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Hydrologic and Water-Quality Effects of the Dinero Tunnel Bulkhead, Sugar Loaf Mining District, near Leadville, Colorado: Implications for Monitoring Remediation

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Objectives

- History of investigations at Dinero tunnel
- Bulkhead design
- Pre and Post-bulkhead monitoring
- Post-bulkhead hydrologic and water-quality changes due to the bulkhead
- Why? Understand changes caused by bulkhead.
  - Demonstrate utility of monitoring information for adaptive management/potential additional remediation
  - *"You can't manage what you don't measure"*.
    - John Jansen, 2014, Keeping the pump primed: groundwater sustainability: National Ground Water Association Industry Newsletter Newzine, April 18, 2014 issue.

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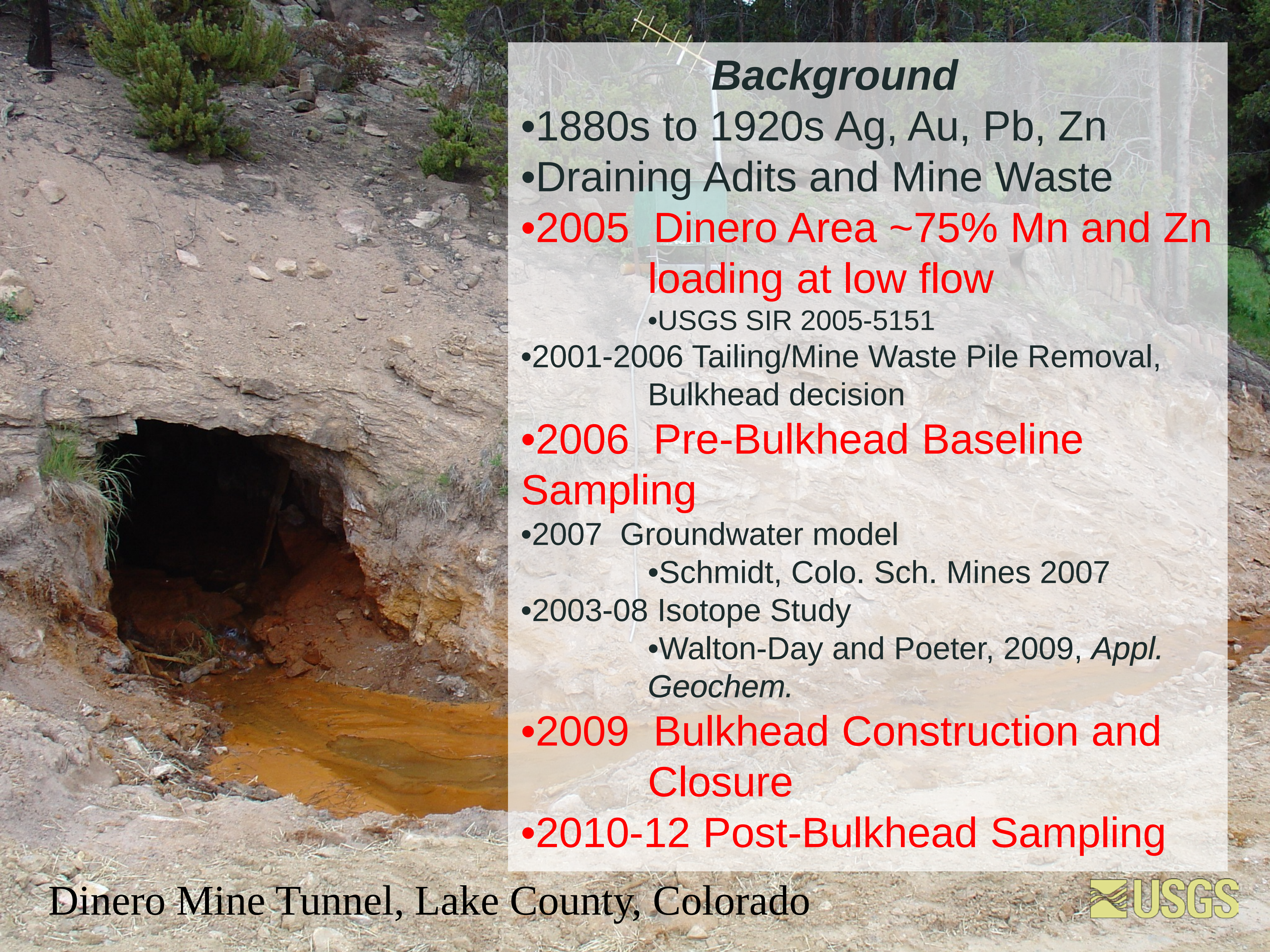
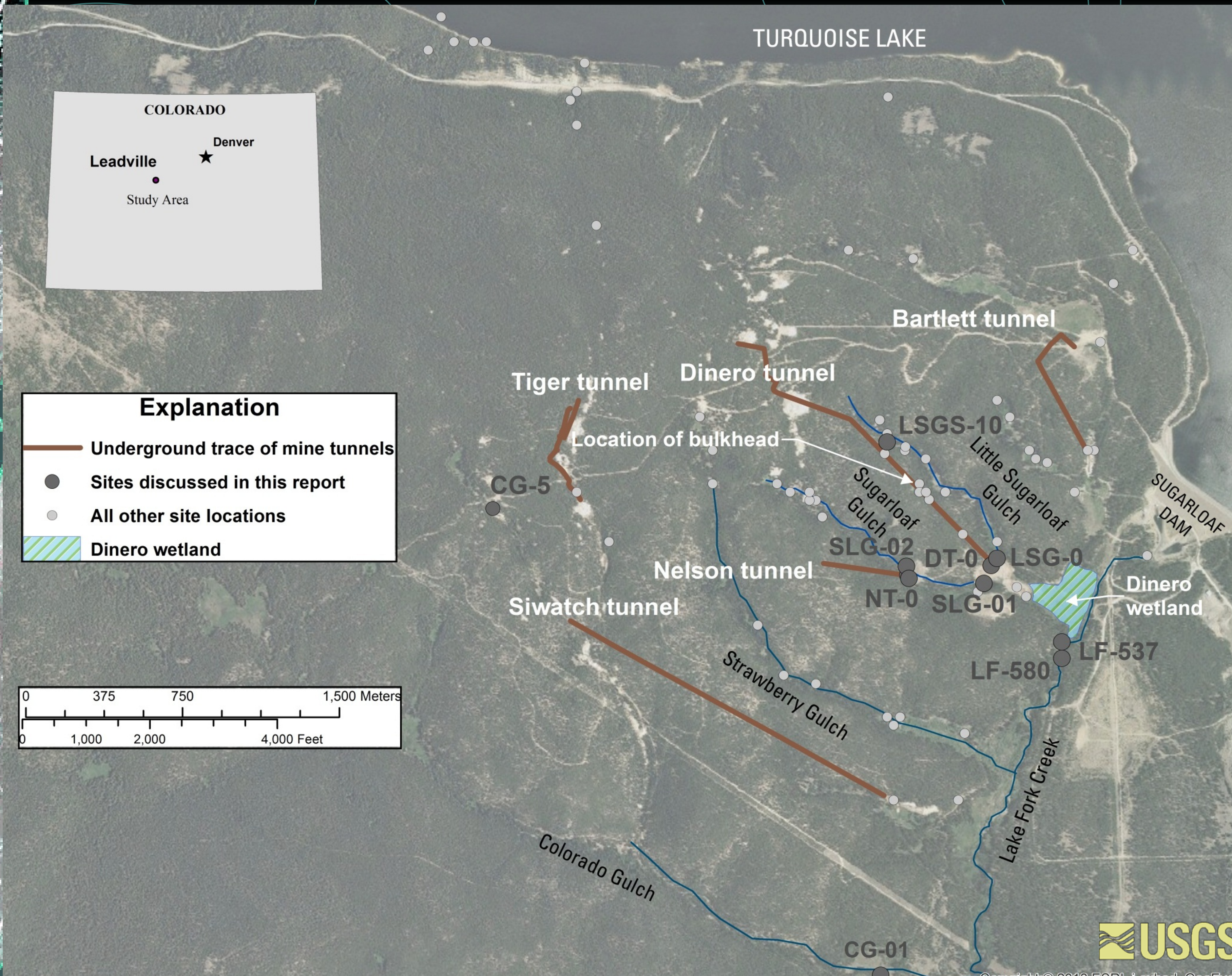
Background

- 1880s to 1920s Ag, Au, Pb, Zn
- Draining Adits and Mine Waste
- 2005 Dinero Area ~75% Mn and Zn loading at low flow
    - USGS SIR 2005-5151
- 2001-2006 Tailing/Mine Waste Pile Removal, Bulkhead decision
- 2006 Pre-Bulkhead Baseline Sampling
- 2007 Groundwater model
    - Schmidt, Colo. Sch. Mines 2007
- 2003-08 Isotope Study
    - Walton-Day and Poeter, 2009, *Appl. Geochem.*
- 2009 Bulkhead Construction and Closure
- 2010-12 Post-Bulkhead Sampling



Dinero Mine Tunnel, Lake County, Colorado


TURQUOISE LAKE
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Denver
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Study Area
Explanation
Underground trace of mine tunnels
Sites discussed in this report
All other site locations
Dinero wetland
0
375
750
1,500 Meters
0
1,000
2,000
4,000 Feet
Bartlett tunnel
Dinero tunnel
Tiger tunnel
LSGS-10
Location of bulkhead
Little Sugarloaf Gulch
Sugarloaf Gulch
CG-5
SUGARLOAF DAM
SLG-02
DT-0
LSG-0
Nelson tunnel
Dinero wetland
NT-0
SLG-01
Siwatch tunnel
LF-537
LF-580
Strawberry Gulch
Lake Fork Creek
Colorado Gulch
CG-01
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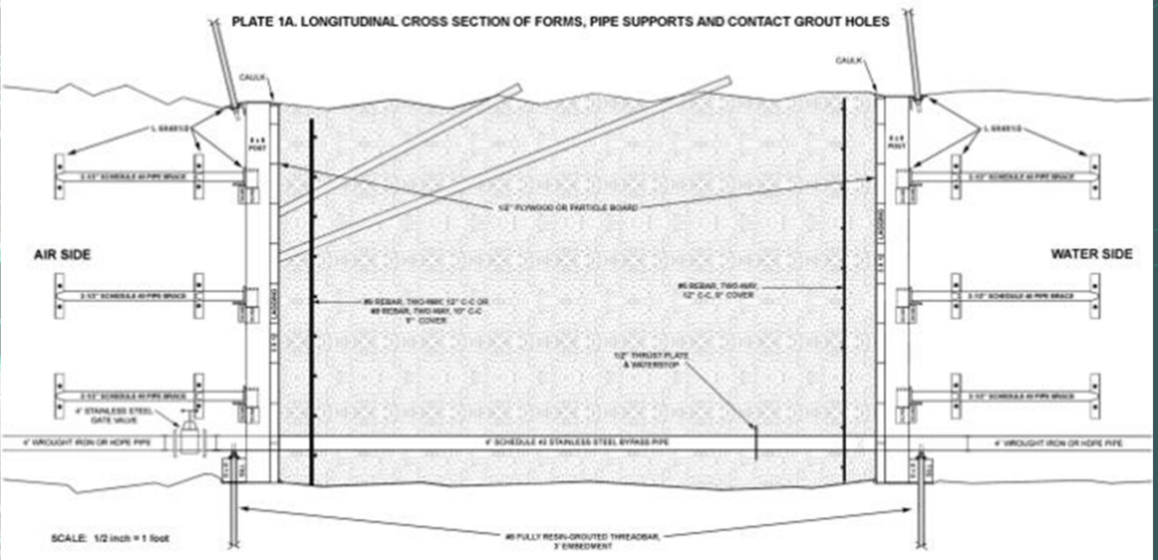
Bulkhead Details

Drawing from John Abel



- Installed 1,250 feet (380 m) behind mine portal
- 15 feet (~ 5m) thick
- Closed in October, 2009

Bulkhead Details

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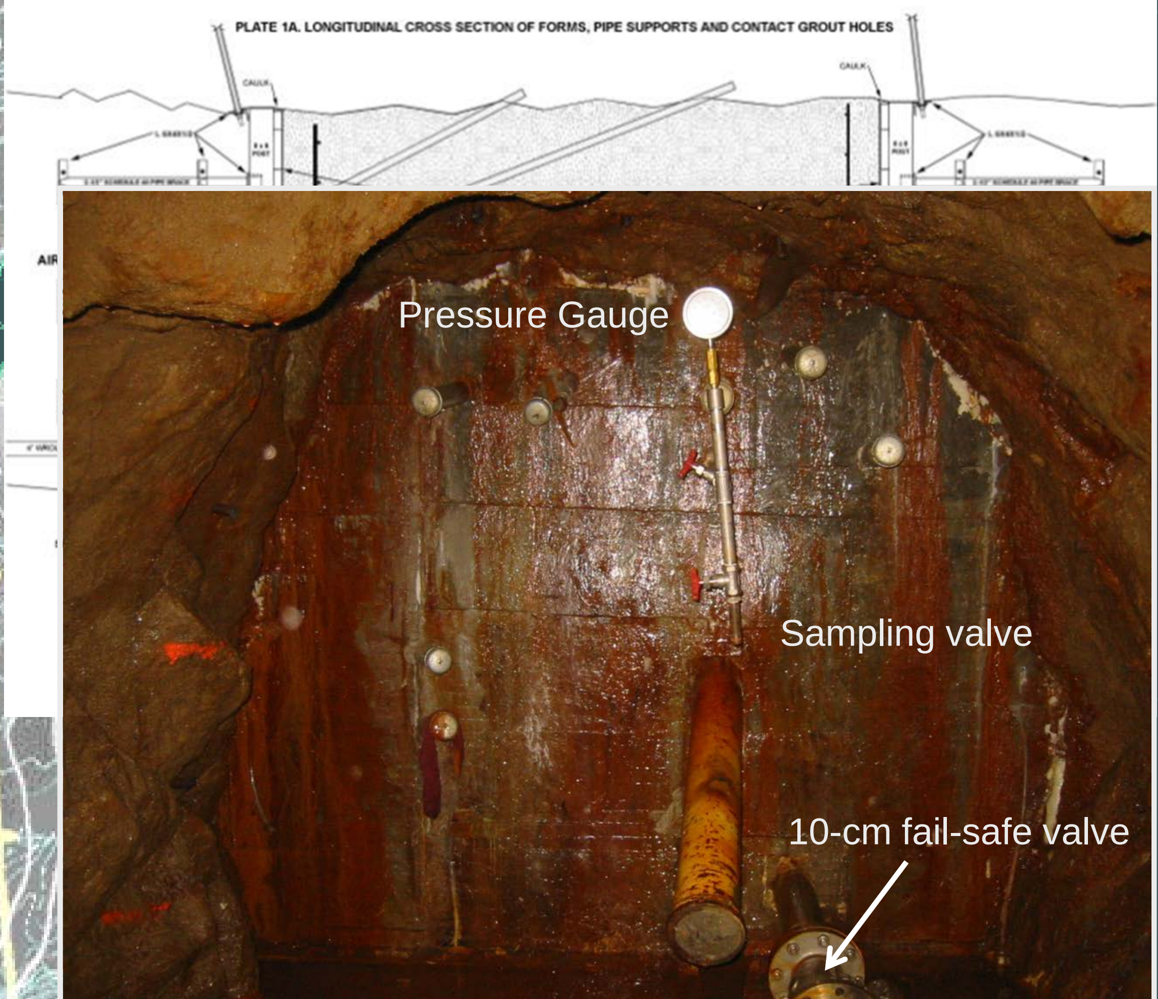

- Installed 1,250 feet (380 m) behind mine portal
- 15 feet (~ 5m) thick
- Closed in October, 2009
- Pipe and valve to allow future mine pool draw down if necessary
- Pressure reached relative equilibrium about 1 year after closing.
- About 377 feet (115 m) pressure head behind the bulkhead

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Pre- Post- Bulkhead Water-Quality Monitoring

- Approach-
  - Measure flow.
  - Collect water-quality samples.
  - 20-70 locations, widespread, gulches, known structures, draining mine features.
  - Filtered (0.45 µm) and unfiltered where possible.
  - Trace elements, major cations via ICP-MS; anions, stable isotopes of water, field parameters.
  - 2006 Pre-bulkhead: June, July, August, October.
  - 2010-2012 Post Bulkhead: High- and low-flow sampling.
- Changes in water quality (good news/bad news) related to changing water table and groundwater flow paths.

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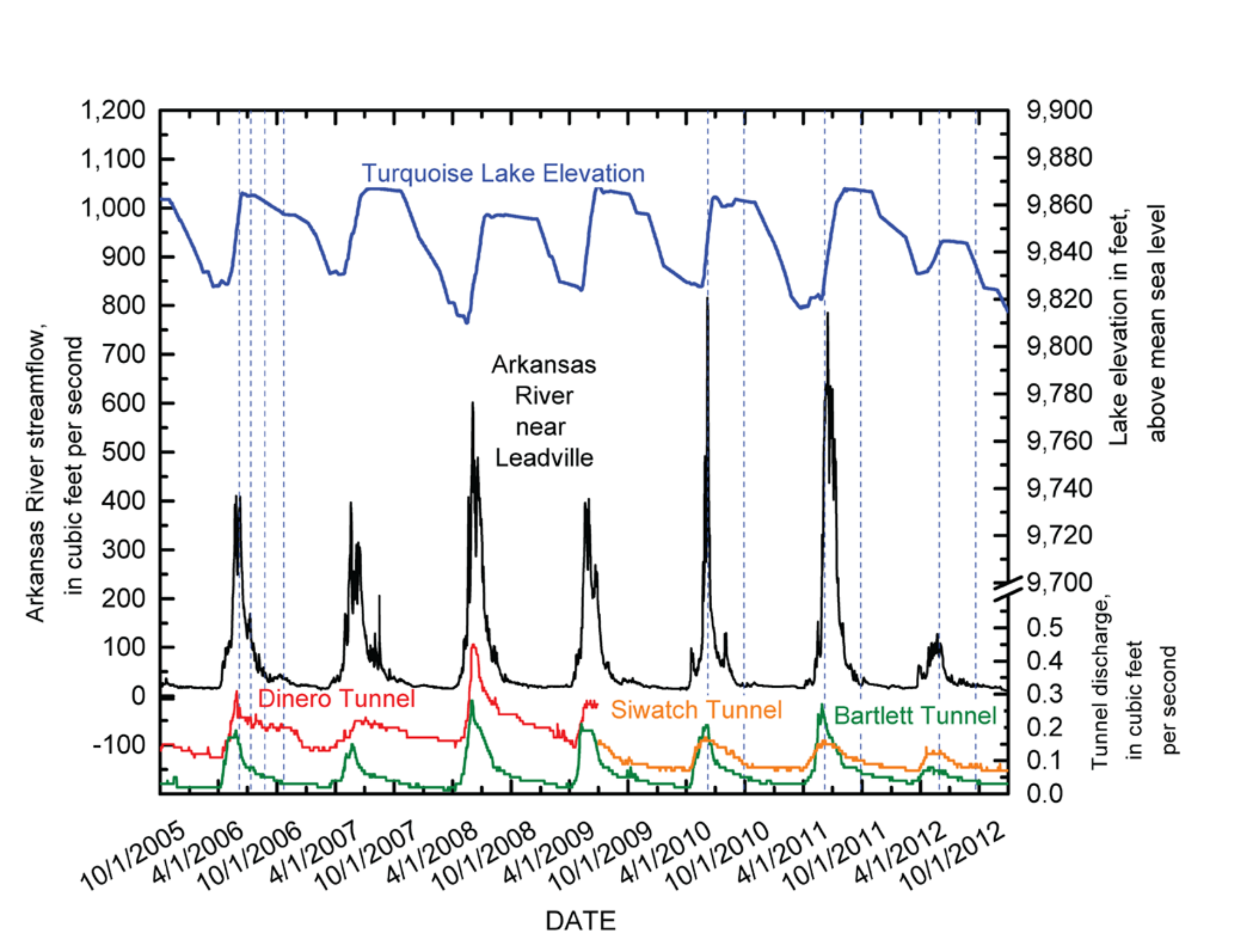
Hydrologic conditions 2006 and 2010-2012

- 2006: near average conditions.
- 2010: near average conditions.
- 2011: greater than average conditions.
- 2012: less than average conditions.
- No change in baseflow in Siwatch or Bartlett tunnels.



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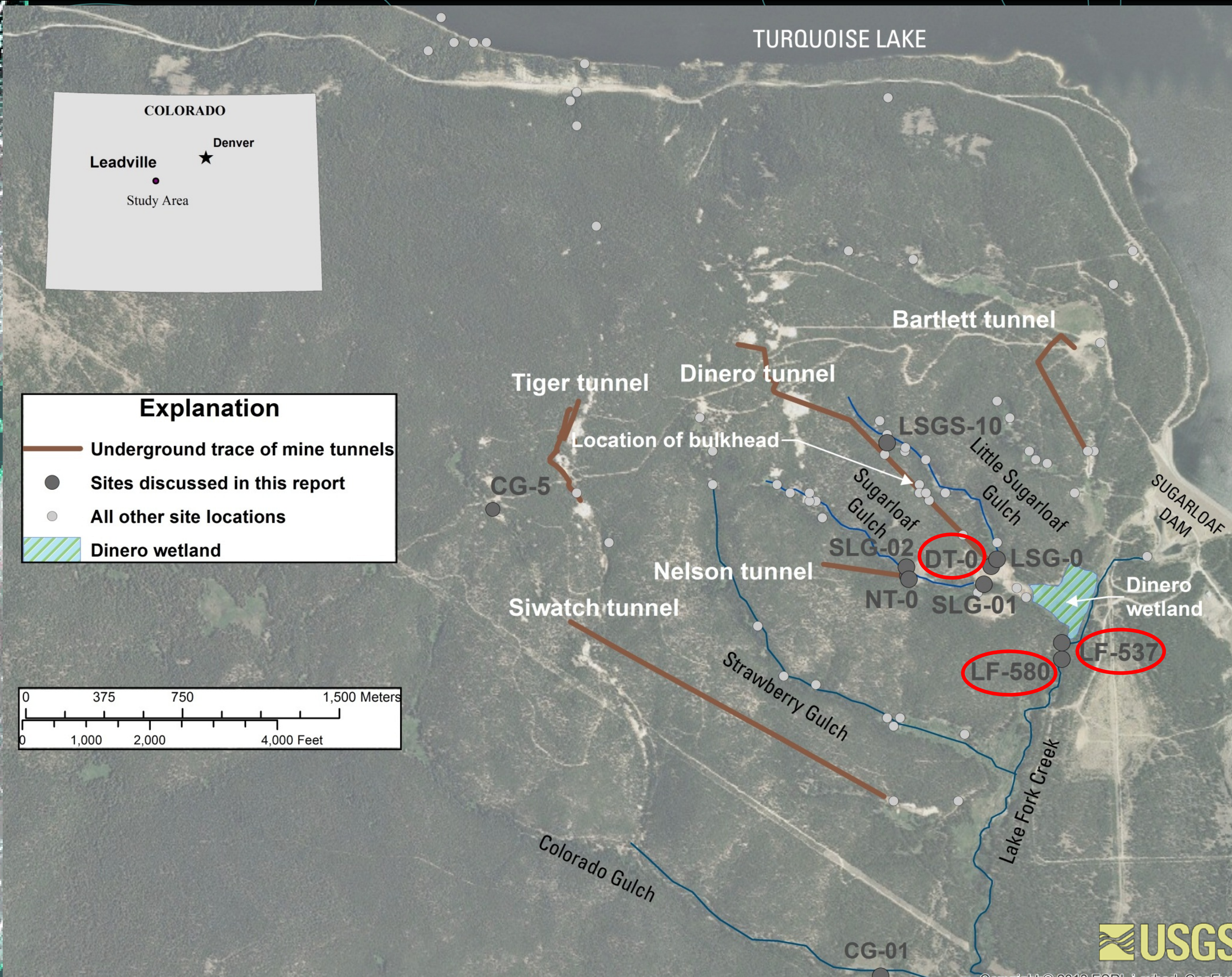
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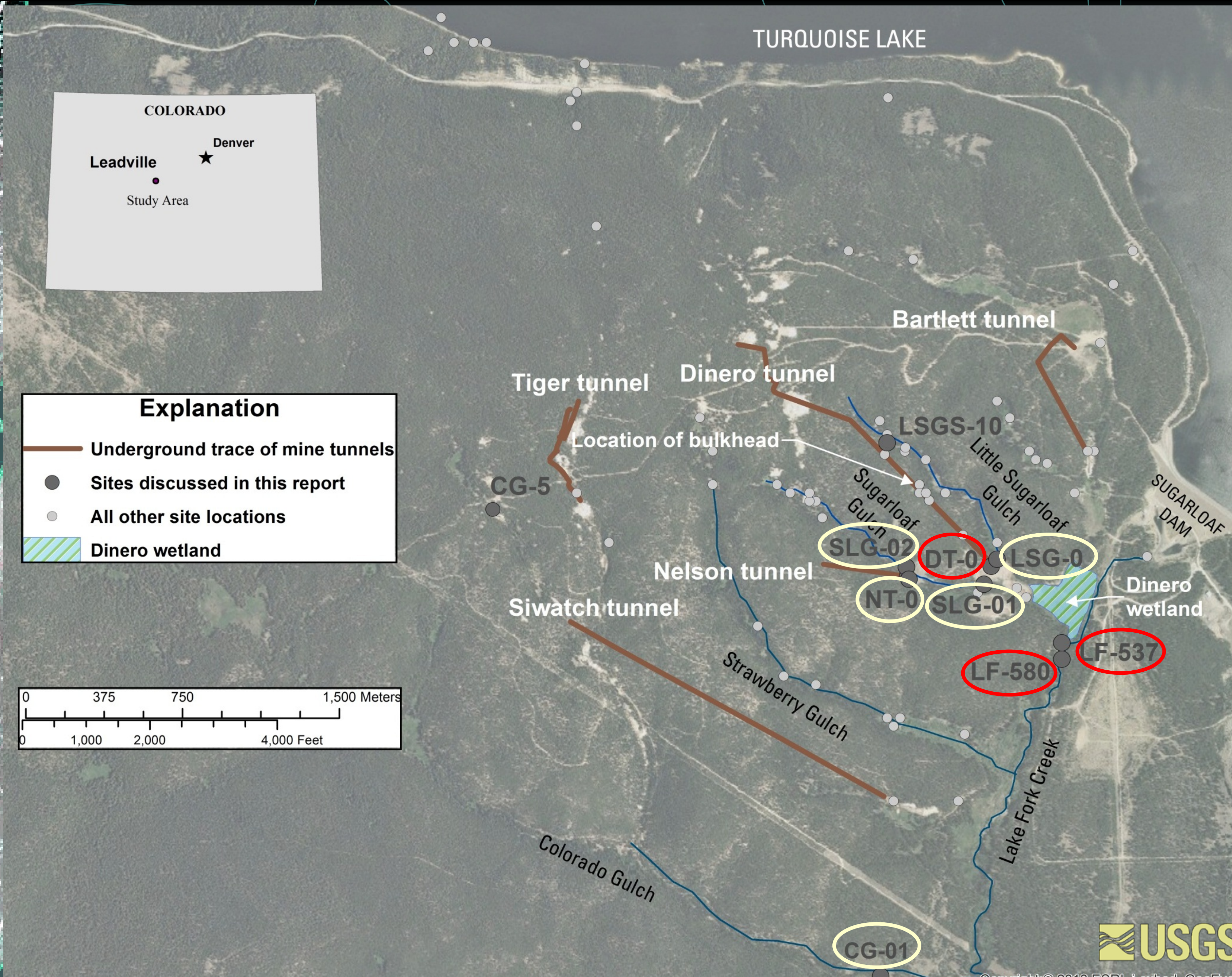
Water Quality Improvement, Lake Fork Creek

	Dinero Tunnel				LF-537				LF-580			
	Disch (ft^3/s)	pH (SU)	Total Zinc Conc. (µg/L)	Total Zinc Load (kg/day)	Disch (ft^3/s)	pH (SU)	Total Zinc Conc. (µg/L)	Total Zinc Load (kg/day)	Disch (ft^3/s)	pH (SU)	Total Zinc Conc. (µg/L)	Total Zinc Load (kg/day)
June '06	0.26	5.2	19,200	12.2	0.069	3.7	9,790	1.65	14.4	7.0	232	8.17
June '10	0.018	6.7	3,230	0.14	0.14	4.5	1,890	0.63	8.3	7.0	49	0.99
June '11	0.045	6.7	4,520	0.50	0.61	4.5	4,170	6.1	17.2	6.5	711	29.9
May '12	0.029	6.5	5,100	0.38	0.021	4.7	4,320	0.22	17.1	7.2	25	1.09
Oct. '06	0.17	6.3	10,100	4.34	0.097	4.2	6,820	1.61	19.4	6.9	61	2.92
Sept '10	0.02	6.4	4,700	0.24	0.002	4.9	2,520	0.010	2.97	6.4	70	0.52
Sept '11	0.04	6.2	6,050	0.58	0.03	4.5	1,720	0.12	2.99	6.6	49	0.37
Sept '12	0.029	6.9	5,390	0.38	0.018	4.4	1,300	0.06	17.3	7.5	34	1.69



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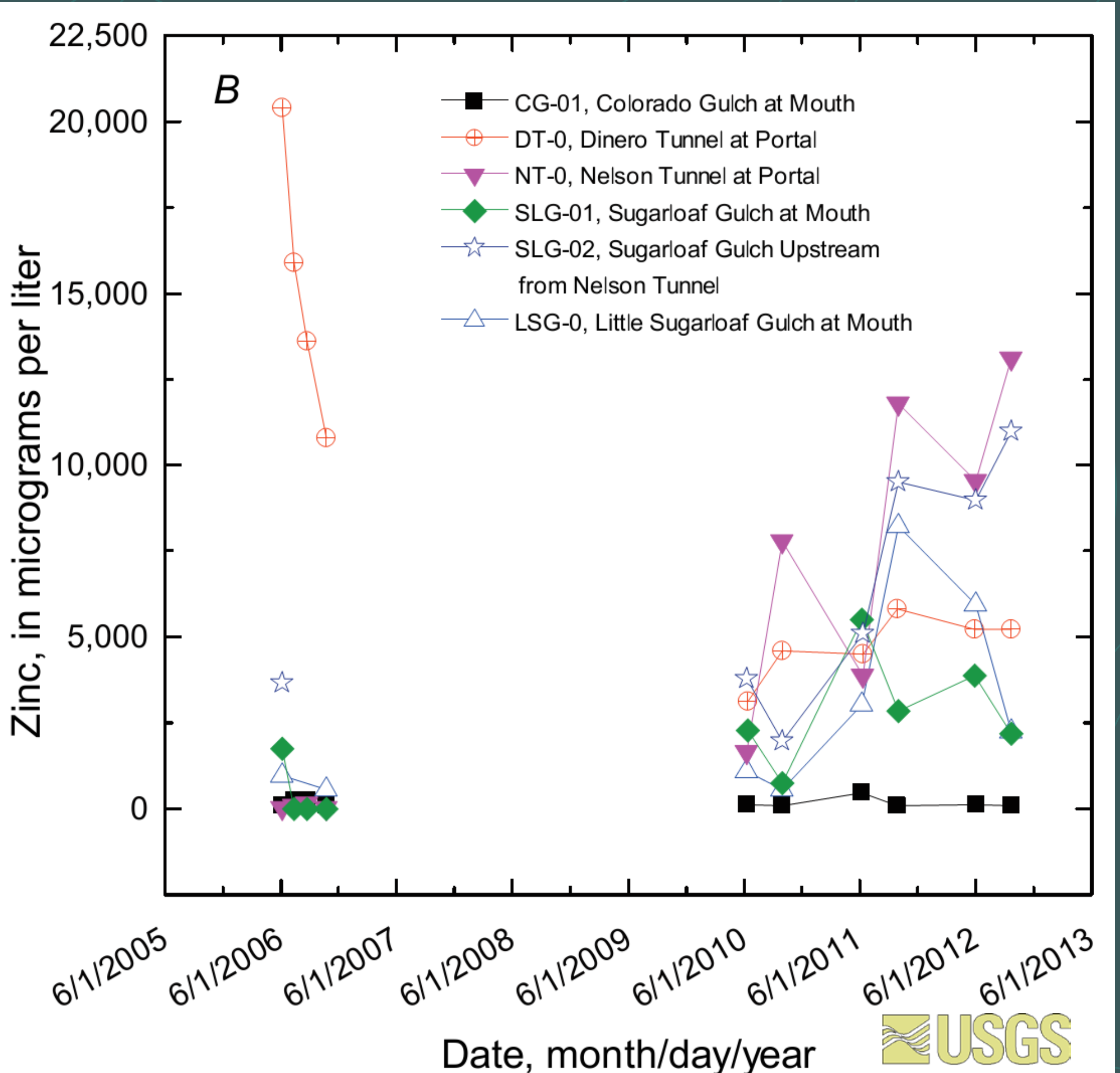
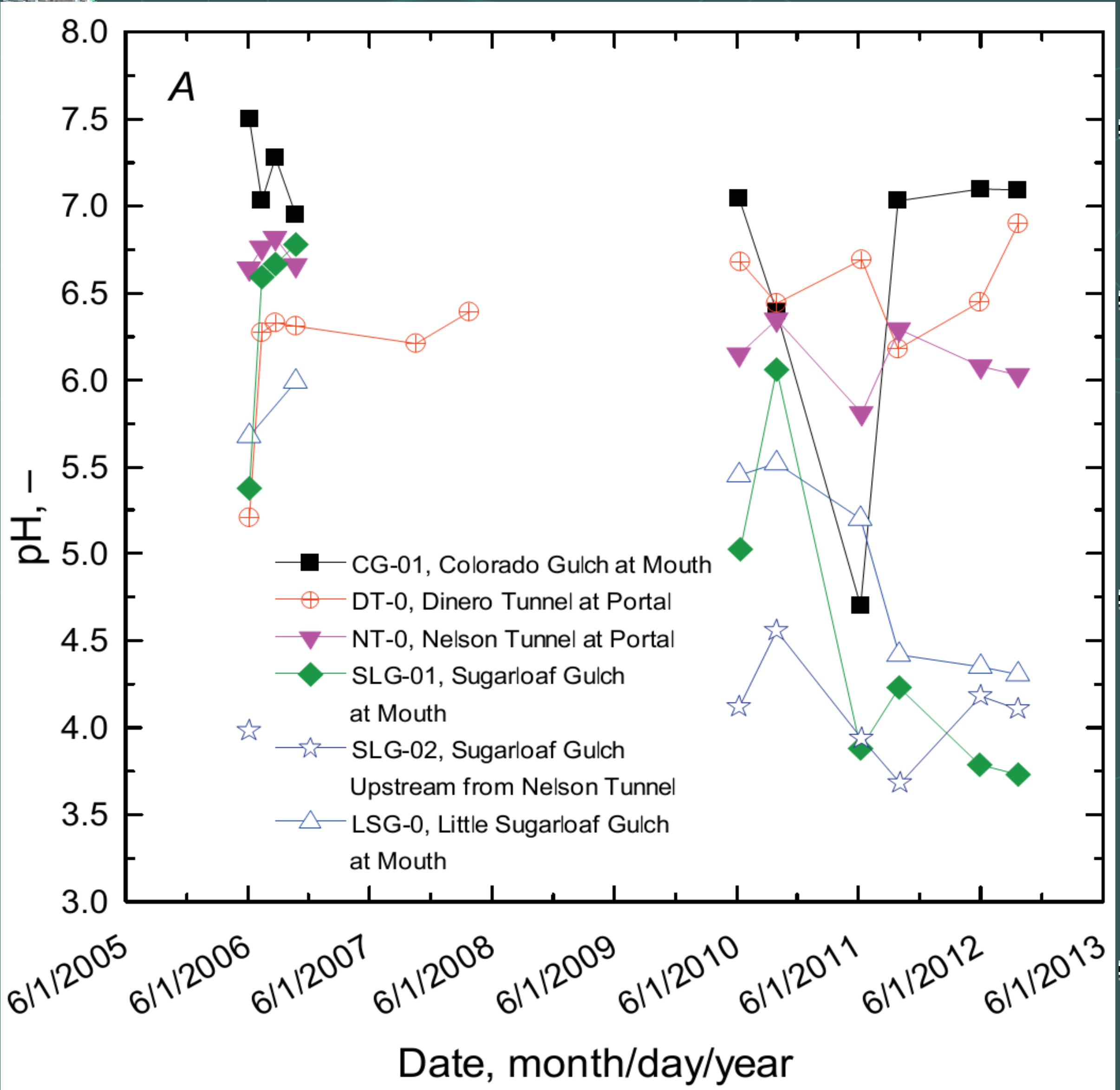
Changes in Zinc Concentration Through Time

- Decrease in zinc concentrations and change in seasonal patterns: Dinero Tunnel
- Increase in zinc concentrations: Nelson Tunnel, Sugarloaf Gulch, Little Sugarloaf Gulch
- CG-01 as control



Changes in pH Through Time



- Slight pH increase at Dinero Tunnel (DT-0)
- pH decrease at Nelson tunnel, Sugarloaf Gulch at mouth, Little Sugarloaf Gulch
- Flow at NT-0 and SLG-02 combines to form SLG-01
  - SLG-01 used to be pH 6
  - SLG-02 flows more now
  - Nelson, iron
- CG-01, compare

Oxidation and precipitation of iron from Nelson Tunnel causes decreasing pH at the mouth of Sugarloaf Gulch

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


Nelson Tunnel, 12 July 2006
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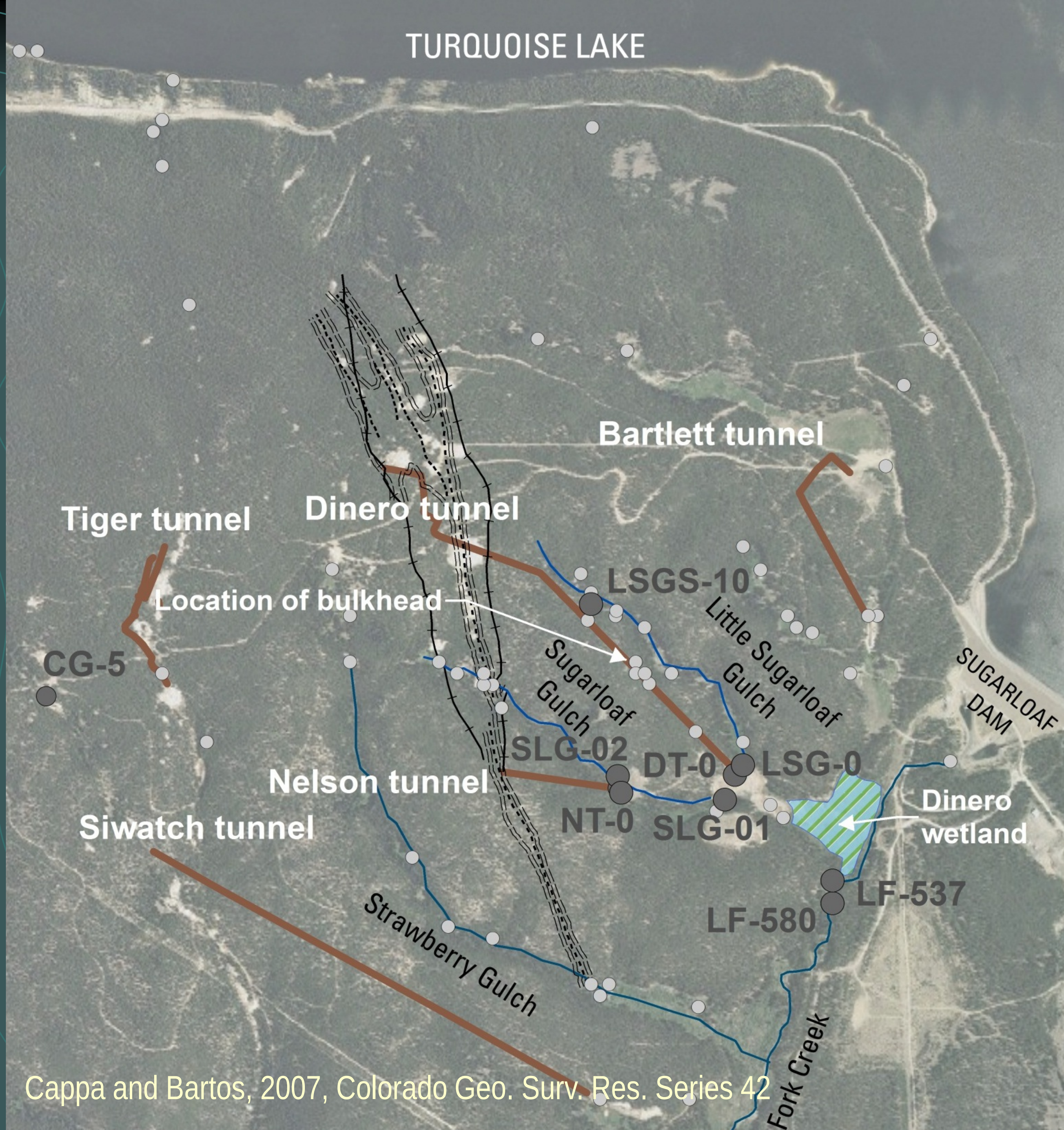
Nelson Tunnel, 24 July 2013
USGS



Cappa and Bartos, 2007, Colorado Geo. Surv. Res. Series 42

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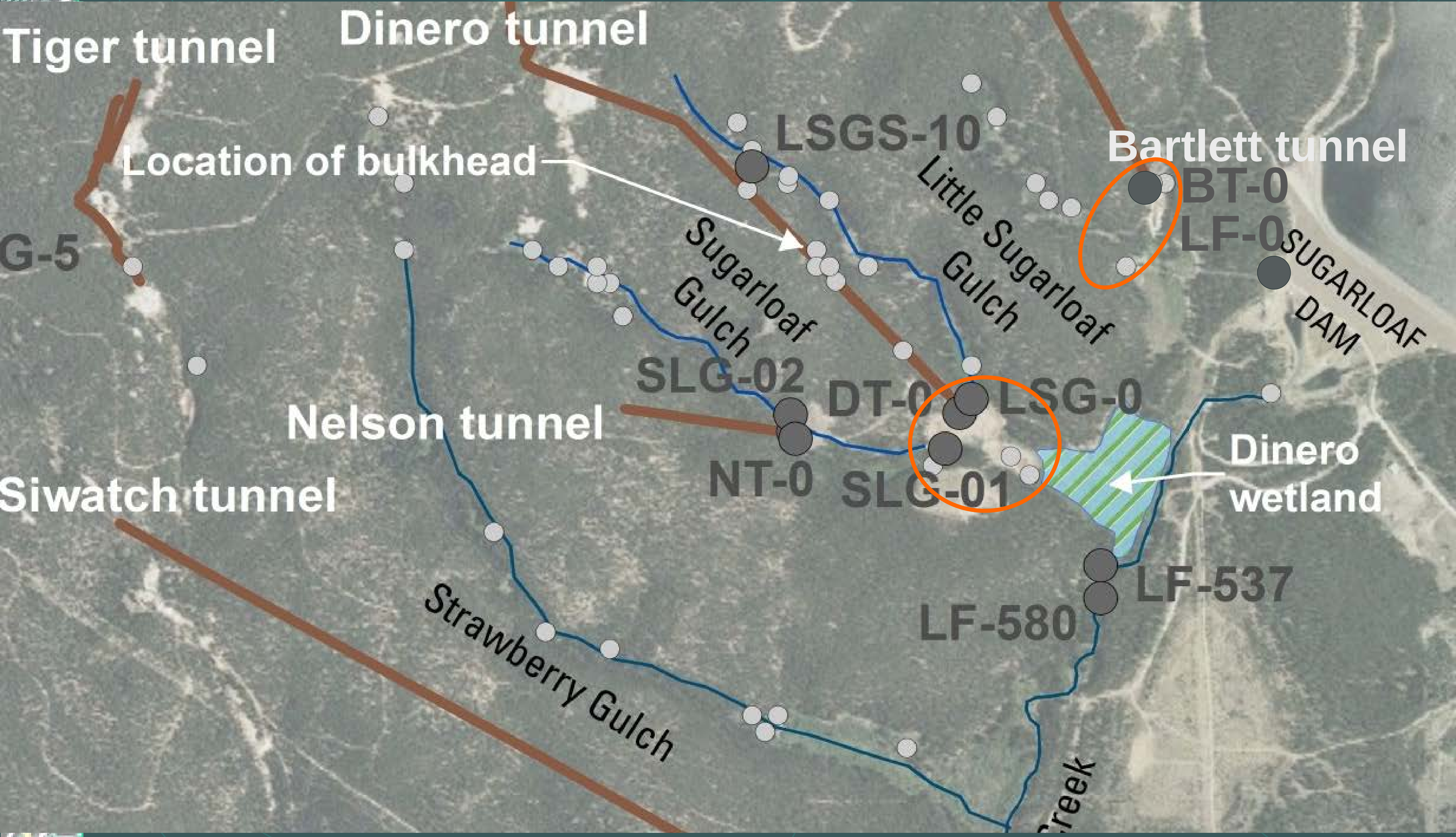
2 views of Zn load

- Source of loads to Dinero Wetland
- Difference between load into and out of wetland



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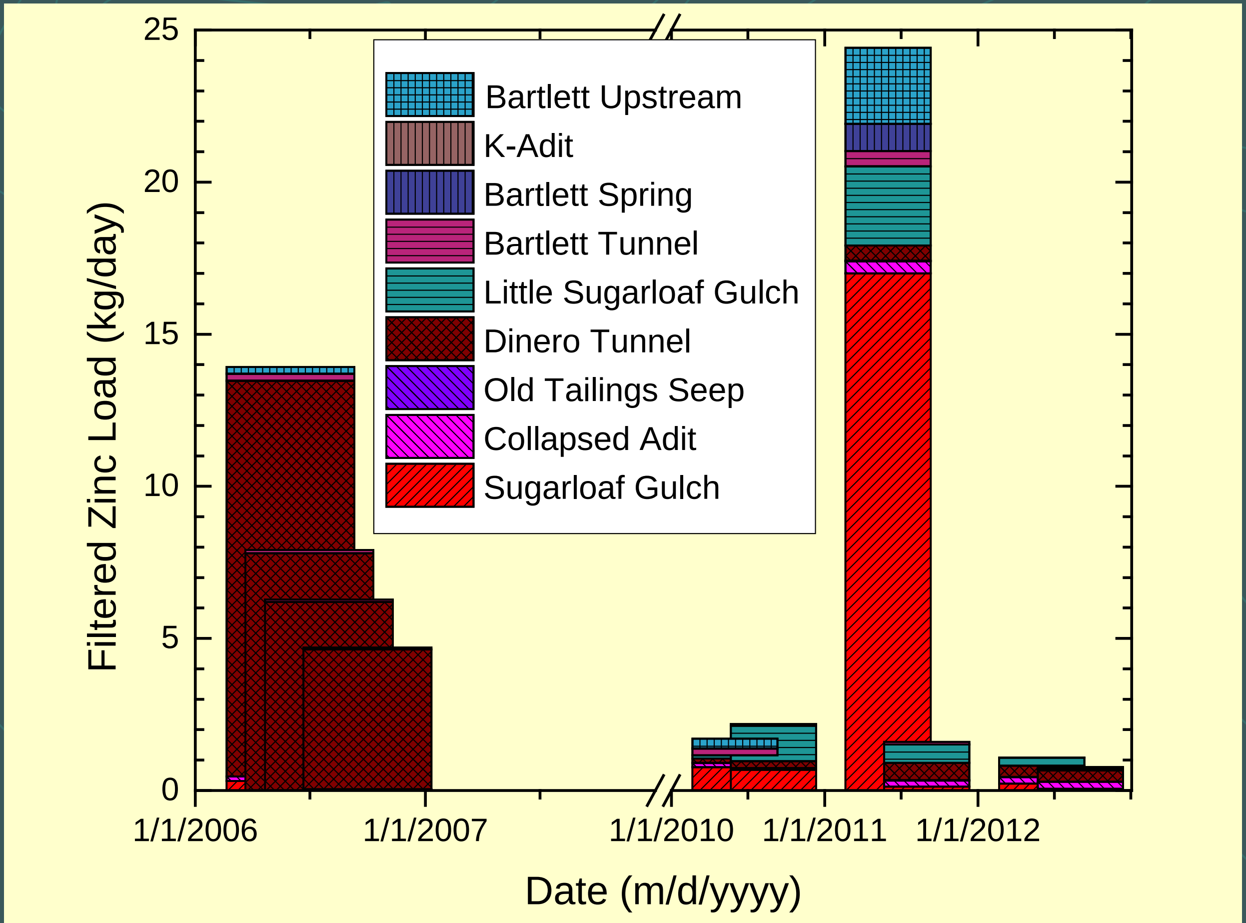
Change in Sources of Loading to Dinero Wetland



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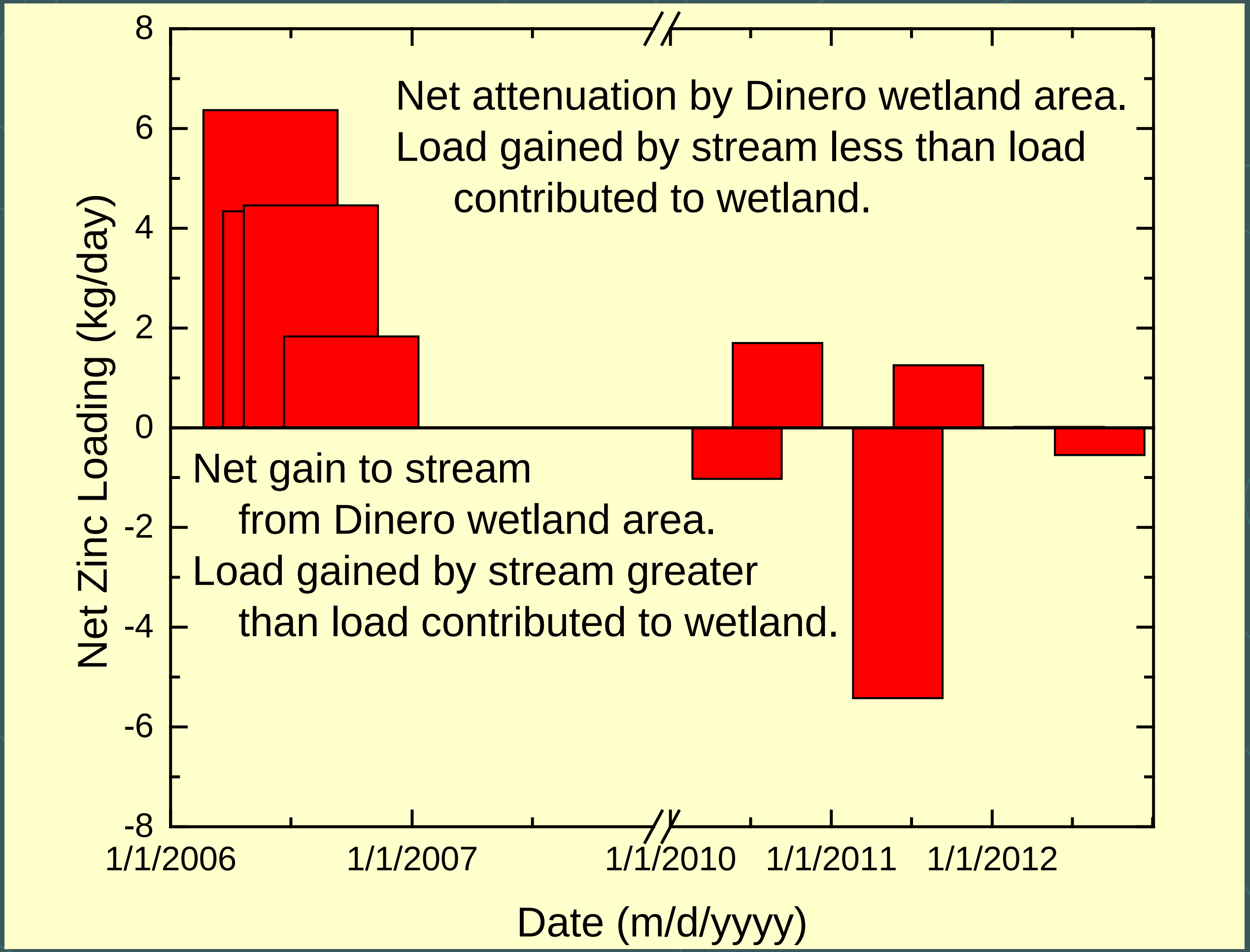
Change in Wetland Retention of Loads



Mixing analysis: water-quality and source water changes at DT-0

- Bulkhead leakage and fractures in tunnel contribute flow to DT-0
- Simple mixing analysis to evaluate water sources at DT-0
- SO_4 assumed as a conservative tracer
- Median of Dripper samples and Median of Structure and Spigot samples chosen as end members
  - Dripper, Structure, and Spigot are different sources of water inside Dinero tunnel.

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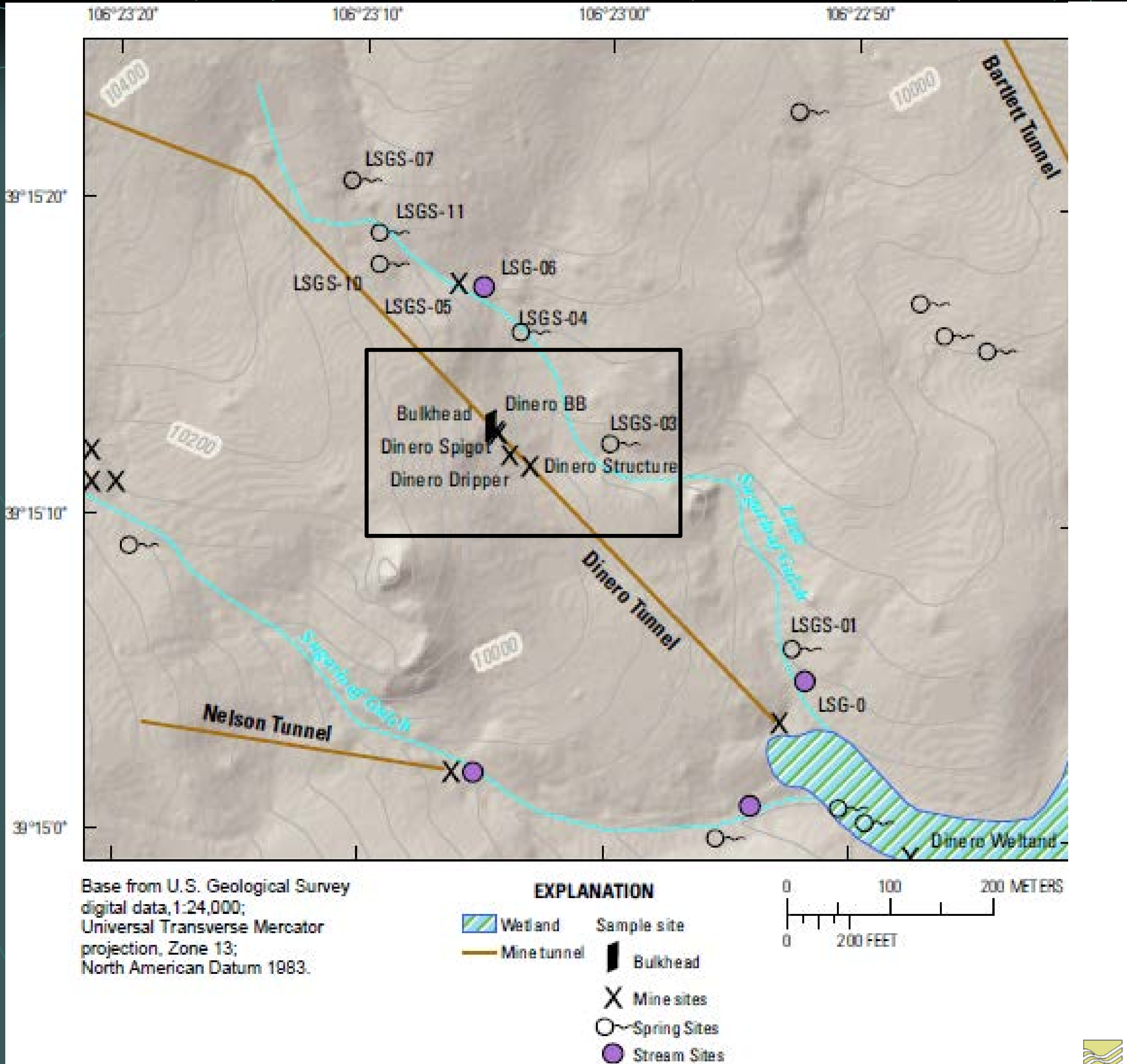
106°23'20"
106°23'10"
106°23'00"
106°22'50"
39°15'20"
39°15'10"
39°15'0"
10400
10000
10200
10000
Bartlett Tunnel
LSGS-07
LSGS-11
LSG-06
LSGS-10
LSGS-05
LSGS-04
Bulkhead
Dinero BB
LSGS-03
Dinero Spigot
Dinero Structure
Dinero Dripper
Little Sugarloaf Gulch
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Sugarloaf Gulch
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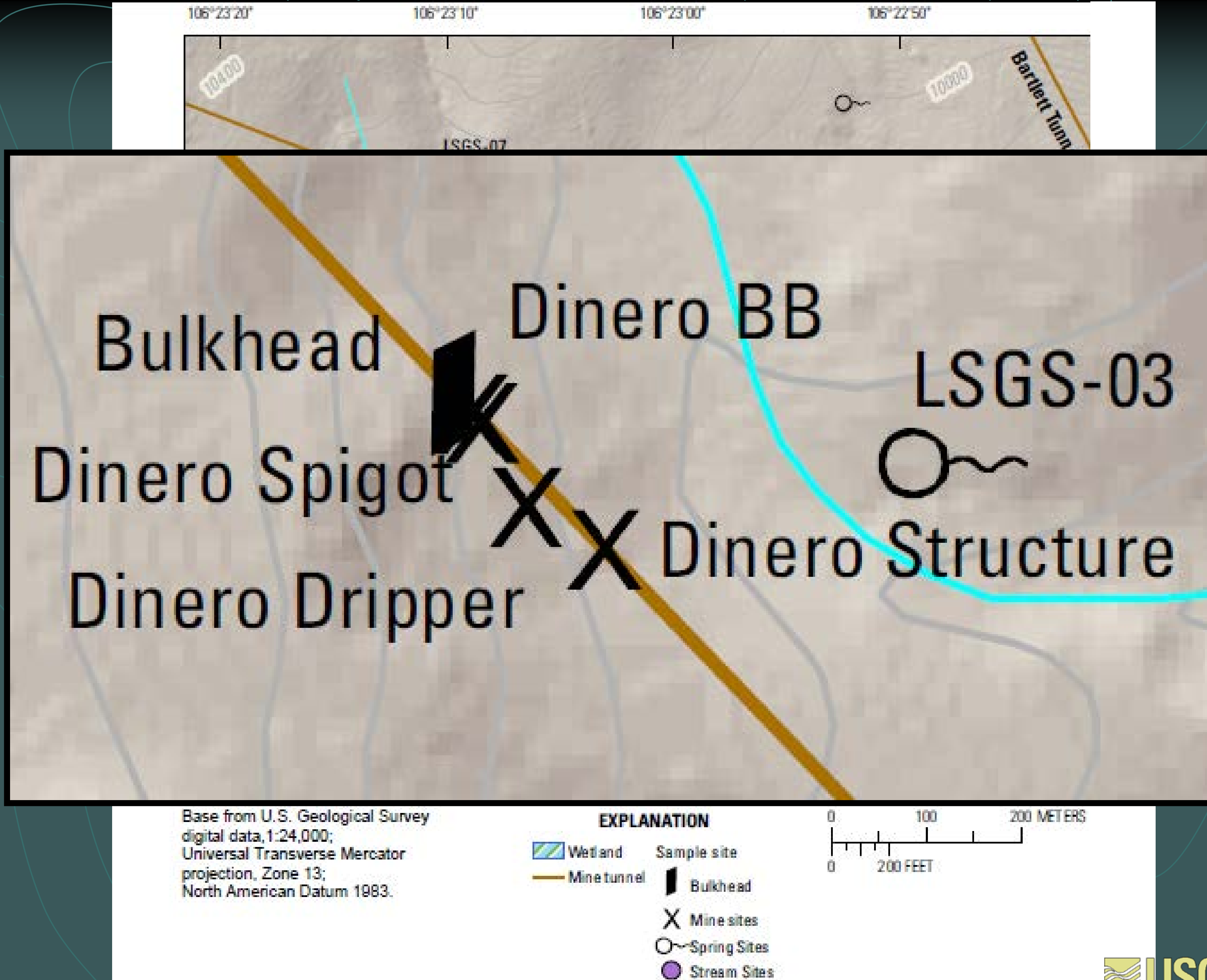
Dinero Wetland
Base from U.S. Geological Survey digital data, 1:24,000; Universal Transverse Mercator projection, Zone 13; North American Datum 1983.
EXPLANATION
Wetland
Mine tunnel
Sample site
Bulkhead
Mine sites
Spring Sites
Stream Sites
0
100
200 METERS
0
200 FEET



106°23'20"
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Spring Sites
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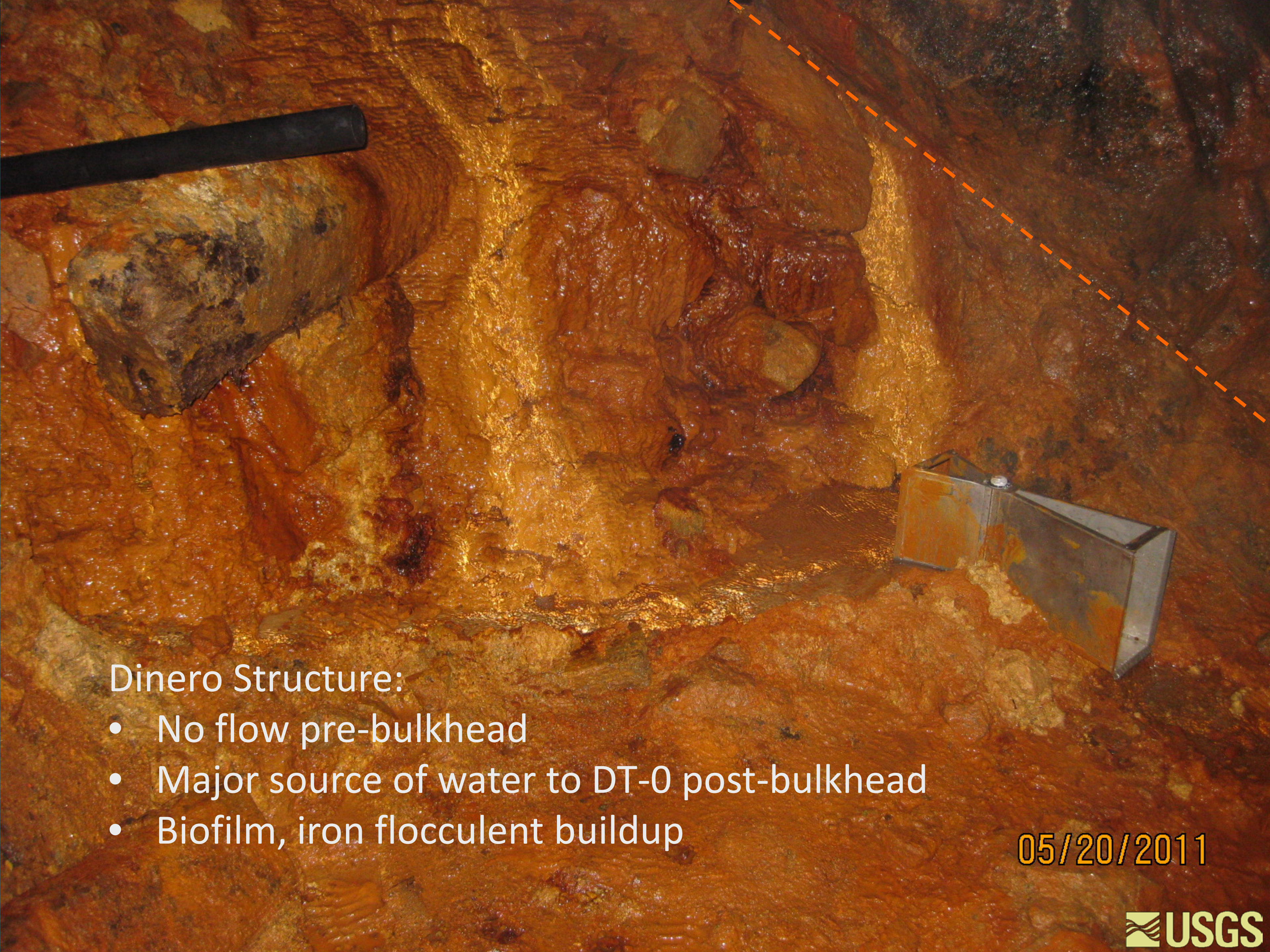
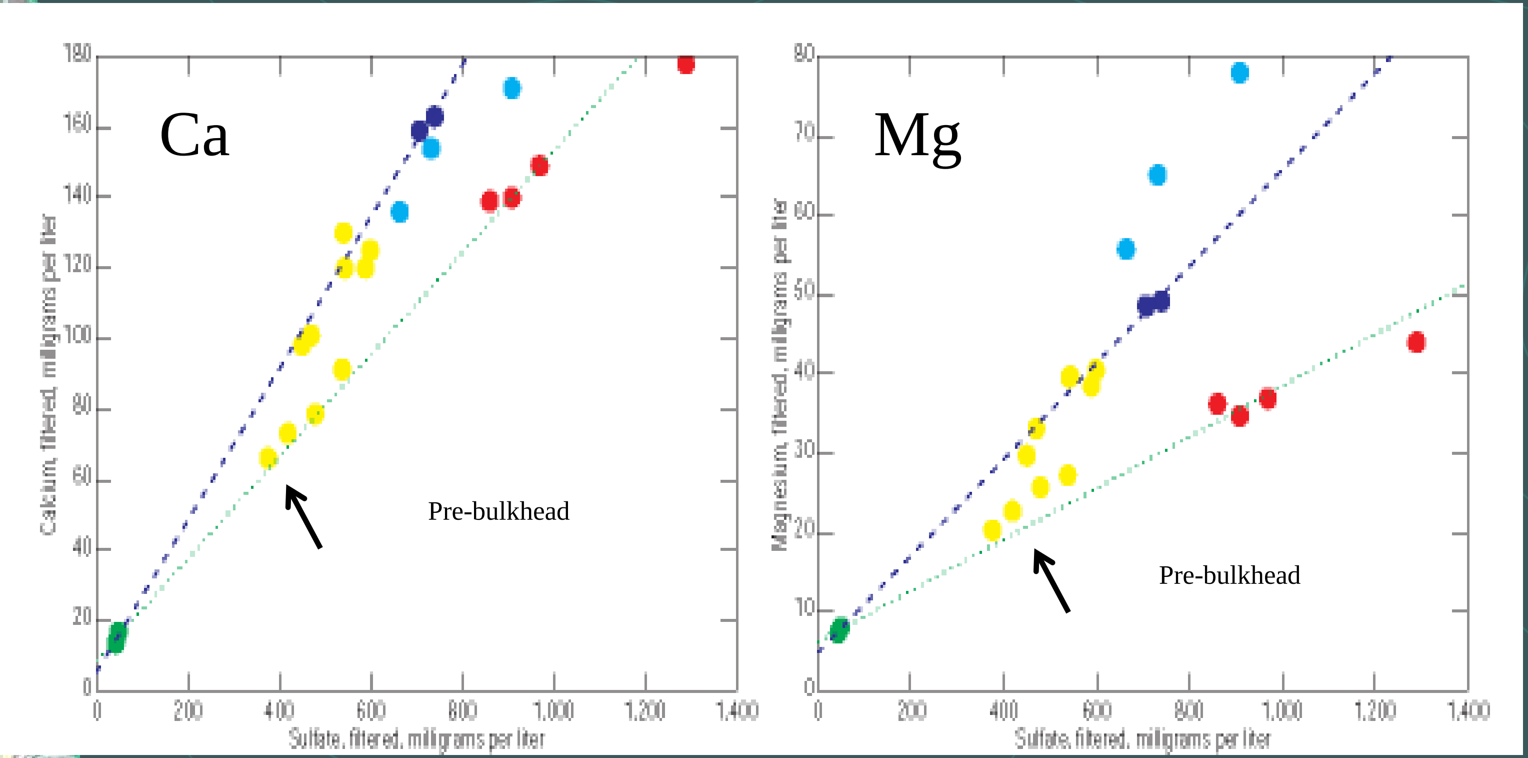
Dinero Dripper
Cleanish, shallow groundwater
06/09/2011
USGS


Dinero Structure:
• No flow pre-bulkhead
• Major source of water to DT-0 post-bulkhead
• Biofilm, iron flocculent buildup
05/20/2011


Spigot
BB
06/09/2011
USGS

Water-quality and source water changes at DT-0

- Pre-bulkhead DT-0 samples: mixture between Spigot and Dripper
- Post bulkhead DT-0 samples: mixture between Structure and Dripper
- New seep (LSGS-10): more like Structure, than Spigot



Spigot
DT-0, Dinero Tunnel
Dripper
LSGS-10
Structure

Geochemical Reactions—PHREEQC and Inverse Modeling- Post Bulkhead Structure and Nelson Tunnel

- Changes between Spigot (mine pool) and Structure (dominant, post bulkhead source of water to DT-0)
  - Spigot (Mine Pool): Fe, SO_4, Mn, Zn > Structure
  - Structure: Ca, Mg > Spigot
  - Structure = Spigot + Calcite dissolution + Zn, Mn precipitation/adsorption
    - Mineral observations at mine dumps indicate Ca-rich rhodochrosite ($MnCO_3$)
  - Mine pool water encountering mineralized veins in oxidizing environment, transported to Structure
- Nelson Tunnel = Spigot (mine pool) + Dripper (shallow, minimally affected by mine drainage) + Carbonate dissolution + Fe/Mn Precipitation

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Summary

- Water quality improvement in Lake Fork Creek.
- Water quality degradation in Nelson Tunnel, Sugarloaf Gulch, and Little Sugarloaf Gulch.
  - Increase in water table affects flow and concentrations in Sugarloaf and Little Sugarloaf Gulches
  - Flow of groundwater from mine pool through mineralized vein behind bulkhead likely causing changes to Nelson Tunnel.
  - Degradation worsens with high-flow events/periods.
- Change in water source at DT-0
  - Mine pool effectively contained behind bulkhead
  - Flow now primarily from mineralized fractures with some contribution from leaking bulkhead.
- Interpretation of continued monitoring results helps refine understanding of processes controlling water quality and hydrology => useful for future remediation/adaptive management

Special Thanks to:

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Any Questions??