GROUNDWATER/SURFACE WATER INTERACTIONS

ADVANCED CHARACTERIZATION TECHNIQUES AND EXAMPLES

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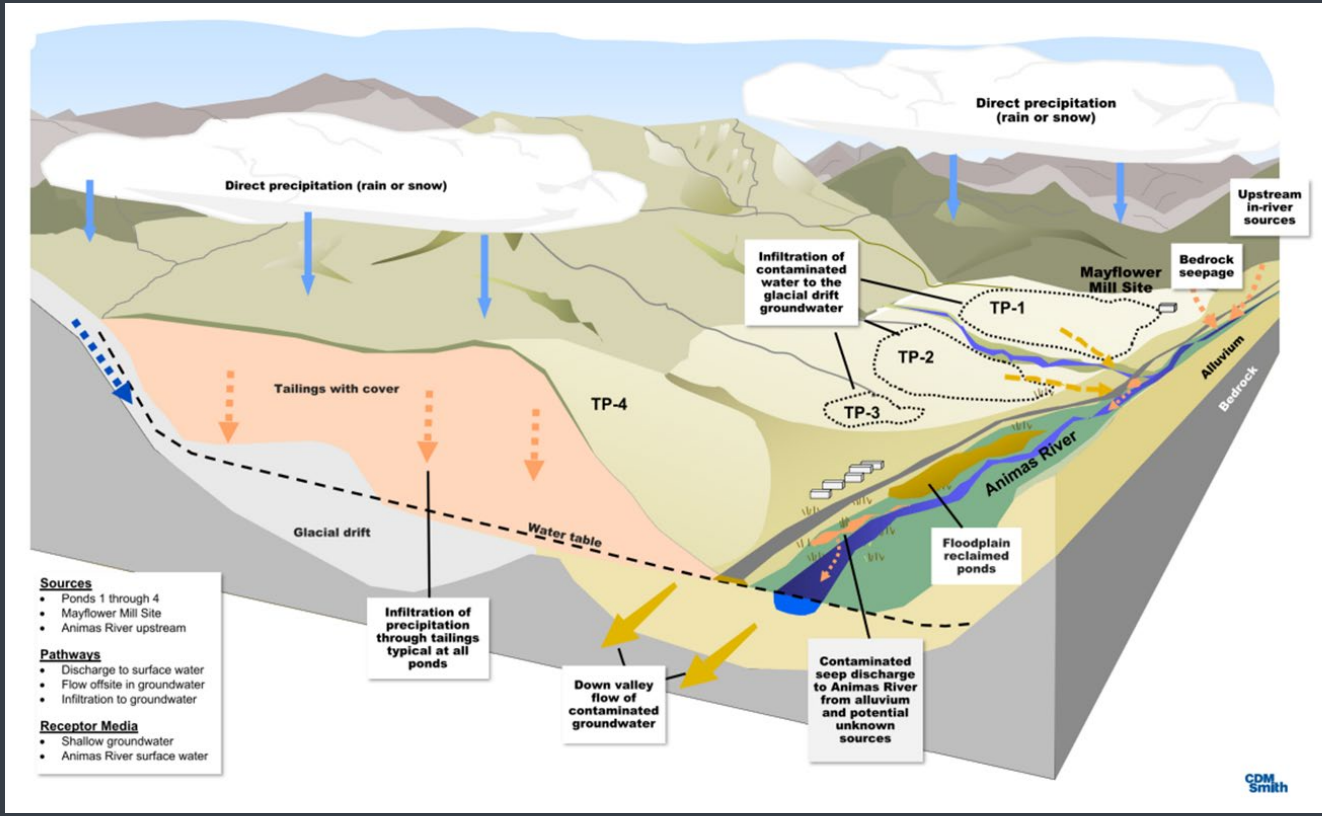
DEVELOPING EFFECTIVE CONCEPTUAL SITE MODELS

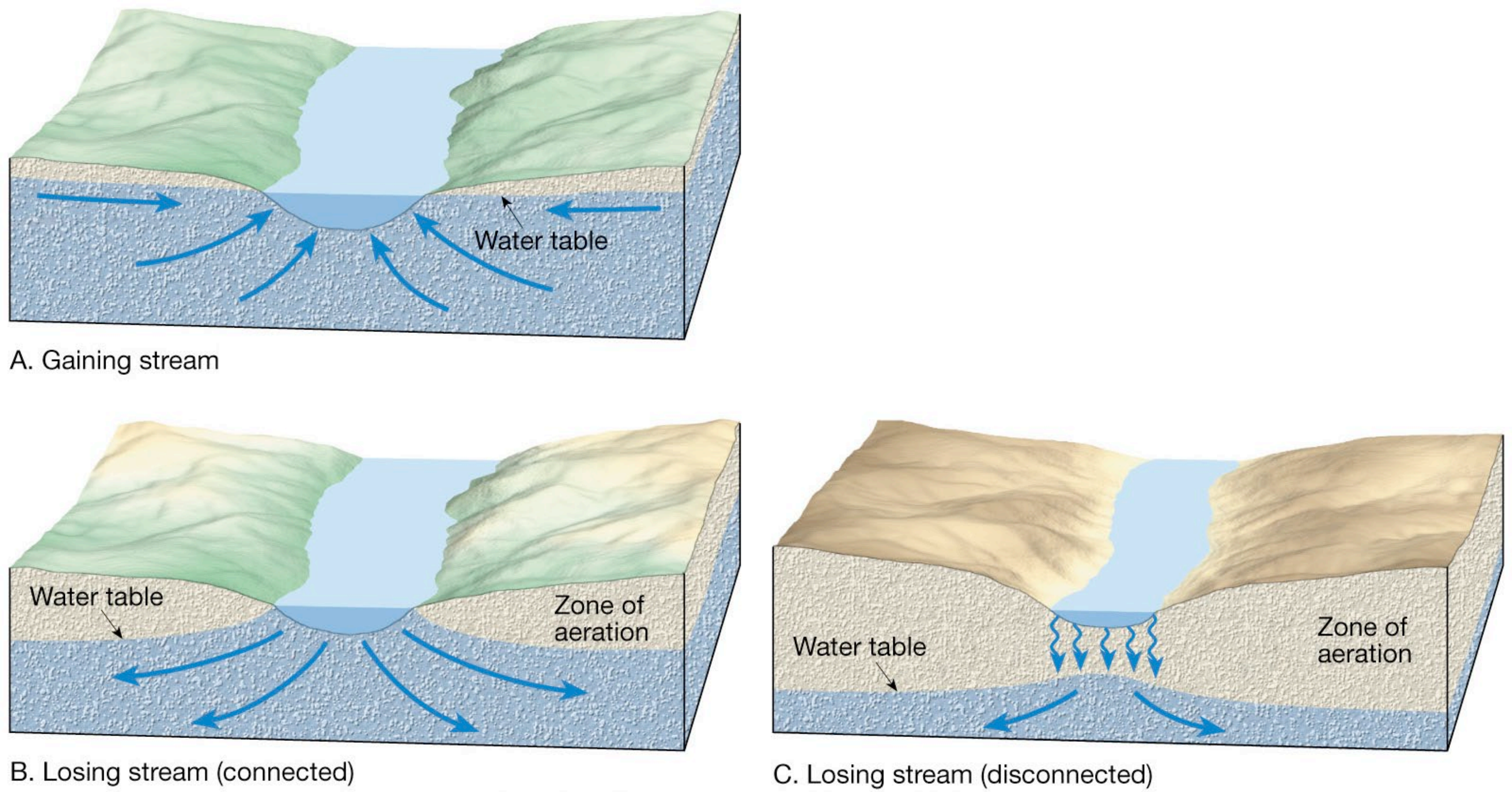
- CSM needs to be informed by knowledge of several components
  - Site hydrology
  - Contaminant transport characteristics
  - Ecological exposure endpoints
- Interaction of these factors dictates location and magnitude of exposure

EFFECTIVE CSMS - SITE HYDROLOGY ISSUES

- Hydraulic connection between GW plume and surface water body
  - Does it exist?
  - If so, is it continual or episodic?
  - When connected, does the direction of water exchange vary?
- Questions need to be addressed to understand timing and location of exposure

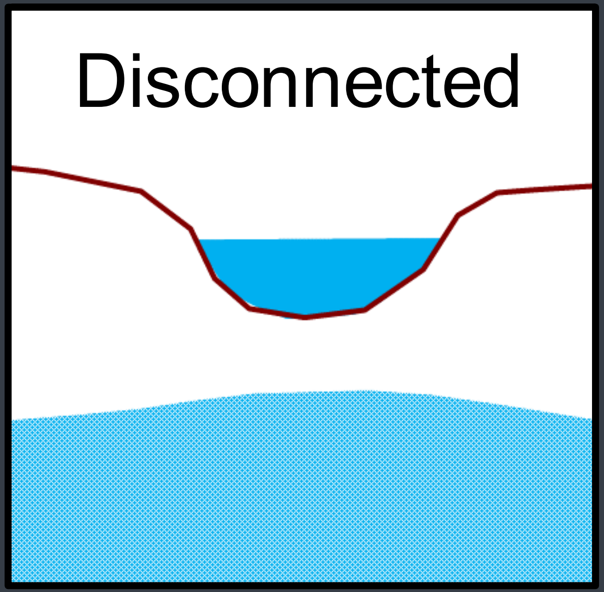


GAINING AND LOSING STREAMS



- Gaining streams are common in the eastern US
- Losing streams are common in recharge areas (headwaters), arid areas (West), and karst regions (SE)
- Disconnected streams are common in arid regions (Western US)
- Many streams have both gaining and losing reaches

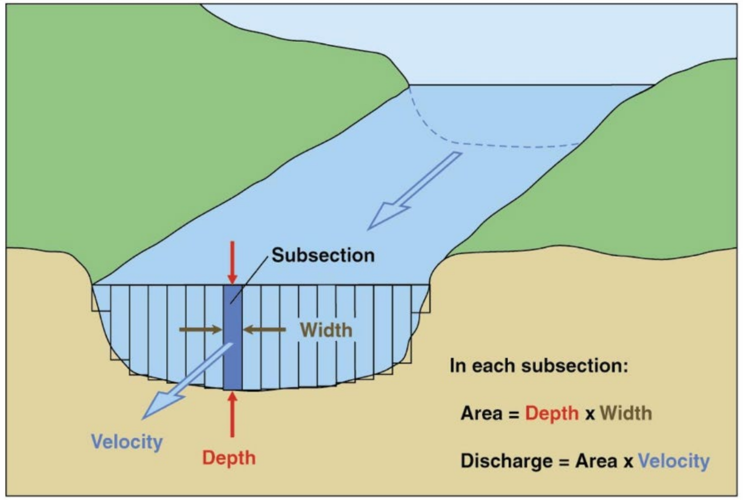
DISCONNECTED STREAMS



- Common to have deep unsaturated zone
- May be episodic for semi-arid climates with extended dry-wet periods
- Need to develop good understanding of local GW table elevation and seasonal variation
  - Episodic (e.g. quarterly) manual measurements of GW table insufficient to assess situation

FLOW IN A STREAM

- Stream Discharge = Area X Velocity
- Used to help identify gaining and losing reaches
- Velocity can be measured in a variety of ways



Mass Flux Measurements

- Needed to ensure exposures scenarios in risk assessment are accurate

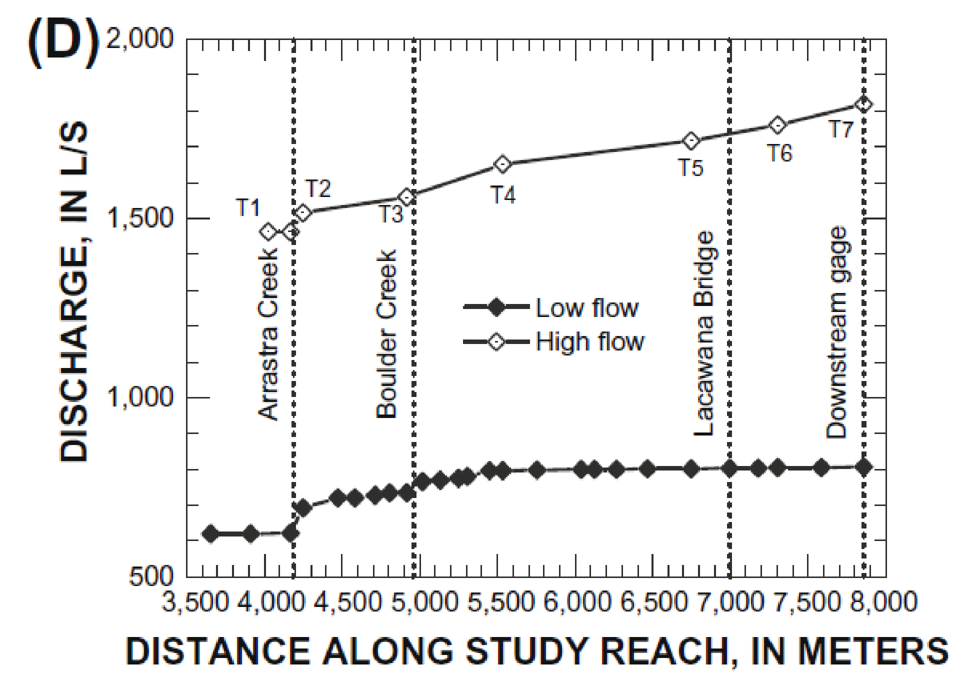
- Needed for Remedial Design
  - Target areas of high flux

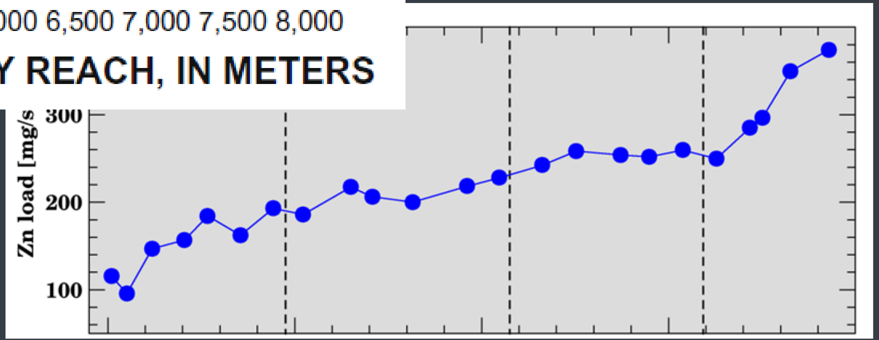
- Flux = Concentration X Flow Rate

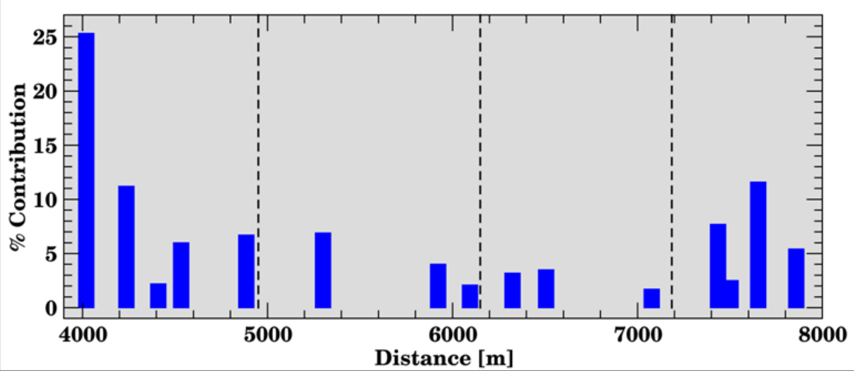
MASS FLUX ESTIMATION

- Direct Measurements of Flux
  - Seepage Meter
  - Diffusion Methods
- Heat Based Methods
  - Can estimate flux when combined with modeling and concentration data
  - Distributed Temperature Sensors
  - iButton temperature logger
- Mass Balance Approaches
  - Incremental Streamflow
  - Surface Water or Groundwater Tracers
  - Point Velocity Probe
- Methods Based on Darcy's Law

MASS FLUX USING SW DATA



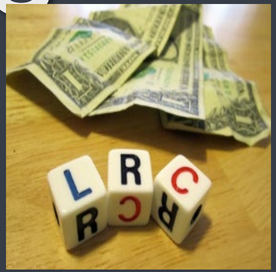




- Data Collected using SW flow data and analytical samples for concentration.
- Surface Water Data shows most of the flow increase is from tributaries
- Loading Profile shows metals load in surface Water
- Interpretation allows for GW load to be estimated.

Equal Discharge Increment Sampling

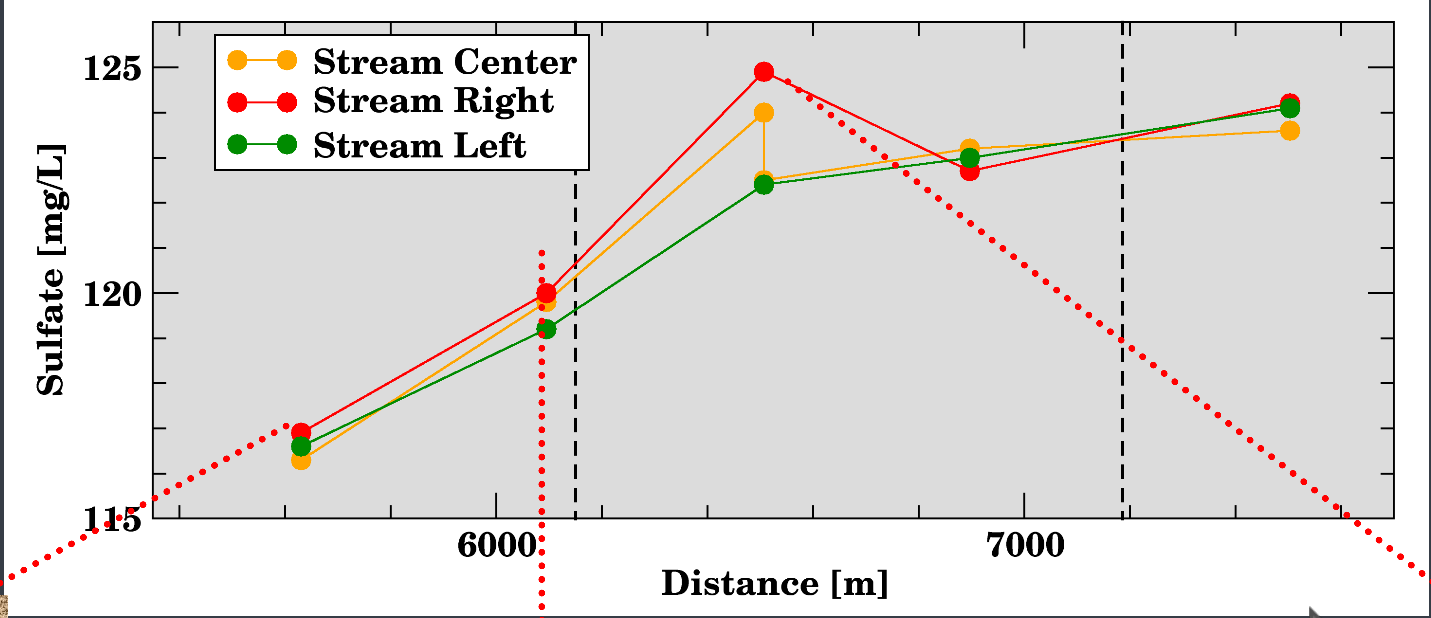
Left Right or Center?



- Used to identify sources of SW loading
- divide transect into thirds based on streamflow
- sample at midpoint of each third (L, R, C samples)

Slide Courtesy of Rob Runkel, USGS

Equal Discharge Increment Sampling



Right Bank Seep
Zn = 27.4 mg/L

Flow

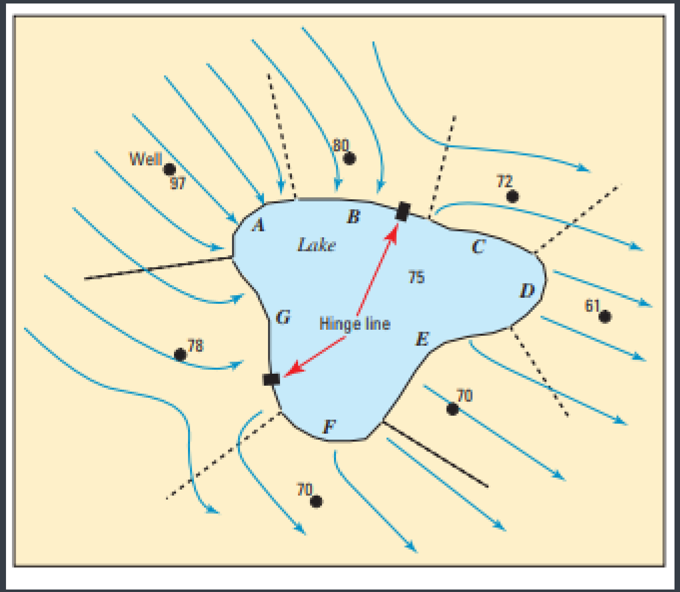
Central Aquifer Groundwater Discharge

Red Seep
Zn = 19.1 mg/L

Slide Courtesy of Rob Runkel, USGS

BEWARE OF DARCY'S LAW

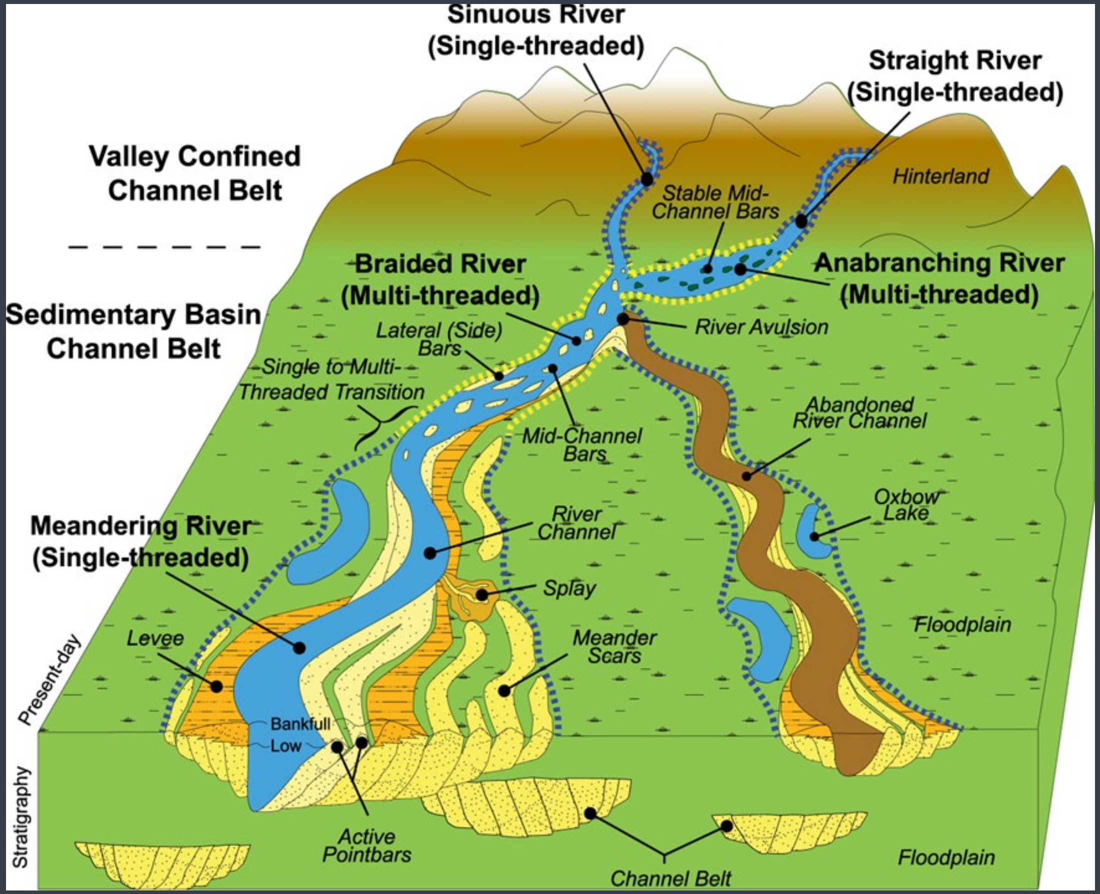
- Q = -KI WHERE Q = FLUX, K = HYDRAULIC CONDUCTIVITY, AND I = GRADIENT
- RELIES ON ESTIMATES OF HYDRAULIC CONDUCTIVITY AND GRADIENT
- COMMONLY USED APPROACH, BUT OFTEN DOES NOT PROVIDE INFORMATION AT THE SCALE REQUIRED FOR REMEDIAL DECISIONS



Rosenberry et. al, 2008. https://pubs.usgs.gov/tm/04d02/pdf/TM4-D2-chap2.pdf

RIVER CHANNEL MORPHOLOGY

- River Gradient affects channel morphology
  - High gradient Rivers are often straight
  - Braided Rivers deposit lots of sediment (base of mountains)
  - Meandering Rivers occur as the gradient flattens
- GW/SW interactions are affected by aquifer and streambed heterogeneity



Nyberg, B., Henstra, G., Gawthorpe, R.L. *et al.* Global scale analysis on the extent of river channel belts. *Nat Commun* **14**, 2163 (2023). https://doi.org/10.1038/s41467-023-37852-8

PUTTING IT ALL TOGETHER

- Heterogeneity in aquifer and streambed both affect contaminant discharge areas
- Many techniques available to get the same information
- CSM and site characteristics should be used to guide approach

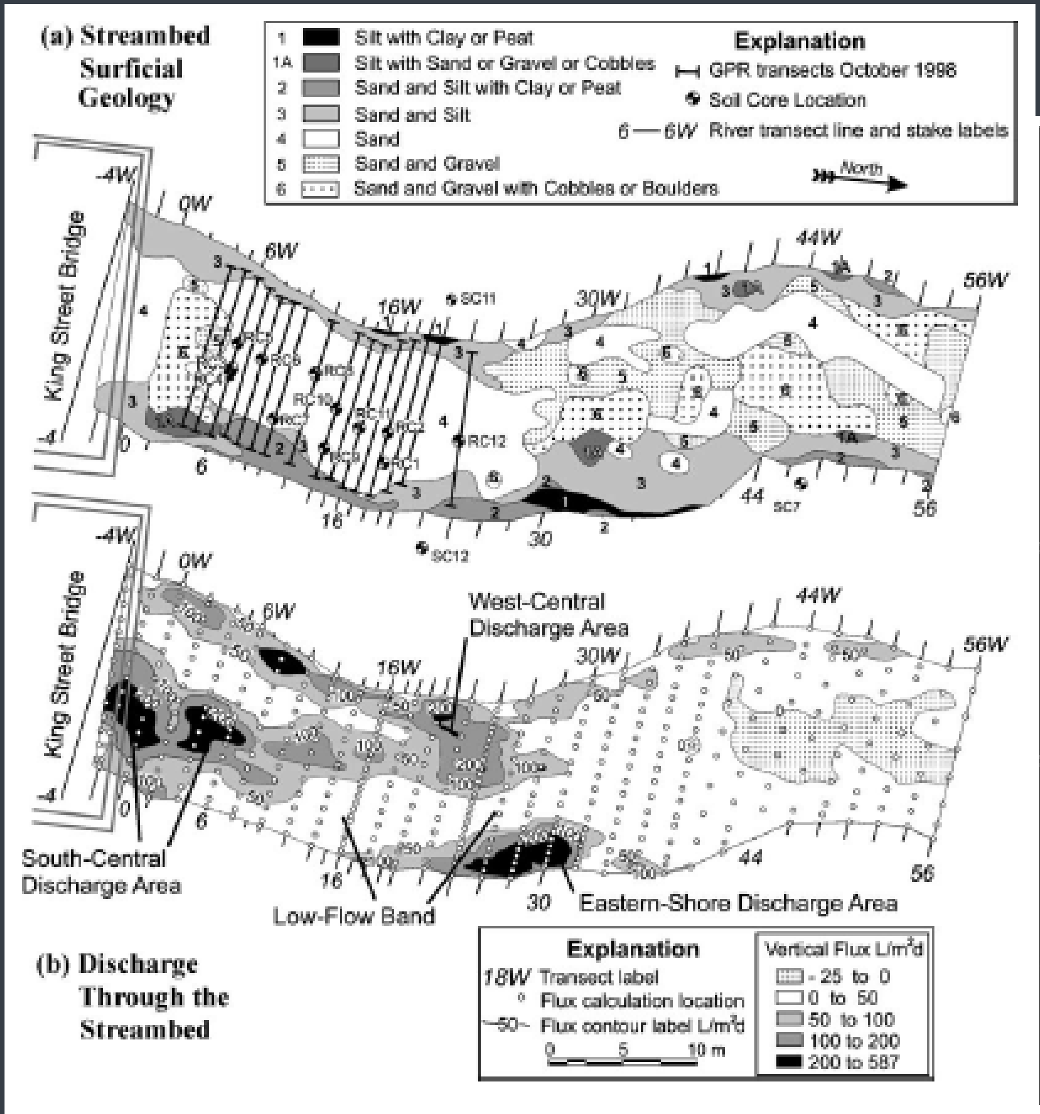
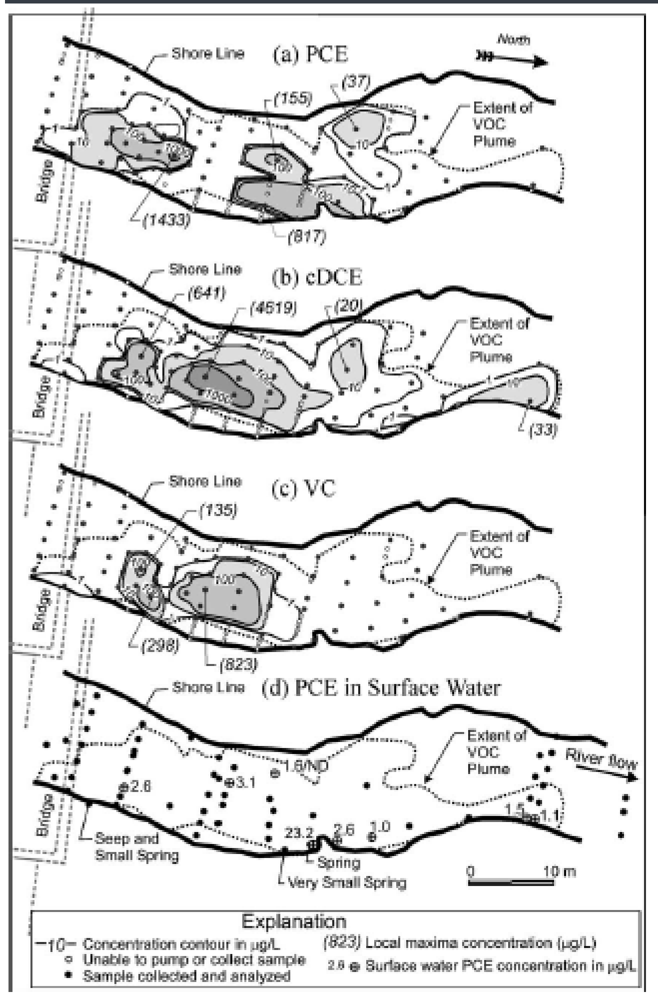


Fig. 3. (a) Map of surficial geology of the streambed and (b) map of vertical water fluxes through the streambed for February 1999.



Conant, Cherry, and Gillham, 2004. Journal of Contaminant Hydrology, 73, 249-279.

FREE RESOURCES

- Ground Water and Surface Water, A Single Resource

  U.S. Geological Survey Circular 1139
  https://pubs.usgs.gov/circ/circ1139/

- Field Techniques for Estimating Water Fluxes Between Surface Water and Ground Water

  U.S. Geological Survey Techniques and Methods 4-D2
  https://pubs.usgs.gov/tm/04d02/

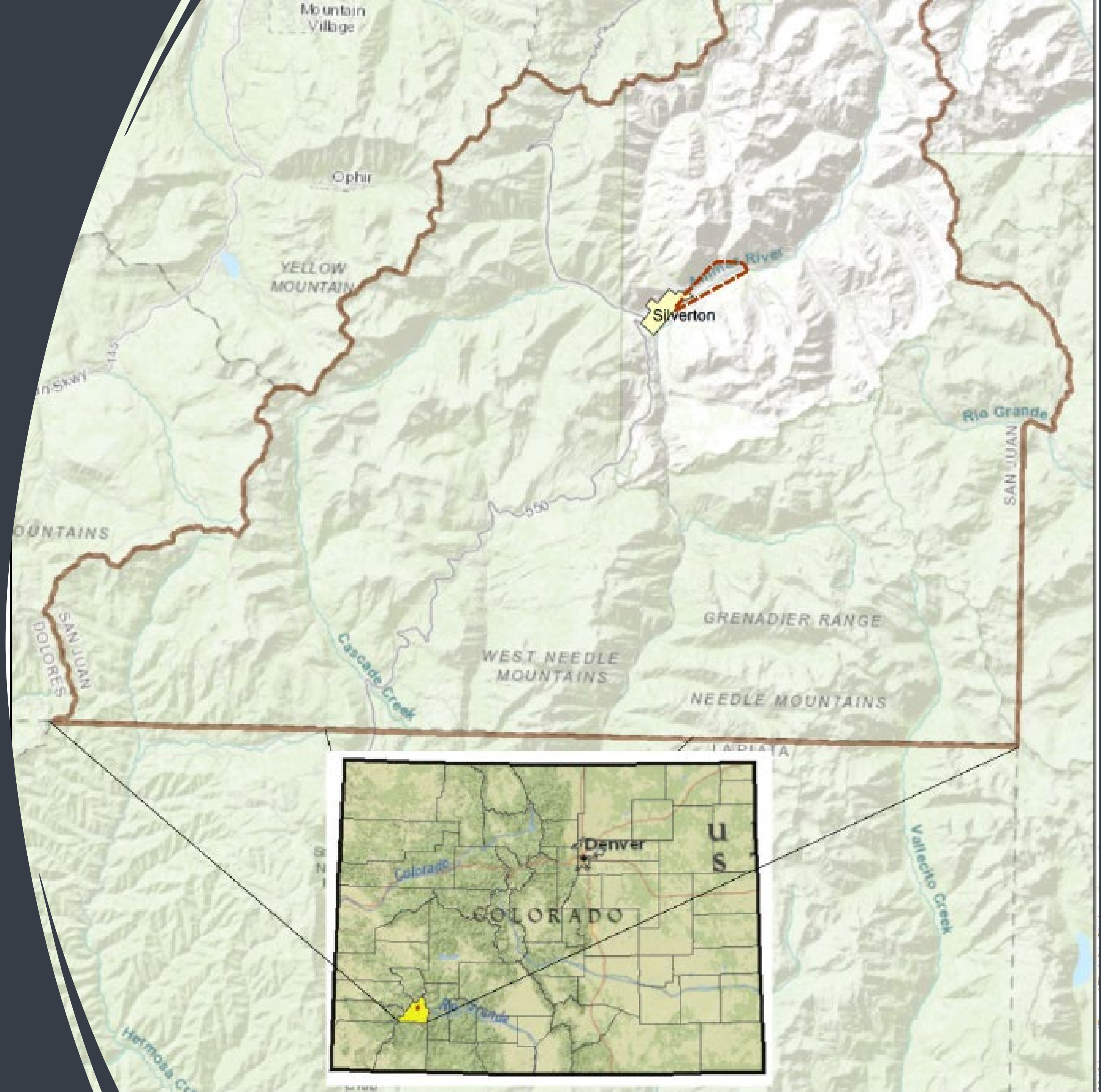
- EPA GW/SW Contaminant Flux Toolbox

- ERAF and GWF white paper on GW/SW interactions

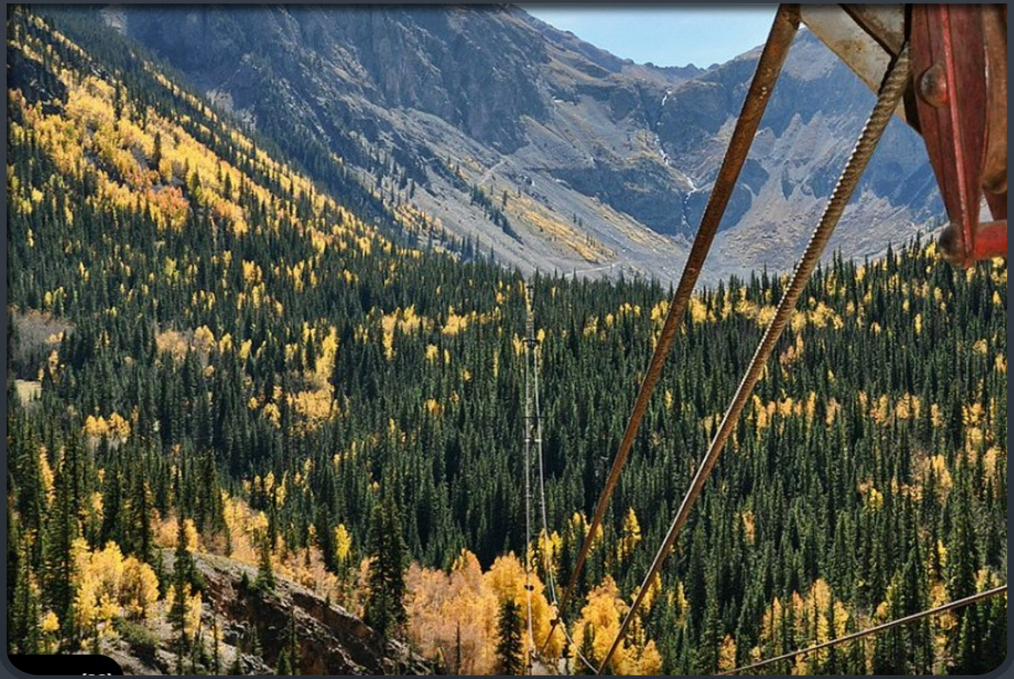
OUTLINE

- Site History
- Conceptual Site Model
- Data indicating GW/SW interaction may be significant
- Data needs
- Tools
- Results
- CSM updates/considerations
- Next Steps

BONITA PEAK MINING DISTRICT OU2



- Large mine waste repository
- Adjacent to Animas River

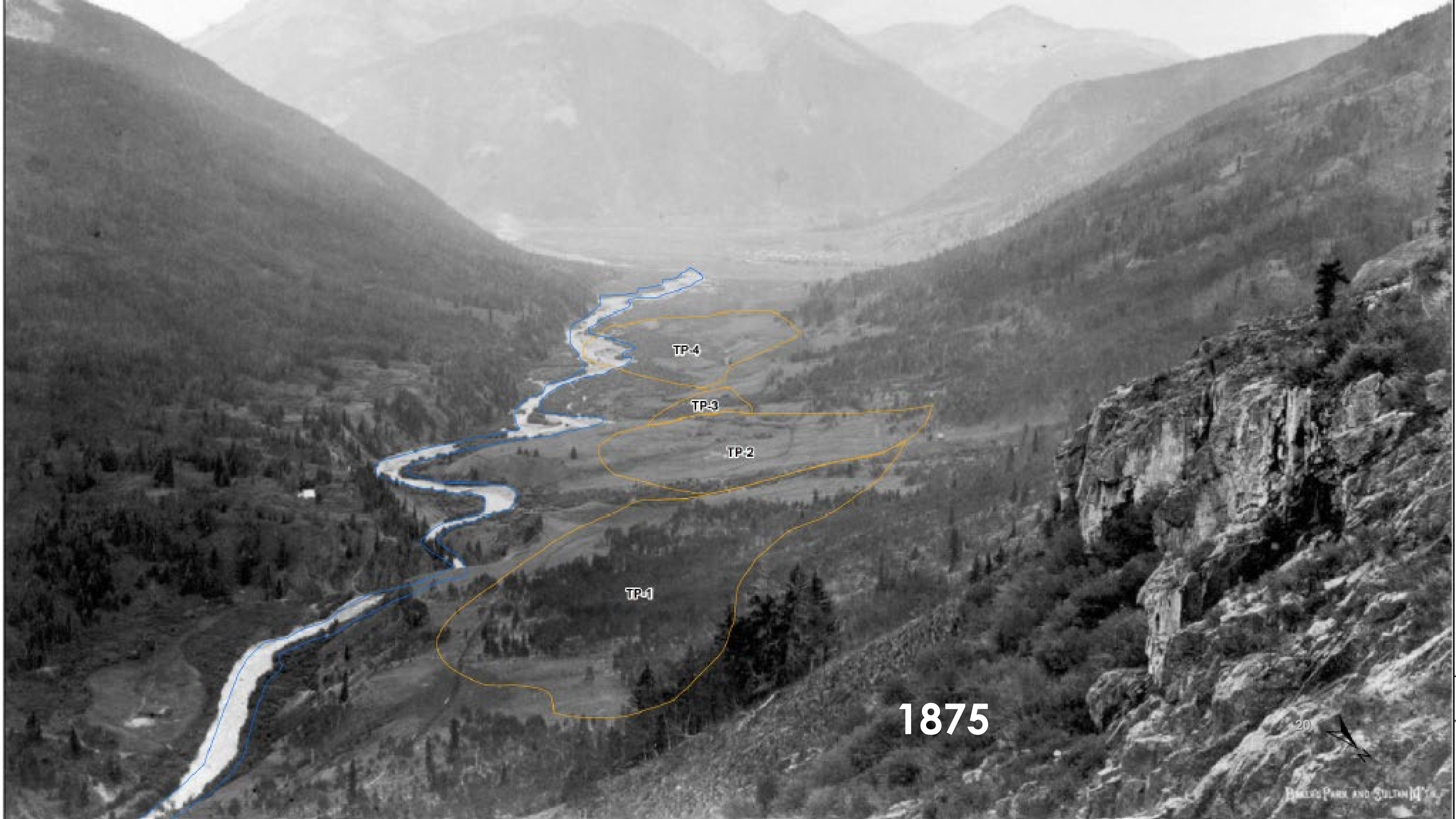


MAYFLOWER MILL

- Flotation Mill
- 1929-1991
- Processed ore from >60 mines

IMPOUNDMENTS

- 4 impoundments
- Impoundment 1 built in 1935
- Impoundment via slurry

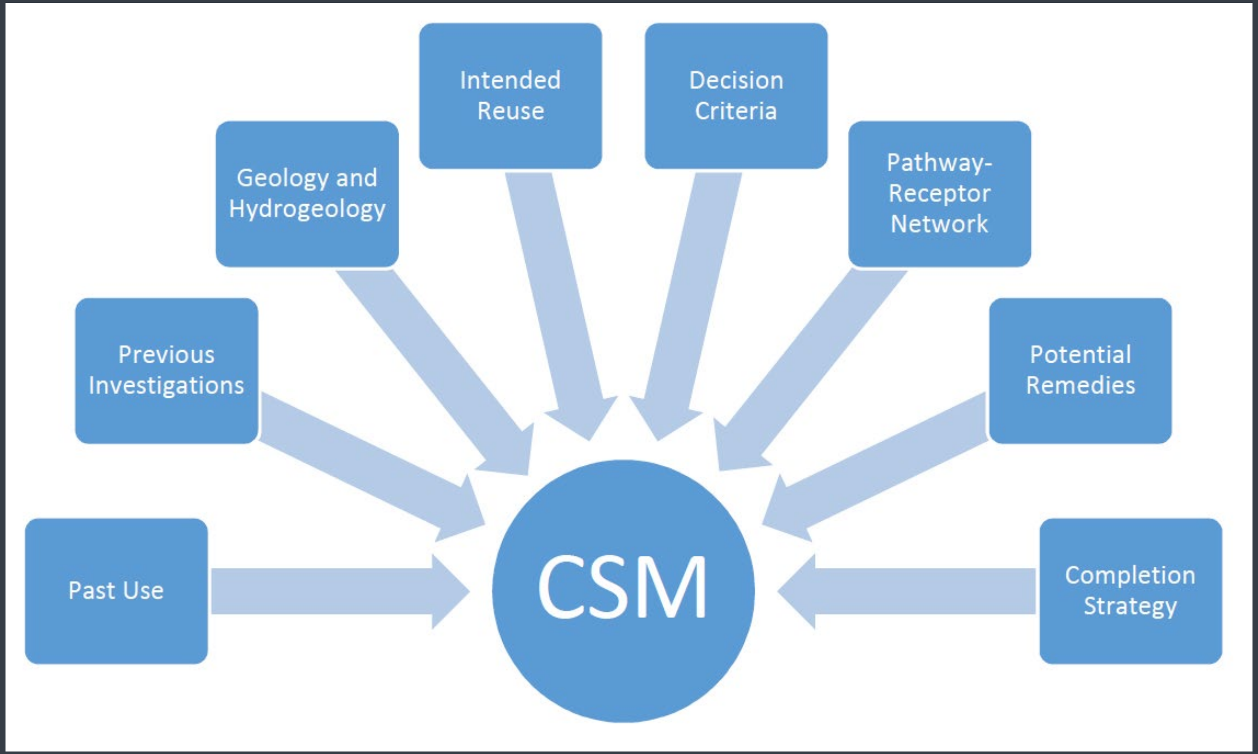

TP-4
TP-3
TP-2
TP-1
1875


June @ 9300’


June @ 10,000’

Conceptual Site Model

- Past Use
- Previous Investigations
- Media and Transport (Geology and Hydrogeology)

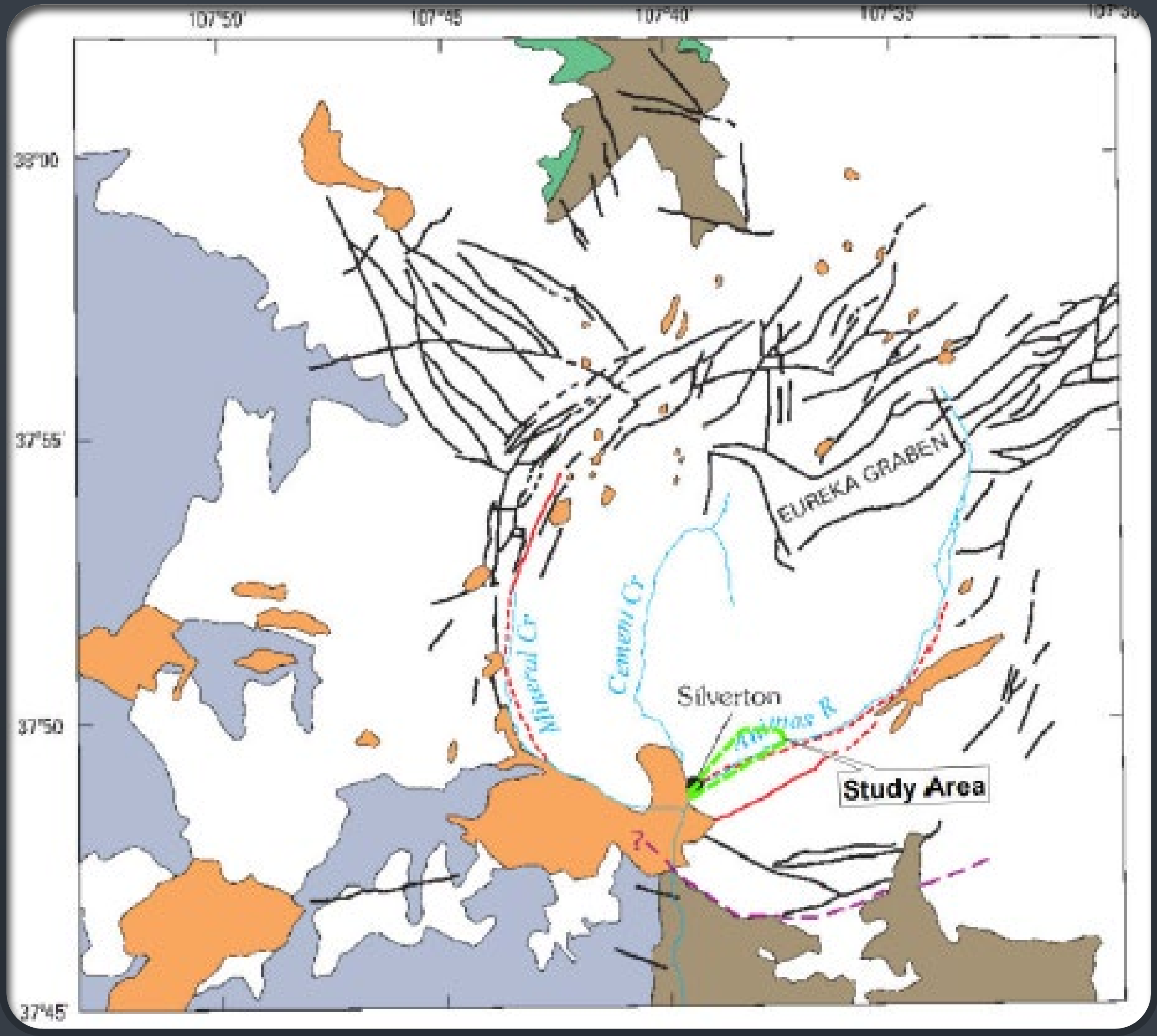


Geology

“Caldera ring faults and associated veins of the Eureka graben and radial vein structures near the margin of the nested San Juan and Silverton Calderas are laterally and vertically continuous…”

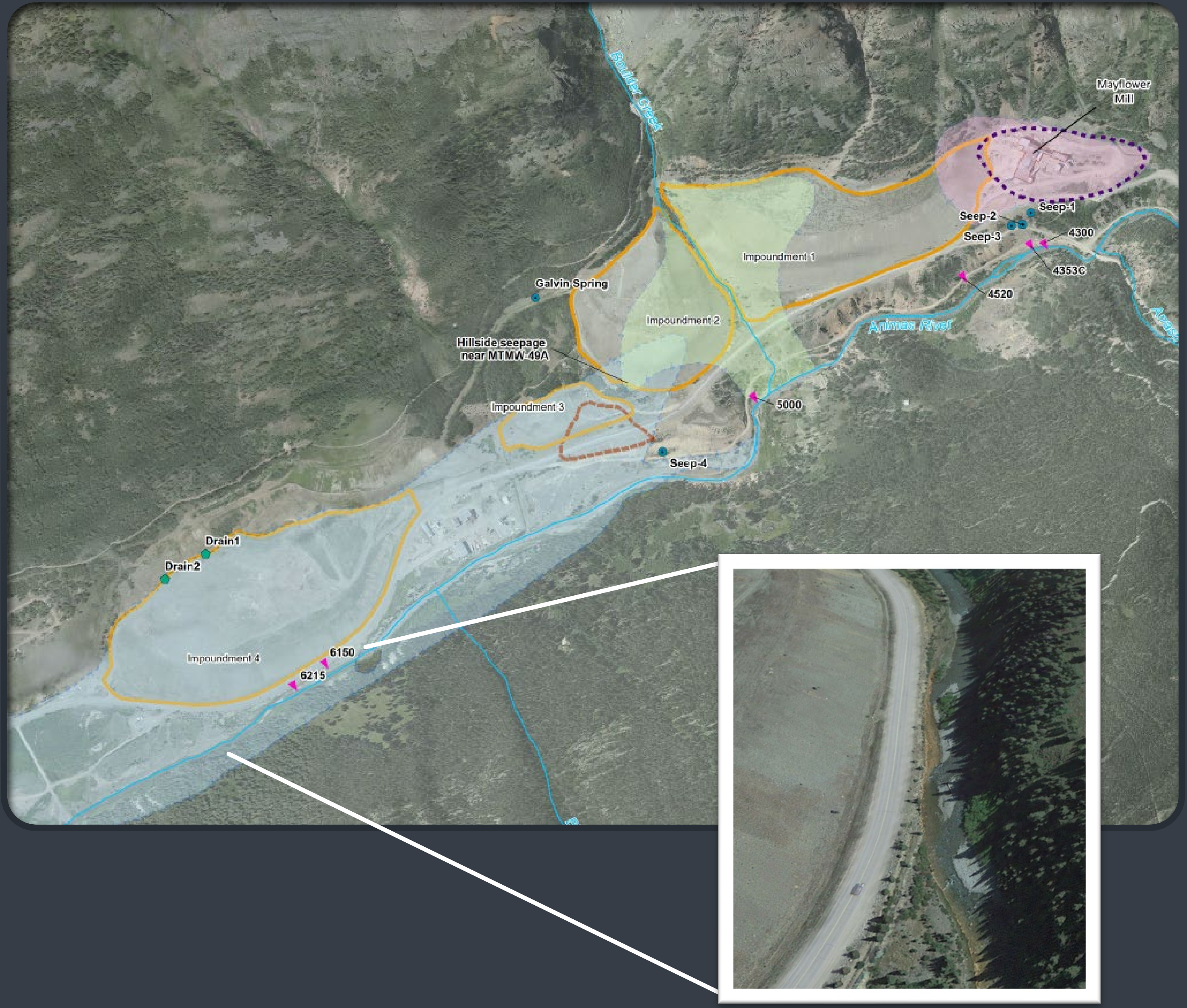
“Thus, these features may be important groundwater flow paths.”

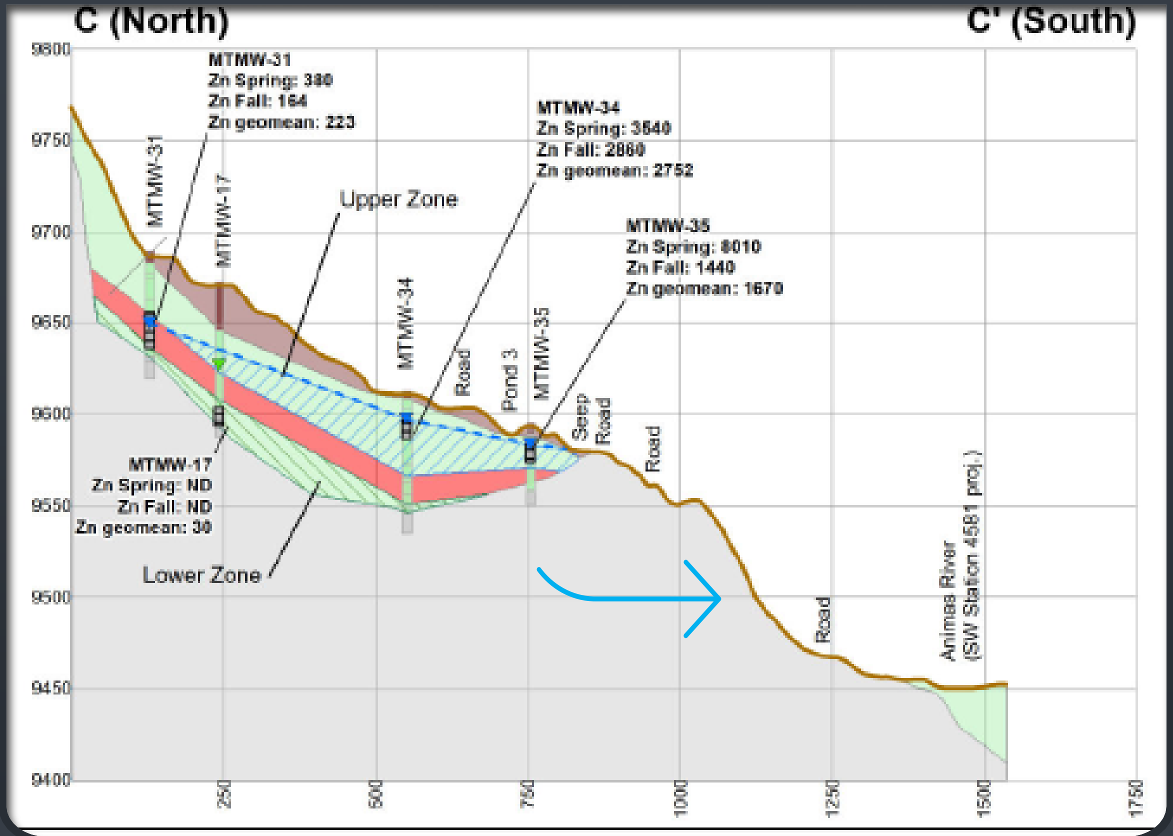
(Yager and Bove, 2007)



GROUNDWATER SYSTEMS

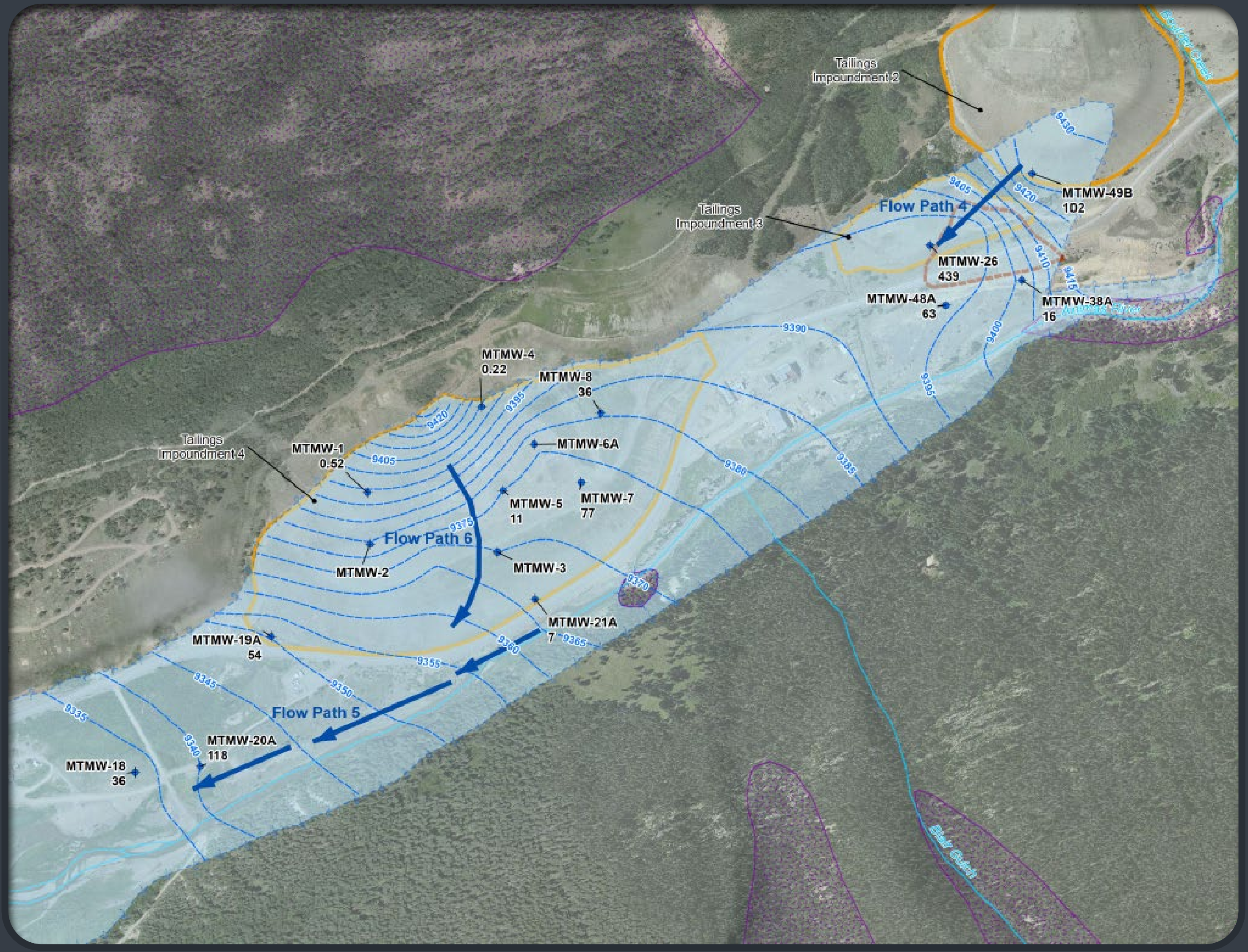
- 3 Aquifers
- All likely discharge to Surface Water
- Numerous significant seeps





MILL AREA

- Perched Aquifer over bedrock
- Closed basin
- Bedrock seeps

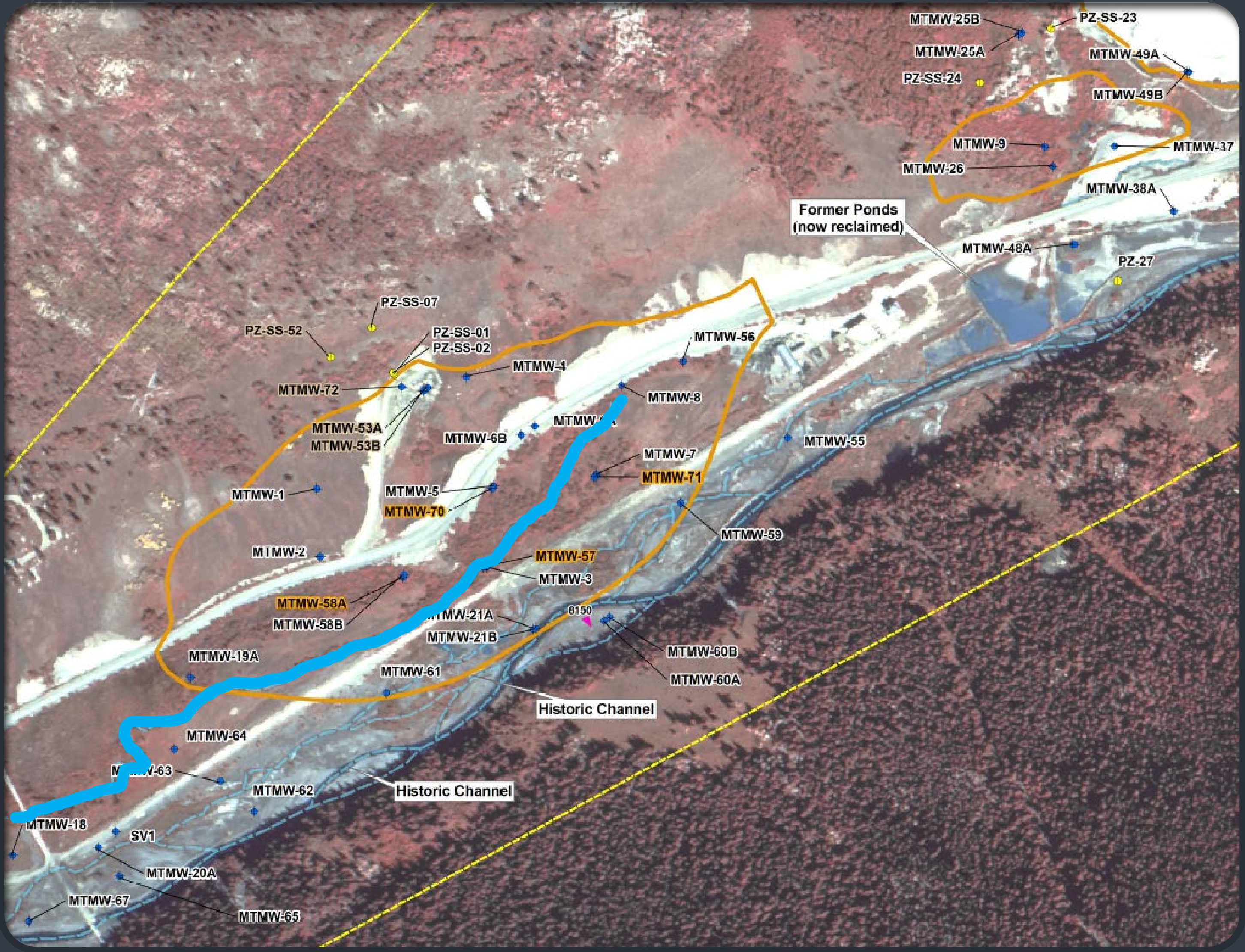


WESTERN GROUNDWATER SYSTEM

1972

- Before realigning river (and road)
- Numerous spring creeks and side channels

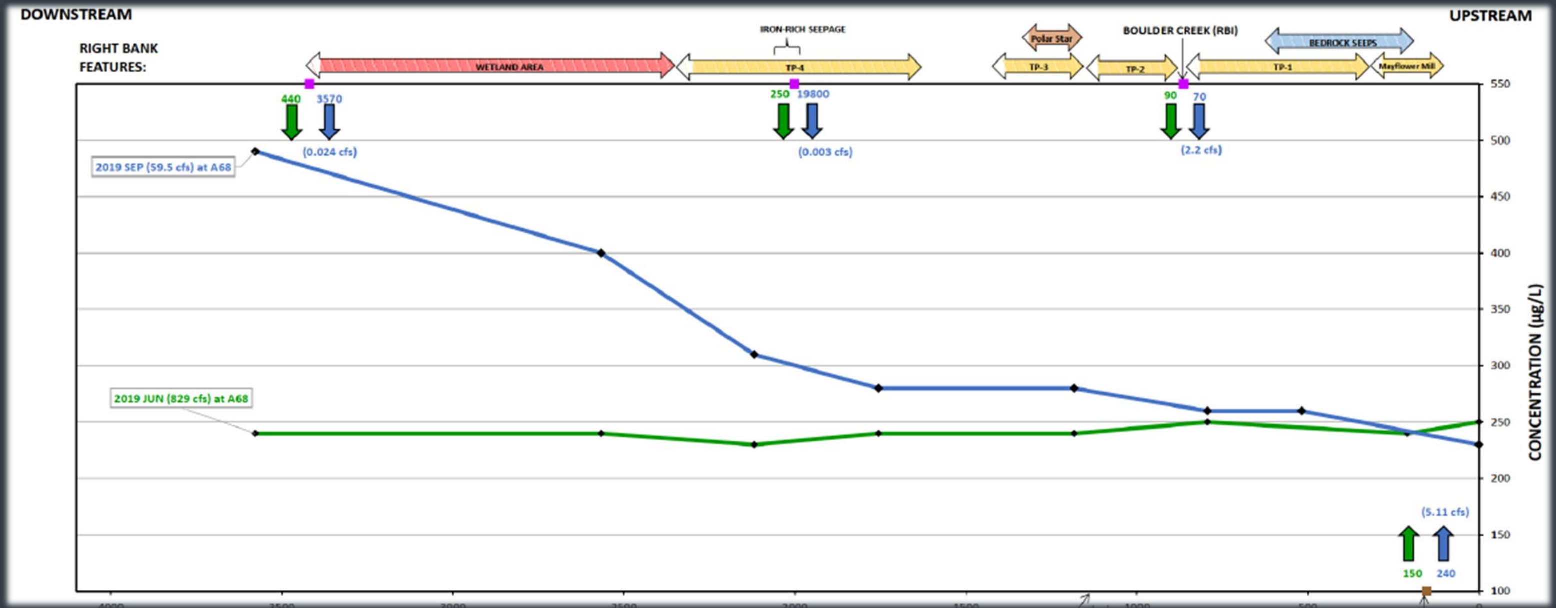
Preferential Pathways!



PREVIOUS INVESTIGATION RESULTS

SURFACE WATER ZINC CONCENTRATIONS

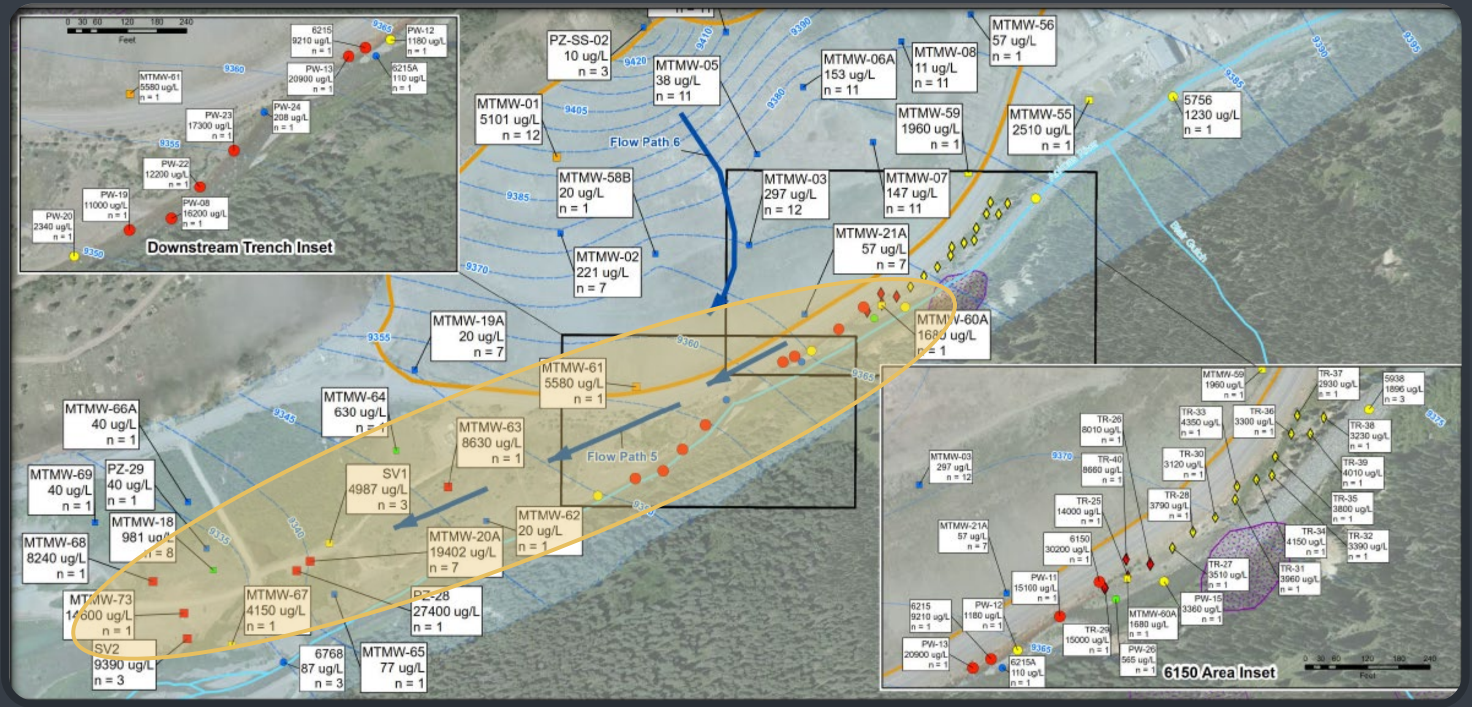
- Sitewide risk driver
- Overall goal to decrease zinc load in river
- Concentrations increase near observed seepage



FLOW

GROUNDWATER ZINC CONCENTRATIONS

- Greatest groundwater impacts along preferential pathways
- Porewater impacts near known seeps



DATA INDICATING GW/SW MAY BE SIGNIFICANT

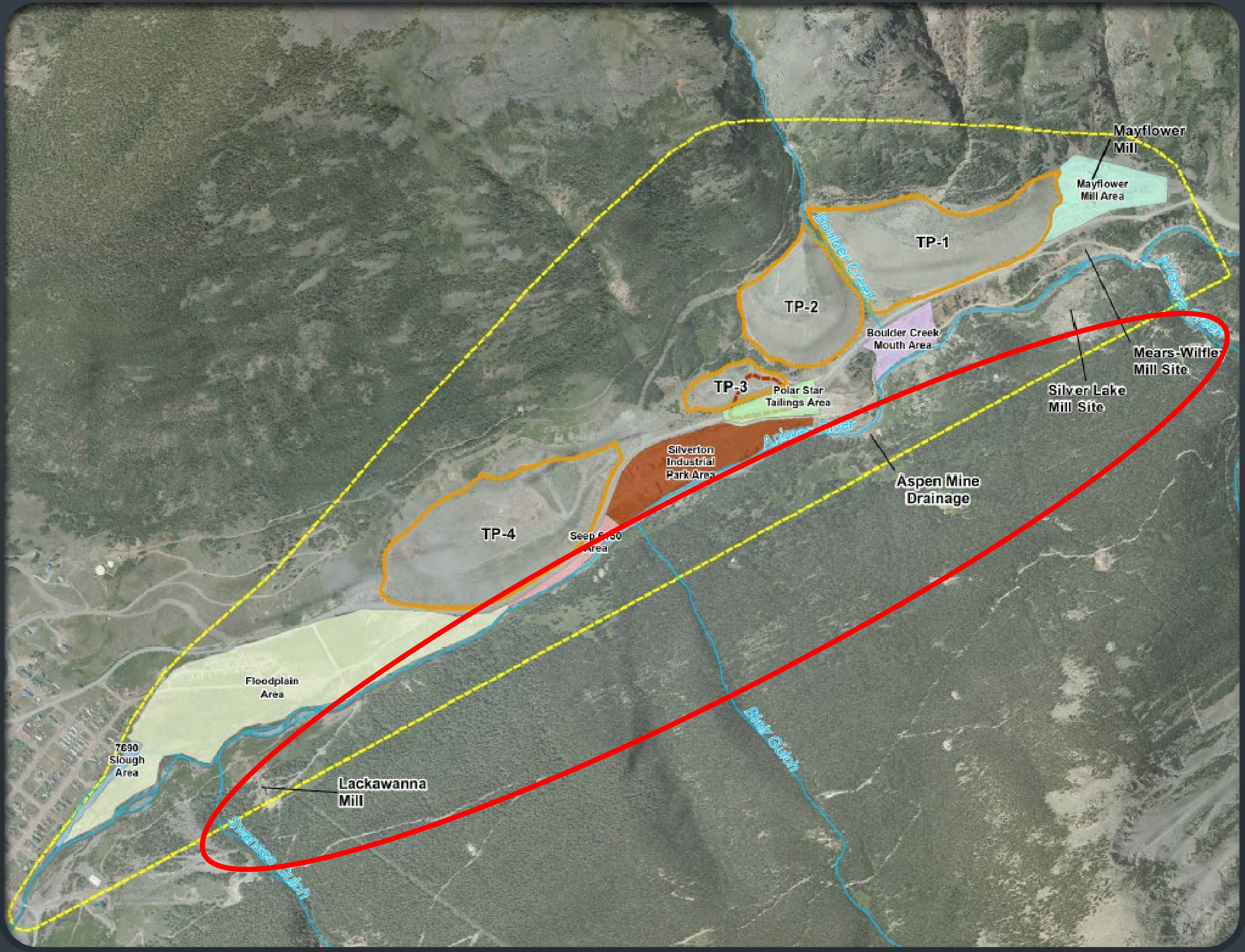
- Proximity
- Site History
- Faulting and fractured bedrock
- Seeps
- GW Potentiometric surface maps
- Surface Water Loading Profiles
- Groundwater Concentration Maps

OTHER CONSIDERATIONS

Other potential sources exist in study area

Natural loading may be high (Background)

Limited impacts in GW below impoundments

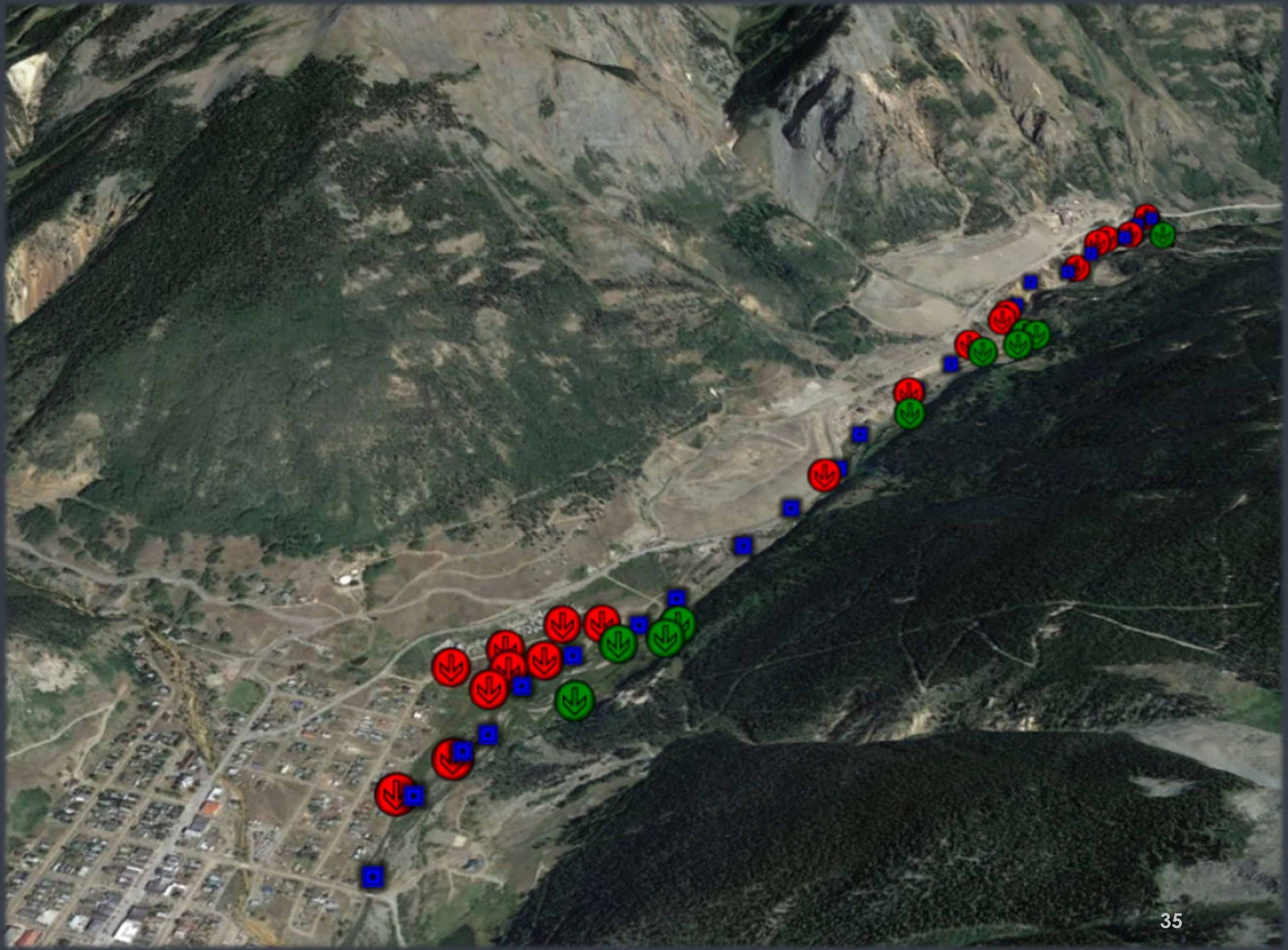


DATA NEEDS

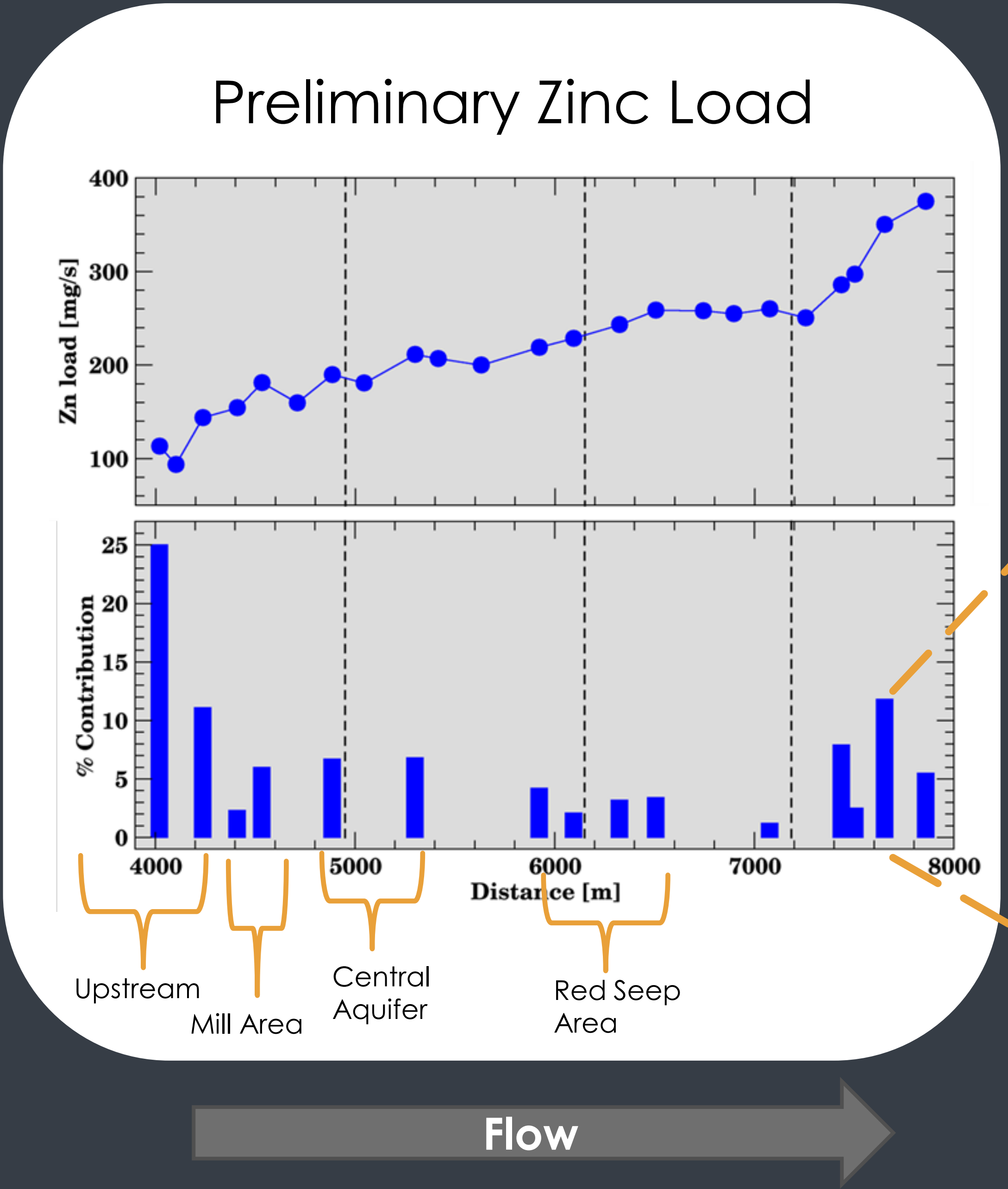
- High Resolution Surface Water Sampling
  - Tracer test
  - Equal Discharge Increment channel sampling
- Identification of discharge zones below the water table
  - FO-DTS to identify sampling targets
- Evaluation of deep groundwater pathway
  - Geophysical investigation
  - Seep sampling

TRACER TEST SAMPLING LOCATIONS

- More accurate estimate of Stream Flow
- Constant tracer injection rate
- Bromide
- Dilution used to determine flow



PRELIMINARY TRACER TEST RESULTS



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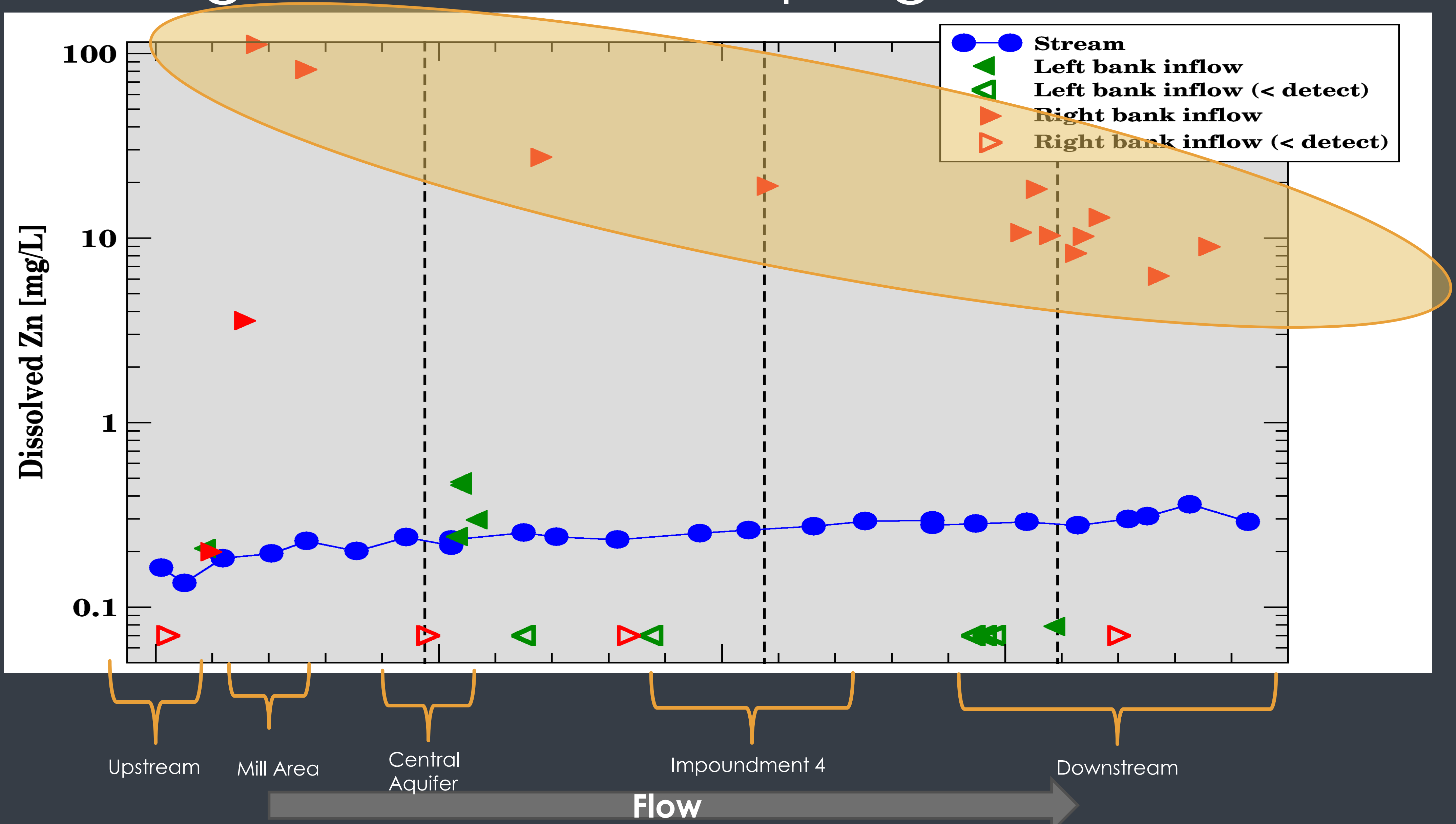
High Resolution Sampling Results



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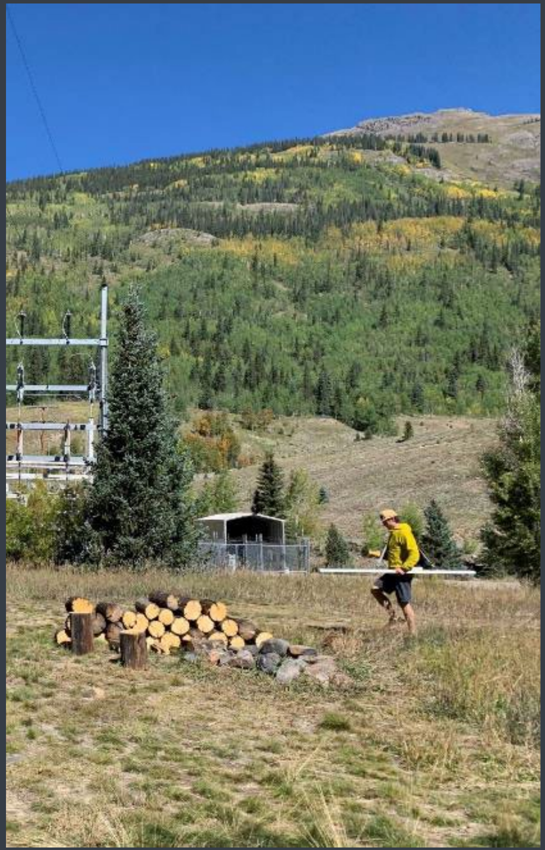
GEOPHYSICAL CHARACTERIZATION APPROACH

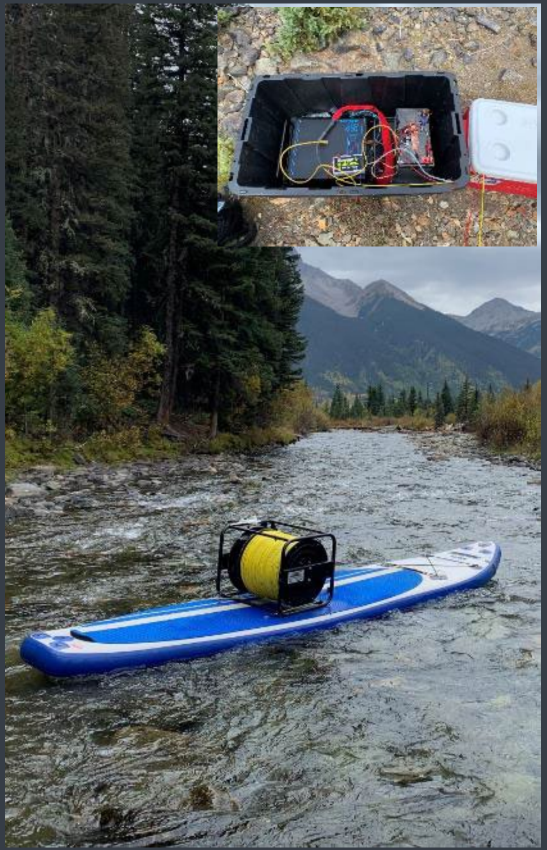
- Fiber Optic Distributed Temperature Sensor (Red/Green)
  - GW Discharge
- Electromagnetic Survey (White)
  - Bulk Electrical Conductivity
  - Fluids + Solids
- Magnetics Survey (White)
  - Ferrous materials
  - Solids

Data Release: Near-Surface geophysical data collected along streams near Silverton, CO, USA. 2020. DOI:10.5066/P97HDPAY



GEM2 FDEM

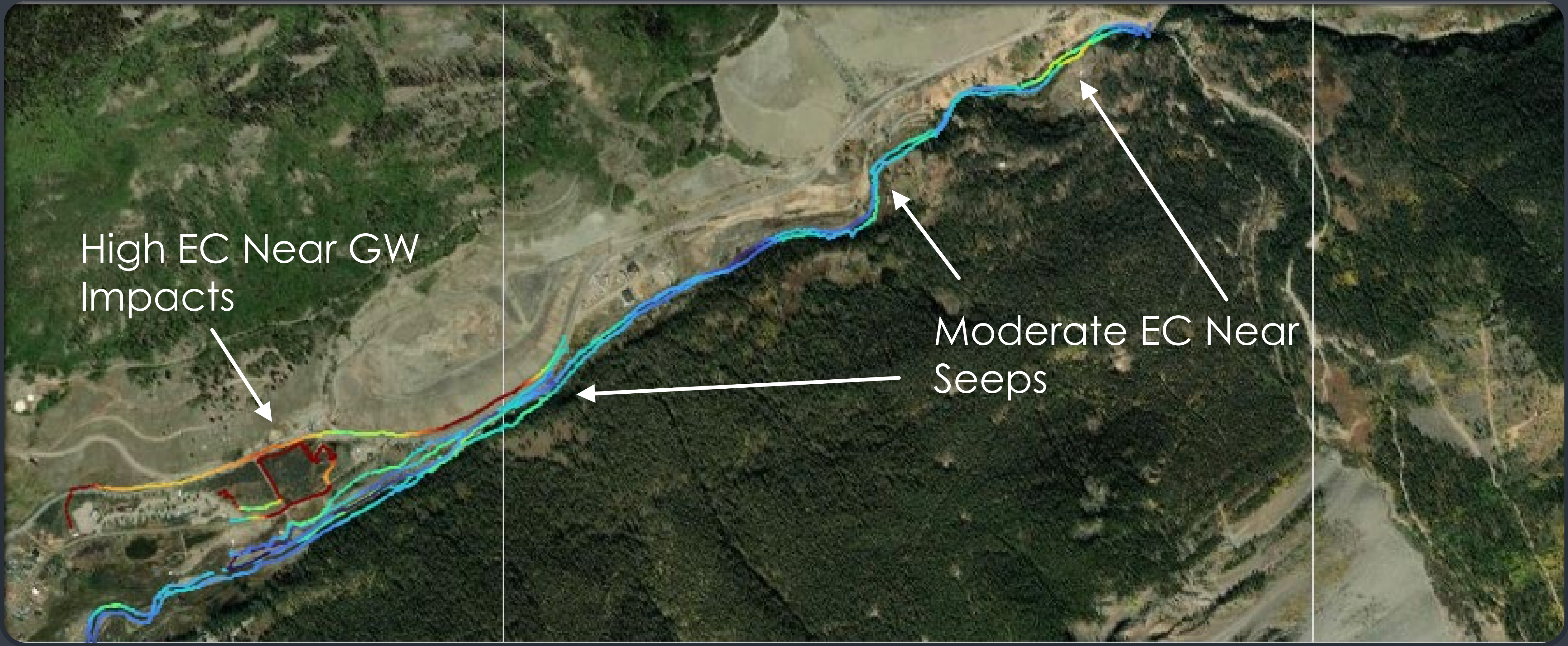
Geometrics G-858 Magnetometer



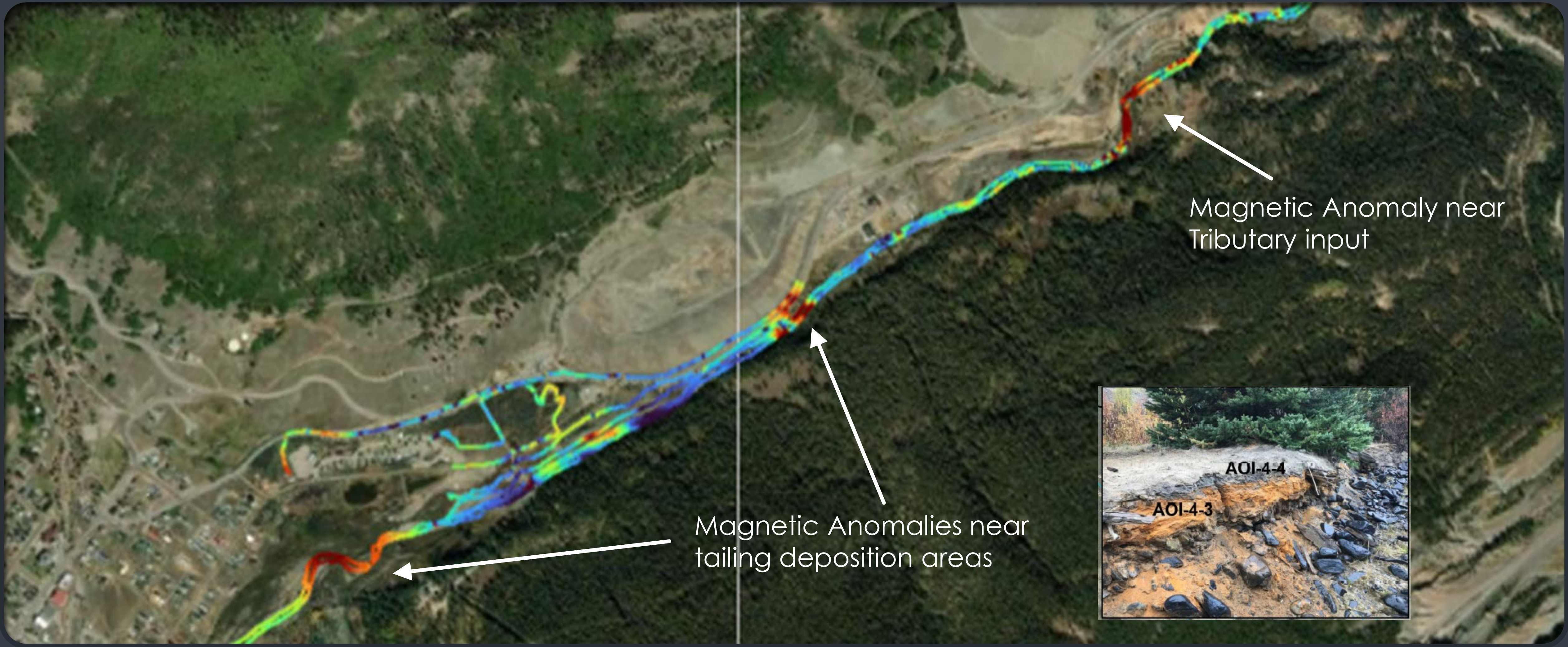
FO-DTS

Slide Courtesy of Dale Werkema, EPA ORD

GEM2 Apparent Electrical Conductivity



Magnetic Susceptibility



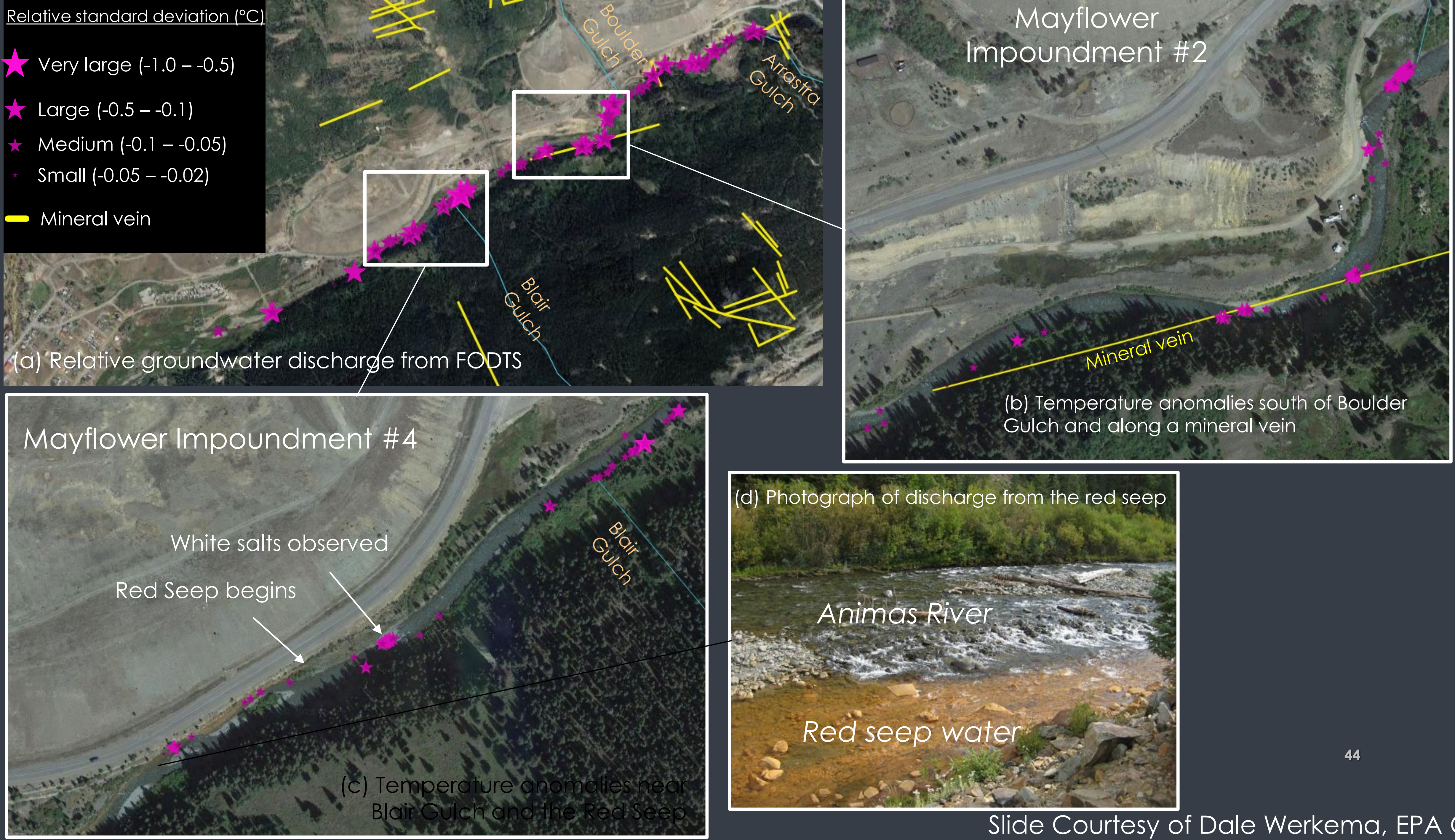
FIBER OPTIC-DISTRIBUTED TEMPERATURE SENSORS

- Temperature can affect glass fibers and locally change light transmission characteristics of the fiber
- Gives nearly continuous temperature measurements
- Identify heterogeneity in streambed and identify areas of enhanced seepage

FO-DTS Data Interpretation

- GW temperature is relatively constant
- SW temperature varies throughout the day
- Standard deviation of temperature data is low near GW discharge zones
- Seep size can be inferred from standard deviation

Slide Courtesy of Dale Werkema, EPA ORD



Slide Courtesy of Dale Werkema, EPA ORD

UPDATED CSM

- Multiple lines of evidence suggest Impoundment 4 impacts GW and SW
- Mineral veins likely preferential GW discharge zones
- GW seeps are more prevalent above Impoundment 4
- North tributary transports large amounts of magnetic material (tailings)

NEXT STEPS

SEEP SAMPLING

ADDITIONAL GW INVESTIGATION/DELINEATION

INVESTIGATION OF POTENTIAL TAILINGS DEPOSITION AREAS

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