Mitigation of Acidic Mine Drainage from Abandoned Hard Rock Mines in the Western US: A Colorado Perspective

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Outline

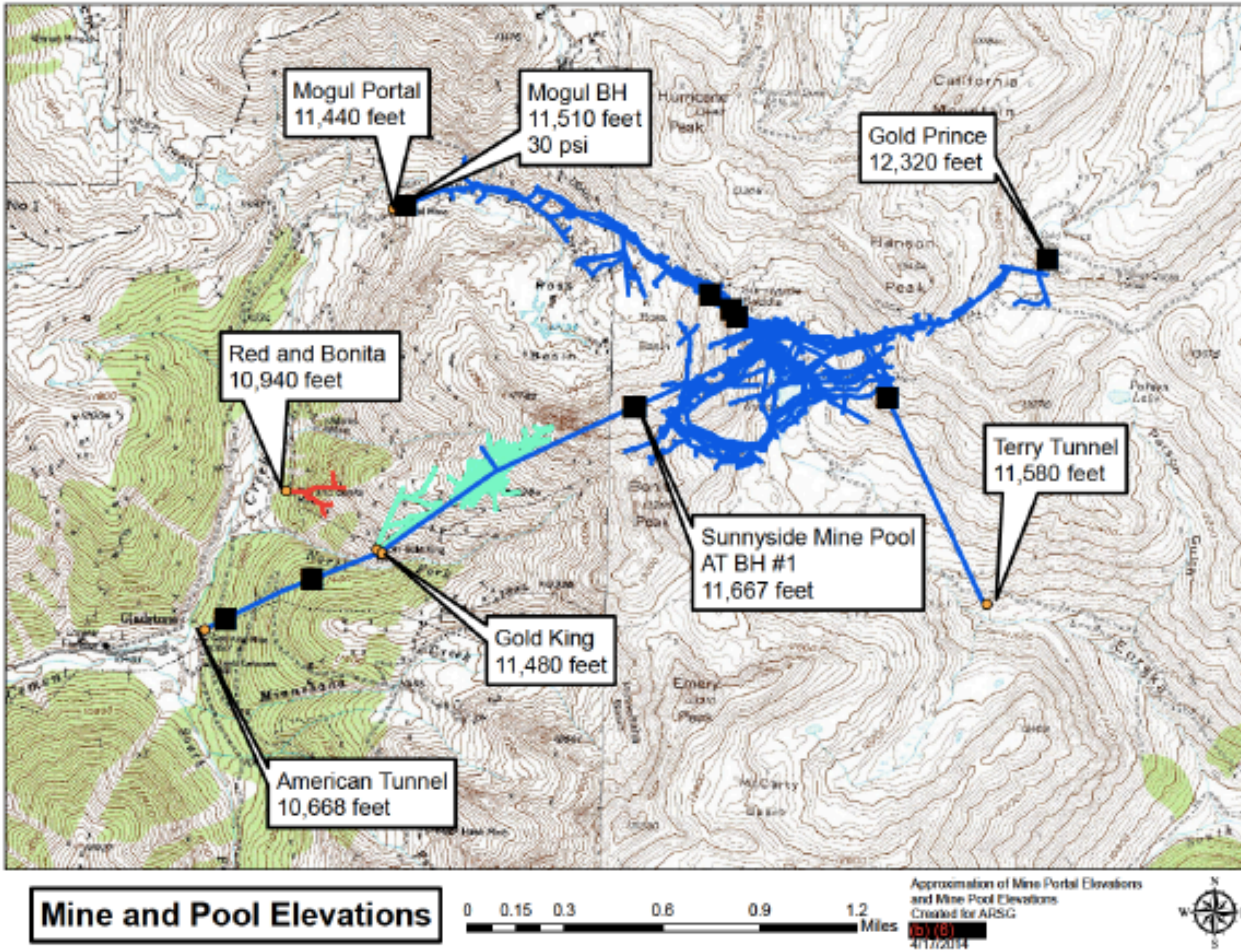
- Impact of hardrock metal mining in Colorado
- Remediation efforts
- Path forward for remediation

Hardrock mining refers to extraction of ore that can only be mined by blasting or drilling to excavate hard minerals such as those containing metals like gold, copper, zinc, nickel and lead

Gold King Mine Spill

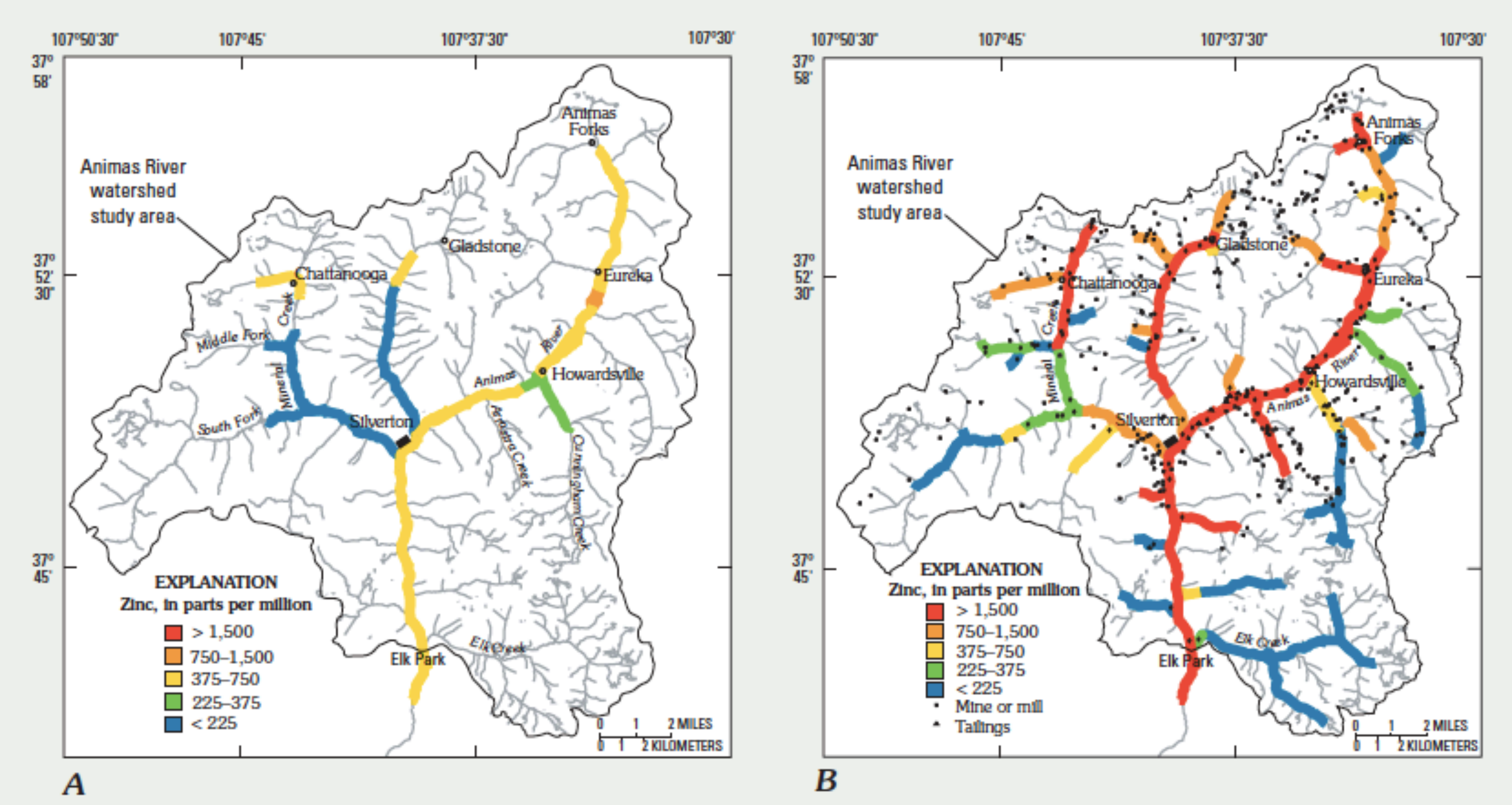
August 5, 2015

Gold King Mine Relative Location



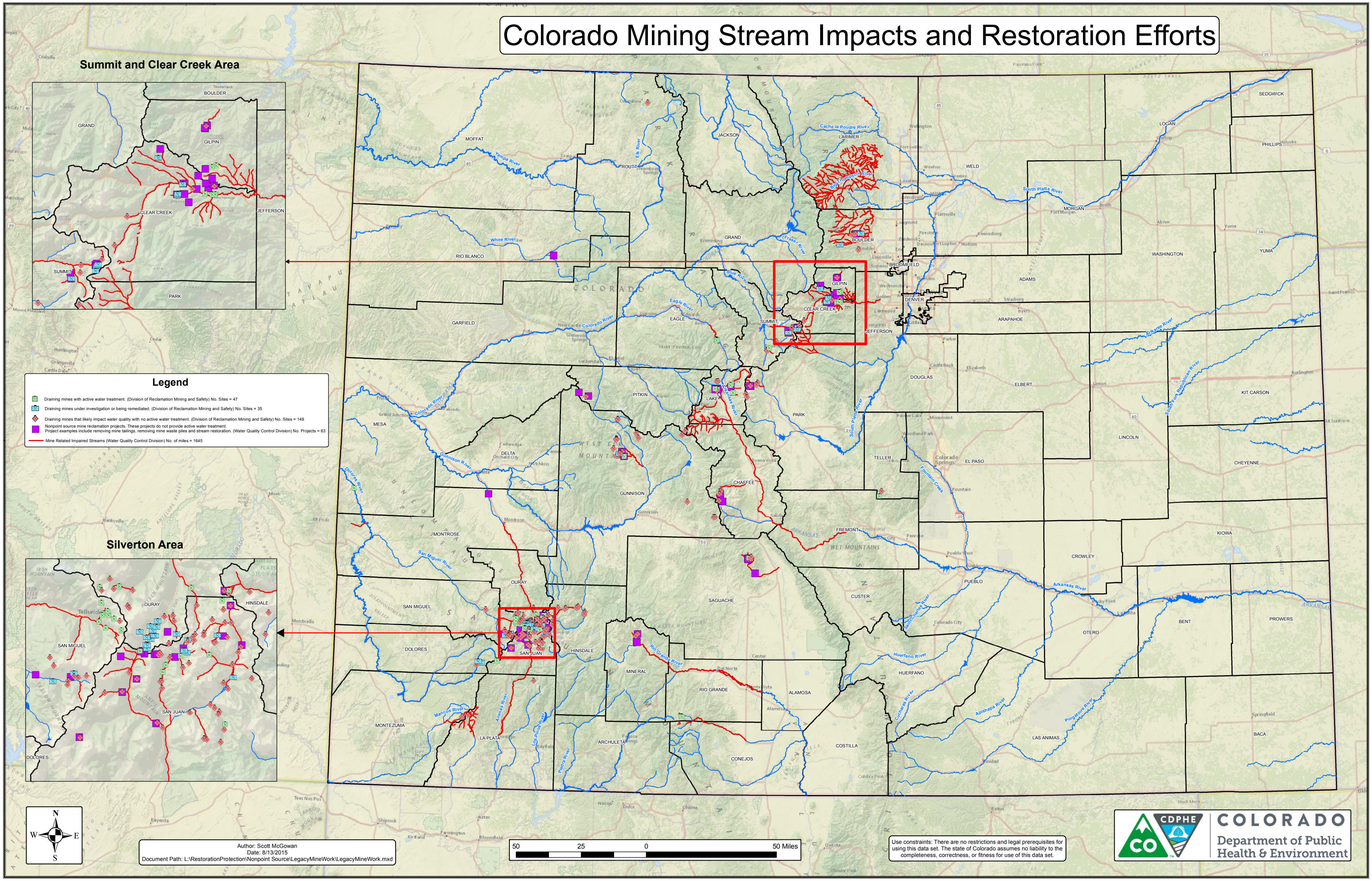
Upper Animas Sediment Zinc

Pre-mining ***Post-mining***

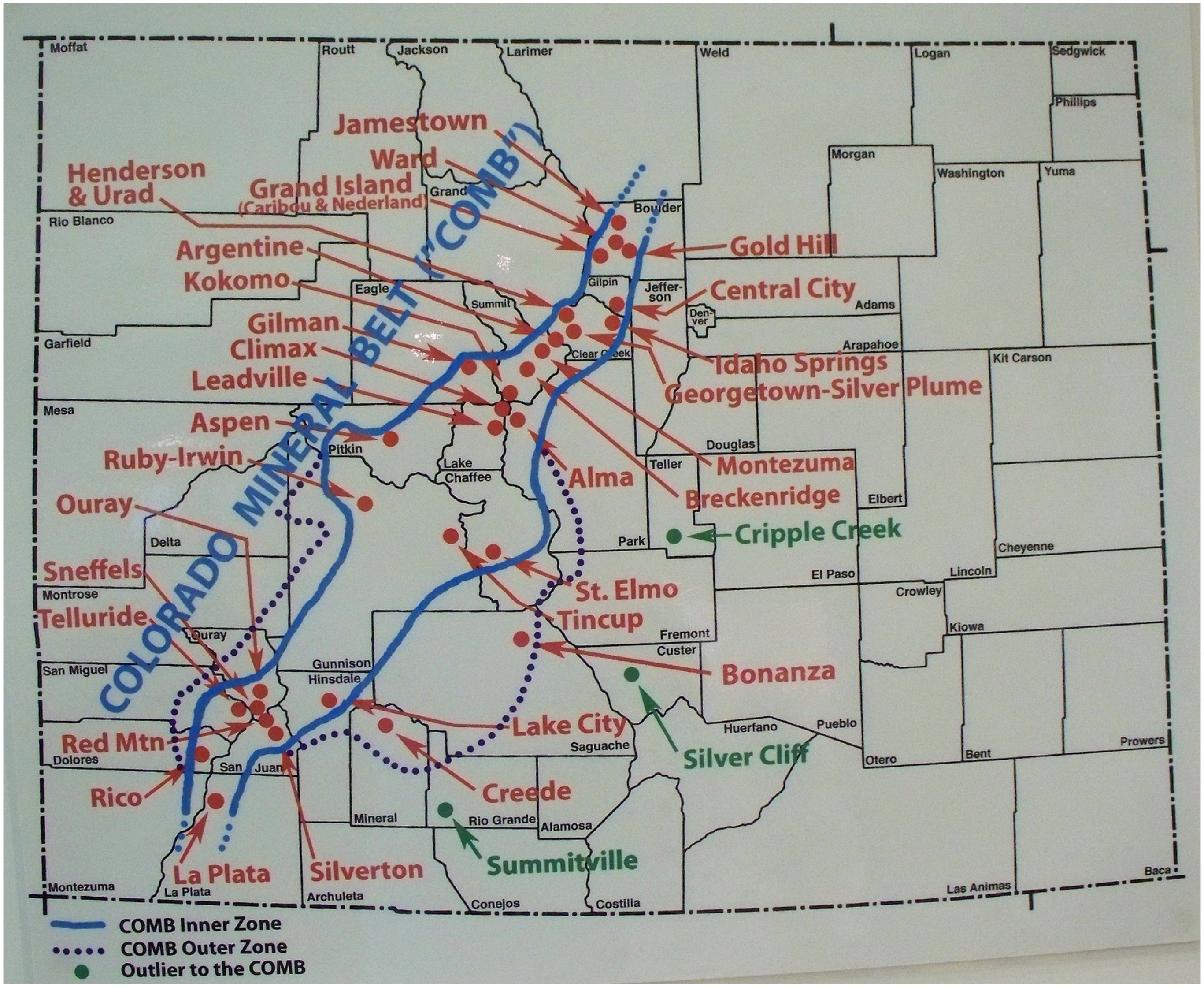


USGS report 2007

Reported Potential Sites = 230

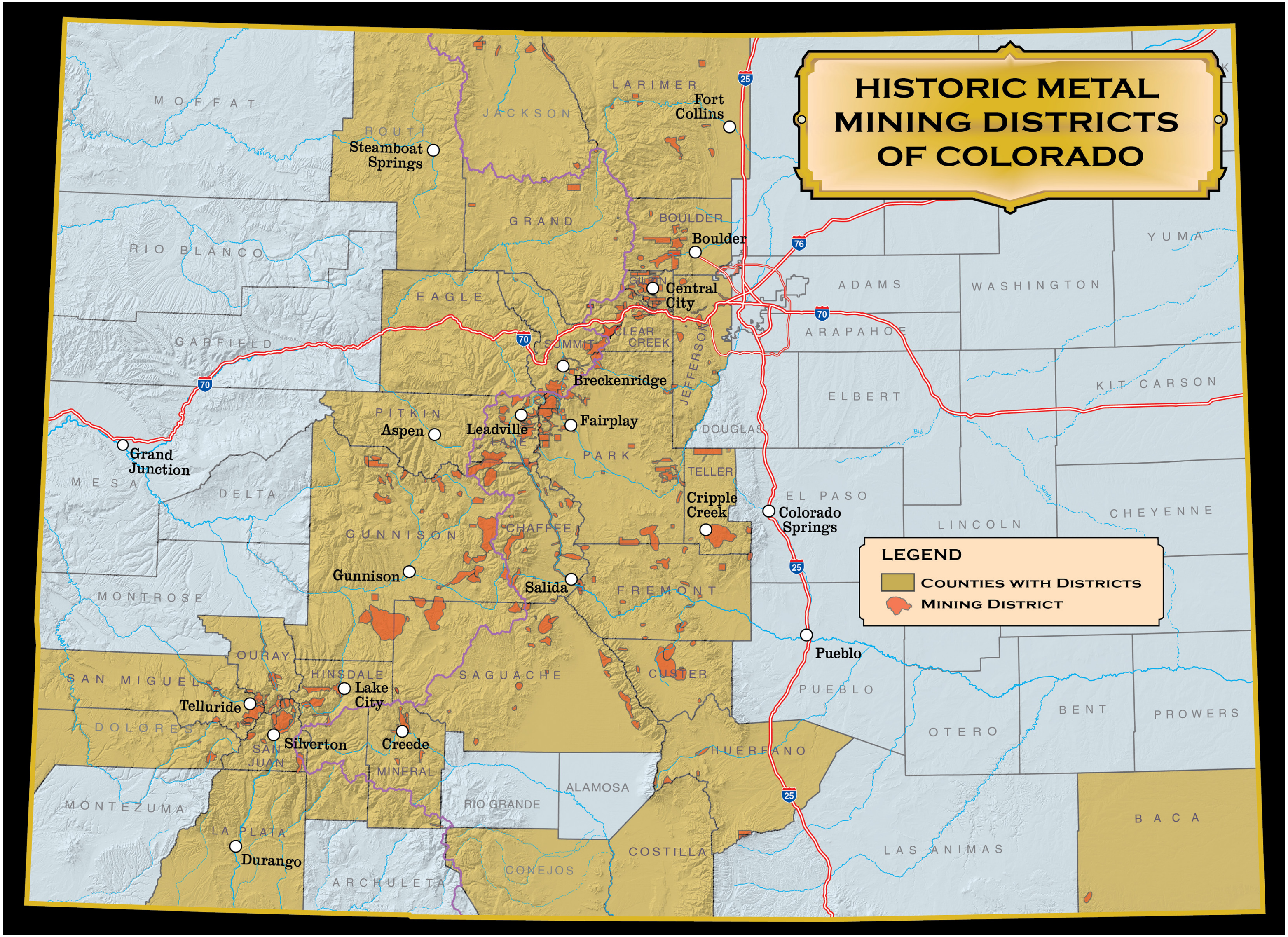


Colorado Mineral Belt



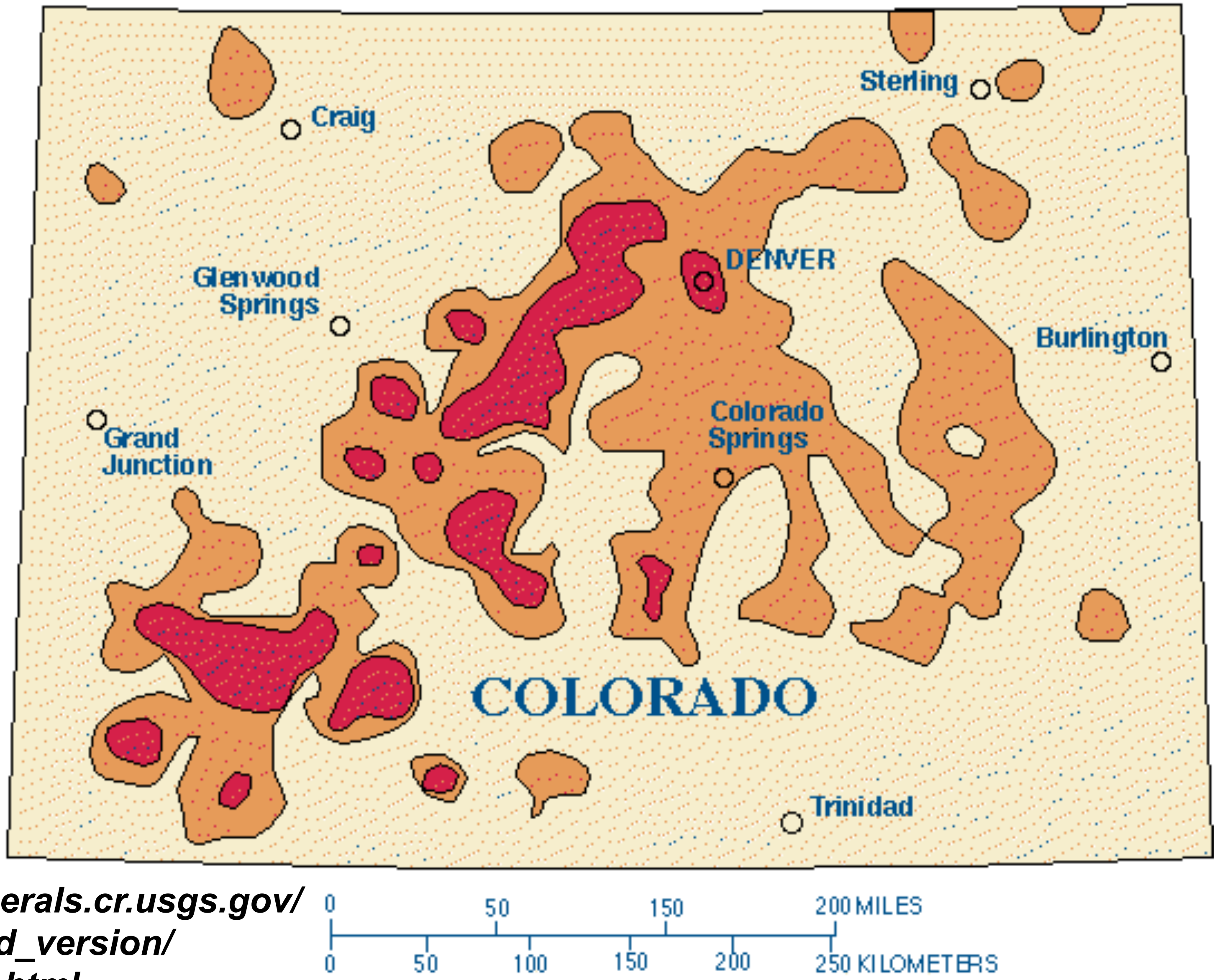
https://www.flickr.com/photos/dr_l_rock/8016976225

Historic Mining Districts in Colorado



http://coloradogeologicalsurvey.org/wp-content/uploads/2013/06/Historic_Mining_Districts_Statebase.jpg

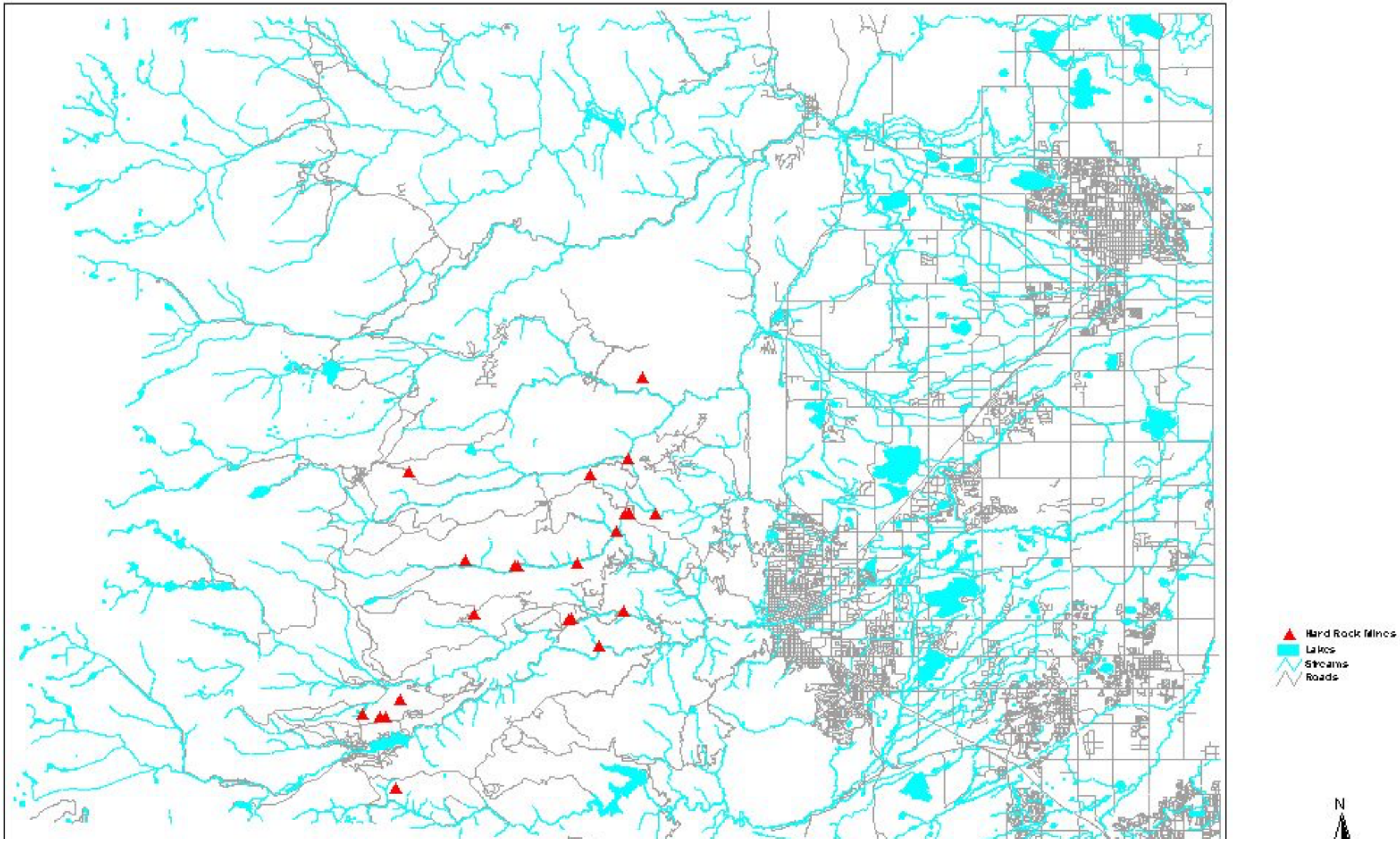
Metal impacted sediment in Colorado



http://minerals.cr.usgs.gov/gips/world_version/7process.html

Boulder County

Historic Hard Rock Mines



Boulder County Mines Identified by CDPHE/CODRMS

COLORADO
Division of Reclamation, Mining and Safety
Department of Natural Resources

GIS Data to accompany Colorado Mining Stream Impacts and Restoration Efforts map

Legend

- Draining mines with active water treatment. (Division of Reclamation Mining and Safety) No. Sites = 47
- Draining mines under investigation or being remediated. (Division of Reclamation Mining and Safety) No. Sites = 35
- Draining mines that likely impact water quality with no active water treatment. (Division of Reclamation Mining and Safety) No. Sites = 148
- Nonpoint source mine reclamation projects. These projects do not provide active water treatment. Project examples include removing mine tailings, removing mine waste piles and stream restoration. (Water Quality Control Division) No. Projects = 63
- Mine Related Impaired Streams (Water Quality Control Division) No. of miles = 1645

Status

R - red symbols
G - green symbols
Y - blue symbols

Mine Name	County	X_UTM	Y_UTM	Status
Bueno	Boulder	465813.00	4441056.00	R
Captain Jack	Boulder	456512.00	4434620.00	Y
Emmett	Boulder	465946.00	4441622.00	R
Evening Star	Boulder	467779.00	4431631.00	R
Fairday	Boulder	463867.00	4440676.00	R
Golden Age	Boulder	469370.00	4441577.00	Y

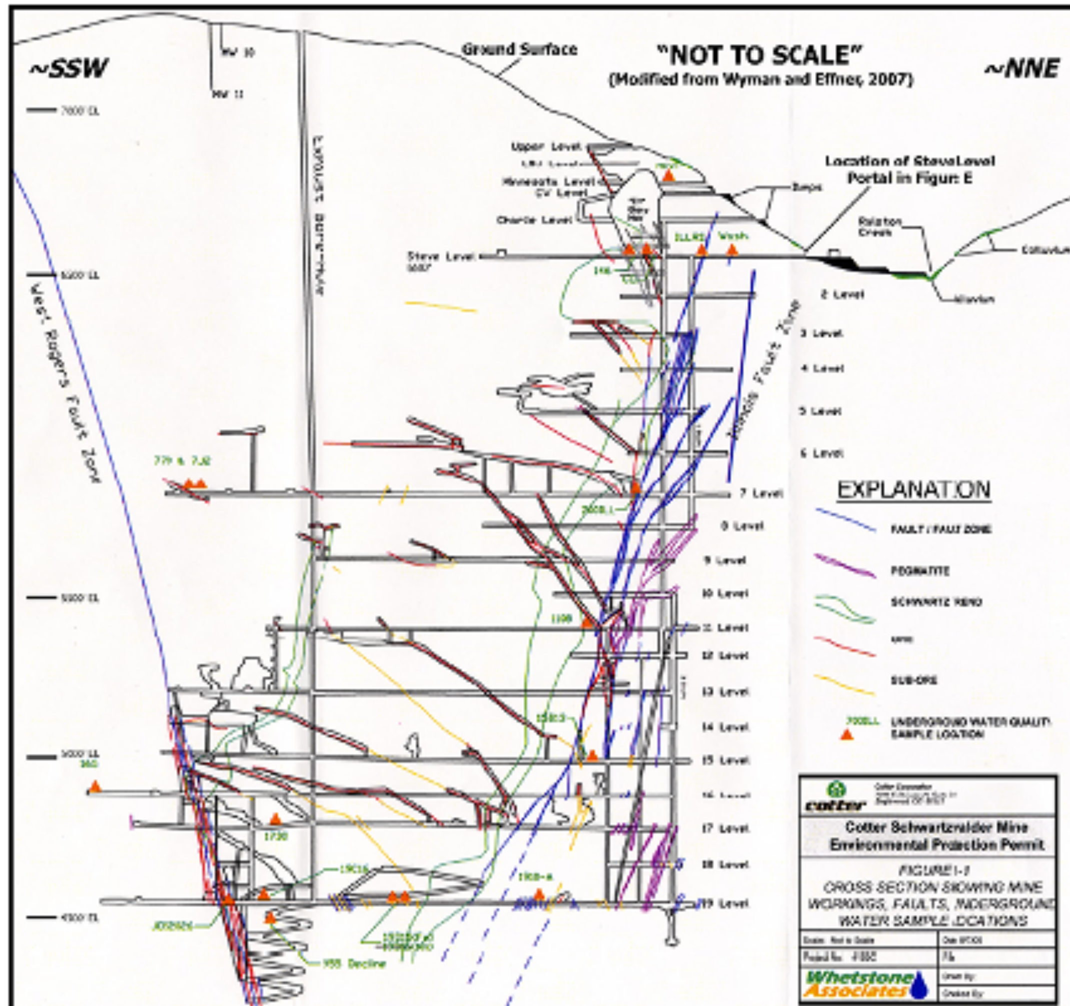
Mining Related Superfund Sites in Colorado

≈ 40% of Active Superfund Sites are Mining Related

- California Gulch/Yak Tunnel, 18 sq mi (As, Cd, Cu, Fe, Lead, Zn)
- Captain Jack Mill/Lefthand Canyon, 11 acres (Sb, As, Cd, Cu, Mn, Pb, Tl, Zn)
- Central City/Clear Creek, 400 sq mi (Al, As, Cd, Cr, Cu, Fe, Pb, Mn, Hg, Ni, Ag, Zn)
- Eagle Mine, 235 acre (As, Cd, Cu, Lead, Zn)
- Nelson Tunnel/Commodore Waste Rock, 5 acres
- Standard Mine (≈ 11,000 ft)10 acre (Cd, Cu, Fe, Mn, Pb, Zn)
- Summitville (≈ 11500 ft) 1400 acre (Al, Cd, Cu, Fe, Mn, Ni, Pb, Zn)
- Bonita Peak Mining District (proposed)

Impact of historic mining on water quality in Colorado is extensive

Ex-situ vs In-situ Treatment Remediation?



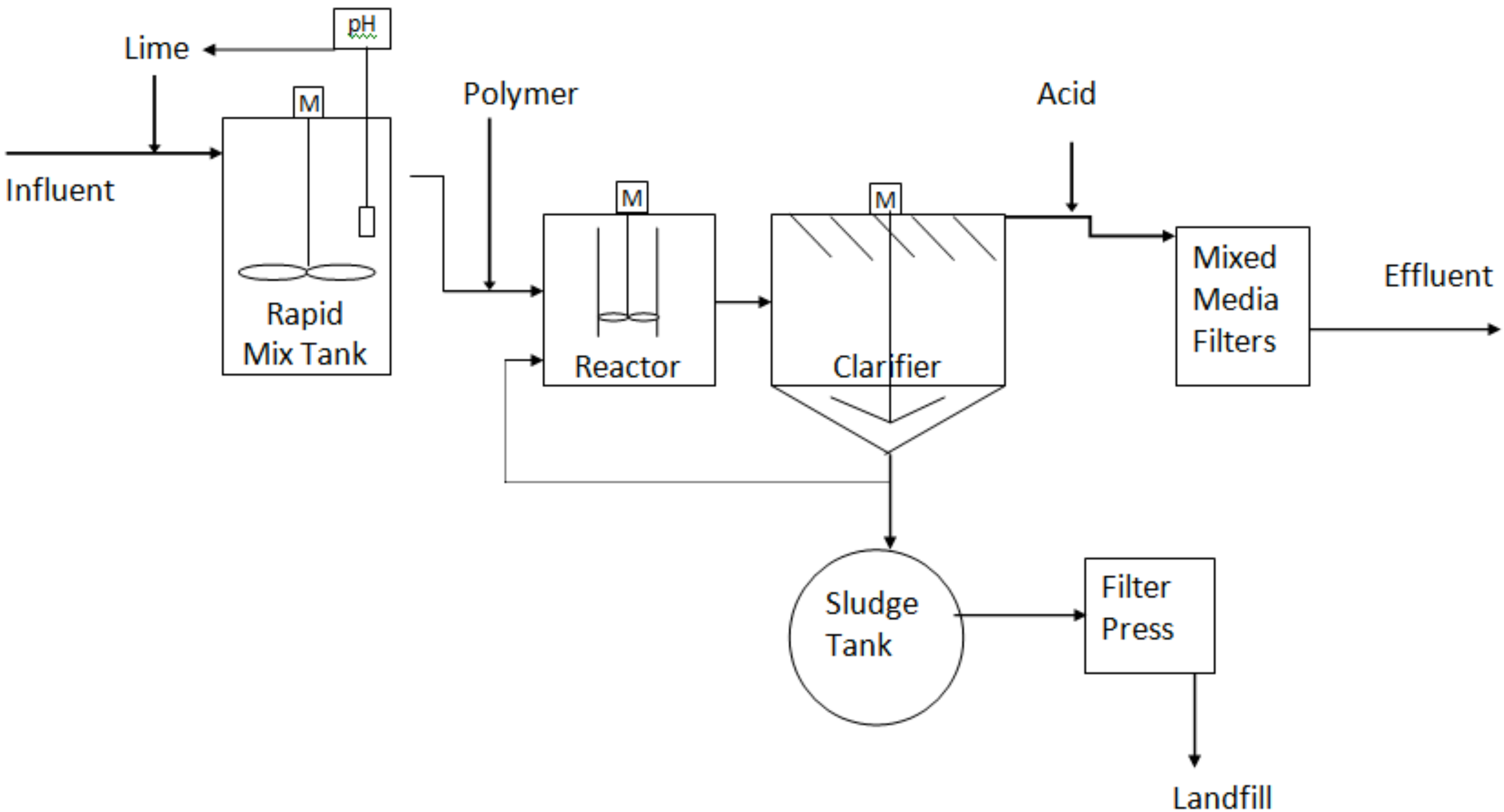
Active Mine Water Treatment (ex-situ)

Activate Mine Water Treatment at Superfund Sites in Colorado

Plant	Affected Waterway	Million Gallons of Water Treated per Year (Projected 2016)
Argo Tunnel	Clear Creek	118
Clear Creek North Fork Plant	North Clear Creek	105
Eagle Mine	Eagle River	135
Summitville Mine	Alamosa River	380
Yak Tunnel	Arkansas River	425
Total		**1163**

100 MGY = 190 gpm = 720 Lpm = 0.27 MGD = 0.42 cfs

Argo Tunnel MWTP Original Design

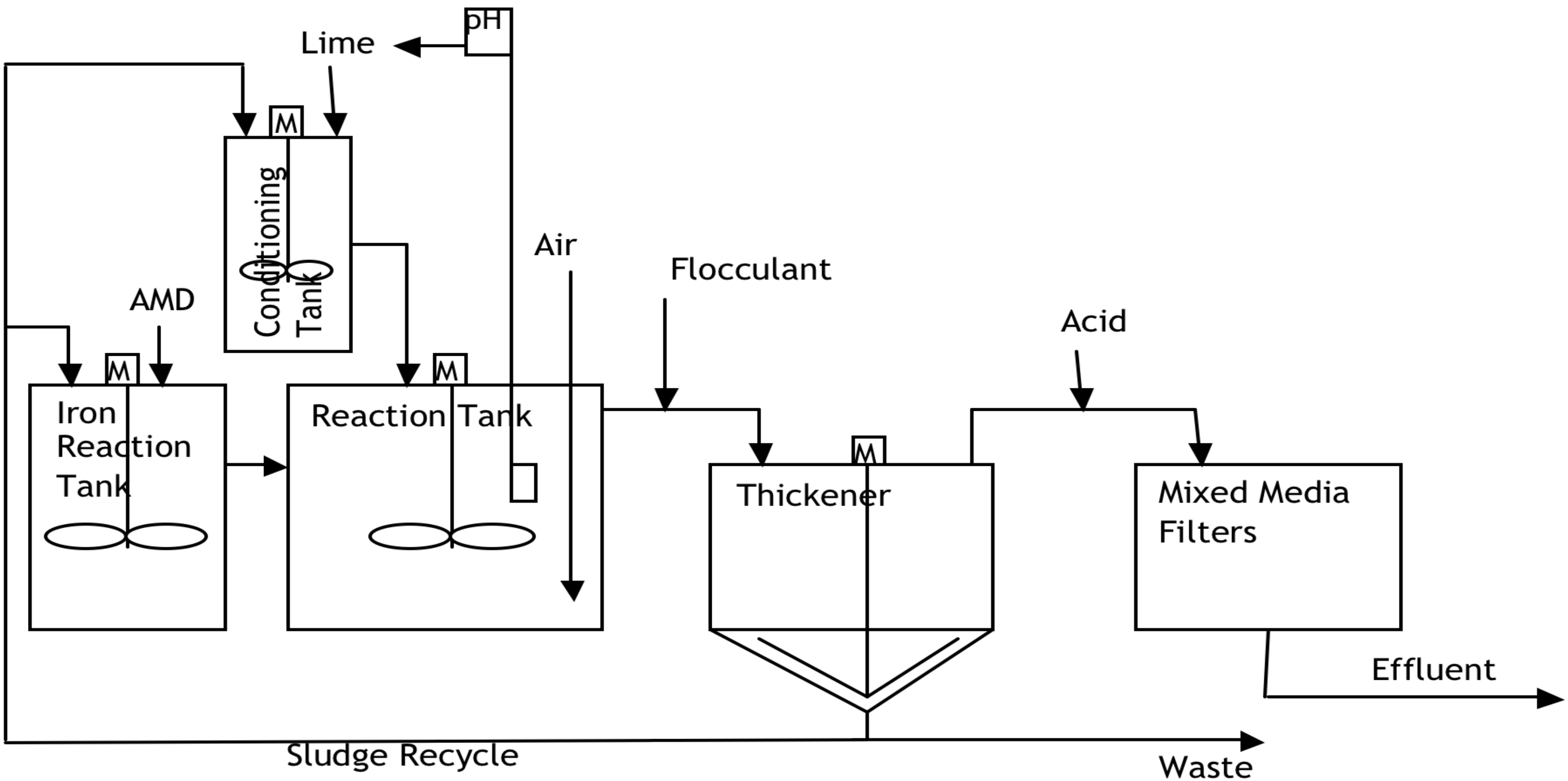


Argo Tunnel Mine Water Treatment Plant Water Quality

Chemistry (µg/L)					
Parameter	Influent			Effluent	
	Minimum	Average	Maximum	Average	Limit
pH (s.u.)	2.8	2.96	3.4	7.81	6.5 – 9.0
Aluminum	7200	21200	35800	198	NA
Copper	1400	4740	7300	6	17
Iron	11400	137000	193000	66	15800
Manganese	30600	90600	130000	253	800
Zinc	13300	45900	70000	26	225
Flow (gpm)	180	263	>700	NA	700

Argo Tunnel MWTP Modified

ATWTF HDS Process Flow Diagram



Benefits of HDS over Conventional Operation Mode

Conventional and HDS Operating Parameters		
	Conventional precipitation operating parameters	HDS operating parameters
Underflow Solids	3.8 %	23.7 %
Filter Cake Solids	17.1 %	33.7 %
Filter Cake Production	734 cf / MG	311 cf / MG
Press Cycle	150 min	10 min
Reaction pH	10.1	9.8
Lime Dose (10% $Ca(OH)_2$)	8.0 lb/1,000 gal	6.8 lb/1,000 gal
Acid Dose (33% HCl)	0.34 lb/1,000 gal	0.13 lb/1,000 gal
Polymer Dose	2.8 ppm	0.7 ppm
Labor	6 FTE	5 FTE
Cost	$ 7.53/1,000 gal	$ 5.75/1,000 gal

Active mine water treatment is effective but expensive

Passive Mine Water Treatment
(ex-situ)

Tiger Tunnel site

Tiger Tunnel average composition in 2011/2012

Parameter	mg/L
Aluminum	48
Copper	4.8
Iron	210
Mn	15
Sulfate	1,100
Zinc	16
pH range	2.4 to 2.7 (s.u.)

Tiger Tunnel flow in liters/min

Year	avg	min	max
2011	100	<0.1	580
2012	26	4	76

High iron low pH water and limestone

EBCT, hr	pH	Fe, mg/L	Al, mg/L	Comments
1.4	4-4.8	25	0	Santomartino et al. 2007 failure after 46 days
13-140	3.0	26	9	Hedin and Wolfe (no date) failure after 200 days, regenerated completely with flushing

Design (Cravotta 1999)

$MS = Q(t_L C/x + t_R \rho_b/n)$
$V = MS/\rho_b$

MS = mass of limestone, kg
Q = flow, m^3/s
t_L = Residence time for longevity, s
t_R = Residence time for reaction, s
C = effuent alkalinity, kg/m^3
x = limestone purity, fraction
ρ_b= Bulk density, kg/m^3
n = porosity
V = volume of reactor, m^3

For low influent Fe and Al (≤ 1-4 mg/L)

Modified design model v1

$MS = Q(t_L C'/x + t_R \rho_b/n)$

$V = MS/\rho_b$

MS = mass of limestone, kg

Q = flow, m^3/s

t_L = Residence time for longevity, s

t_R = Residence time for reaction, s

C = effuent alkalinity, kg/m^3

C' = alkalinity required, kg/m^3

x = limestone purity, fraction

ρ_b= Bulk density, kg/m^3

n = porosity

V = volume of reactor, m^3

Values used in Modeling

$Q = 6.3 \times 10^{-3}\ m^3/s$

$t_L = 1\ yr = 3.15 \times 10^7\ s$

$C = 0.1\ kg/m^3$ as $CaCO_3$

$C' = 0.93\ kg/m^3$ as $CaCO_3$

$x = 0.95$

$t_R = 15\ hr = 54{,}000\ s$

$\rho_b = 1300\ kg/m^3$

$n = 0.5$

Comparative limestone system designs

Design	V, m^3	EBCT, hr
Cravotta*	70	30
Figueroa v1*	830	366
Tiger actual**	22	10

* One year design life

** Design life not given

EBCT = V/Q

Tiger Tunnel Adit 2014

Tiger Tunnel system after 1 year

Limestone design lessons learned

The limestone requirement is dominated by the influent metal acidity and needs to be explicitly included in design

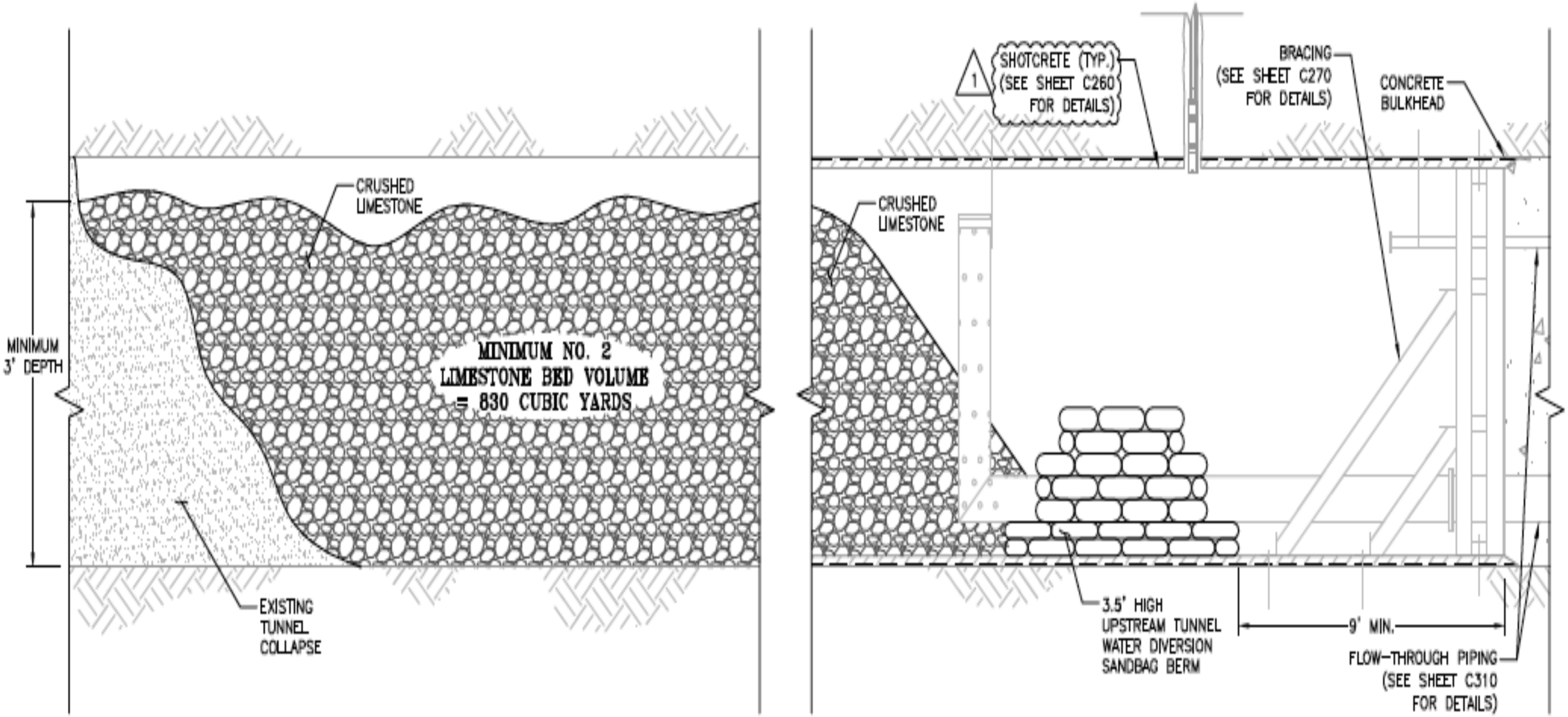
An increase in limestone reactor reactor volume will be required to accommodate collection of iron and aluminium precipitates

Limestone dissolution kinetics for high iron and low pH water needs to be assessed to determine appropriate hydraulic retention time

Hybrid Mine Water Treatment (In-situ)

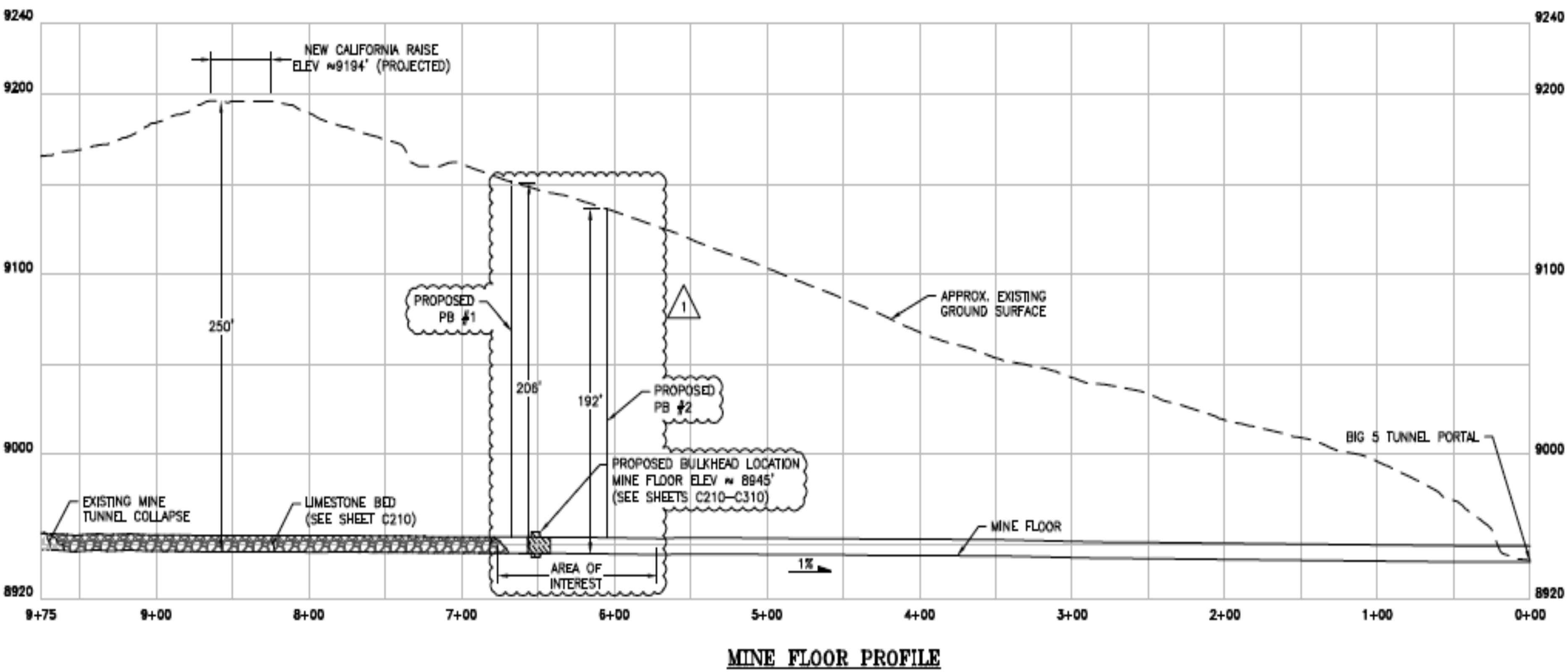
Big Five Tunnel and Portal

Proposed Captain Jack In-situ Remedy



Batch Treatability Dose: 0.6 mL 25% NaOH
Calculated Limestone Mass: 1300 tons

Captain Jack Remedy Profile



Hydrobiogeochemistry is complex

- *Microbial ecology*
  - *Indigenous community*
  - *Redox reactions*
  - *Nutrient availability*
  - *Microbial competition*
  - *By-product formation*
- *Geochemistry*
  - *Metal speciation*
  - *Sorption*
  - *Dissolution*
  - *Precipitation*
  - *Redox reactions (abiotic)*
- *Physical*
  - *Flow*
  - *Bulk phase mass transport*
  - *Interface mass transfer*
  - *Mixing*

Outcome of in-situ remedy pending

Managed passive treatment concept

- Improvement vs numeric goal
- Periodic addition of reagents
- Periodic maintenance
- Solar or wind energy enhanced
- Wireless monitoring

Use Multiple barriers

1. Hydrologic diversion of clean water
2. Flow control
3. Sequential treatment processes
   a. pH adjustment
   b. Iron and aluminum precipitation
   c. Zinc, copper, lead precipitation
   d. Nuisance by-product management

Future of managed passive treatment

- Managed passive treatment is a cost effective way to improve water quality
- Hydrologic management of clean water is paramount
- Integrated and systematic demonstrations needed

Take home messages

Challenges and opportunities exist in Colorado to improve water quality

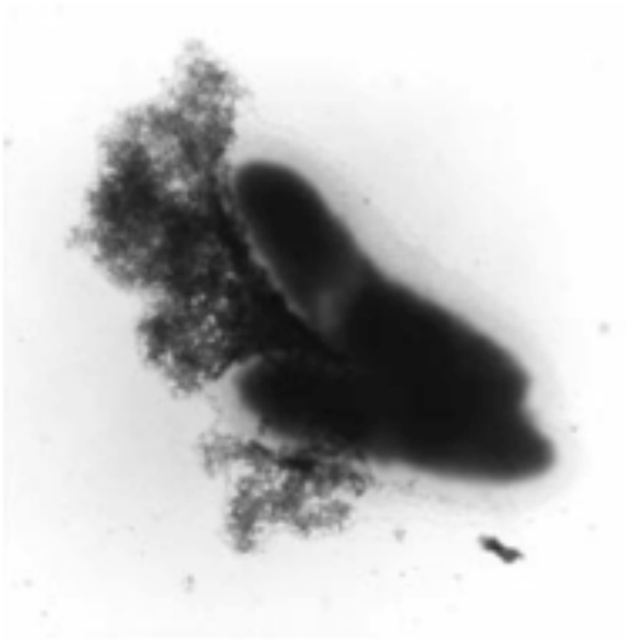
Systems approach needed to understanding the complex interrelationships.

Framework of coupled microbial ecology, geochemistry and reactive transport critical

Elucidation of coupled processes needed to improve remediation schemes

Questions

Thank you for your attention



Microbes rock!

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