

Characterization of Water Quality in a Hydrothermally Altered and Historically Mined Watershed, Warden Gulch, Colorado

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Project Background

- During the 1990's CGS participated in an inventory of historic and abandoned mines on US Forest Service lands.
 - Environmental degradation rating
 - Physical hazards present
- Two mines in Warden Gulch were rated with an Environmental Degradation Rating of 4 (out of 5).
- In 2003, the USFS requested a watershed characterization study as well as more detailed studies on two mines in Warden Gulch.

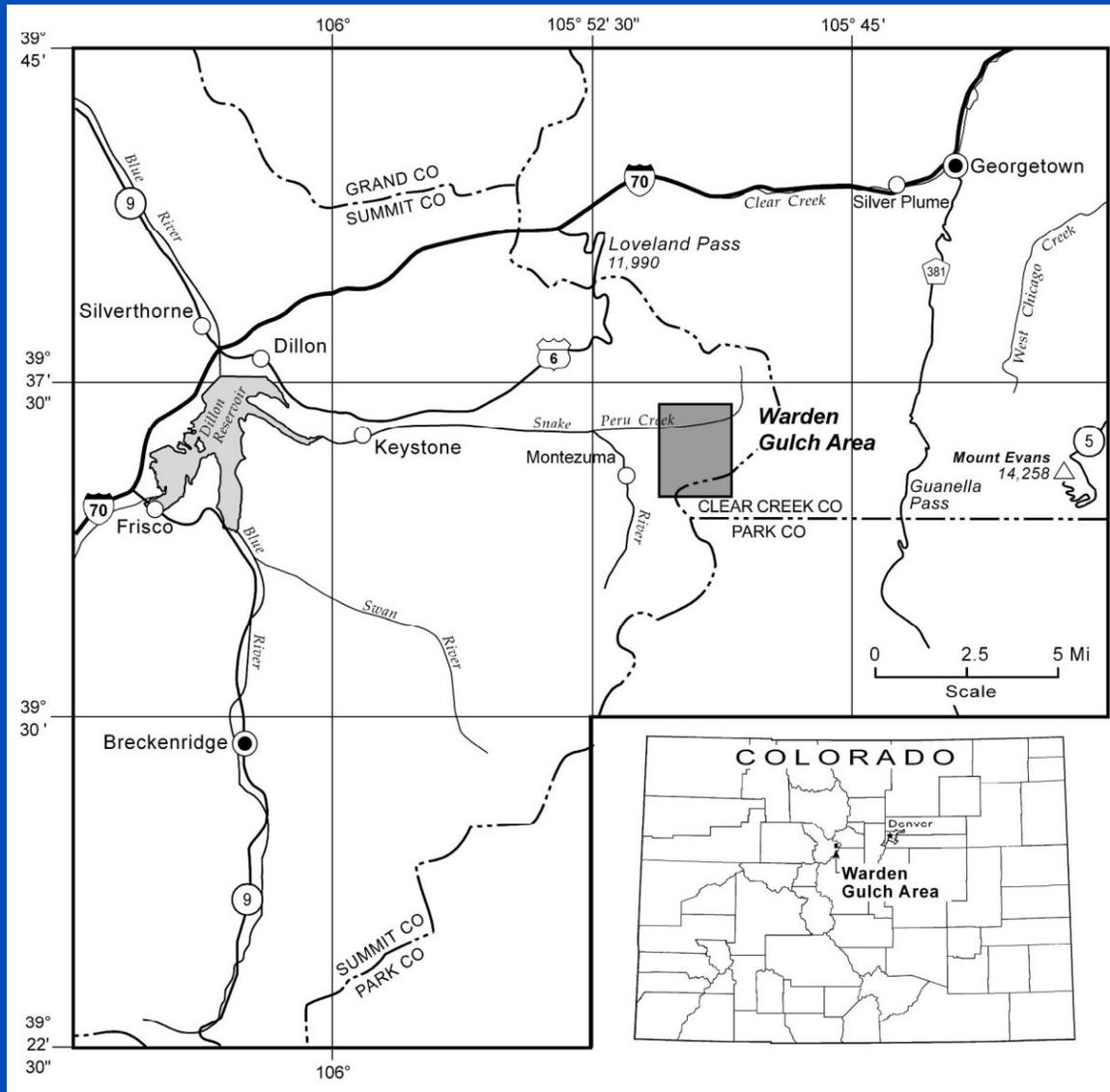


Project Objectives

- Characterize the water chemistry conditions throughout the watershed
- Determine the natural conditions present
 - Hydrothermally altered bedrock throughout the watershed contributing to Natural Acid Rock drainage?
- Determine the contribution and effect of historic mine workings on water chemistry
 - Draining mine workings contributing to Acid Mine Drainage?
- Differentiate between naturally occurring and anthropogenic water quality impairment



Warden Gulch



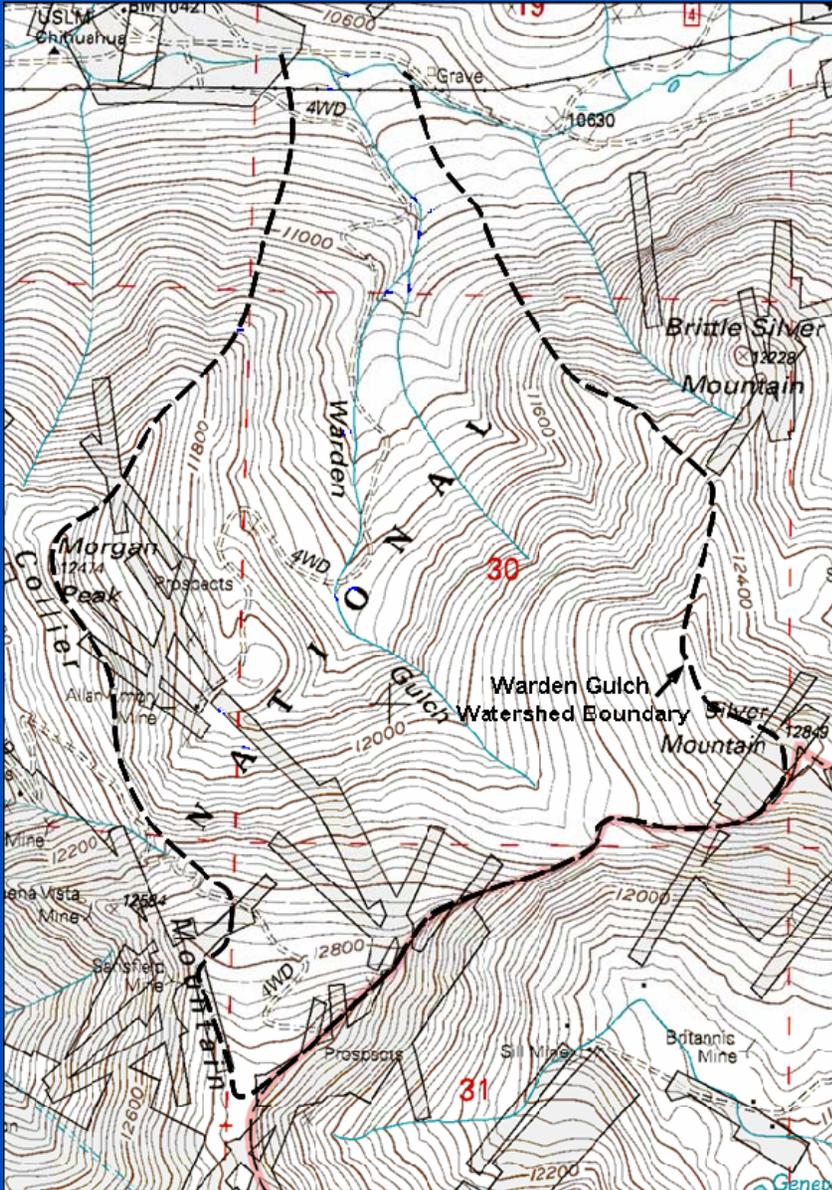
-70 miles West of Denver

-Snake River Watershed is the focus of ongoing restoration studies and remediation efforts

-Snake River upstream of Keystone has severely impaired water quality

Warden Gulch → Peru Creek → Snake River → Lake Dillon → Denver water supply

Warden Gulch



- Elevations range from 10,500' at the confluence with Peru Creek to 12,849' on Silver Mountain summit.
- Southern watershed border is the Continental Divide ridgeline (~12,800')
- Snow dominated precipitation pattern and snowmelt streamflow regime
- Recorded mining activity from 1875-1953
- Historic mine workings:
 - 15 adits and associated waste rock dumps





View of Collier Mountain from the Continental Divide, looking to the northwest
Allen Emory Mine group workings visible



Warden Gulch during October 2004
sampling event

- Low Flow ~230 gpm (0.5 cfs)

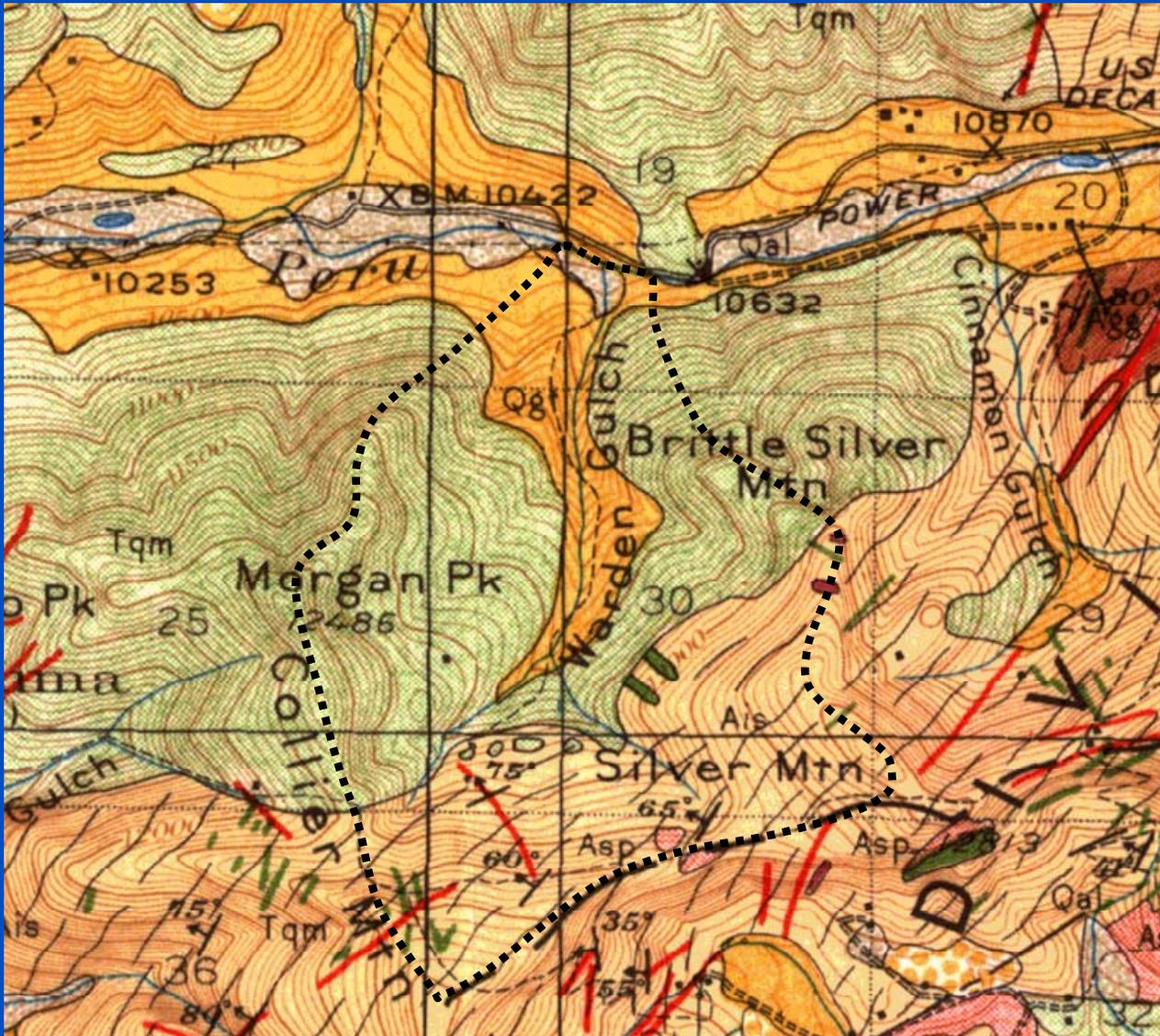
Note red staining on streambed



Waste rock dump directly adjacent to
Warden Gulch



Warden Gulch Geology



Montezuma Stock 35-45 Ma

- Igneous quartz monzonite intrusion

Idaho Springs Fm ~1700 Ma

- Metamorphic gneiss & schist

Montezuma Shear Zone

- Highly fractured
- Intensely altered rocks
- Localized mineralizing fluids
- Silver-lead-zinc veins/deposits

Hydrothermally altered rocks through out the watershed

Sulfide deposits:

- pyrite, galena, sphalerite

Project Approach

- Determine the water chemistry and metal loadings (grams/day) during both high and low flow conditions.
 - High flow: Snowmelt contributing to surface flow and shallow groundwater recharge
 - “Flushing” of mobile metals out of adits and through mine waste rock piles.
 - Less effect from deeper groundwater
 - Low flow: Groundwater discharging to stream network
 - Groundwater may be less affected by shallow mine workings
 - More reflective of naturally occurring conditions



Sampling Approach

- Two sampling events:
 - June 2004 (High Streamflow conditions)
 - October 2004 (Low Streamflow conditions)
- Water tests (pH and Conductivity): Numerous (>20), various locations
- Water samples:
 - Actively draining mine adits
 - Flowing surface streams, whether draining mines or not
 - Streams receiving either adit or surface streams
 - Sampled above and below contributing stream to “bracket” stream’s contribution
- Waste rock dump samples
 - Composites collected from the dump (0 – 6” depth) on a grid pattern
- Fieldwork conducted by David Bird and Bob Wood



Sample Parameters Measured

- Water tests:
 - pH
 - Conductivity
- Water Samples:
 - Flow (volume/time), pH, conductivity, alkalinity
 - Ions: K^+ , Na^+ , Ca^{2+} , Cl^- , F^- , SO_4^{2-}
 - Metals: Al, Fe, Cd, Cu, Pb, Mg, Mn, Ni, Ag, U, Zn, Tl, Cr
 - Metalloids: arsenic (As), antimony (Sb)
- Waste Rock Samples:
 - Net Acid-Base Potential
 - Suite of oxides (SO_4 , Fe_2O_3 , P_2O_5 , etc.)
 - Suite of metals similar to water analyses



Water Chemistry Results Summary

- Waters are acidic throughout the watershed
 - pH 3.36 – 5.12 (8 of 25 < 4 pH)
- Peru Creek drops by a full pH unit downstream of the Warden Gulch confluence
- Al, Cd, Cu, Fe, Mn, Zn above State water quality standards in all samples



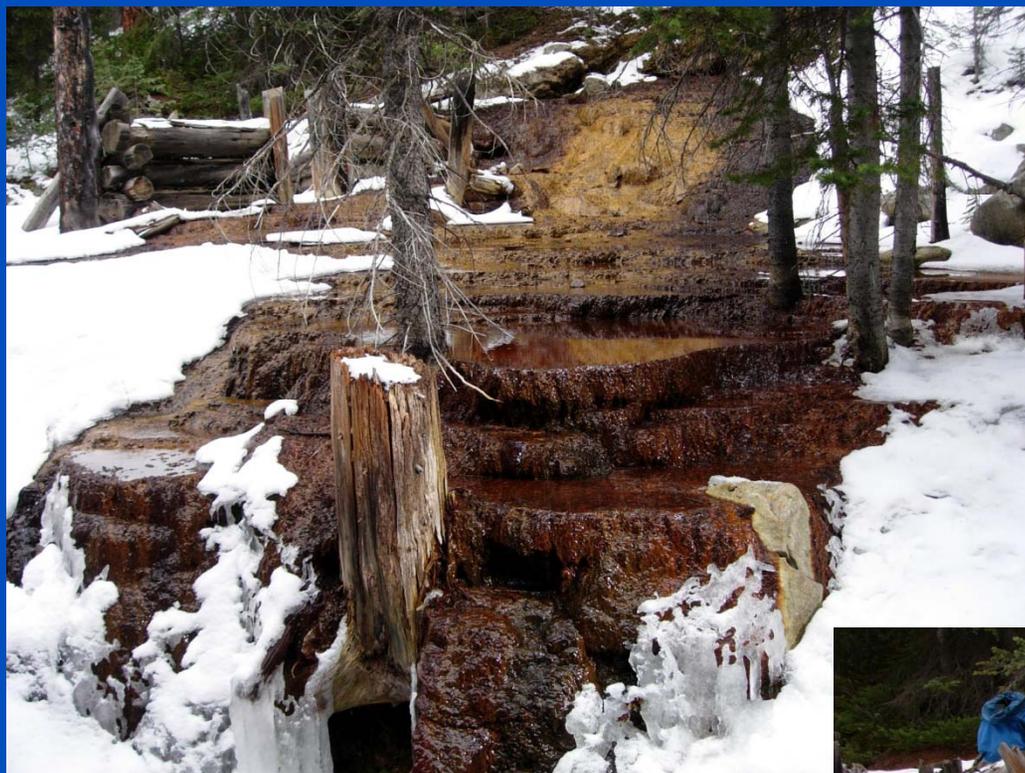


Adit #101

Draining adit in Lower Warden Gulch

Ferricrete deposits

Only flowing point source in watershed



~6 gpm (June)

pH of 3.7

Al concentration: 82,000 $\mu\text{g/L}$

Fe concentration: 110,000 $\mu\text{g/L}$

Mn concentration: 30,700 $\mu\text{g/L}$

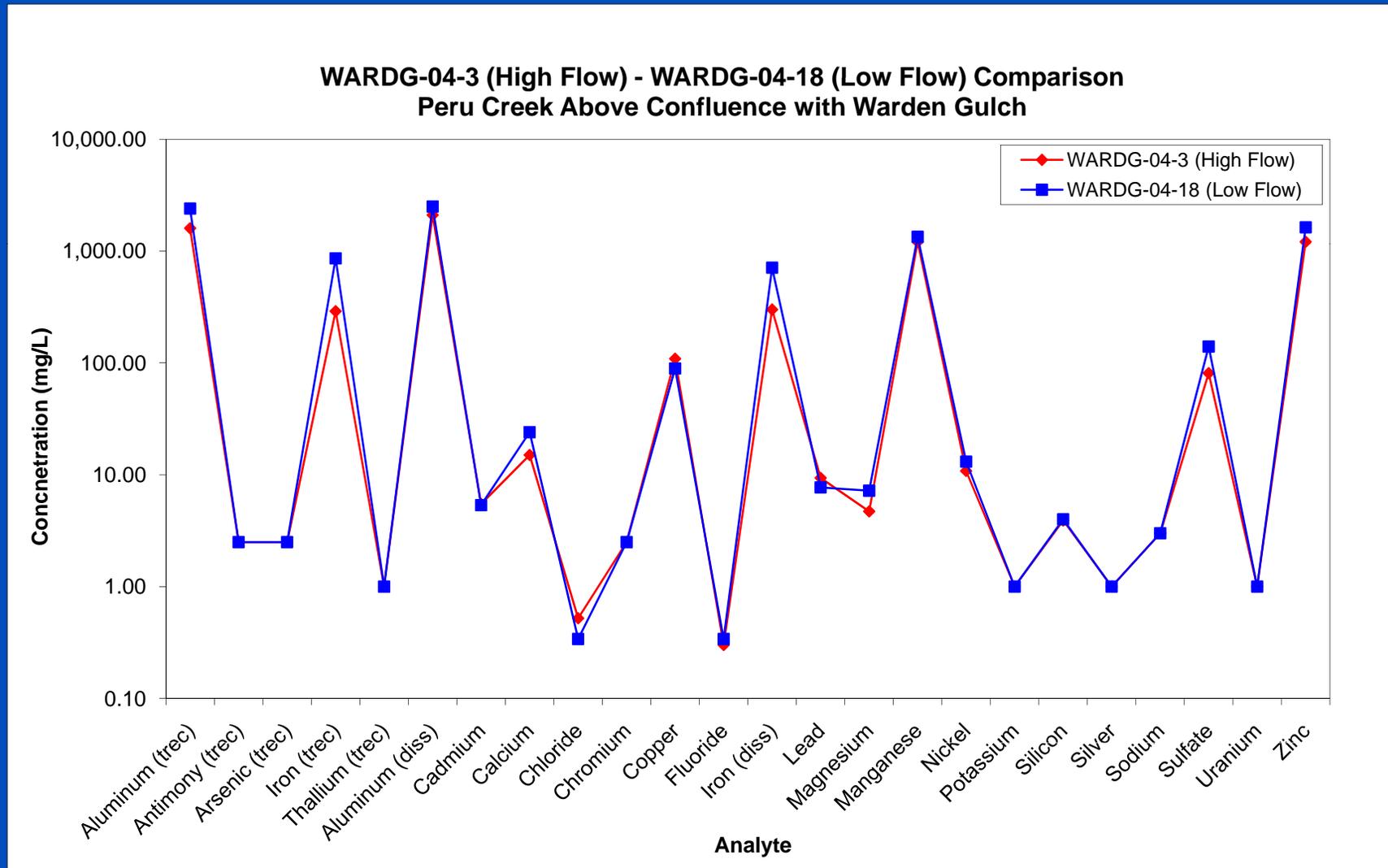
Zn concentration: 6,950 $\mu\text{g/L}$

SO_4 concentration: 1,100 $\mu\text{g/L}$





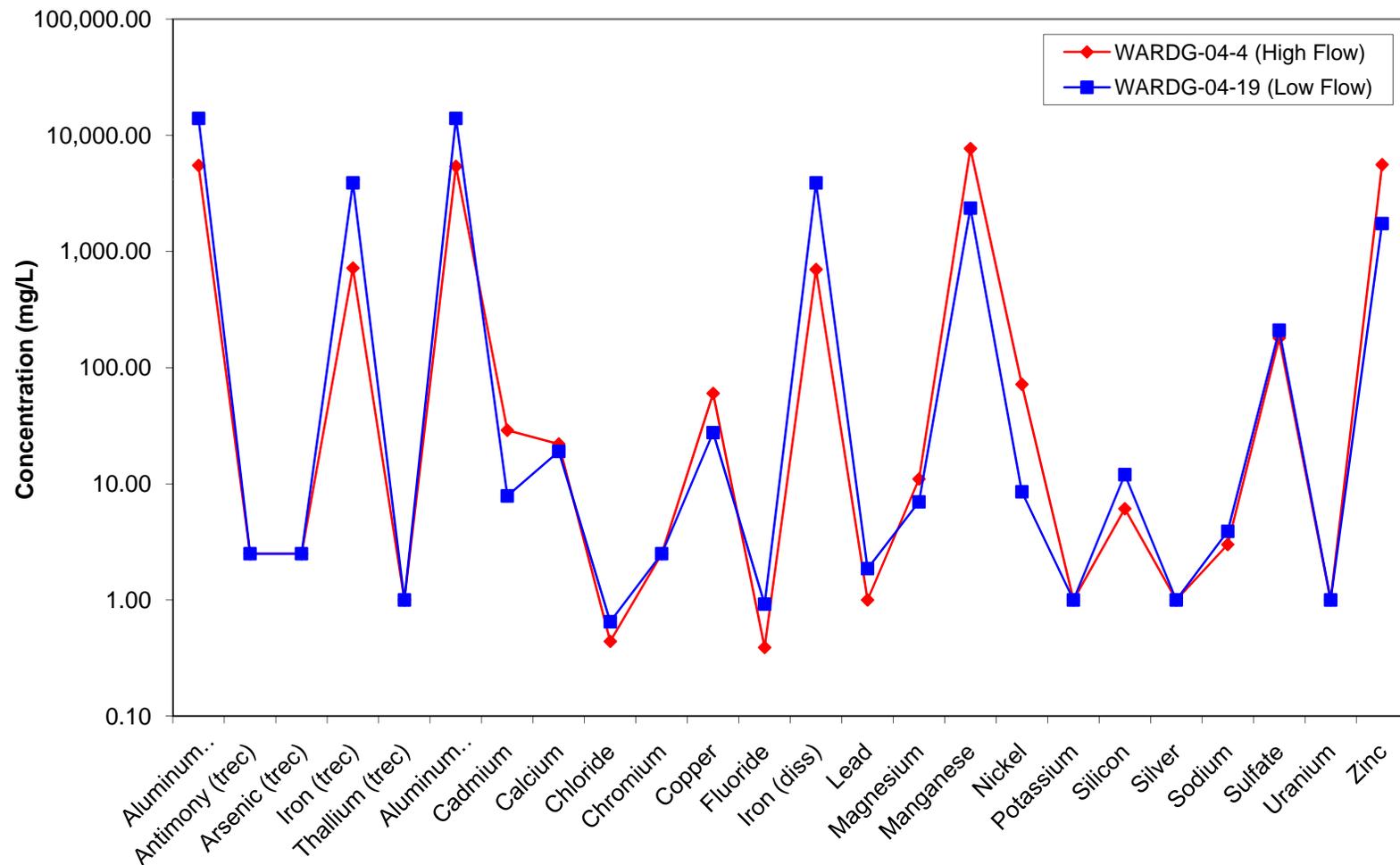
Expected (and observed in Peru Creek) results: Lower concentrations at high flow due to dilution by increased flow volumes





Observed results in Warden Gulch: Higher concentrations in some metals at high flow

WARDG-04-4 (High Flow) - WARDG-04-19 (Low Flow) Comparison
Warden Gulch Above Confluence with Peru Creek



High Concentrations at High Flow Phenomenon

- Likely Suspects:
 - Surface waters present during Spring snow melt infiltrating bedrock and colluvium (talus)
 - Surface waters infiltrating and draining waste rock piles
 - Similar materials (hydrothermally altered and mineralized bedrock)
 - Similar redox conditions in the unsaturated (vadose) zone
- Unlikely due to contribution from Adit #101
 - Adit Discharge: 1 – 6 gpm
 - vs
 - Warden Gulch: 200 – 1070 gpm



Conclusions

- Loading (grams/day) calculations indicate the only point source in the watershed (Adit #101) contributes:
 - High Flow ~6 – 15% of metal loads in the watershed
 - Low Flow ~0.5 – 5% (except Fe ~46%) of metal loads in the watershed
- Non-point sources of metals and acidity account for ~85% of the load in surface waters.
 - The naturally altered bedrock of the watershed
 - Waste rock piles from historic mining activity
- Problematic from a remediation perspective
 - 1 Adit: Straightforward techniques will only solve ~15% of the problem
 - Extensive (>15) waste rock piles throughout the watershed
 - Expensive to remove or sequester (difficult working environment)



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Thank You

