ACID MINE DRAINAGE SOURCE AREA INVESTIGATIONS : 2011-2013

LANDUSKY MINE SITE, MONTANA

David Donohue, P.G. Melissa Schaar, P.G.

HydroSolutions Inc

Helena, Montana

May 1, 2014

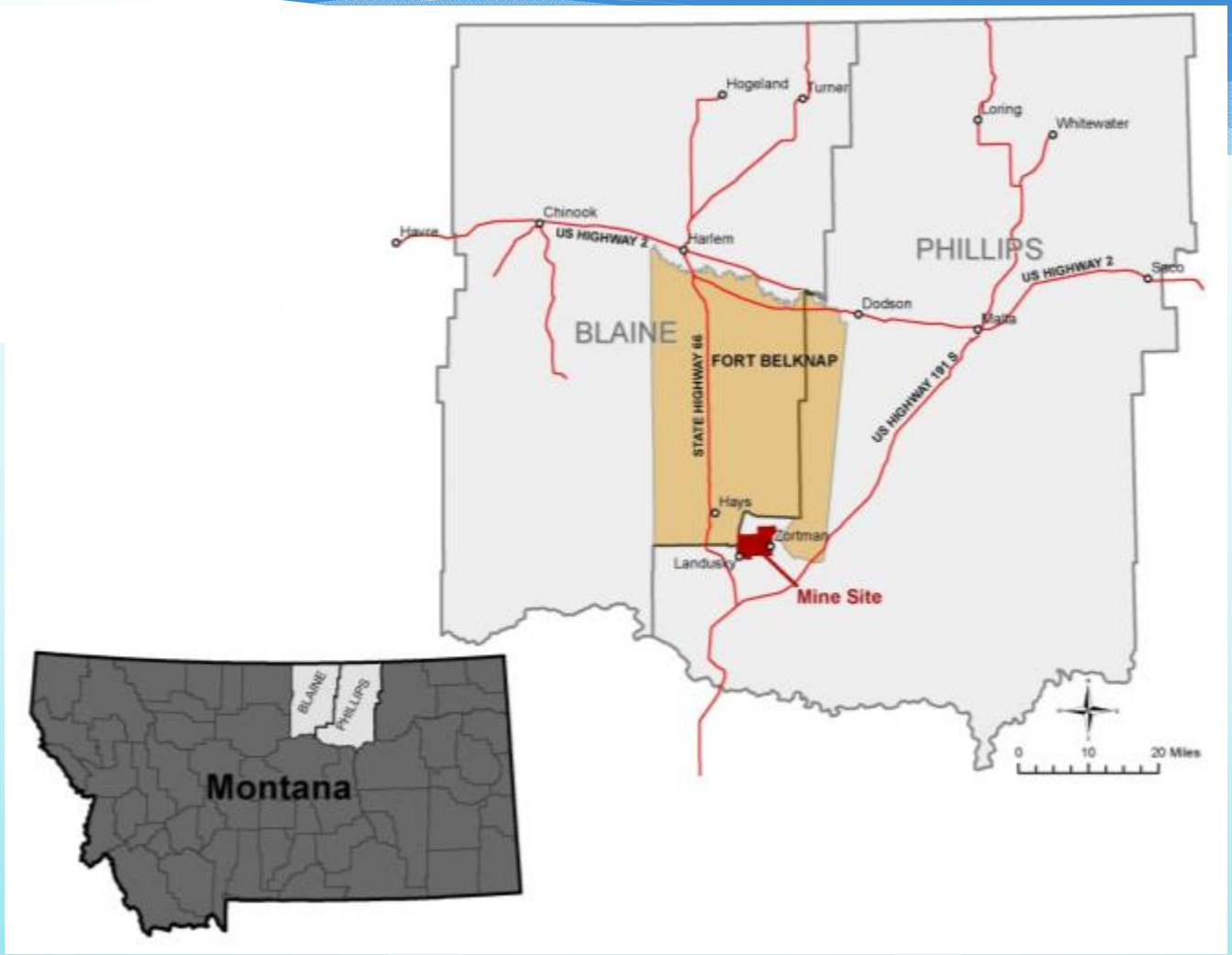
Presentation Outline

* Previous Investigations
* Source Control and Feasibility
  * Aquifer Testing
  * Tracer Tests
  * Swift Gulch Flows
  * Hydrograph Analysis
  * Geochemical Analysis
* Future Reclamation Thoughts

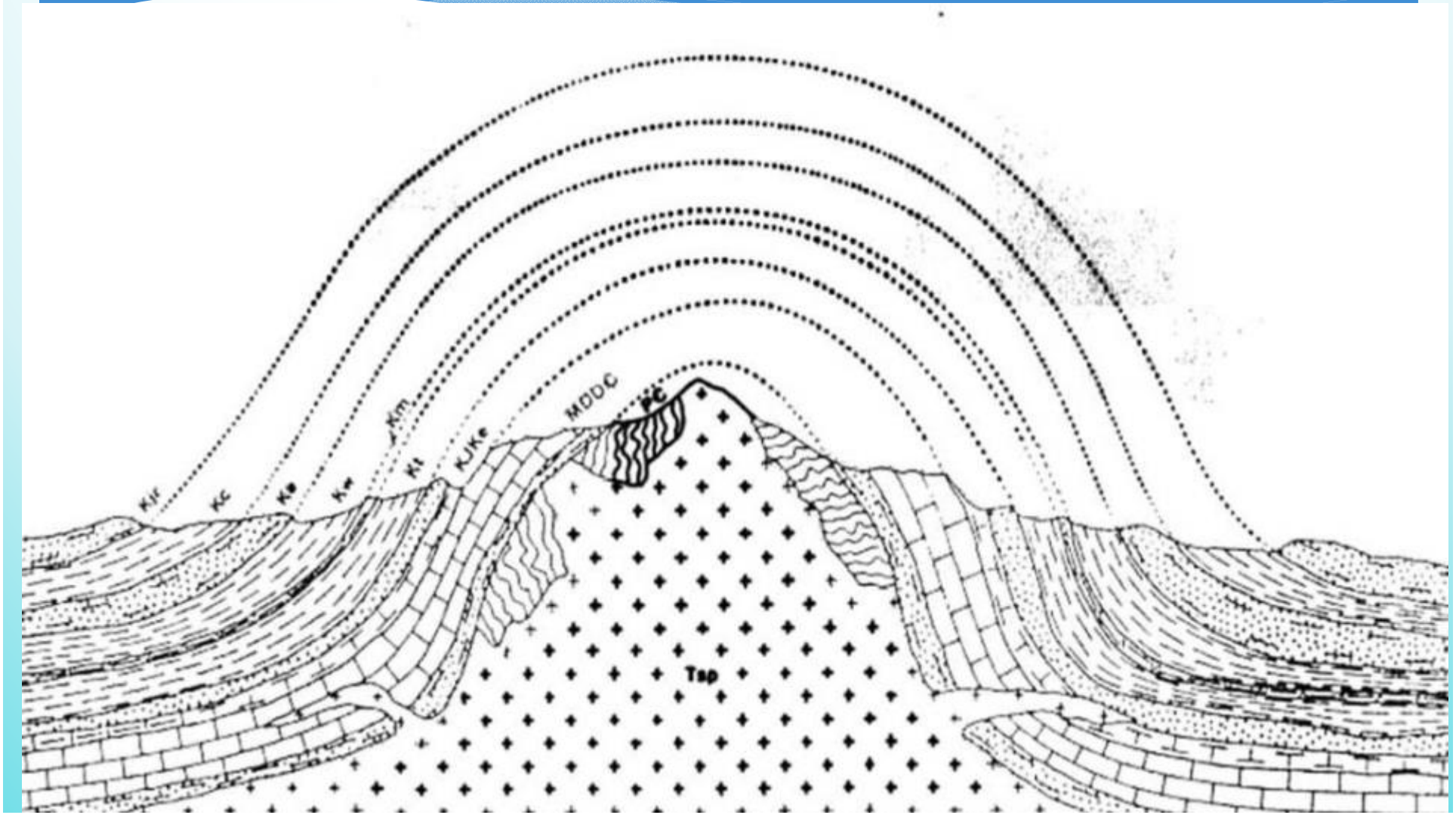
Project Sponsors

* Montana DEQ
* U.S. BLM
* Montana DNRC
* Spectrum Engineering, Inc. (Landusky Site Manager)

Zortman - Landusky Mine Sites

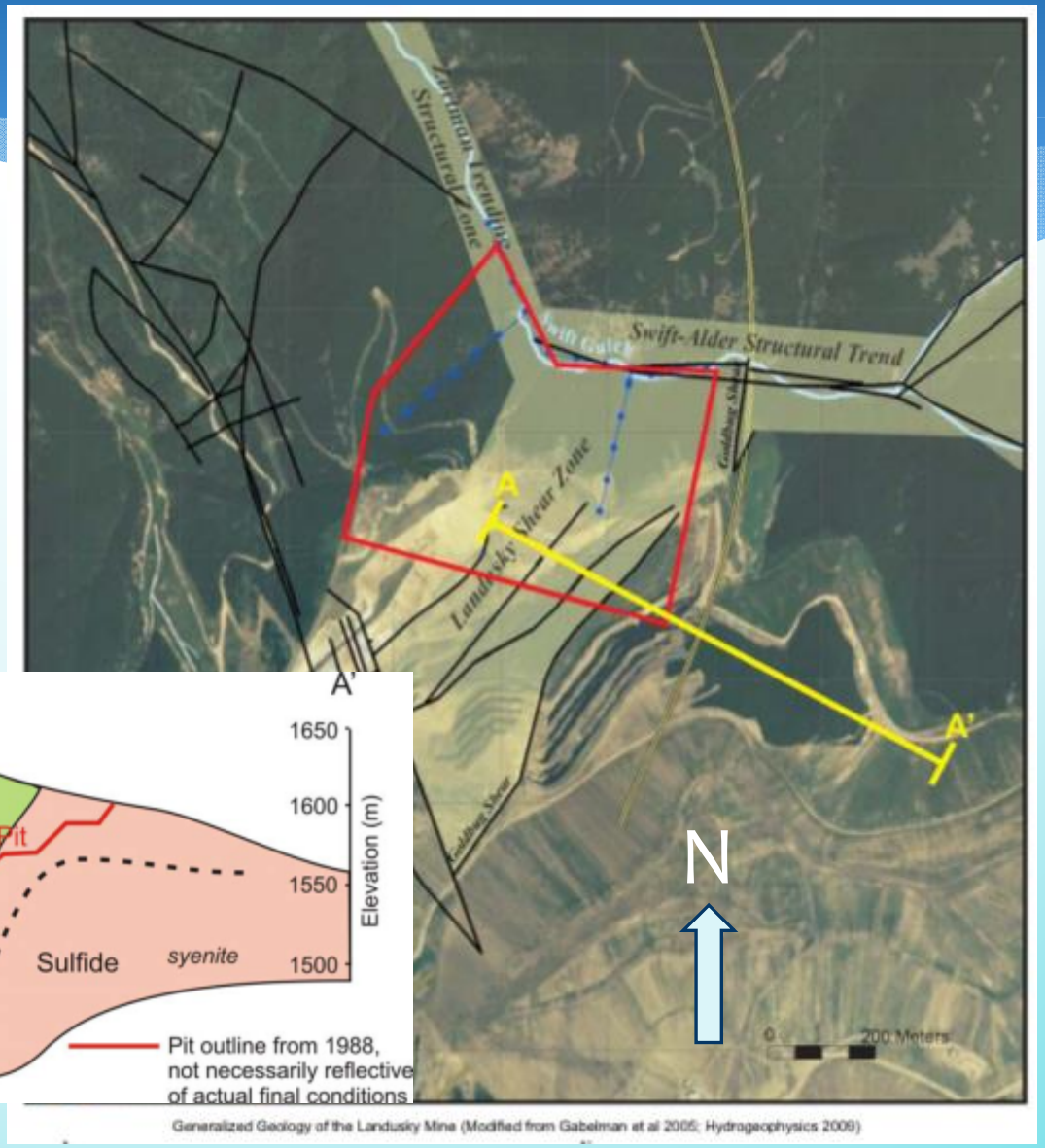


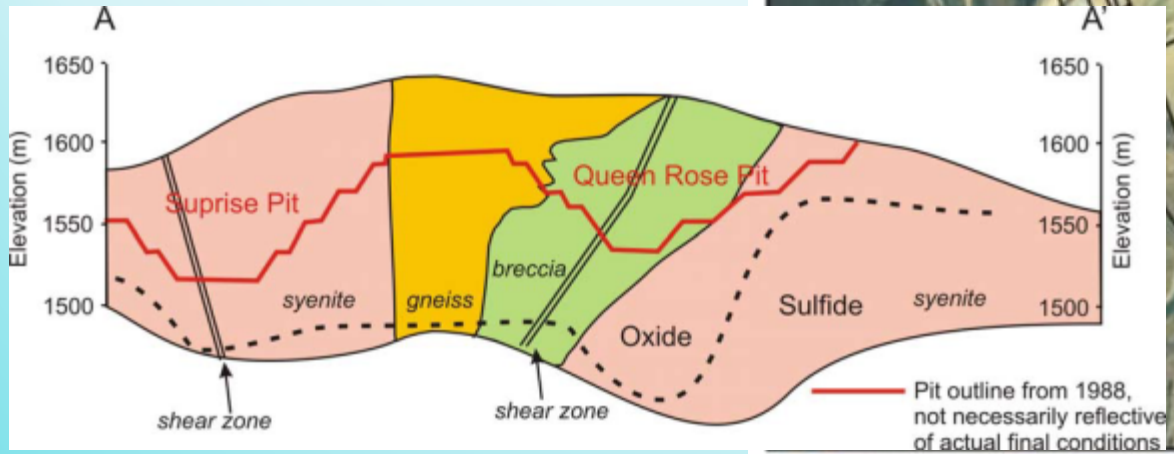
30-Second Geo-explanation



Fractured Bedrock Aquifer

Generalized Fault Trace Map





Generalized Geology of the Landusky Mine (Modified from Gabelman et al 2005; Hydrogeophysics 2009)


Swift Gulch
N
ZL-405
Suprise Pit
August – Little Ben Pit
Office/Shop
Northern Landusky Pit Complex

Hydrogeologic Investigations - Pre-Source Control Investigation

* Supplemental EIS – 2001
  * Major reclamation - 2002 and 2005
* Artesian WS-3 Hydrogeology Test - 2001
* Tracer Dye Investigation - 2003 and 2004
* Monitoring Well Installation - 2008
* Aquifer Test - 2008
* Geophysical Investigation - 2009

Previous Hydrogeologic Investigations

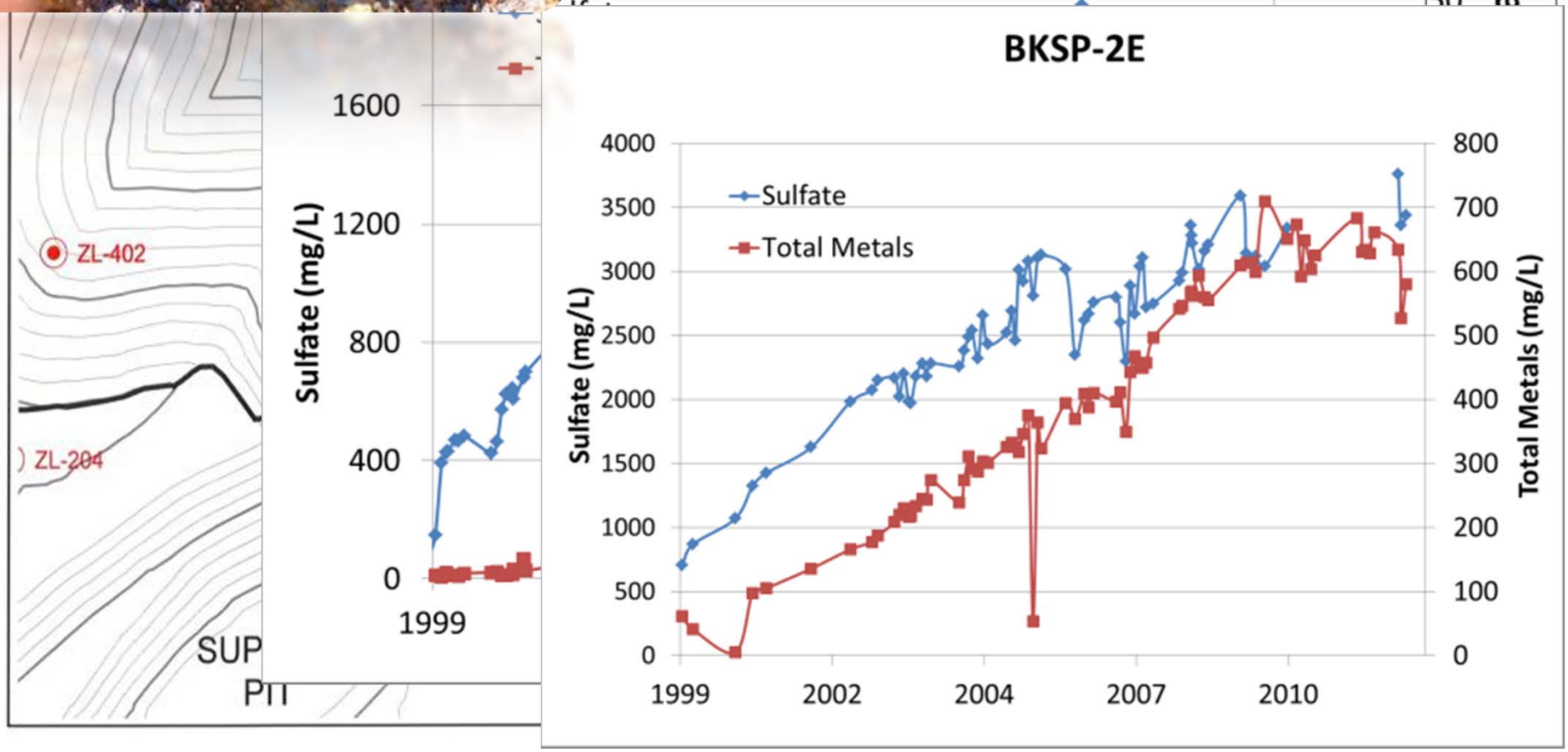
Investigation results helped identify subsurface conditions:

* Groundwater flow controlled by complex shear zones with general NE orientation and crosscutting fault structures
* Shear zones are major conduits for ARD movement from mine complex to Swift Gulch

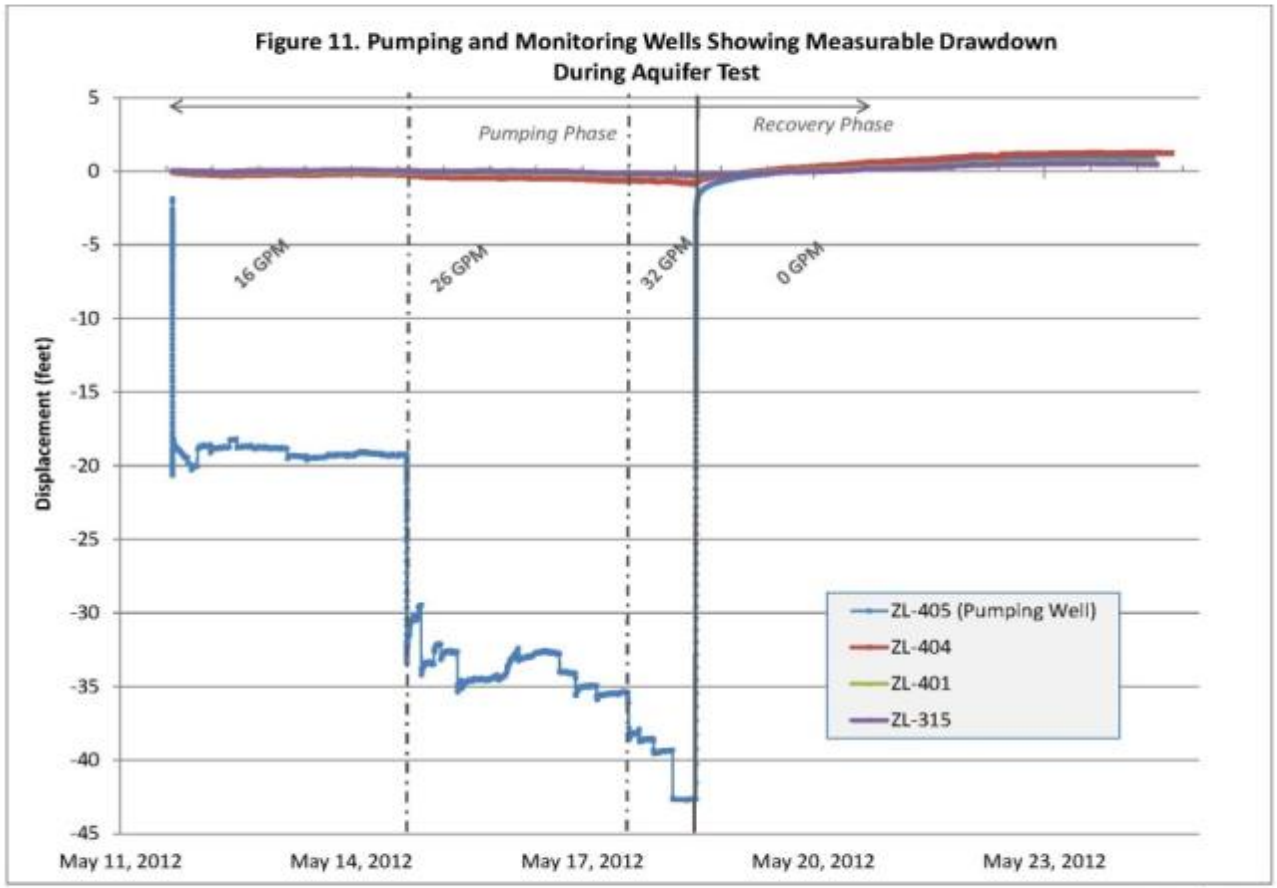
Source Control Prioritization and Feasibility Evaluation (2011-now)

* 7-Day Aquifer Test
* Forced Gradient Dye Tracer Test
* Natural Gradient Dye Tracer Test
* Flume Installation and Flow Monitoring in Swift Gulch
* Mine Water Balance
* Groundwater Hydrograph Analysis
* Geochemical Investigation

Why Source Control ?

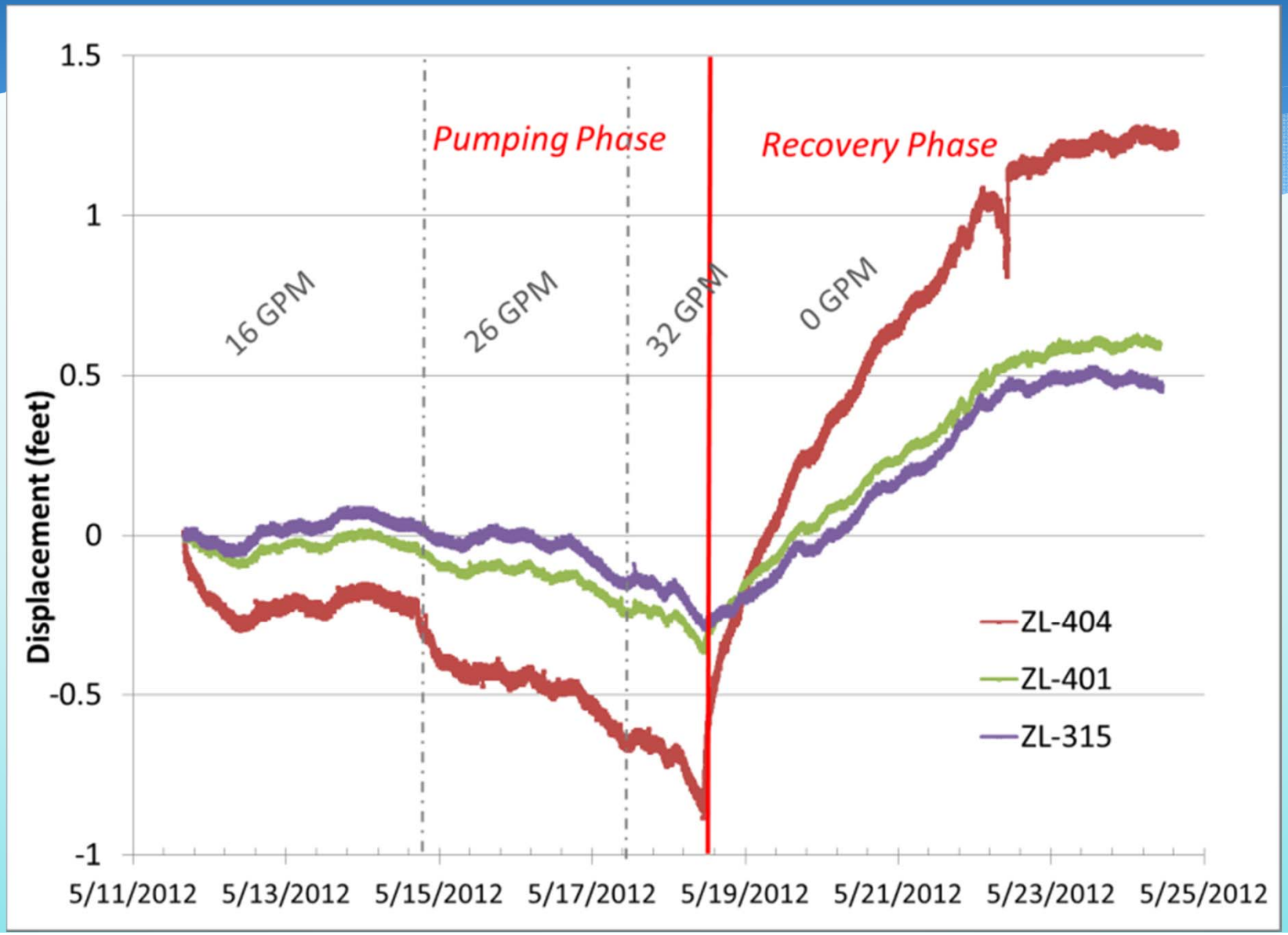

ZL-313
Sulfate
Total Metals
100
90
80
70
60
50
L-19
300
1600
1200
800
400
0
1999
Sulfate (mg/L)
ZL-402
ZL-204
SUP
PIT
BKSP-2E
Sulfate
Total Metals
4000
3500
3000
2500
2000
1500
1000
500
0
800
700
600
500
400
300
200
100
0
1999
2002
2004
2007
2010
Sulfate (mg/L)
Total Metals (mg/L)

Pumping and Monitoring Well Drawdown during Aquifer test



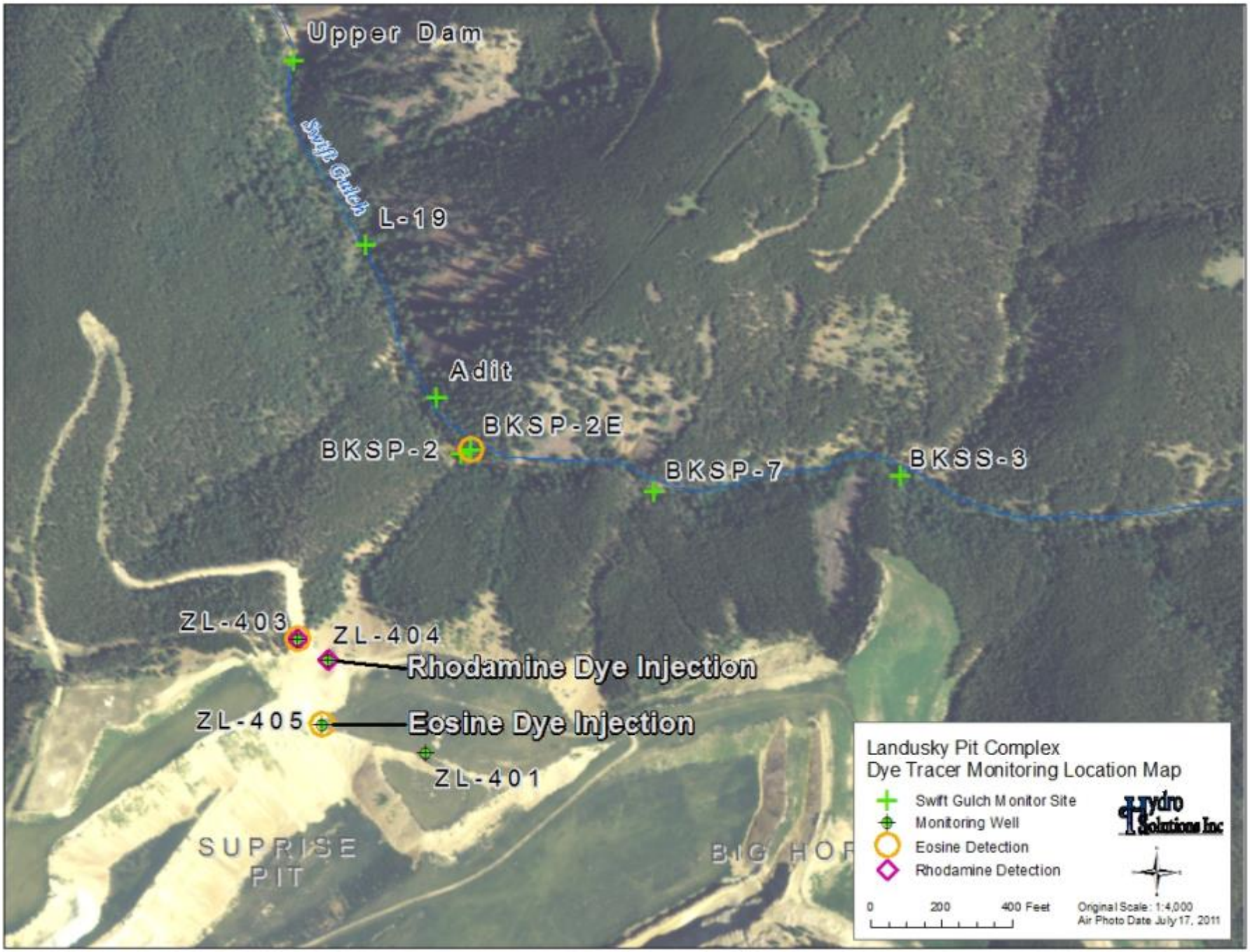
Hydro Solutions Inc

Monitoring Well Response



Aquifer Test Results

* Calculated transmissivity values from the aquifer test ranged from 439 to 630 feet^2/day, representative of the bulk aquifer (comparable to 2008 48-hour test)
  * Calculated hydraulic conductivity - 8 to 50 feet per day
* At early pumping times, the flow is dominantly linear with water entering the fracture system from the aquifer at the same rate per unit area
* As pumping test progresses, flow pattern changes from linear to radial with more discharge derived from the aquifer matrix


Upper Dam
Swift Gulch
L-19
Adit
BKSP-2E
BKSP-2
BKSP-7
BKSS-3
ZL-403
ZL-404
Rhodamine Dye Injection
ZL-405
Eosine Dye Injection
ZL-401
SUPRISE
PIT
Landusky Pit Complex
Dye Tracer Monitoring Location Map
Swift Gulch Monitor Site
Monitoring Well
Eosine Detection
Rhodamine Detection
Hydro Solutions Inc
0
200
400 Feet
Original Scale: 1:4,000
Air Photo Date July 17, 2011

Activated carbon sampling packet

Forced Gradient Dye Tracer Test Results

* Rhodamine breakthrough in ZL-405 in 12 hours
  * No detection of Rhodamine WT in Swift Gulch after one year
  * Rhodamine was detected in matrix well ZL-403

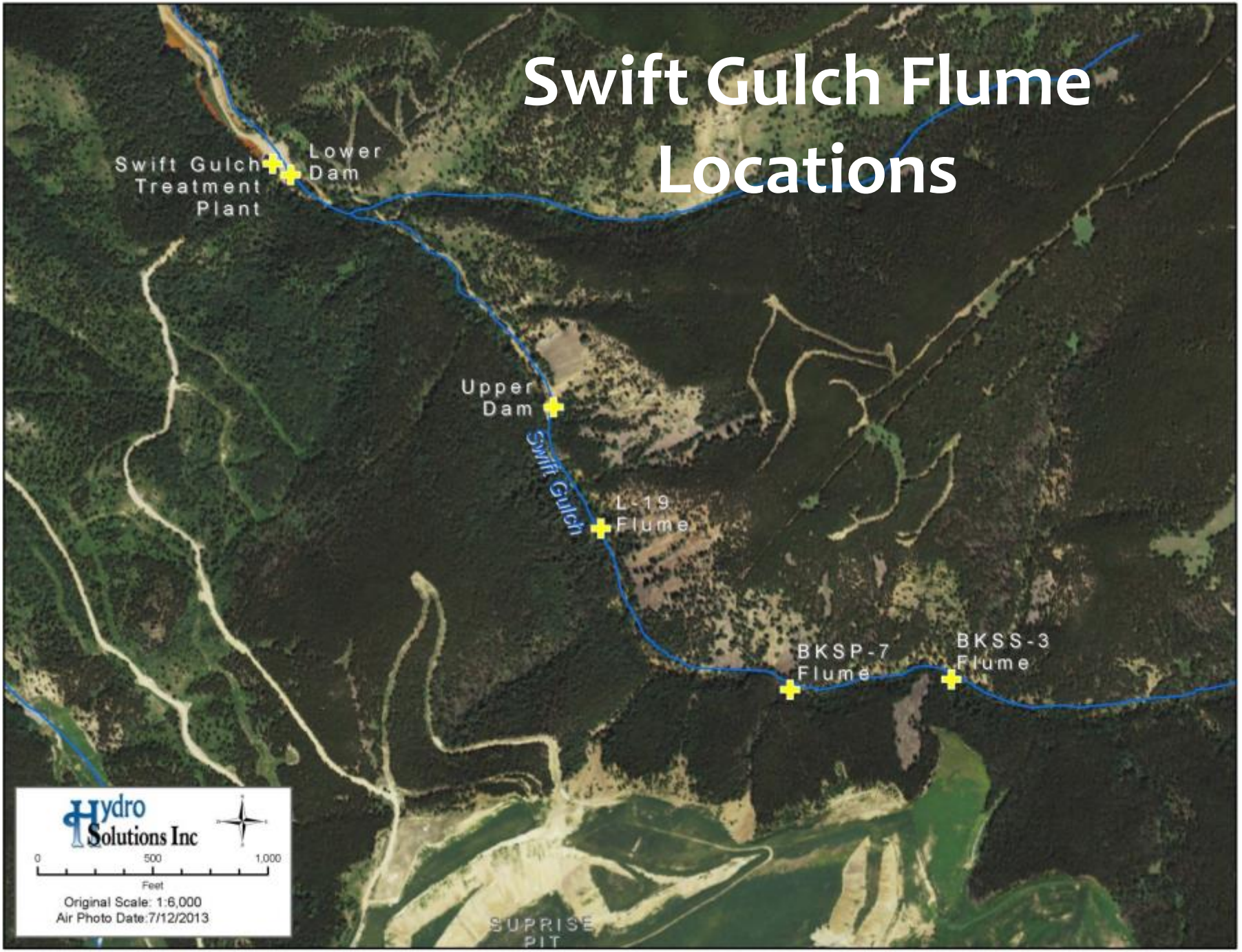
Natural Gradient Dye Test Results

* Eosine detected in BKSP-2E within 3 months (one time detection)
  * (Travel time was estimated at 2 to 10 months)
* Eosine detected in downgradient/cross gradient matrix monitoring well ZL-403 within 12 months

Tracer Test Conclusions

* Dye attenuation likely occurred somewhere in the pathway
* Dye tracer detection in Swift Gulch was very low concentration and likely too diluted to be detected in other Swift Gulch sample locations
* Delayed arrival of eosine seen in downgradient matrix well is as expected
* Interaction of the fractures and matrix is evident
* Rapidly disintegrating quality of downgradient matrix water samples provides evidence for the connection
* Matrix and shear zones need to be considered as "one whole package" as the remedial alternatives are developed and considered
* Continual deterioration of the matrix may present new long term geochemical and water quality remediation challenges

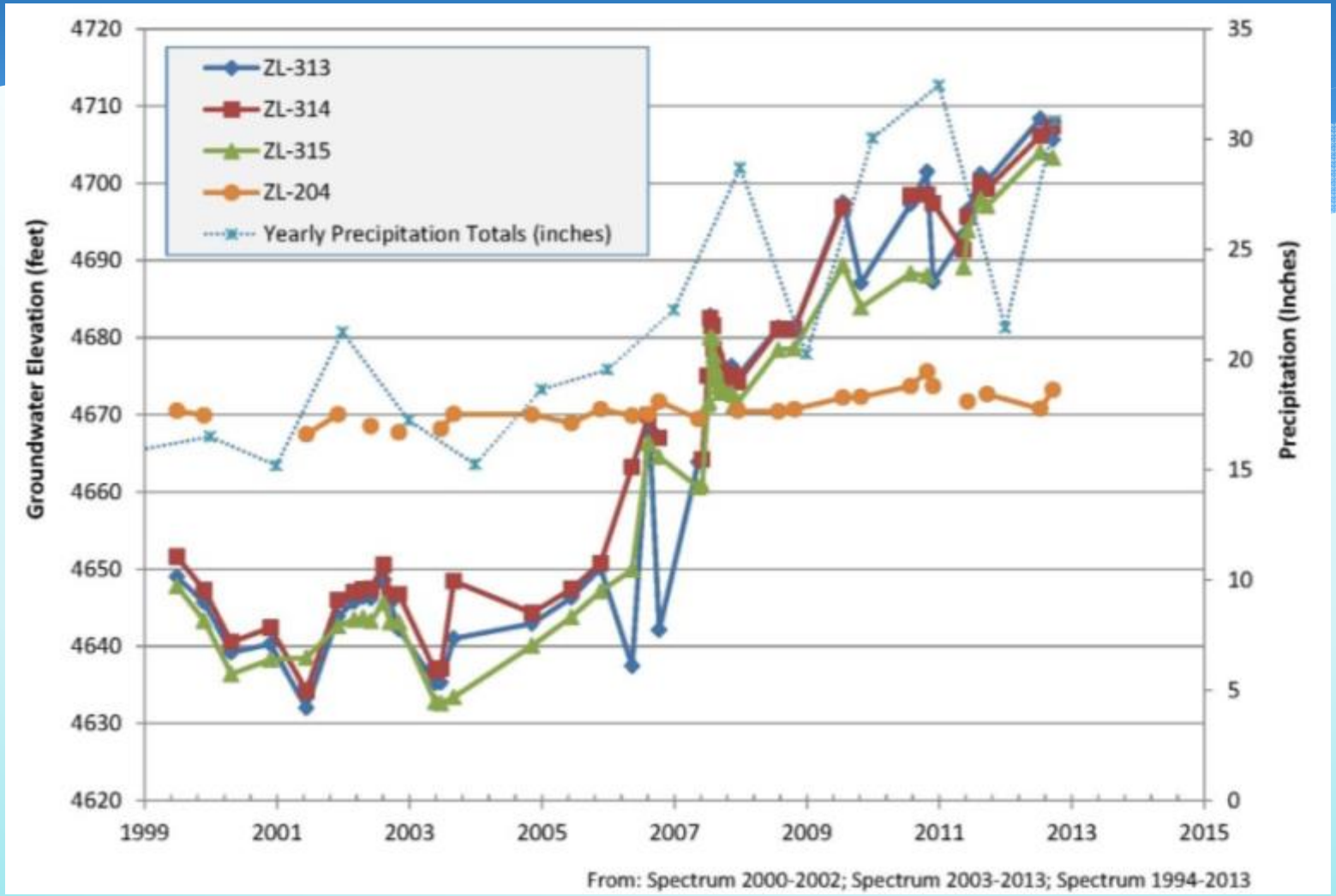
Swift Gulch Flume Locations



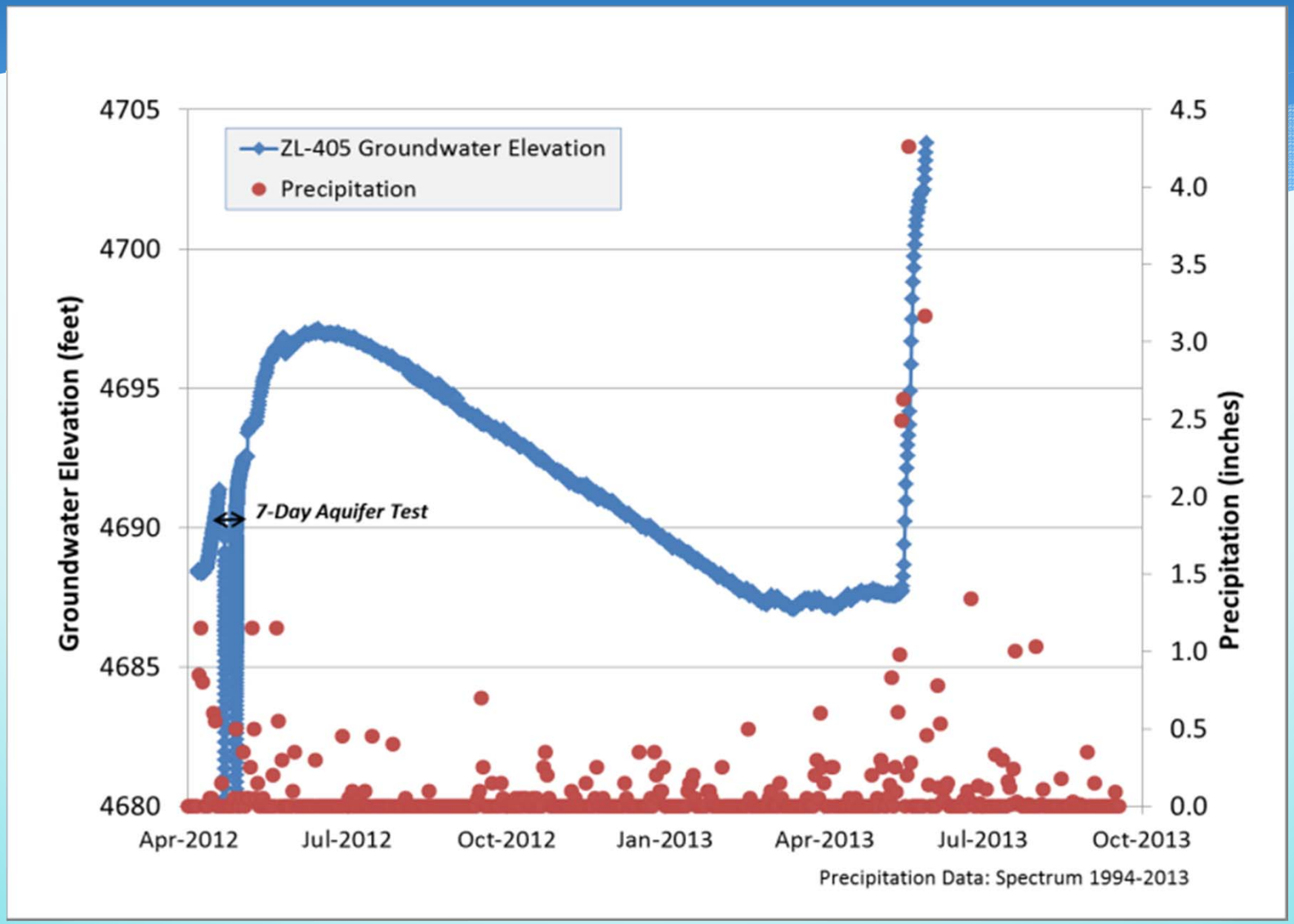
Swift Gulch Base Flow Study Results

* Flow through the upper reaches of Swift Gulch responds directly to and is almost entirely dependent upon snowmelt and precipitation runoff
* Results of the study indicate that base flow in Swift Gulch increases from the upper most station monitored BKSS-3 to station L-19 through known surface seeps and groundwater discharge
* In the reach below L-19 to the lower dam, Swift Gulch is identified as a losing reach and appears to lose between 21 gpm to 28 gpm
* For the period that was monitored, the Swift Gulch water treatment plant has a successful capture rate of 80% at the upper and lower dams

Historical Groundwater Levels



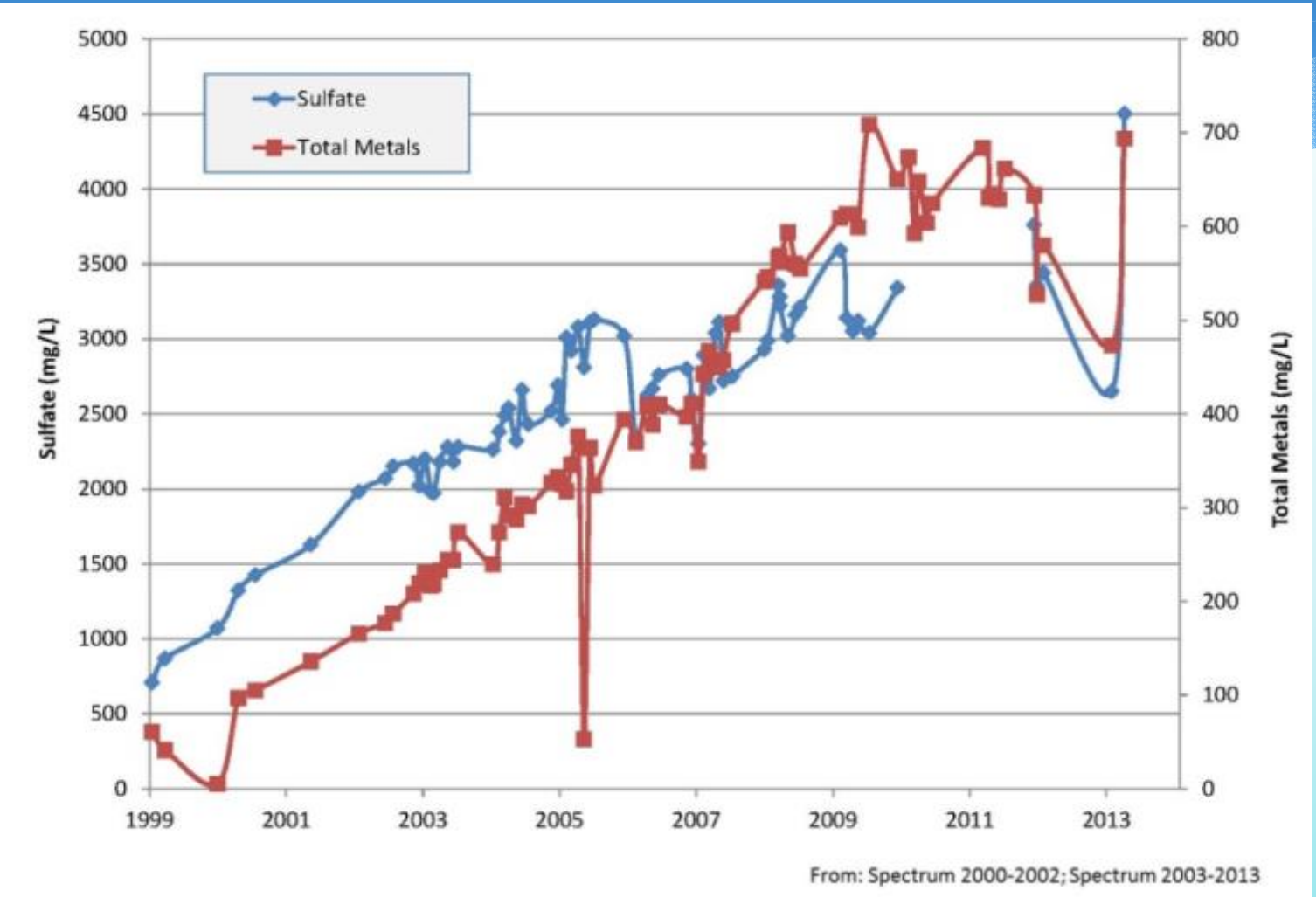
Hydrograph for Monitoring Well ZL-405



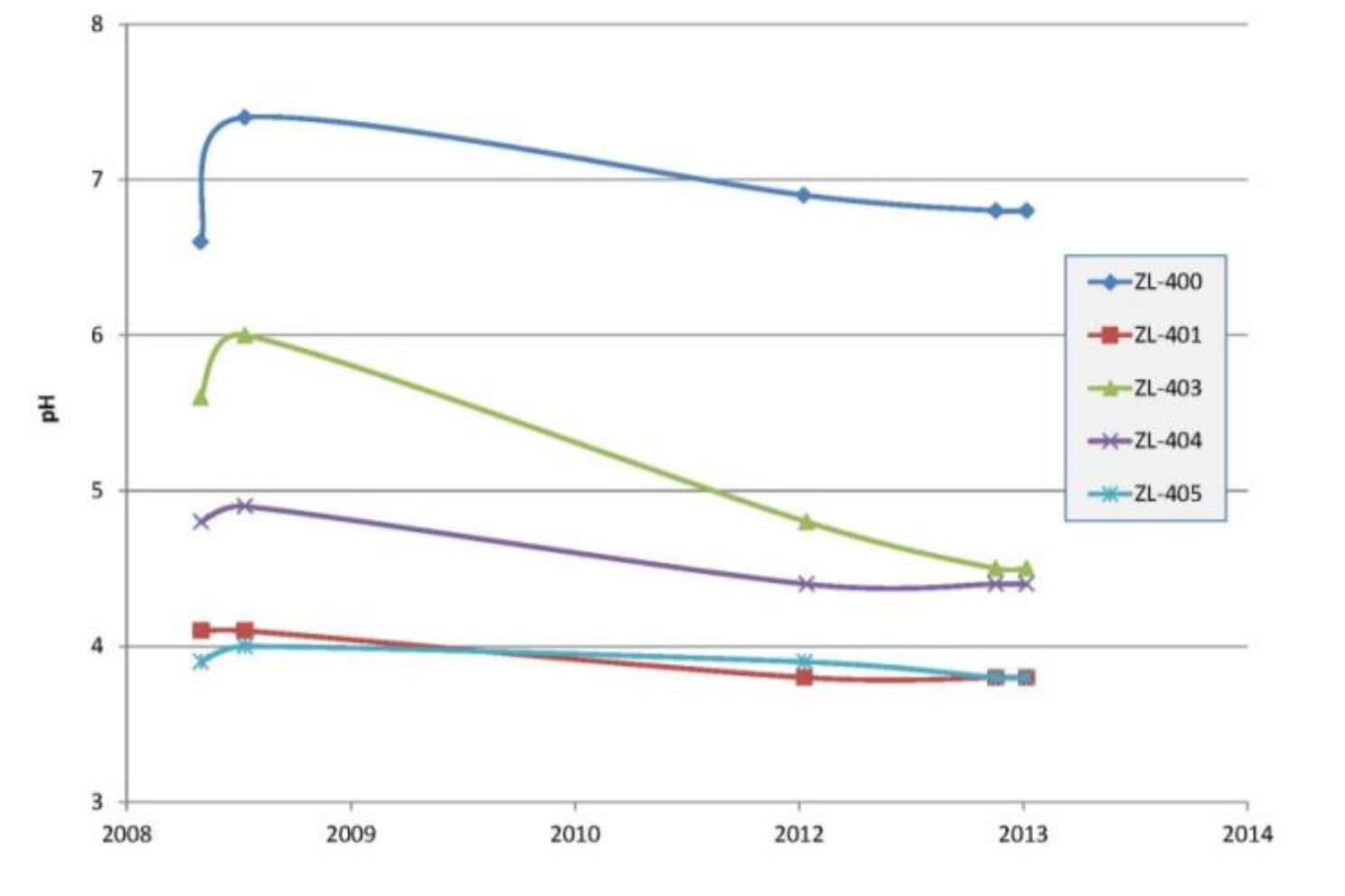
Why Geochemical Investigation at Landusky

* Geochemical data gaps for Northern Landusky Pit wells, general chemistry
* Expanding/Complementing dye tracer results
* Traditional Approaches may not capture big picture
* A multi-isotope approach, along with general chemistry, can characterize source water, flow paths, and groundwater contribution to Swift Gulch

Sulfate and Total Metal Concentrations of Spring BKSP-2E



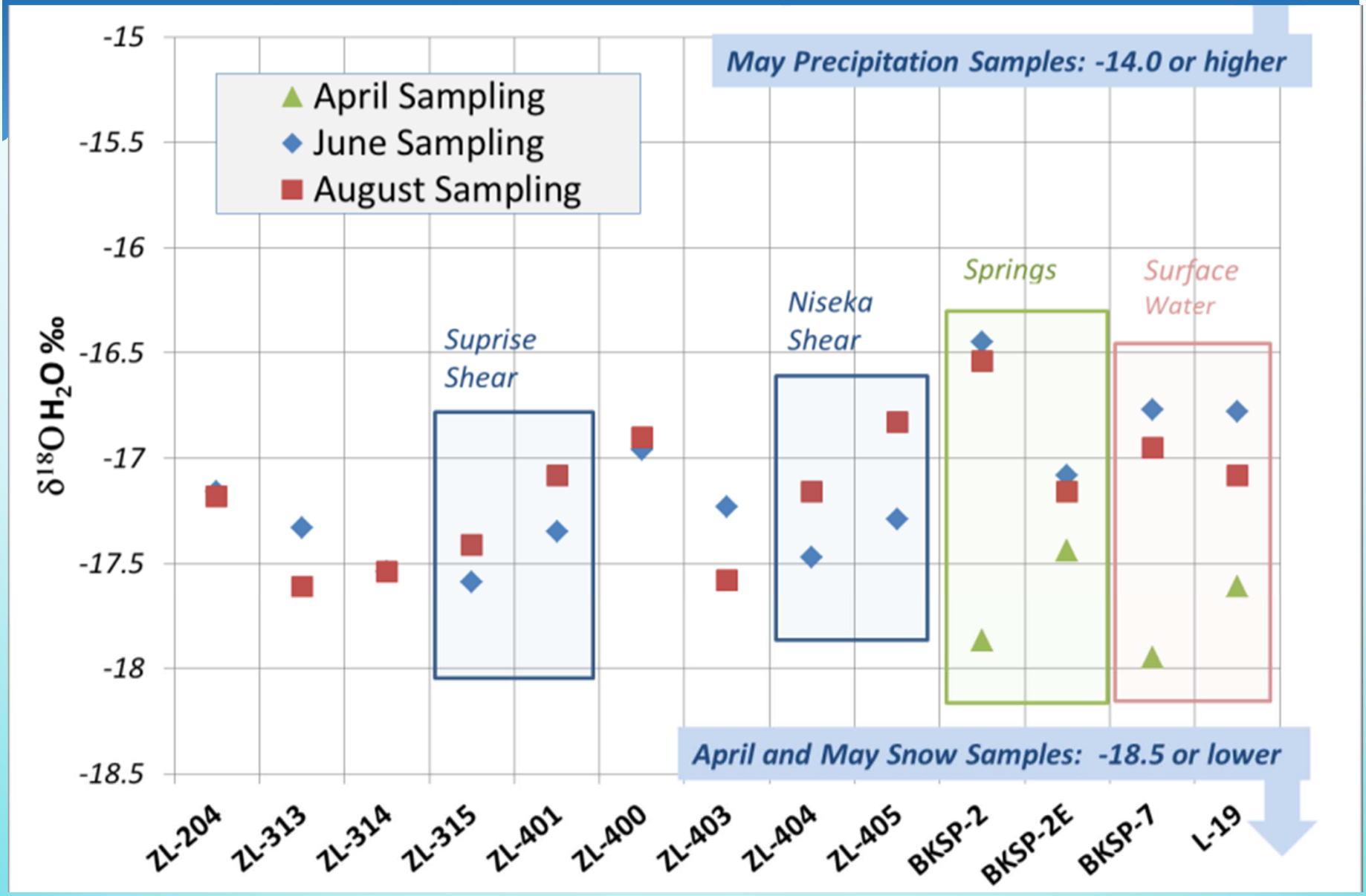
pH for Landusky Pit Monitoring Wells



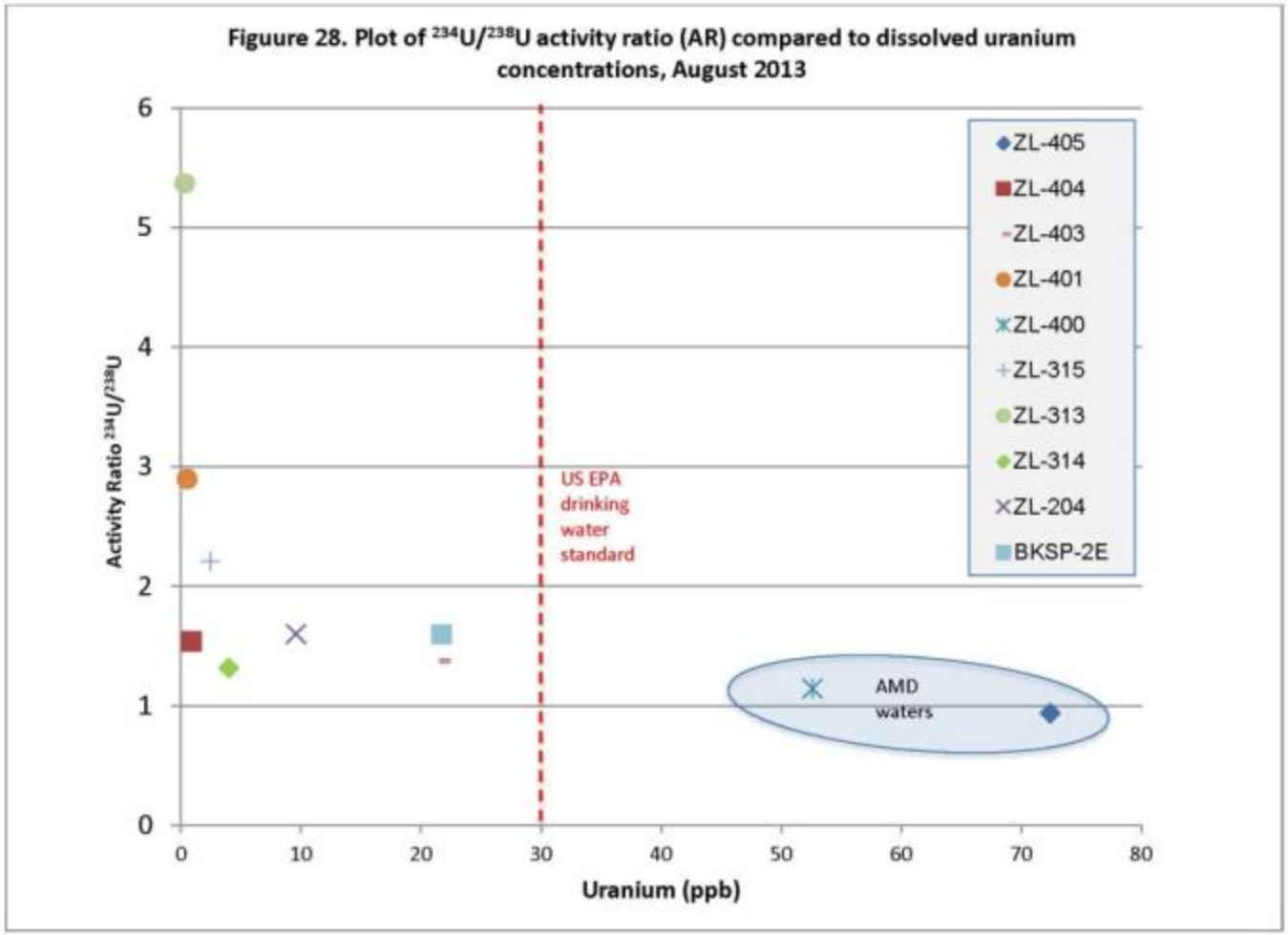
Geochemical Parameters and Justifications

Analyte	Justification
Oxygen ($^{18}O/^{16}O$) Hydrogen ($^{2}H/^{1}H$)	Estimate the source , water-rock interactions
Strontium ($^{87}Sr/^{86}Sr$)	Indication of flow path history
Uranium ($^{234}U/^{238}U$)	Interconnectivity, groundwater flow paths and rates, assess groundwater mixing and volumes, and assess water-rock chemical interactions
Field Parameters: Eh, pH, DO, and SC	Geochemical modeling and metal speciation
Major Cations and Anions, Trace Elements, and Metals	In combination with a multi-isotope approach, useful for characterizing source water, flow paths, and groundwater contribution to surface water

Landusky Monitoring Locations $\delta^{18}O$ H_2O ‰, Seasonal Variations



Plot of $^{234}U/^{238}U$ activity ratio (AR) compared to dissolved uranium concentrations, August 2013



Geochemical Results

* In general, over time, metals and sulfate concentrations have been increasing and pH has been decreasing in Swift Gulch and groundwater from the northern Landusky Pit monitoring wells
* Groundwater associated with the Niseka Shear appears to be undergoing geochemical degradation due to continual AMD contributions
* The uranium isotopic results indicate that the monitoring wells associated with the Niseka Shear are mainly AMD water with the same isotopic signature found in the August-Little Ben pit

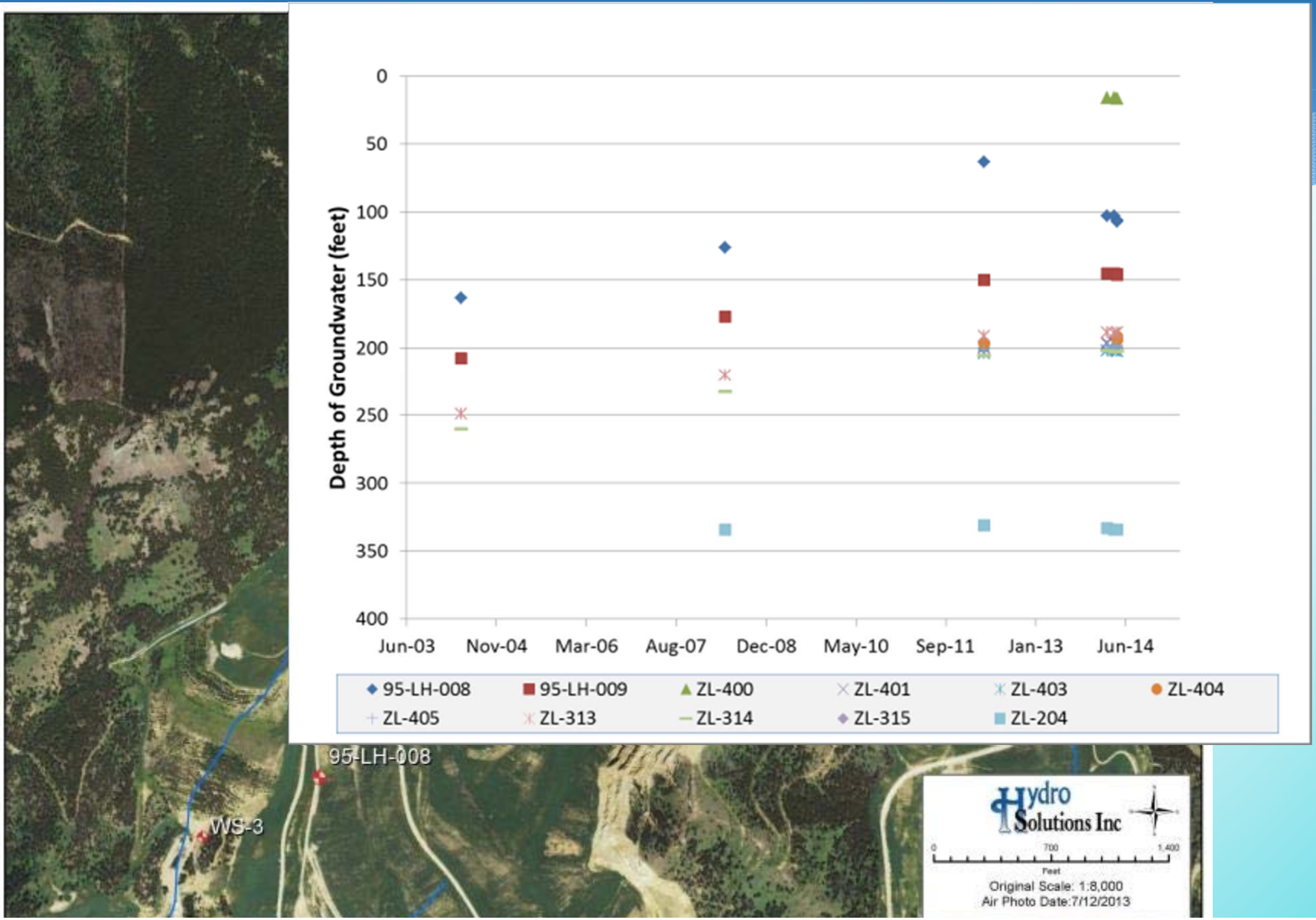
Geochemical Conclusions

* Wells completed in the same fracture system showed different isotopic signatures but similar seasonal variations
* The different isotopic signatures are attributed to additional deep groundwater mixing as the fracture system extends further from the Landusky Pit Complex
* The high AR results for the deeper groundwater well ZL-313, and very low aluminum, sulfate, and iron concentrations, suggest that the deeper groundwater is less affected by AMD water
* AMD does not appear to extend into the adjacent King Creek drainage basin

Future Reclamation Thoughts

* Installation of large-diameter pumping wells in the Landusky Pit Complex
  * Assessing the chemistry directly within the reclaimed pits
  * Provide wells for remedial alternative pilot testing directly in the source areas
* Water management of Artesian Well WS-3 and monitoring water level response in the Landusky Pit Complex
* Volume control within the Landusky Pit Complex to reduce volume of AMD to Swift Gulch
* In-Situ bio-treatment source control

Historic and Current Water Levels for Monitoring Wells Associated with Artesian Well WS-3, Opened April 9, 2014



Thank you

David Donohue
davidd@hydrosi.com
Melissa Schaar
melissas@hydrosi.com

Helena office: 406-443-6169

www.hydrosi.com

Hydro Solutions Inc