EPA Webinar Series on Hardrock Mining Geochemistry and Hydrology: predicting water chemistry, identifying release pathways, and evaluating reclamation strategies.

Workshop 2 – Mining-Influenced Water – Pathways for Offsite Releases –
Mike Wireman –US EPA Region 8

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FOCUS OF THIS TALK

1. Fate and transport of contaminants from mine related facilities

- Conceptual hydrogeologic model
- Geologic controls
- Geochemical controls

3. Environmental characterization of contaminant transport pathways

- Geology / Ore body
- Water levels / flow
- Mass loading
- Isotopic data
- Hydrologic tracing
- Hydrometrics
- Geochemical modeling
- EMMA
- Borehole tools

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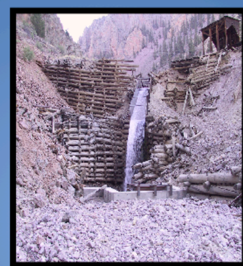
CERCLA sites vs. NEPA sites

- EPA / USGS / State mining agencies have developed characterization tools and evolved conceptual understandings re: the hydrology of mine impacted watersheds thru remedial investigations at CERCLA NPL sites
- Data and understandings from these efforts are useful for developing initial conceptual models at NEPA sites and guiding facility locations and hydrologic monitoring programs at hardrock mines

SOURCES OF METALS AT HARDROCK MINE SITES

- WASTE ROCK
- TAILINGS AND TAILINGS OUTWASH
- PITS / IMPOUNDMENTS
- UNDERGROUND WORKINGS
- PROCESSING FACILITIES
- NATURAL SOURCES

"Merlot" ponds –leachate from waste rock
Leadville, CO



Commodore waste rock –Creede, CO

Iron bog –Silverton CO

Rosia Poeni –RO (copper)

Emperious tails –Creede, CO

Big Five adit –Ward, CO

Environmental issues -Metals transport

- Metals / acid transported from major mine-related sources via:
  - Runoff (snow & rain)
  - GW Flow / Interflow
  - Streamflow
  - Air

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Elements of conceptual hydrogeology model – Fractured rock settings

- **Strong GW / SW Interaction at watershed –sub-watershed scale**
  - Gaining Streams in upper reaches
  - Strong Upward Gradient in Valley Bottom
  - Many Seeps / Springs – useful as monitoring points
  - Interflow is important
- **Highly preferential groundwater flow**
  - Bulk Porosity / K low but can be locally high
  - High relief – high gw velocity along preferential flowpaths
- **Multiple GW flow systems**
- **Significant seasonal variation in flow / water level**
- **GW / SW chemistry influenced by mineralogy of ore body – @ quasi-watershed scale**

Role of GW in metal deposition

- Fundamental fluid genetically relating all metals deposits
  - Ore mineralogy & distribution controlled significantly by subsurface hydrologic environment
    - Takes part in redox reactions
    - Transport
- Hydrothermal alteration and mineral emplacement

- Natural concentrations in gw typically very low (< 1 mg/l) - except in vicinity of ore bodies- due to:
  - Low solubility
  - Adsorption
  - Cation exchange
  - Complexation as hydrolyzed species

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Geologic Controls on F& T

Geology of Ore Deposits

- **Genesis of metals deposits**
  - **Commonly found in igneous / metamorphic rocks (can be redistributed in sed. rocks)**
  - **Occurs as vein, replacement and disseminated deposits – important to know which**
  - ***Most precious /heavy metal mines occurs in fractured rock environments***

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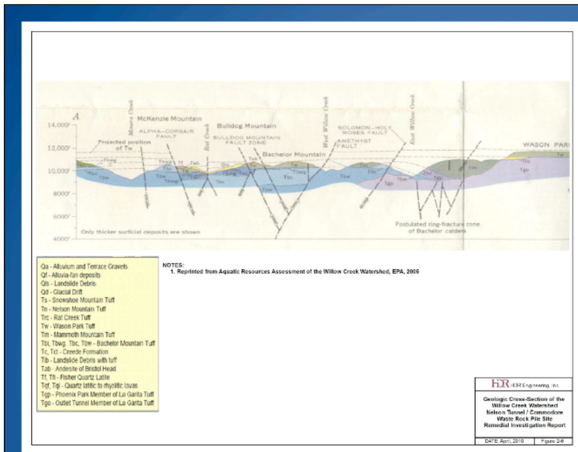
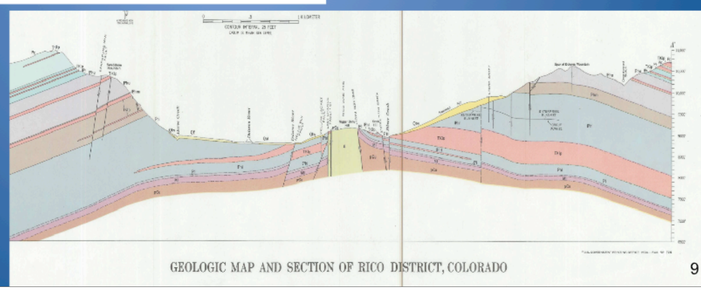


Creede mining district

Volcanic tuffs bounded by graben faults

Rico mining district

Carbonate formations, intruded by igneous rocks, are significant aquifers & host the ore body



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Geologic controls on transport

Groundwater storage and flow occurs preferentially in discontinuities in fractured rocks

- Bedding planes
- Faults and shear zones
- Fractures (joints)
- Foliation –including cleavage
- Zones of chemically altered rock
- Carbonate formations "inter-bedded" with igneous / metamorphic rocks

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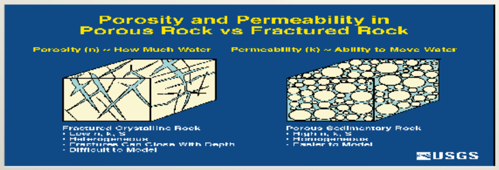

DARCY'S LAW HIGHLY CONSTRAINED – WATER TABLE MAPS ARE OFTEN INAPPROPRIATE

Fault Trace – In Vicinity of Koehler Tunnel Drainage

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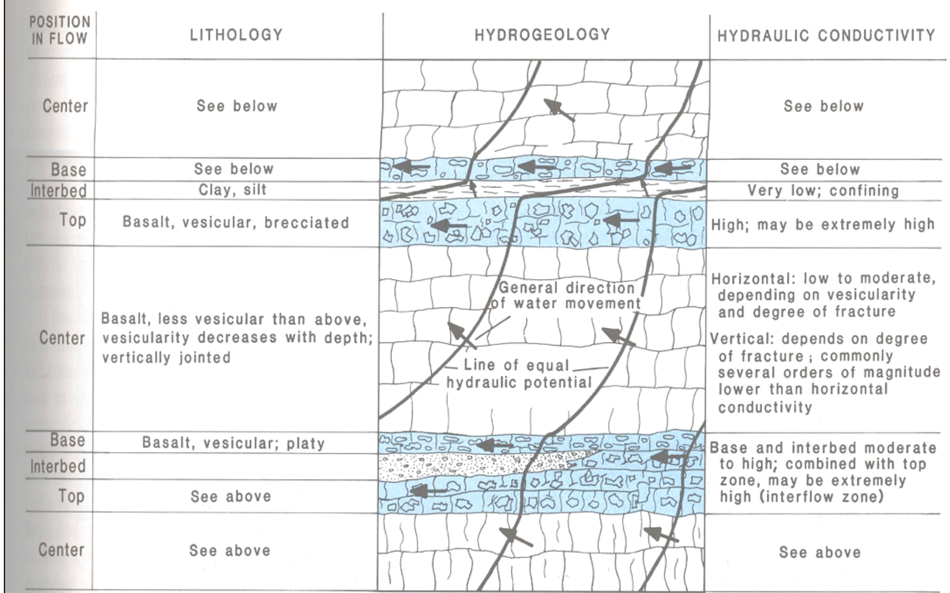

Figure 4. Intraflow structural controls on water movement in a discharge area of the Snake River Group.

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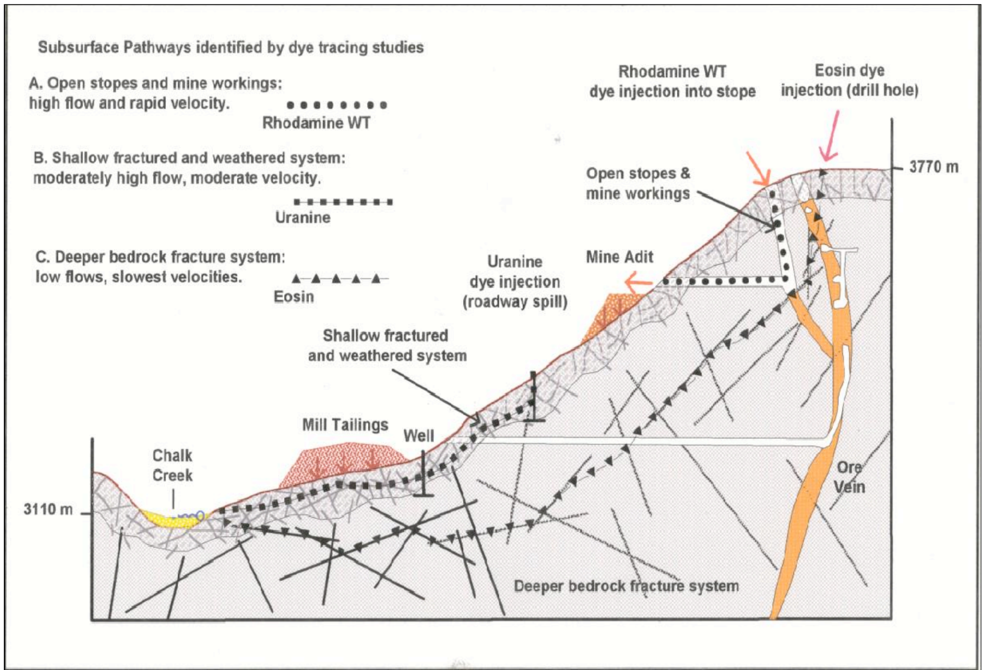

Conceptualized ground water flow systems

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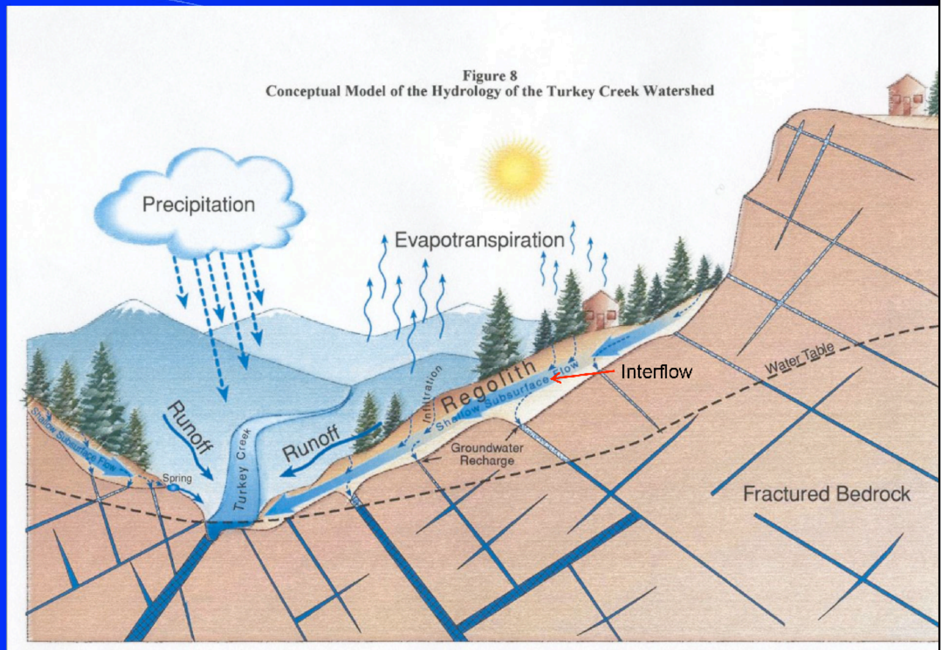

Watershed management in fractured-rock settings

Geochemical processes that affect concentration, species and distribution of metals in environment

- **Redox reactions**
  - Metals tend to be oxidized –not reduced
  - Water is catalyst - Microorganisms are also an important catalyst
- **Carbonate mineral dissolution**
- **Hydrolysis**
- **Cation exchange**
- **Adsorption**

Acid generation

Stoichiometry of Pyrite Oxidation

PYRITE OXIDATION:

$$FeS_2 + \frac{7}{2}O_2 + H_2O \rightarrow Fe^{2} + 2SO_4^{2-} + 2H^+$$

FeS_2 - Pyrite

Stoichiometry of Pyrite Oxidation

Fe^{2+} OXIDATION

$$Fe^{2+} + \frac{1}{2}O_2 + H^+ \rightarrow Fe^{3+} + \frac{1}{2}H_2O$$

Fe 2+ - ferrous iron

Stoichiometry of Pyrite Oxidation

FERRIC HYDROXIDE PRECIPITATION:

$$Fe^{3+} + 3H_2O \rightleftharpoons Fe(OH)_3 + 3H^+$$

Fe 3+ - ferric iron

Other precipitation reactions that form acidity

Gibbsite

Al3+ + 3H2O Al(OH)3 + 3H+

Manganese Oxide

2 Mn2+ + O2 + 2H2O 2MnO2 + 4H+

Low pH = greater metals solubility

Oxidation also catalyzed by microorganisms

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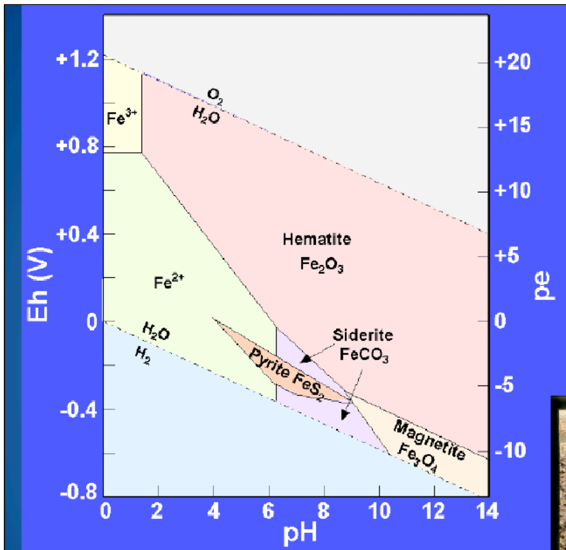

IRON

Ferricrete, New World Mining Dist., MT

Environmental characterization – Key tools

- Flow / water level measurements
- Water chemistry / flow weighted mass loading
- Stable water and radioactive isotopes
- Steam Tracing
- GW tracing

Setting a flume underground

IMPORTANT TO SAMPLE OVER FULL HYDROGRAPH!

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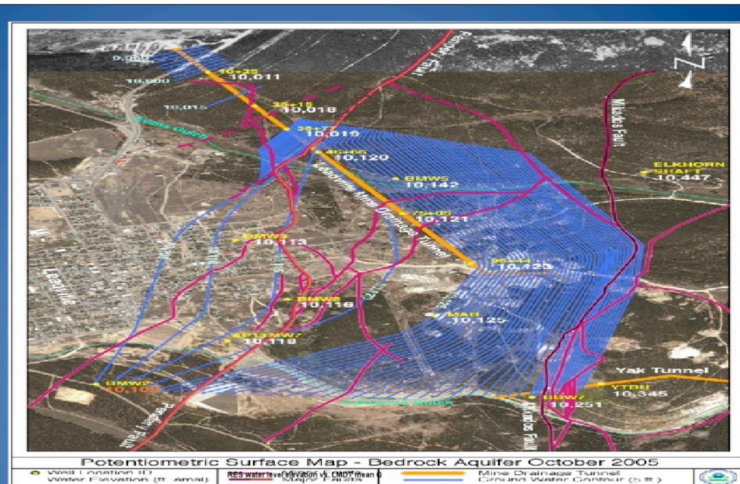
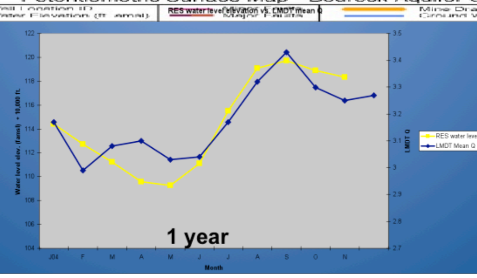
Bedrock Potentiometric surface – Leadville Mining district



LMDT portal discharge (blue) vs. RES water level (yellow) (mine pool -gw)



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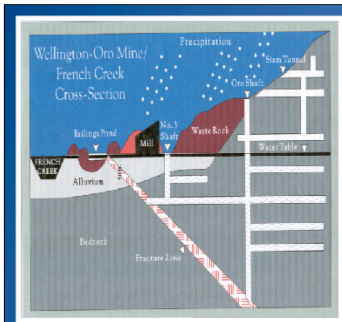
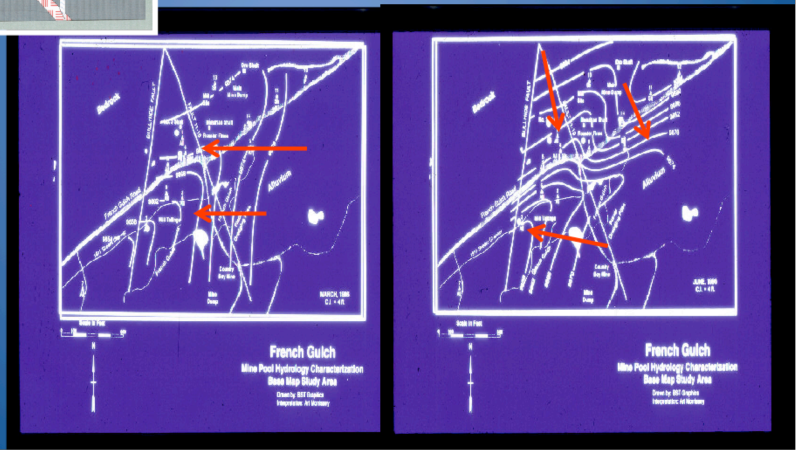


Seasonal discharge from fracture zone to River due to seasonal high head in mine pool

Discharge from fault into fluvial sediments in valley bottom results in very different water table in June than in March



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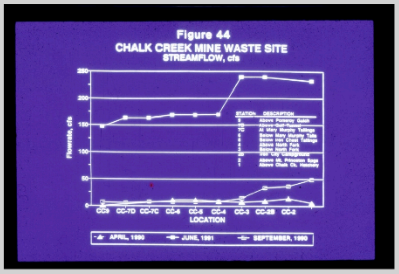
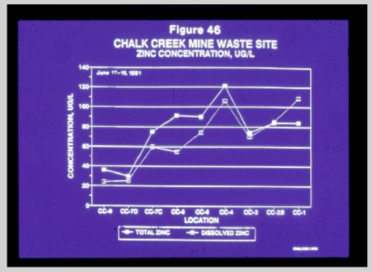
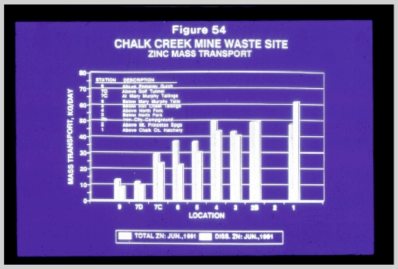
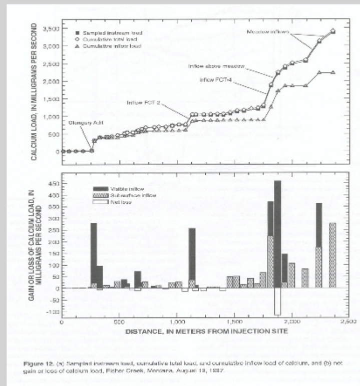
MASS LOADING / MASS TRANSPORT / MASS BALANCE









Useful for understanding sources and distribution of metals in riparian / aquatic environments

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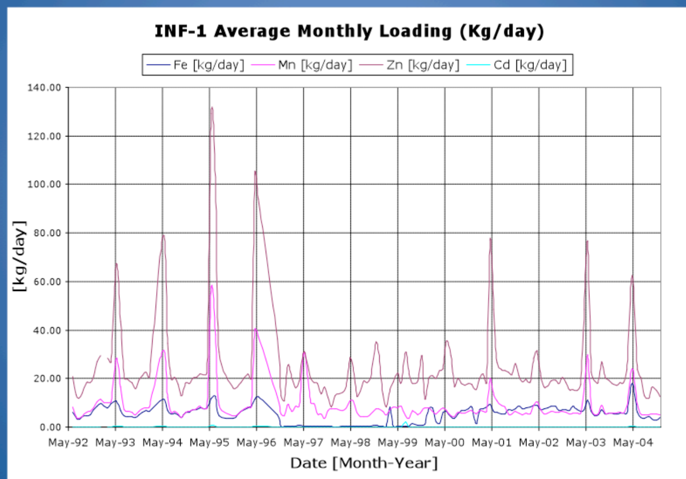
Mass loading

METAL LOADING AT LMDT PORTAL



Note – Significant decrease in load after 1996 and annual spike in May

Environmental Isotopes

- Isotope = atoms of the same element with a different number of neutrons (different mass)

Name	electrons	Protons	Neutrons	Abundance
^{16}O	8	8	8	99.76%
^{18}O	8	8	10	0.20%

STABLE ISOTOPES

- Do not decay spontaneously (stable over time)
- Examples: ^{18}O, ^{2}H, ^{13}C
- *Used as Tracers*

RADIOACTIVE ISOTOPES

- Emit alpha and beta particles and decay over time
- Examples: ^{3}H (Tritium), ^{14}C
- *Used for Dating*

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ISOTOPES COMMONLY USED IN HYDROGEOLOGY

Isotope	Symbol	Molecule	Type	Half-life
Deuterium (Source of water)	D	H_20	Stable	---
Oxygen- 18 (Source of water)	^{18}O	H_20	Stable	---
Tritium (Age - time since recharge)	^{3}H	H_20	Radiogenic	12.7 years
Sulfur- 35 (1)	^{35}S	SO_4^{2-}	Radiogenic	87 days
Carbon – 14 (Age)	^{14}C	CO_2	Radiogenic	5730 yrs

(1) – Still in proof of concept

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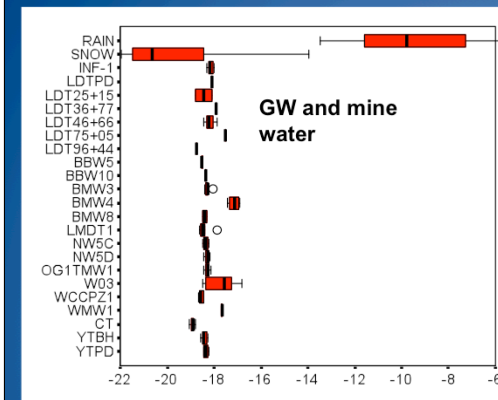
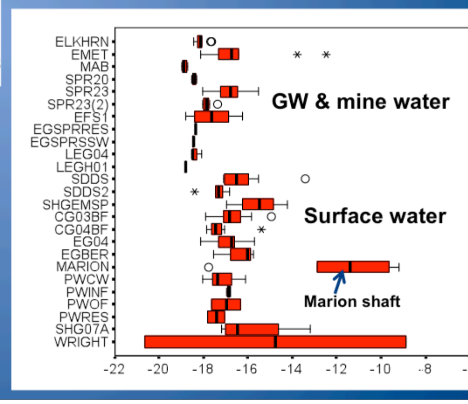
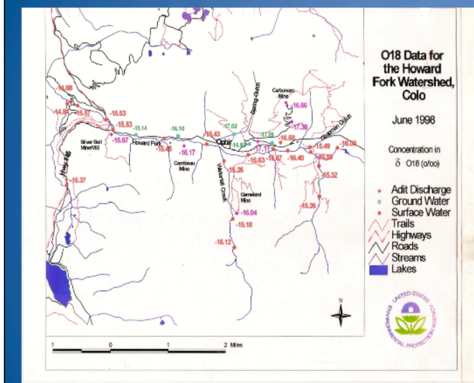
Delta ^{18}O Data

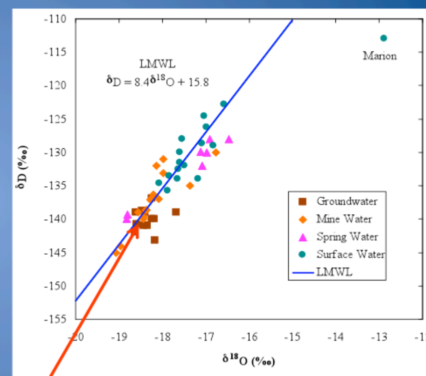


Water in Marion shaft has significant surface water / rain input – water in all other shafts are groundwater /snow dominated



Isotope Data -water samples -





LMDT PORTAL –DISCHARGE – Leadville, CO

Howard Fk. Of San Miguel River – San Juan Mountains – SW Colorado

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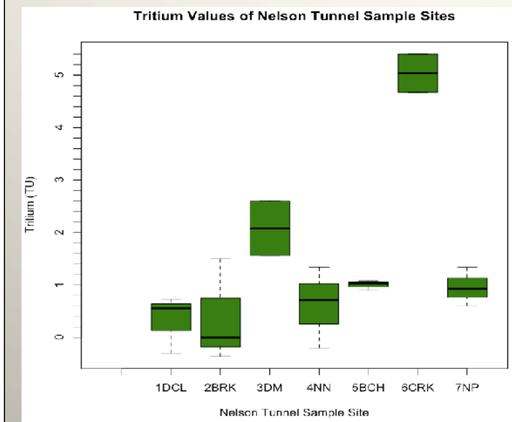
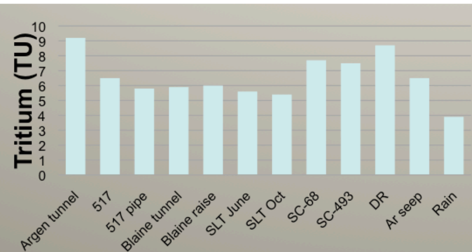
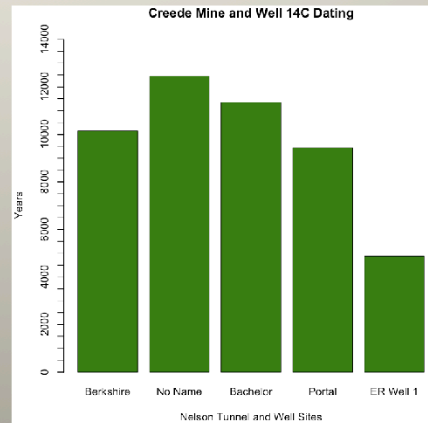
Dating groundwater / mine water







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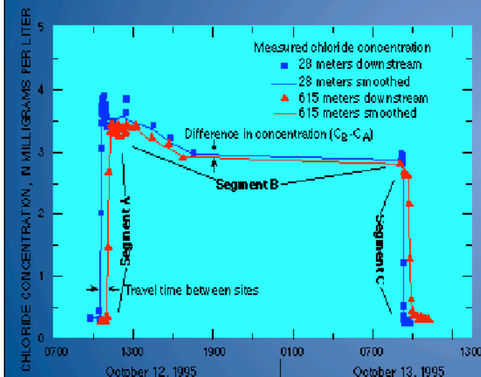
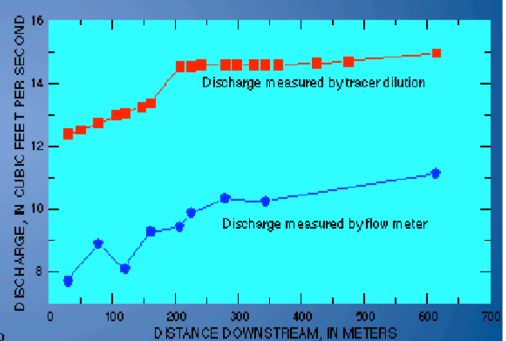
STREAM TRACING

- ✓ Inject conservative tracer (lithium) @ constant concentration / rate for extended injection time
- ✓ Bring stream concentration to "plateau"
- ✓ Sample for tracer & metals at frequent / specified intervals – sw / gw
- ✓ Accurate stream flow based on dilution
- ✓ Can be used to locate gw inflows
- ✓ Combine with sediment data to characterize / quantify contaminant loads in streams

STREAM TRACING





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Stream trace - Redwell Basin- a small alpine catchment in Colorado (USGS)

The “Red Well” is a natural spring-

- **low pH (<4), high Fe**
- **natural acid drainage**
- **more than 2500 years old**

Redwell Creek - In-stream tracer test

- Add LiCl continuously to upper reach of stream (both Li^{+} and Cl^{-} are conservative).
- Monitor conductivity at several downstream sites to track arrival of tracer.
- After about 24 hours, sample stream from bottom to top.
- In Redwell Creek (2 kilometers), USGS collected 68 samples in about 4 hours.

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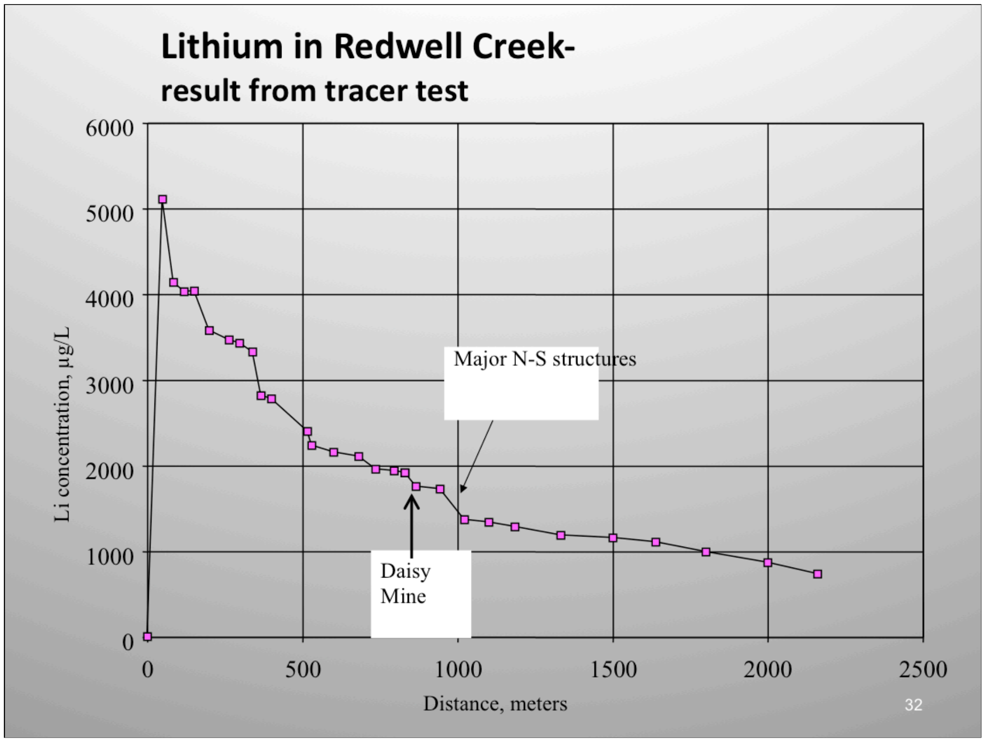
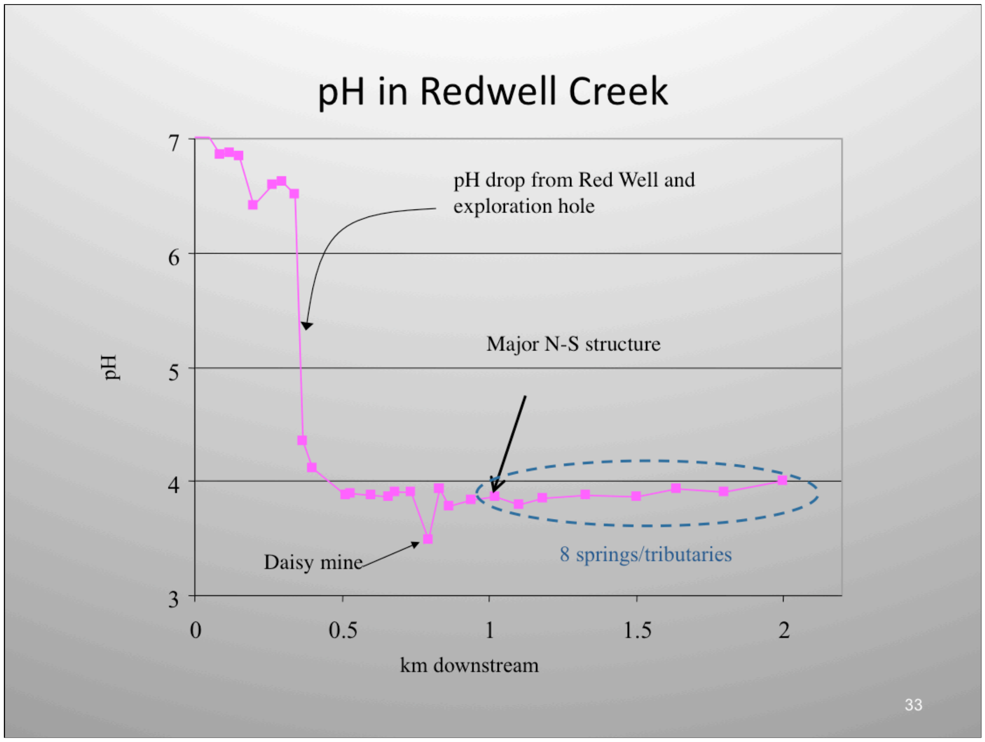


Lithium in Redwell Creek-
result from tracer test
6000
5000
4000
3000
2000
1000
0
Li concentration, µg/L
Major N-S structures
Daisy
Mine
0
500
1000
1500
2000
2500
Distance, meters
32


pH in Redwell Creek
pH drop from Red Well and exploration hole
Major N-S structure
Daisy mine
8 springs/tributaries
pH
7
6
5
4
3
0
0.5
1
1.5
2
km downstream
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GROUNDWATER TRACING

I. USED IN A VARIETY OF HYDROGEOLOGIC SETTINGS – COMBINE W / SW TRACING

II. LOTS OF USE IN KARST – MORE RECENTLY IN FRACTURED ROCKS

III. USEFUL FOR CHARACTERIZING GW FLOW PATHS IN FRACTURED ROCK SETTINGS

IV. APPLICATION TO TUNNEL TRACING?

- TRACING IS EMPIRICAL
  - ✓ FEWER ASSUMPTIONS
- DATA USED TO HELP DETERMINE
  - ✓ FLOW VELOCITY (D/T) / FLOW RATE (V/T)
  - ✓ GW DISCHARGE TO STREAMS
  - ✓ FLOW DIRECTION AND FLOW SYSTEM BOUNDARIES
- CAN PROVIDE QUANTITATIVE DATA
  - ✓ COMBINE W/ DISCHARGE DATA
  - ✓ CONTAMINANT FATE

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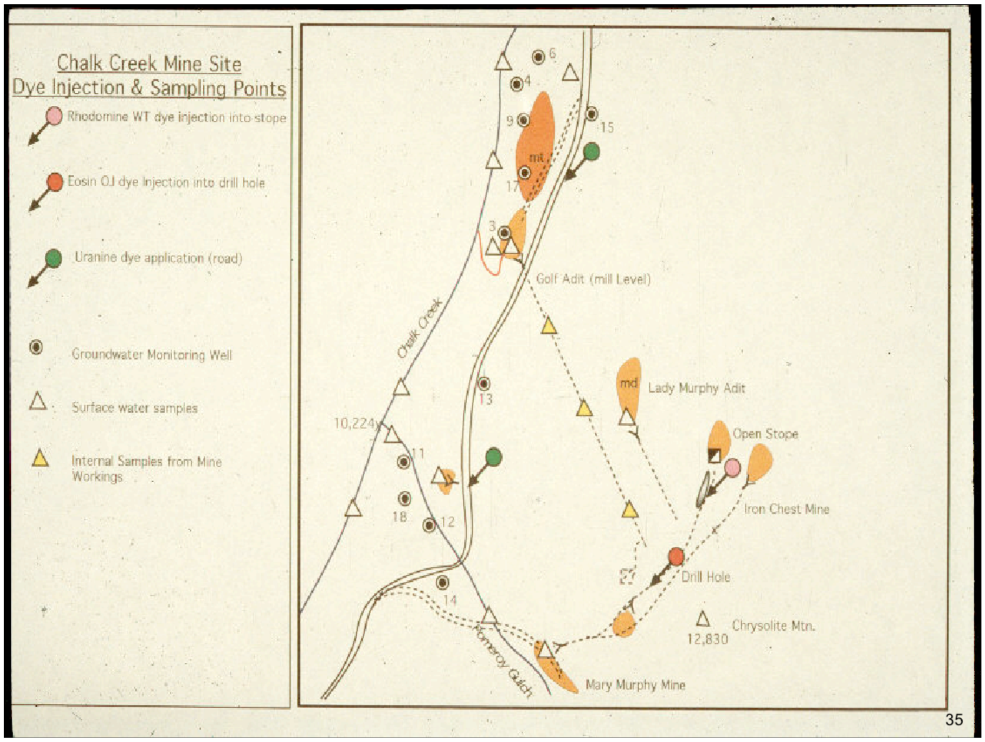
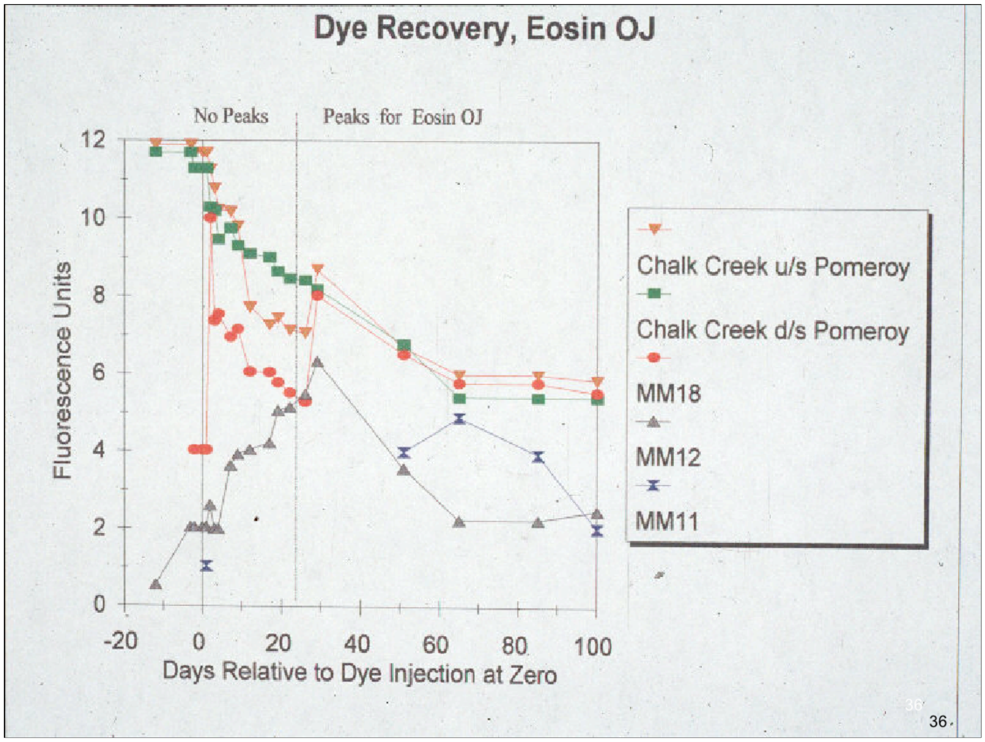
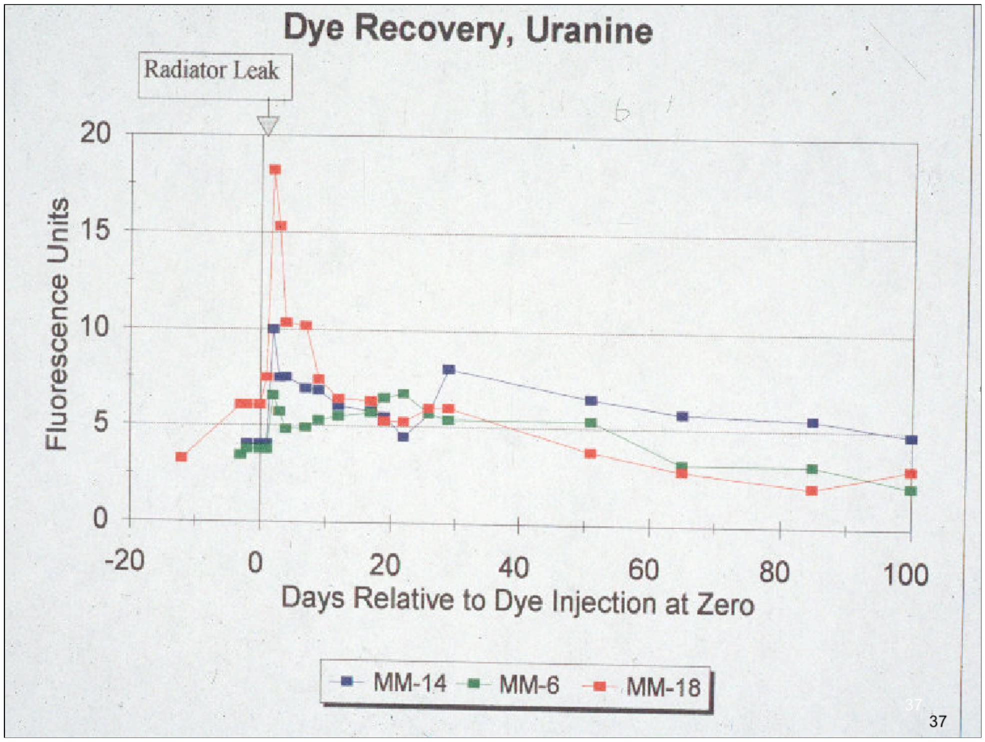
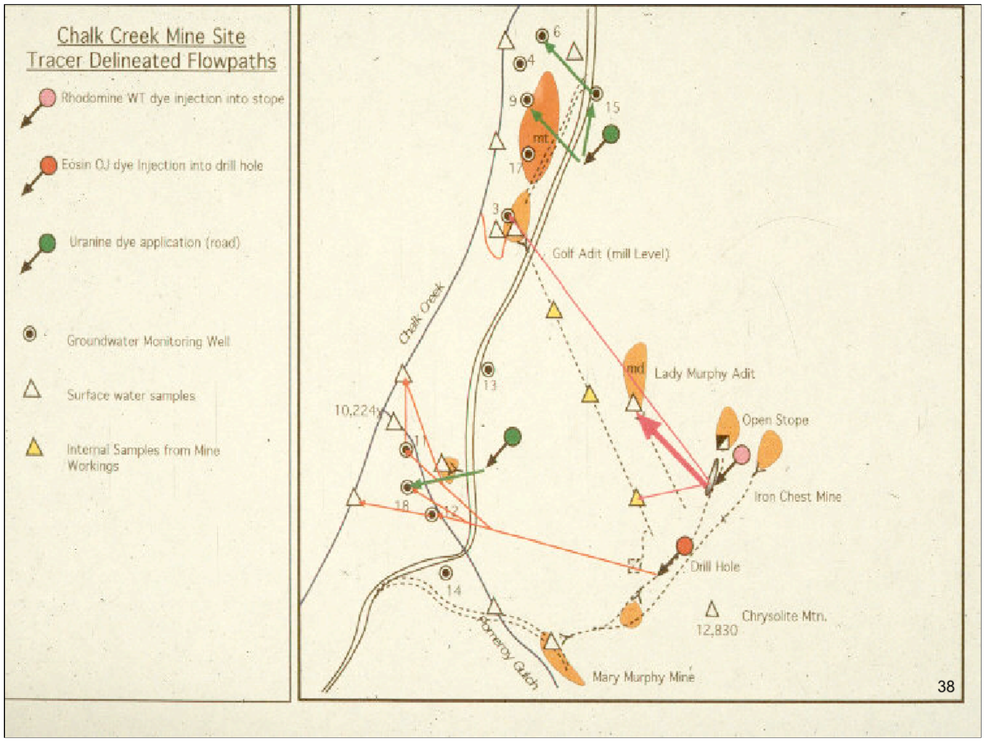


Chalk Creek Mine Site
Dye Injection & Sampling Points
Rhodomine WT dye injection into stope
Eosin OJ dye injection into drill hole
Uranine dye application (road)
Groundwater Monitoring Well
Surface water samples
Internal Samples from Mine Workings
Chalk Creek
Golf Adit (mill Level)
Lady Murphy Adit
Open Stope
Iron Chest Mine
Drill Hole
Chrysolite Mtn.
12,830
10,224
Mary Murphy Mine
Pomeroy Gulch
35


Dye Recovery, Eosin OJ
No Peaks
Peaks for Eosin OJ
Fluorescence Units
Days Relative to Dye Injection at Zero
Chalk Creek u/s Pomeroy
Chalk Creek d/s Pomeroy
MM18
MM12
MM11
36


Dye Recovery, Uranine
Radiator Leak
20
15
10
5
0
Fluorescence Units
-20
0
20
40
60
80
100
Days Relative to Dye Injection at Zero
MM-14
MM-6
MM-18
37


Chalk Creek Mine Site
Tracer Delineated Flowpaths
Rhodomine WT dye injection into stope
Eosin OJ dye Injection into drill hole
Uranine dye application (road)
Groundwater Monitoring Well
Surface water samples
Internal Samples from Mine Workings
6
4
9
15
mt
17
3
Golf Adit (mill Level)
Chalk Creek
md
Lady Murphy Adit
13
10,224
Open Stope
11
18
12
Iron Chest Mine
Drill Hole
14
Chrysolite Mtn.
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Pomeroy Gulch
Mary Murphy Mine
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Thank You!
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