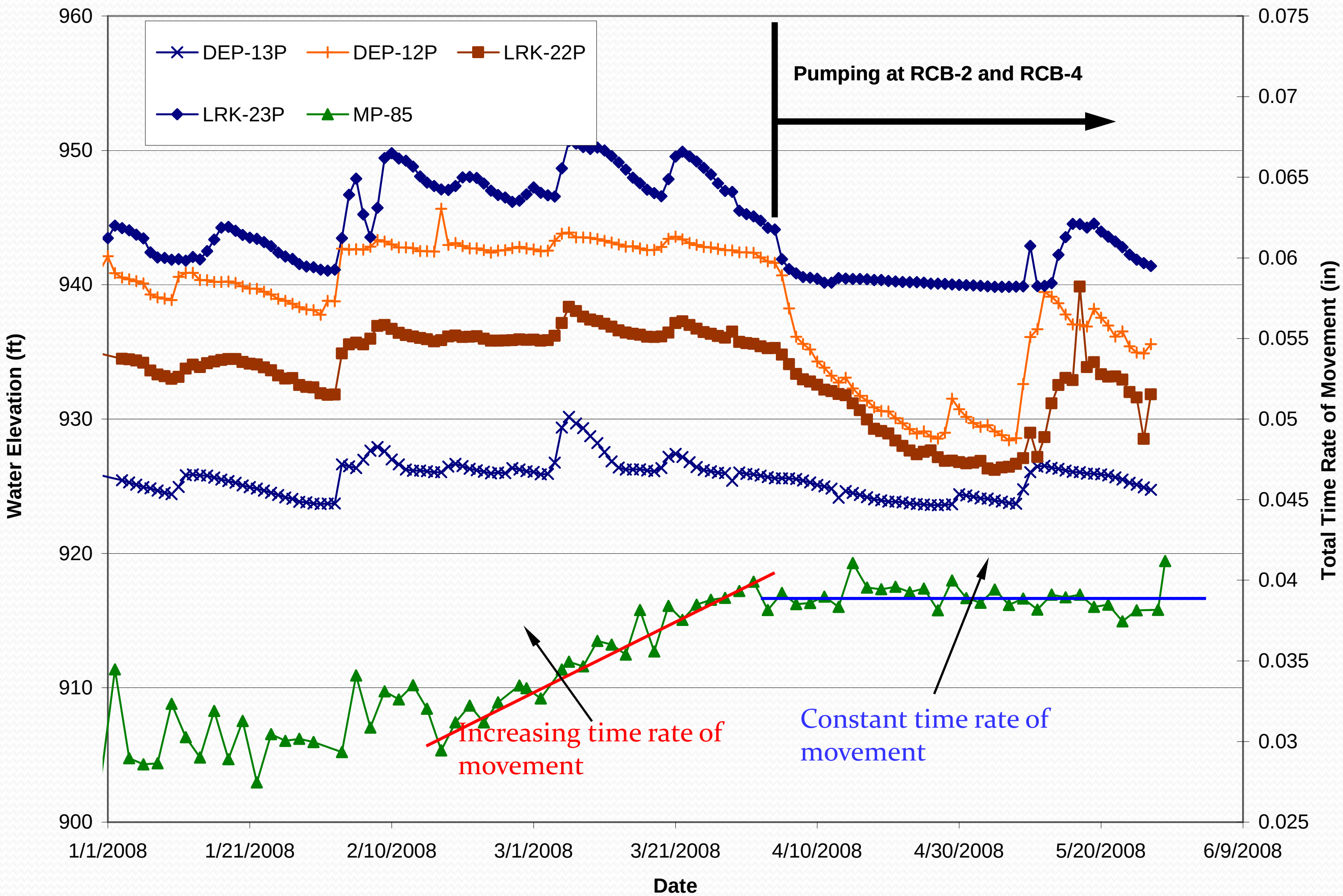
Pumping Impact on Other "Wells"



Pumping Impact on Piezometers



Pumping Impact on Movements



Construction Monitoring Points

- Surface monitoring points along designated cross-section
- Measure visually during construction
- Compare to survey measurements

Construction Monitoring Point

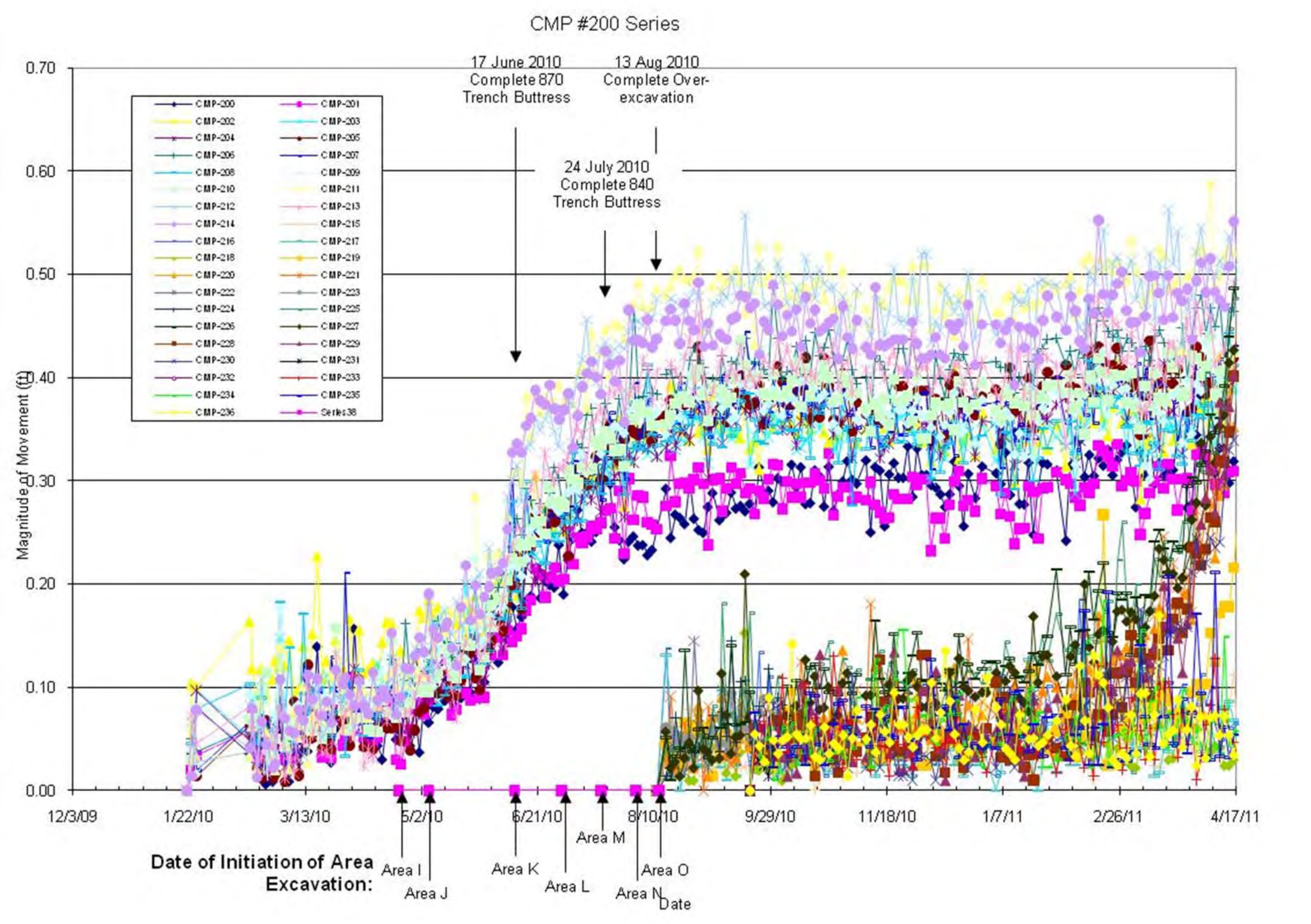
- Install CMPs along designated cross-section
- Align with construction activity – above and below
- Check twice daily by visual observation
- Include “anchor pins” as surface monitoring points

Construction Monitoring Points

Movable Pipe

Fixed Pipe

CMP Response to Construction



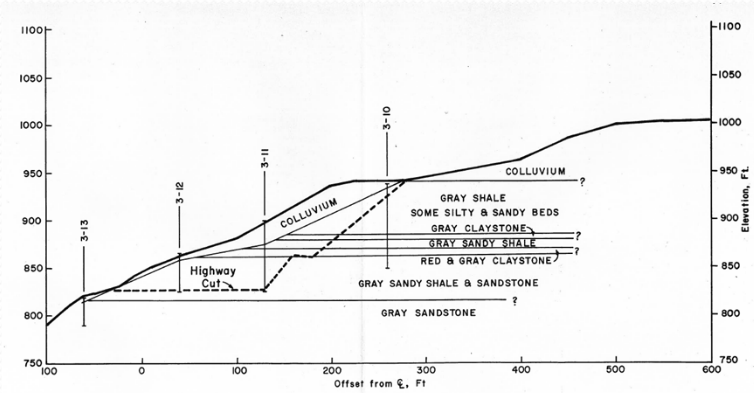
Lessons from Instrumentation and Monitoring

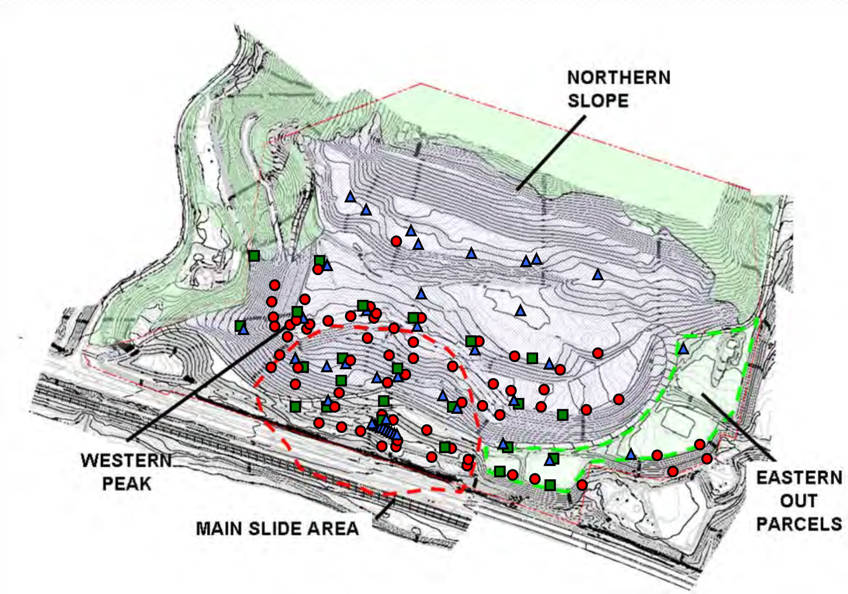
- Surface Monuments
  - Inexpensive and very helpful
  - Correlate well to slope inclinometer response
  - Flexible "as-needed" implementation
  - Density of monuments delineates areas
- Slope Inclinometers
  - Delineates movements at depth with precision
  - Incremental trends very helpful
  - Expensive to replace
  - Surface monuments extend benefits

Lessons from Instrumentation and Monitoring

- Piezometers and Wells
  - Confirm variability across site
  - Confirm lack of "water table"
  - Small diameter limits pumping and easily damaged
  - Aggressive pumping of prolific zones beneficial
- Construction Monitoring Points
  - Linear extension of surface monument concept
  - Very helpful to monitor construction effects
  - Can impact surface water and construction progress
  - Easiest system to monitor

Summary and Conclusion





- Geology (generally) and colluvium (specifically) can be a maddening to the geotechnical engineer
- Simple instrumentation plays a critical role in assessing the problem and controlling the solution