Application of Tracer Studies in Assessment of Abandoned Mines

Examples from two abandoned mines

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August, 2014

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Tracer Studies

- Broad application in assessment of abandoned mines
- Provides empirical information to inform and test CSM
  - MIW generation
  - Contaminant transport pathways
  - Effects to receiving waters
- Supports assessment of complex subsurface transport pathways
  - Porous media flow
  - Fracture flow
  - Pipe flow

Two Examples:

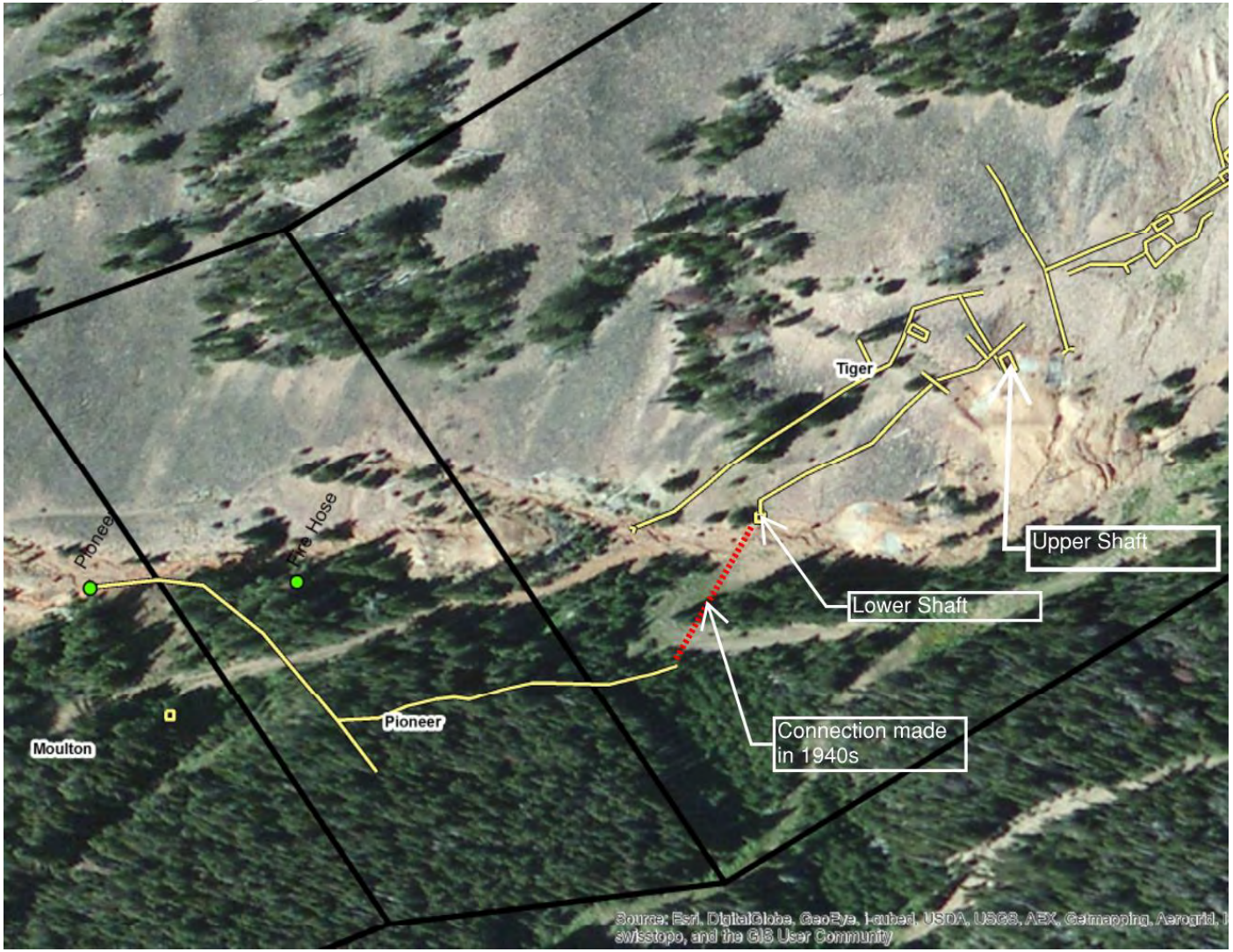
Tiger Mine, Montana

- Designed to characterize infiltration pathways for water flowing into the mine
  - Support assessment of approaches to reduce infiltration
- Based on CSM
  - Geometry of UG workings
  - Points of infiltration
  - Discharge points
- Two fluorescent dye tracers

Blue Ledge Mine, California

- Designed to assess MIW inflows to surface water
  - Dispersed inflow from groundwater
  - Inflows from springs and tributaries
- Based on CSM
  - Surface discharges from mine waste dumps
  - Discrete discharge from adit portals
- Salt tracer

Tiger Mine: General Overview



Tiger Mine: Fluorescent Dye Tracers Used

Eosine

- Use in tracing for ~50 years
- Fluorescence not dependent on pH
- Light sensitive
- Low sorption properties

Fluoroscein

- Used in tracing for >100 years
- Fluorescence decreases in acidic waters
- Light sensitive
- Low sorption properties

- Eosine and Flourscein often used together in tracer studies
- Laboratory methods provide for quantitative measurement of both tracers in water samples or charcoal packets

Injection of Fluorescent Dye Tracers

Dye placed on melting snow

Dye injected in solution

Monitoring of Fluorescent Dye Tracers

Charcoal Detector

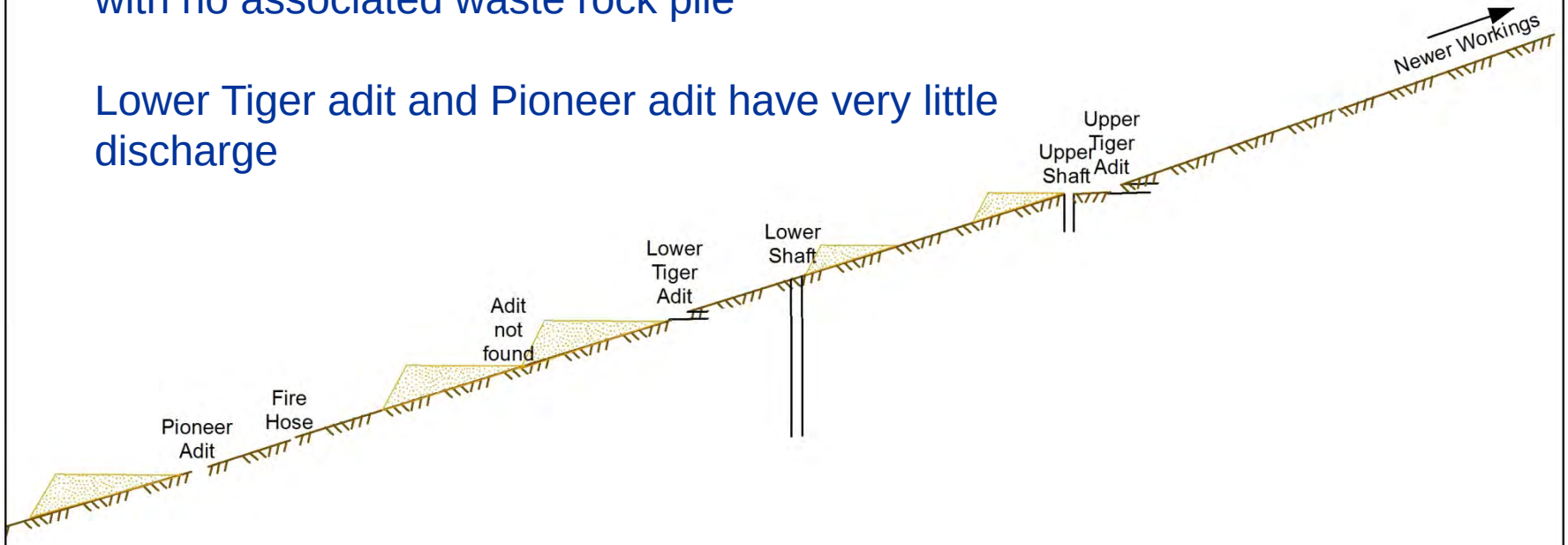
Charcoal Detector Installed at MIW Discharge Point

Tiger Mine Known Surface Configuration

Several waste rock piles – assume an adit at each pile
Two shafts – one open more than 100 feet

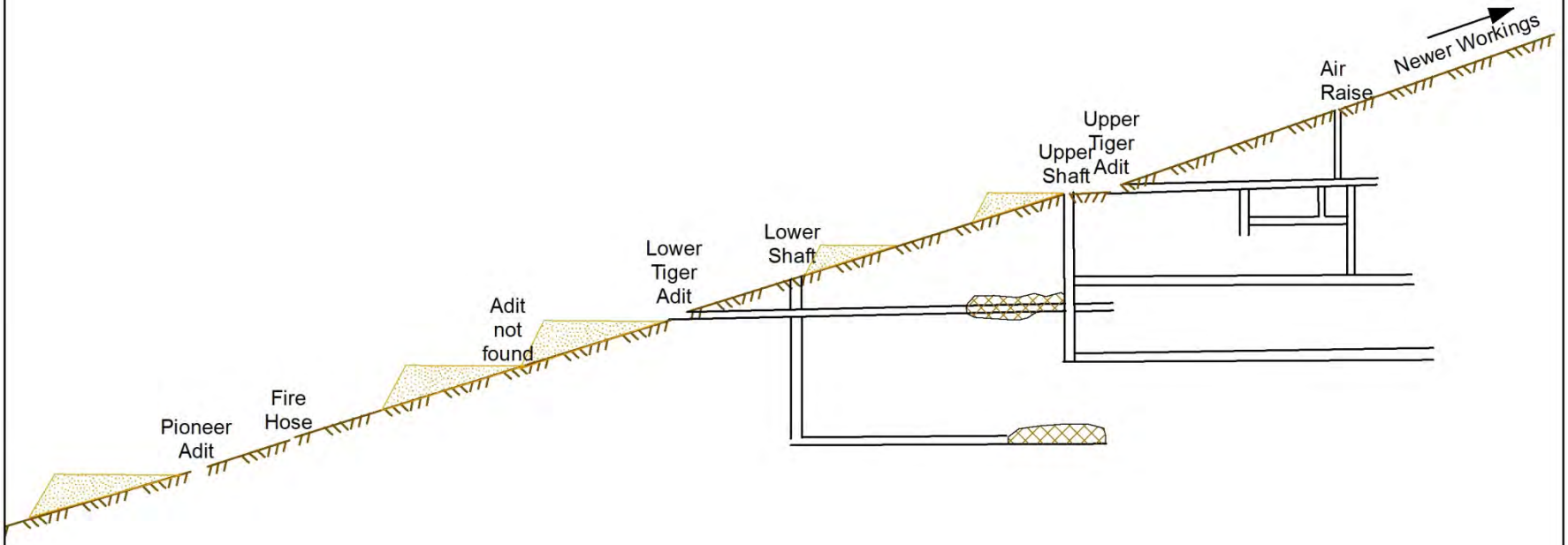
Fire Hose is a significant seasonal discharge of MIW with no associated waste rock pile

Lower Tiger adit and Pioneer adit have very little discharge



Tiger Mine Known Surface Configuration plus 1900 workings cross-section

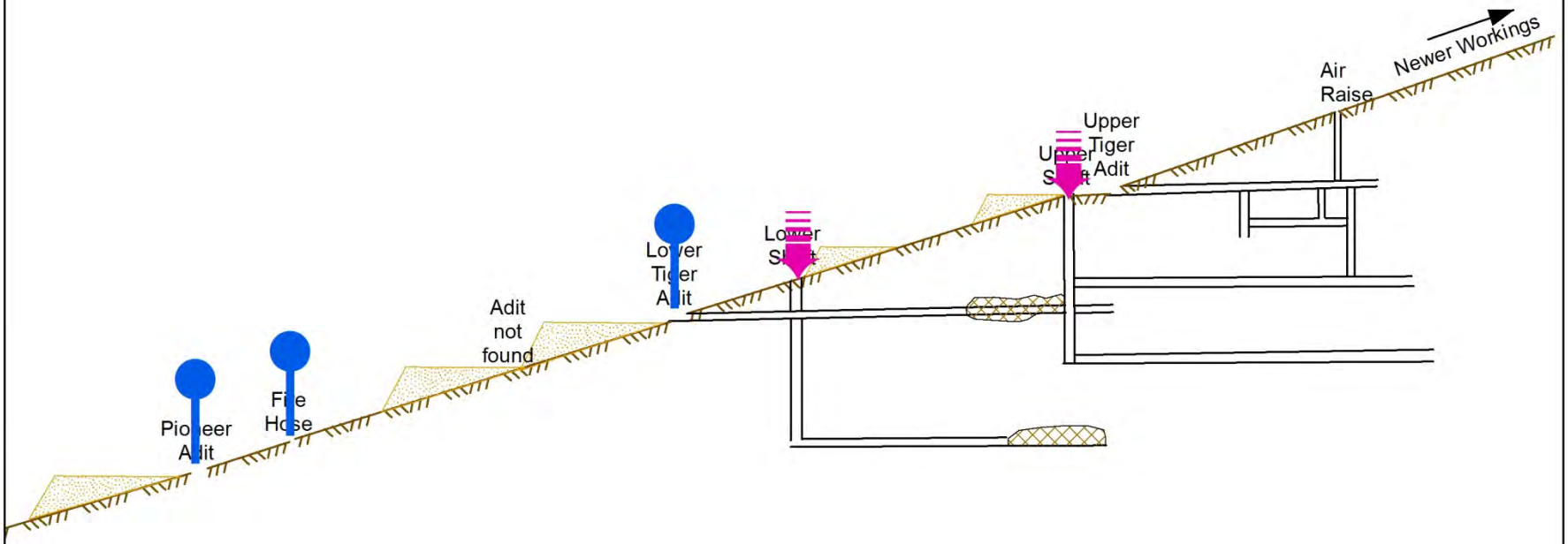
Shafts are not connected
No drain for lower shaft on cross-section



Tiger Mine Tracer Injection

Injected dye into shafts and flushed with water (pink arrows)

Monitored at adits and Fire Hose using charcoal packets (blue lolipops)

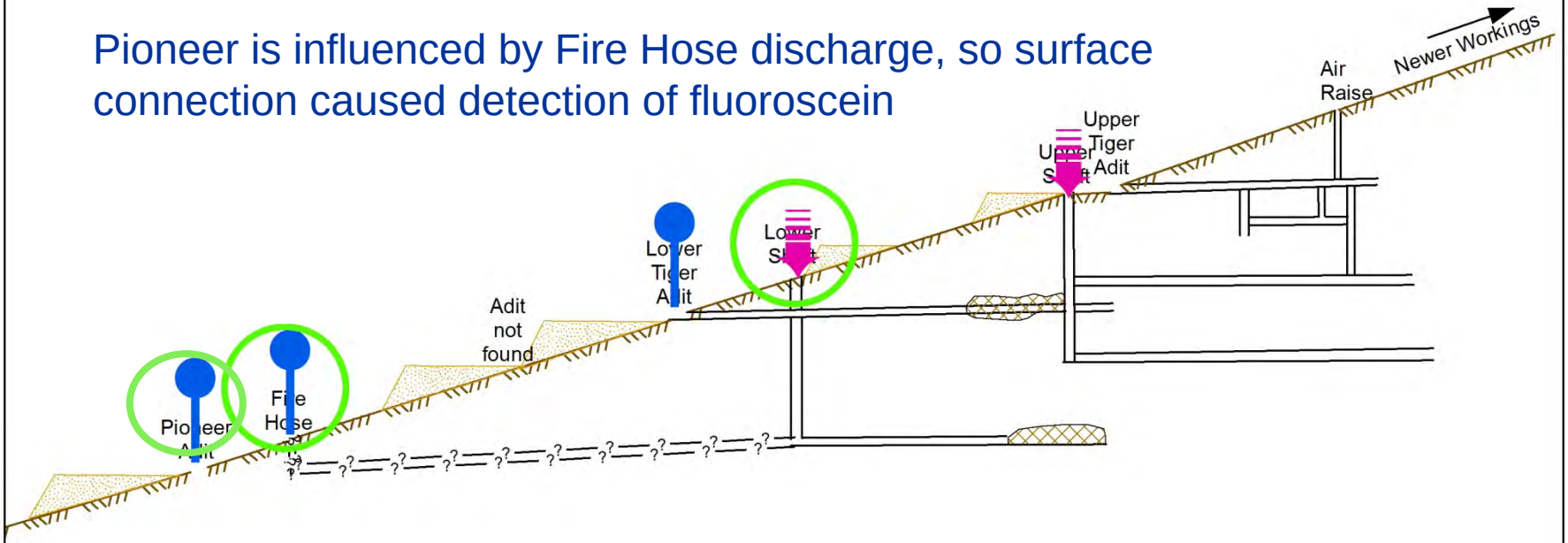


Tiger Mine Tracer Injection Results

Fluoroscein found in Fire Hose, Pioneer, and downstream surface water (green circles)

Lower shaft and Fire Hose must have subsurface connection

Pioneer is influenced by Fire Hose discharge, so surface connection caused detection of fluoroscein

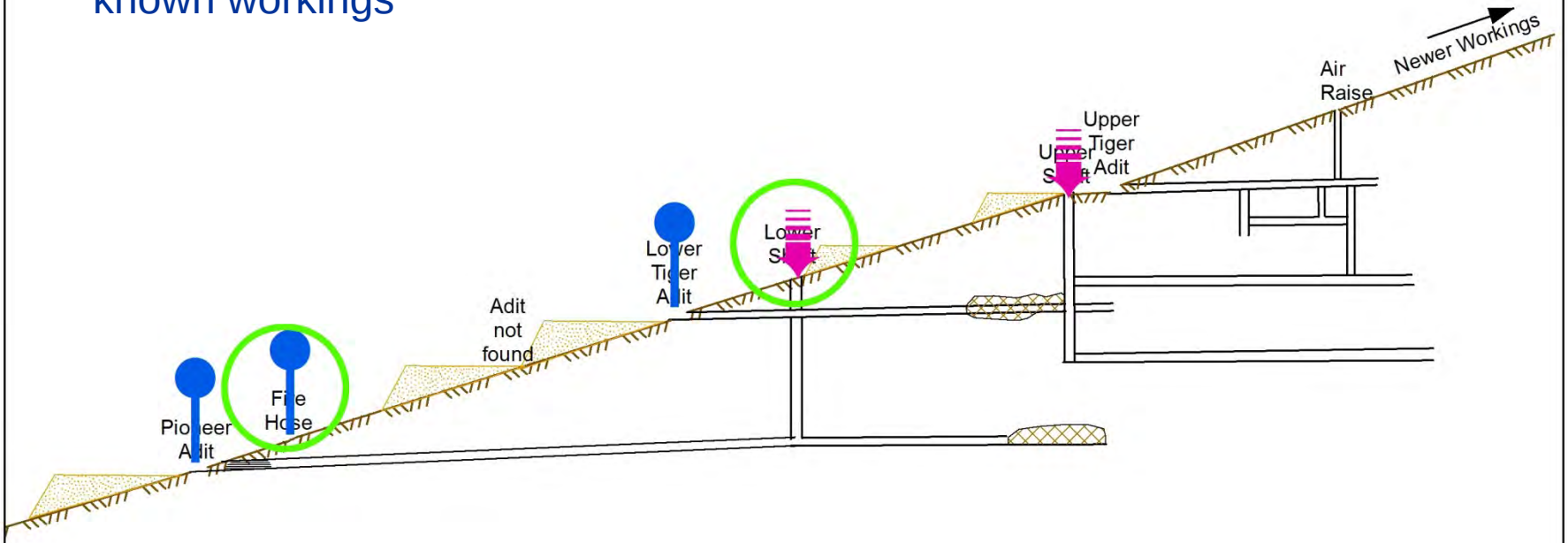


Eosine from Upper shaft not detected in any samples

Tiger Mine with 1940 Cross-Section

Additional workings cross-sections were found after the tracer injection test was completed

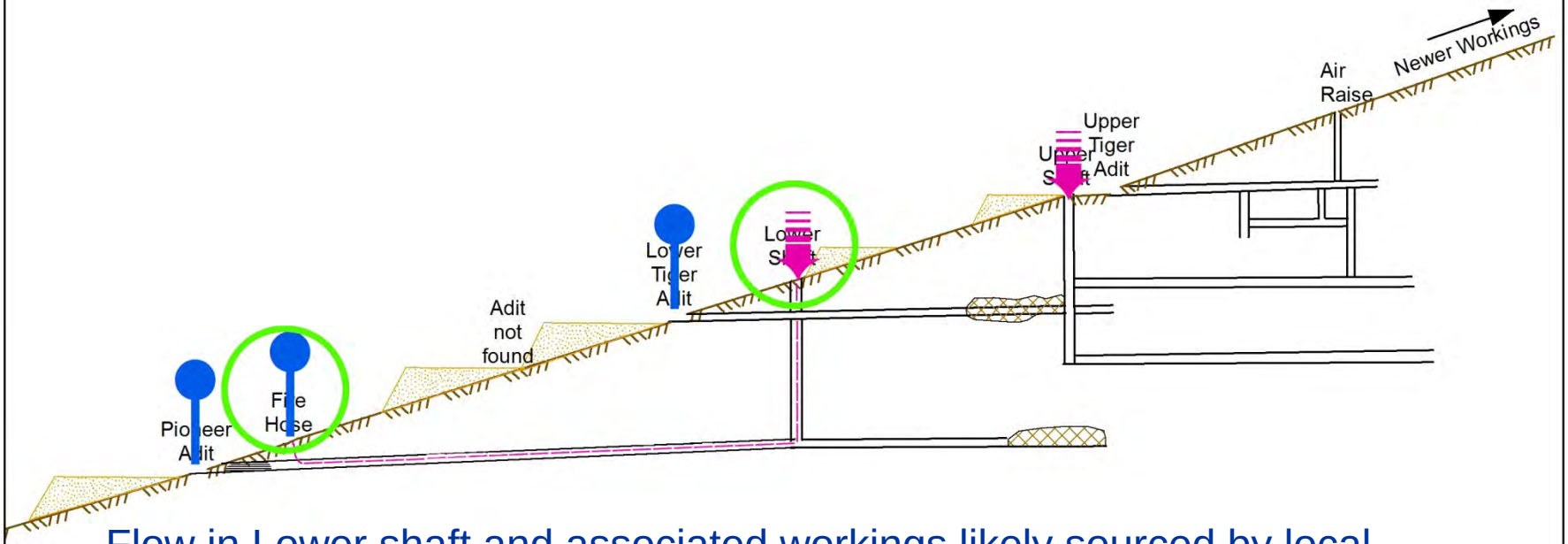
Lower shaft is connected to the Pioneer adit, but Fire Hose has no known workings



Tiger Mine Results

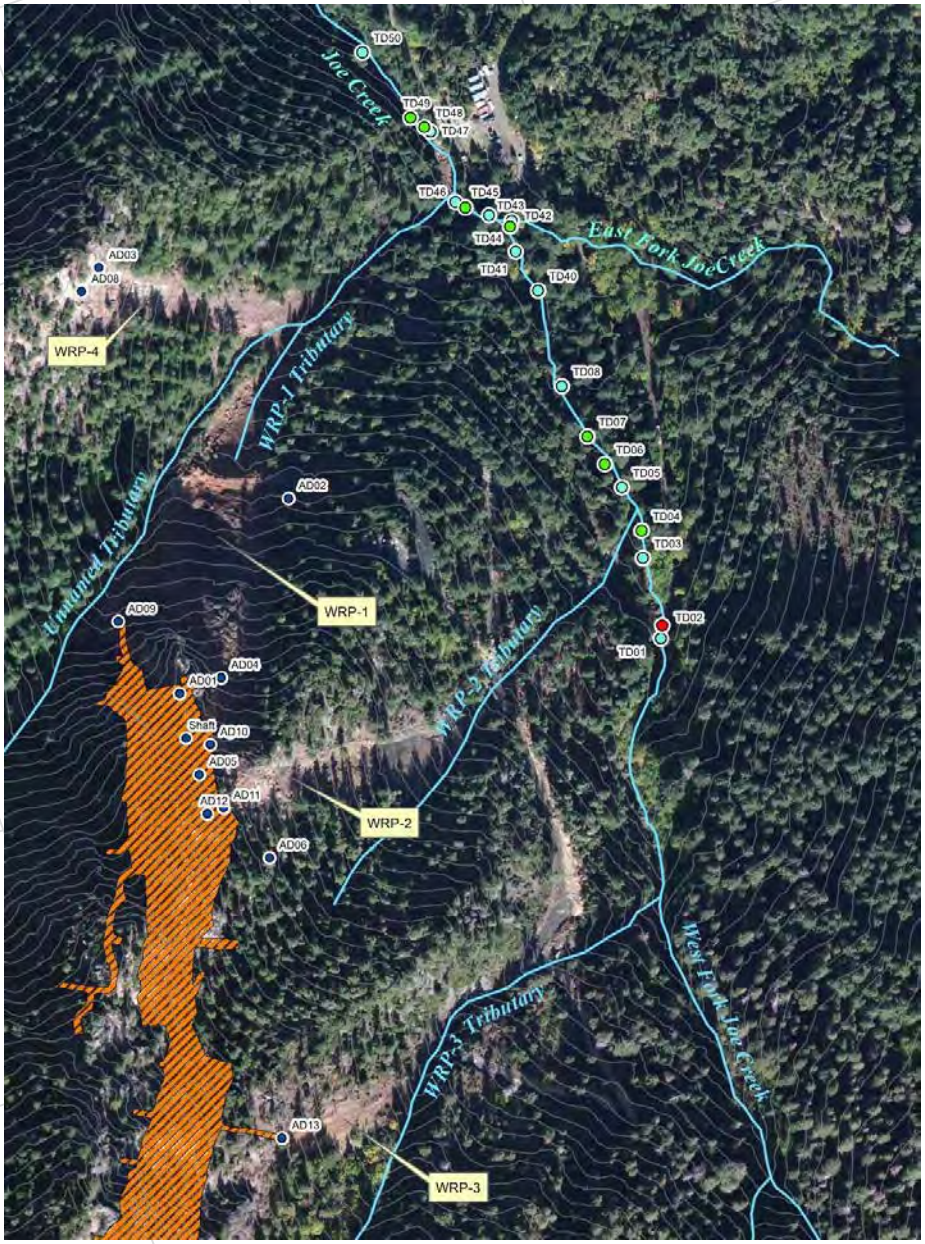
Pioneer adit is collapsed and flows very little

Fire Hose flows with exuberance during spring melt



Flow in Lower shaft and associated workings likely sourced by local snowmelt into Lower shaft and workings because of seasonal nature

Fire Hose is likely a fracture allowing relief around collapsed Pioneer Adit



Blue Ledge Mine: Tracer Dilution Test

- Designed to assess effects of underground mine workings and former waste rock dumps on Joe Creek
  - Identify MIW transport pathways to Joe Creek
- Tracer Injected into Joe Creek at known rate
- Tracer dilution measured downstream to estimate discharge
- Water chemistry measured downstream to estimate loading

Blue Ledge Mine: Selected Tracer

Sodium Bromide

- Appropriate for circumneutral pH MIW
- Background concentration of bromide very low in natural waters
- Not light sensitive
- Low sorption properties
- Relatively inexpensive

Blue Ledge Mine: Tracer Injection

Tracer injected for 24 hours prior to sampling

Chemical Metering Pumps

Tracer Injection Lines

Monitoring of Bromide Tracer

All springs sampled for tracer and water quality parameters

Numerous points sampled within Joe Creek

Tracer Dilution- Calculation of Discharge

$$Q_S = \frac{Q_{INJ} C_{INJ}}{C_A - C_{BG}}$$

Where:

Q_S= Stream flow at sampling point

Q_{INJ}= Tracer injection rate

C_A= Tracer concentration at plateau

C_{INJ}= Tracer injection concentration

C_{BG}=Background tracer concentration

- Tracer dilution method provides for accurate calculation of discharge in turbulent mountain streams
- Calculated discharge includes flow in hyporheic zone of stream
- When coupled with water chemistry, provides for accurate calculation of loads

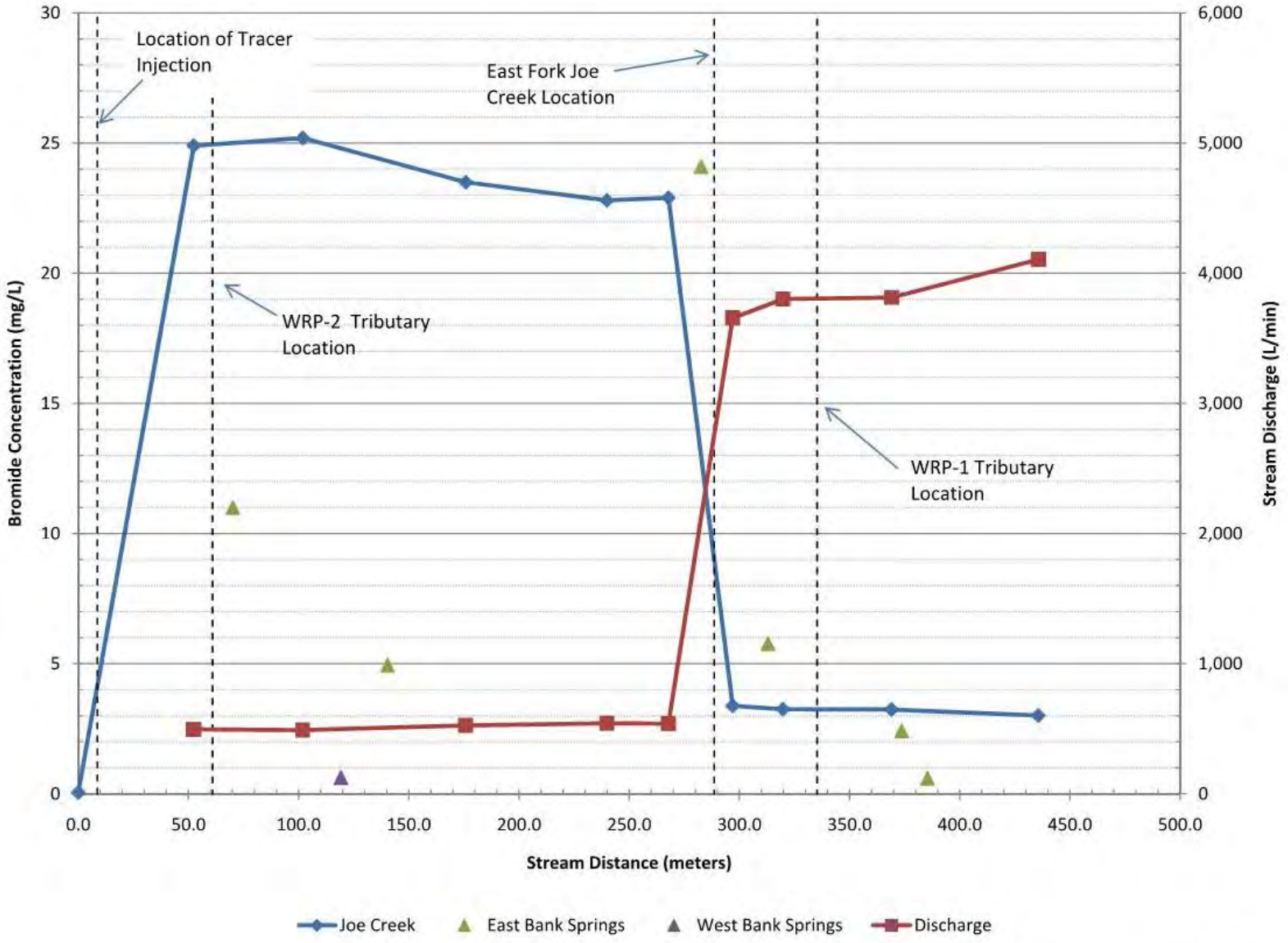


Figure 2

Tracer Dilution Test : Bromide Data and Calculated Discharge

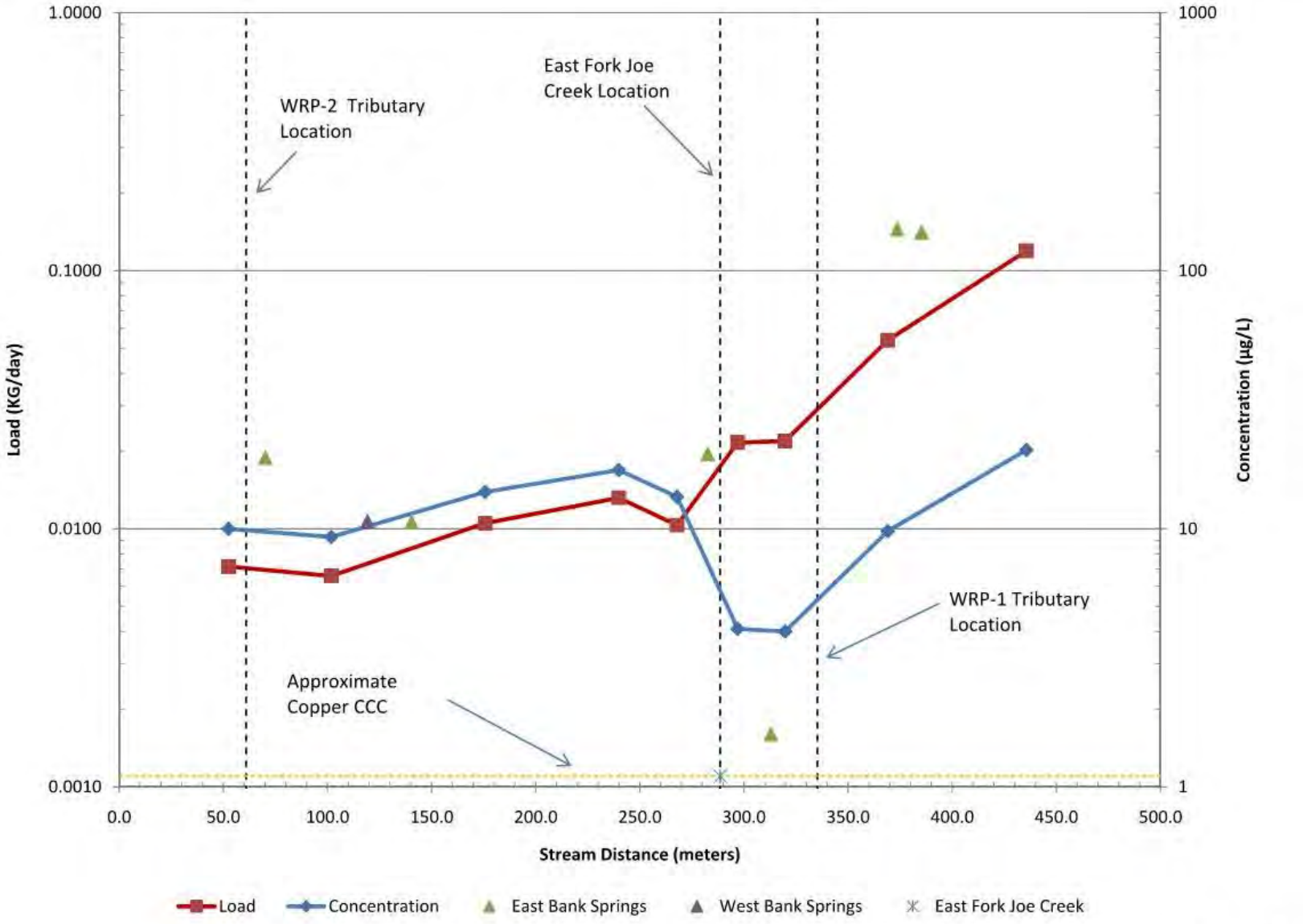


Figure 3
Tracer Dilution Test: Copper Data

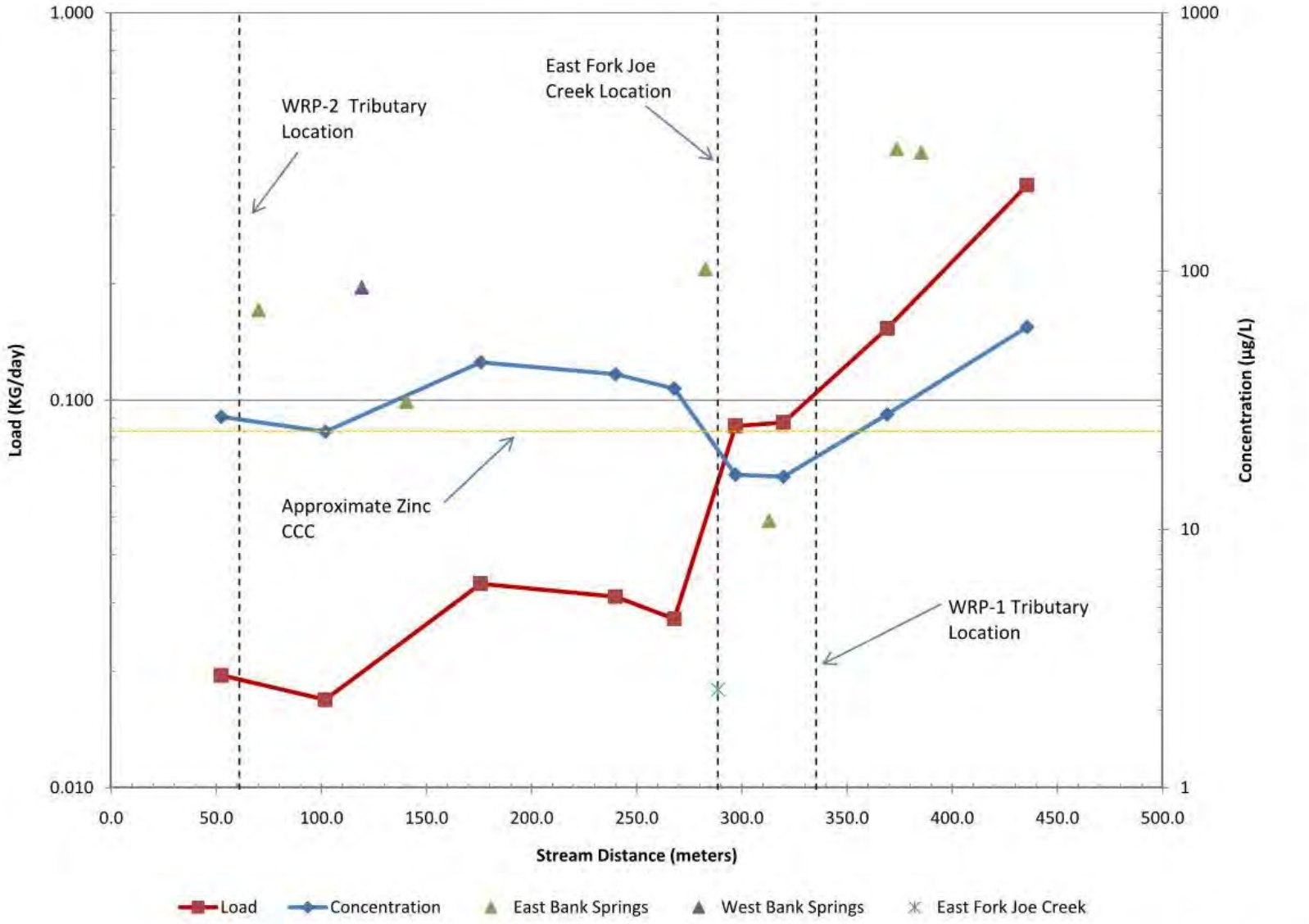


Figure 4
Tracer Dilution Test: Zinc Data

Blue Ledge Mine Results

- Groundwater inflows to Joe Creek are a major contributor to water quality effects
  - Remediation of known surface discharge points only (i.e. adit portals, waste rock dumps) would not be expected to markedly improve Joe Creek water quality
  - Previously unidentified area downstream of Joe Creek and on opposite side of the creek causing major effects to water quality
    - These source materials were delineated in 2014
- CSM modified as a result of tracer test data
- Tracer test data provided for evaluation of MIW transport in groundwater prior to installation of monitoring wells
  - Potential installation of monitoring wells in the future will be guided by tracer test data

Conclusions

- Broad application in assessment of abandoned mines
- Can be used in both qualitative and quantitative approaches
  - Presence/absence surveys to assess contaminant transport pathways
  - Quantitative tracer dilution tests
- Provides empirical data to inform and test CSM
- Efficient approach to investigate complex subsurface transport pathways
  - Porous media flow, fracture flow, pipe flow