Case Study: Big Five In-Tunnel Treatment System at the Captain Jack Mill Superfund Site

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Overview

- Background & Site History
- Mine Water/Subsurface Remedy Concept & Features
- Results of Initial Operation
- Problem Solving
- Next Steps

Big Five Tunnel Portal & Settling Pond

Captain Jack Mill Superfund Site

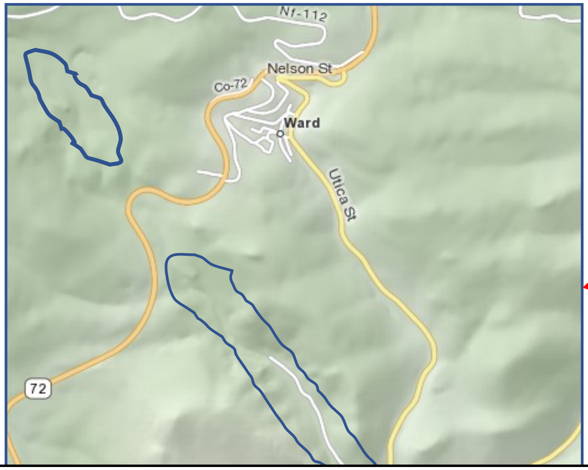
- Historic gold & silver mining and milling area
  - 1860's intermittently through 1992
- Between 8,550 and 9,040 feet above sea level
  - Small area, major features span less than a mile
- Big Five Tunnel discharges AMD into Lefthand Creek
  - Cd, Cu, Mn, & Zn main contaminants of concern
  - pH Range 2.6-4.5
- Relatively low flows:
  - 20 to 160 gpm

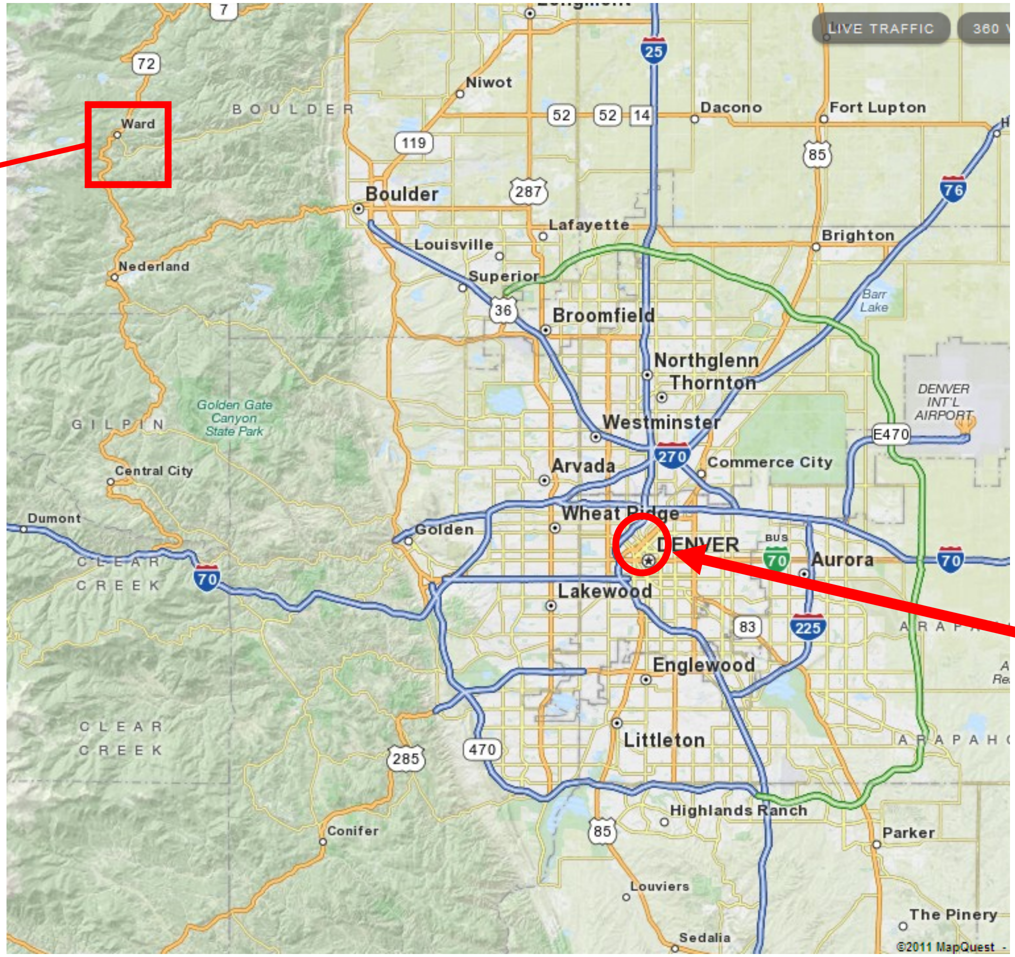

Big Five Adit Discharge


Big Five Waste Dump

Opportunity to Implement Novel Technology

- Less than 50 miles from Denver, in Boulder County, Colorado
- Near the small town of Ward





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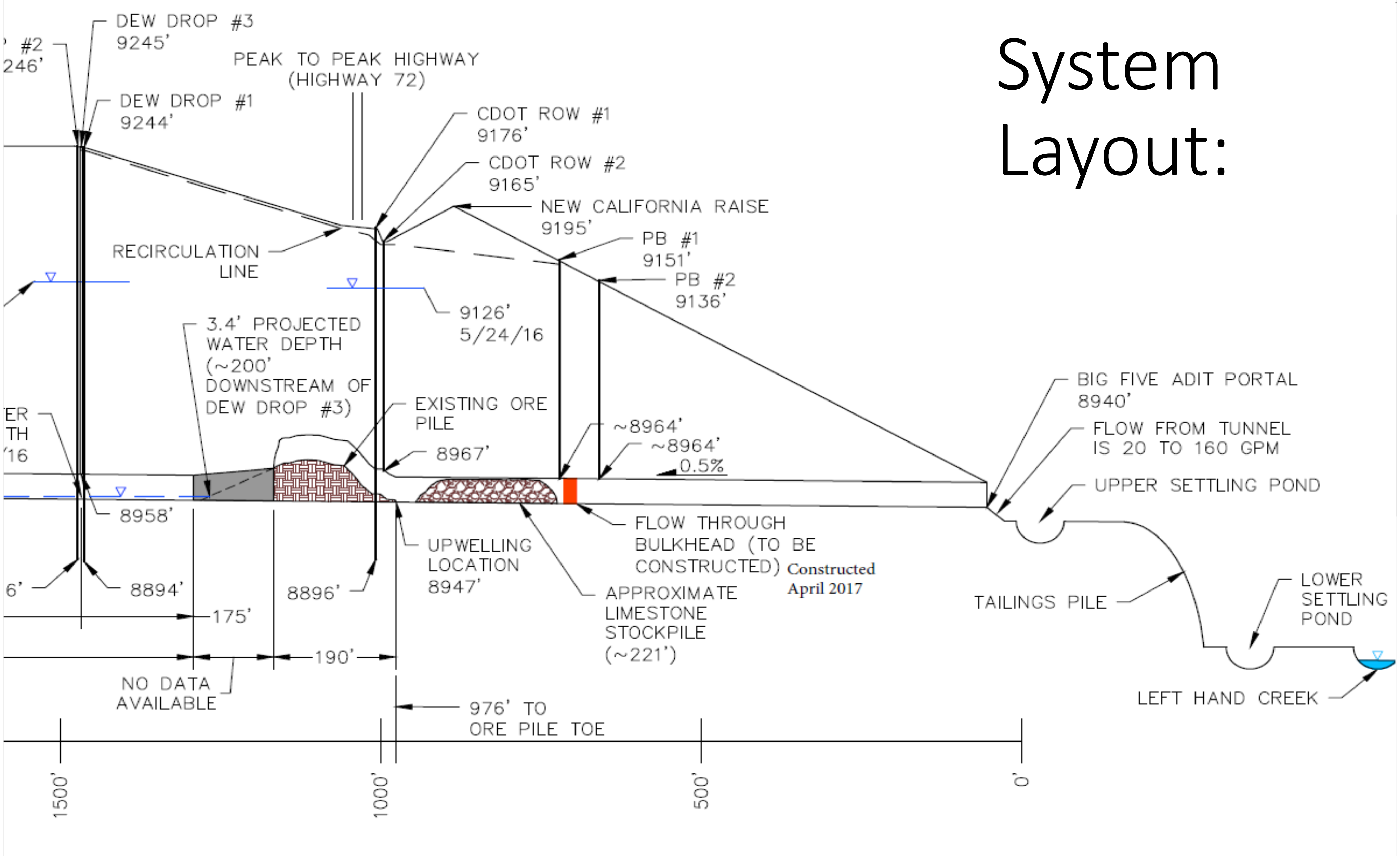
Subsurface Remedy: Concept

- Record of Decision 2008; Treat water 'in-situ' (in-tunnel)
- Submerge mineralized source materials in order to minimize contact with oxygen by impounding water behind an engineered bulkhead
  - Diffusion of O_2 orders of magnitude slower in water than air
  - $FeS_2 + O_2 + H_2O = Fe^{+3} + H_2SO_4$
- Neutralize impounded mine-pool water
  - Objective to slow oxidation & leaching reactions & reduce metals solubility
- Provide recirculation of water
- Option to add organic carbon to drive biological sulfate reduction/sulfide generation

Subsurface Remedy: Components

- A concrete bulkhead with stainless steel piping & valves
  - Water can be released to manage the water elevation in the tunnel mine pool
- 220 feet of tunnel packed with gravel sized crushed limestone, inby of bulkhead that was expected to provide some initial neutralization
- Recirculation system allows water to be pumped from just inby of the bulkhead to a borehole intersecting the tunnel up gradient, ~900 feet away
  - Goal was to move water through the limestone section and bring neutralized water to upgradient portion of the mine pool
- Flexibility
  - Capability to add caustic (NaOH- liquid) if additional neutralization is needed
  - Option to add liquid or slurried carbon source to promote sulfate reduction & precipitate metal as sulfides
- Initial operation was to employ simplest method first (flooding & initial limestone neutralization) and then adjust system as needed

System Layout:



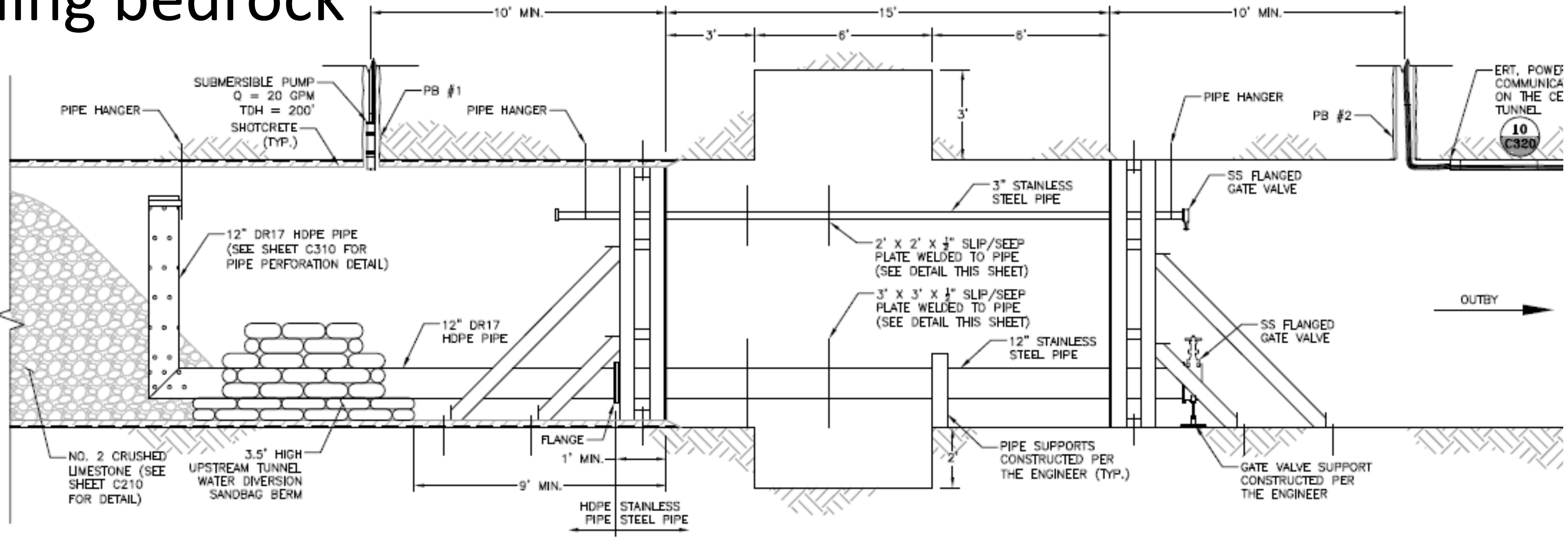
Remedy Installation: Limestone Placement

Mucker loading limestone into tunnel

Limestone: 2 feet from tunnel ceiling

Concrete Bulkhead Design

- Located 600 feet inby of portal
- Approximately 200 feet below ground
- Keyed into surrounding bedrock
- 15 feet long, 6x3 ft key sections
- 2 pipes – Stainless Steel
    - 12” lower pipe, 3” upper pipe



SIDE VIEW PROPOSED BULKHEAD

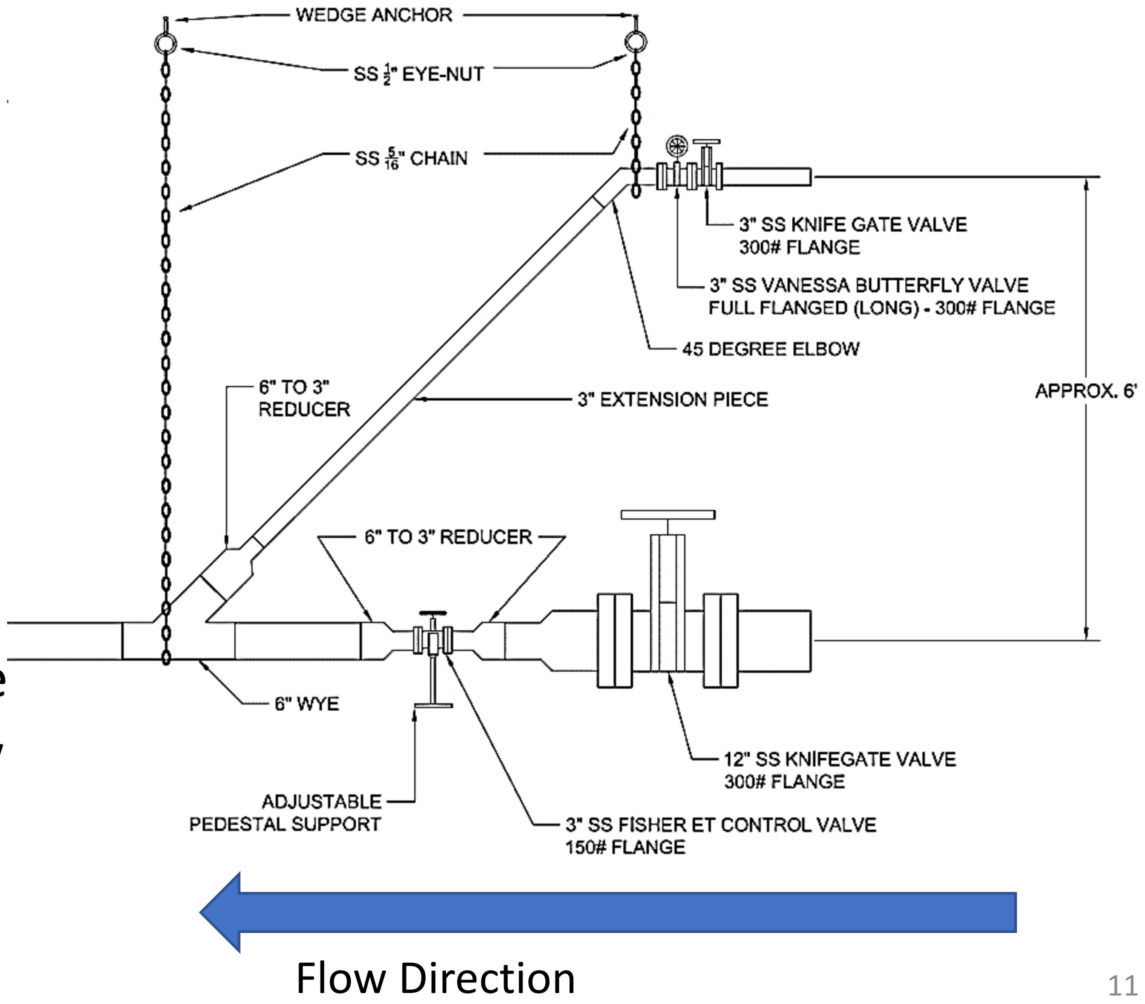
0 2' 4' 8'

SCALE:3/8"=1'

Concrete Bulkhead Installation

Pipe and Valve System Considerations

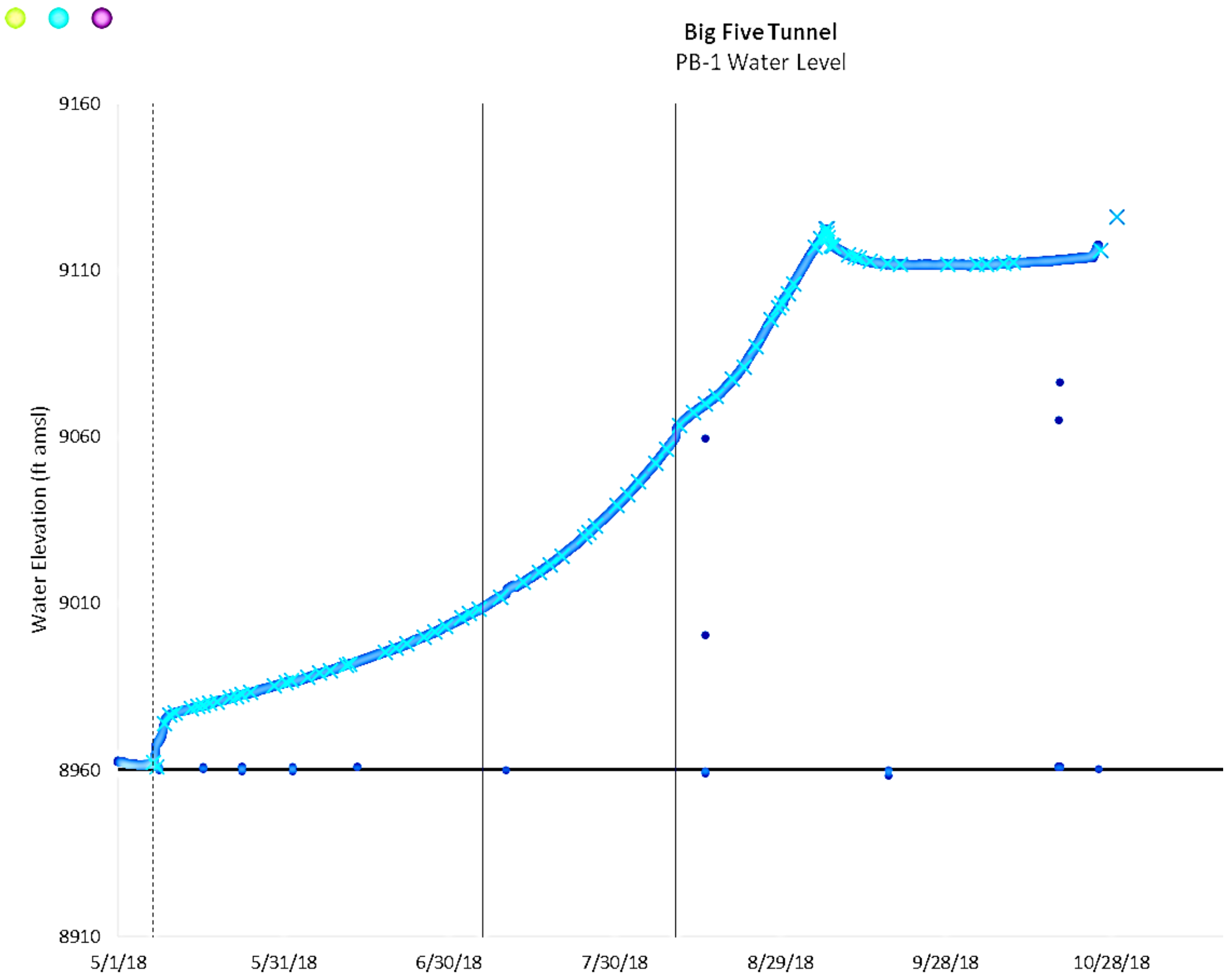
- Wanted to be able to adjust/regulate flow rate from bulkhead pipes
- Many valves can cavitate from pressure changes in flow reduction applications
    - Maintenance considerations?
- Solution:
    - Primary isolation valve for on/off operation
    - Secondary specialized flow control valve
    - Allows planned replacement of the flow control valves in the future
- All 316 Stainless



Completed Valve and Piping system

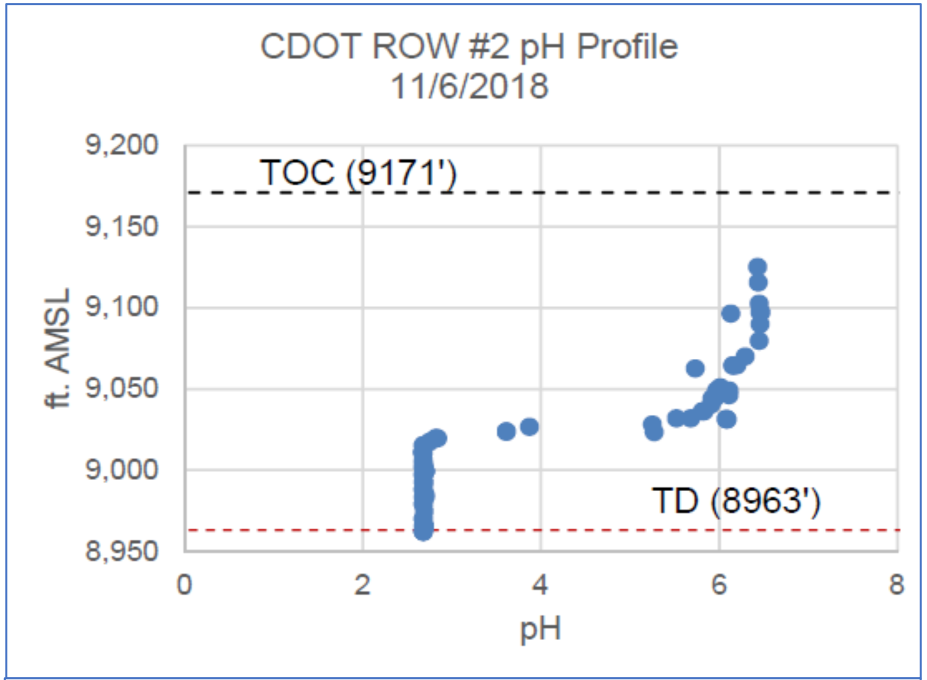
System Installed: What Happened Next?

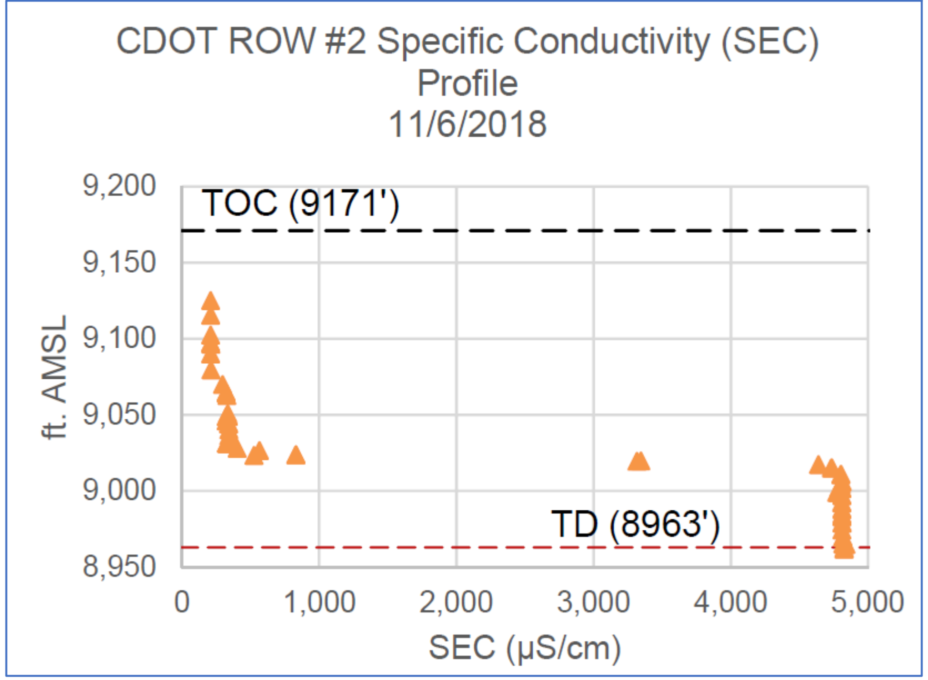
- Closed valves spring 2018
- Filled faster than expected
  - ~ 160 ft in 4 months, measured at borehole just inby of bulkhead
  - Hight to top of casing of borehole: ~198 Ft
- Valve opened early Sept 2018 to prevent further increase in level
- Mine pool water did not appear to migrate into surrounding ground nor equilibrate at a steady level
  - Not consistent with previous understanding of permeability of the subsurface



Stratification in Monitoring Boreholes

- Sampling of borehole `300 ft inby of bulkhead indicated limestone was working
  - But not mixing in recirculation system?
  - Determined sampling techniques were not representative of mine pool water as the water level increased
  - Stratification in borehole was significant
- Limestone had a positive impact before valve closure, but was not having a impact at higher water levels
  - No evidence that alkalinity was moving with recirculation
- Water Quality had gotten much worse!





Significant Water Quality Changes: Why?

mg/L	Maximum Conc. Pre-Remedy 2014-2016	Maximum after Valve Closure Fall 2018*
Al	10	140
Cd	0.014	0.77
Cu	5.4	57
Fe	24	830
Mn	5.0	130
Zn	2.2	140
pH	2.6	2.4 (1.8)
Water Level	3 feet	151 feet

* Worst water quality, not averaged over time

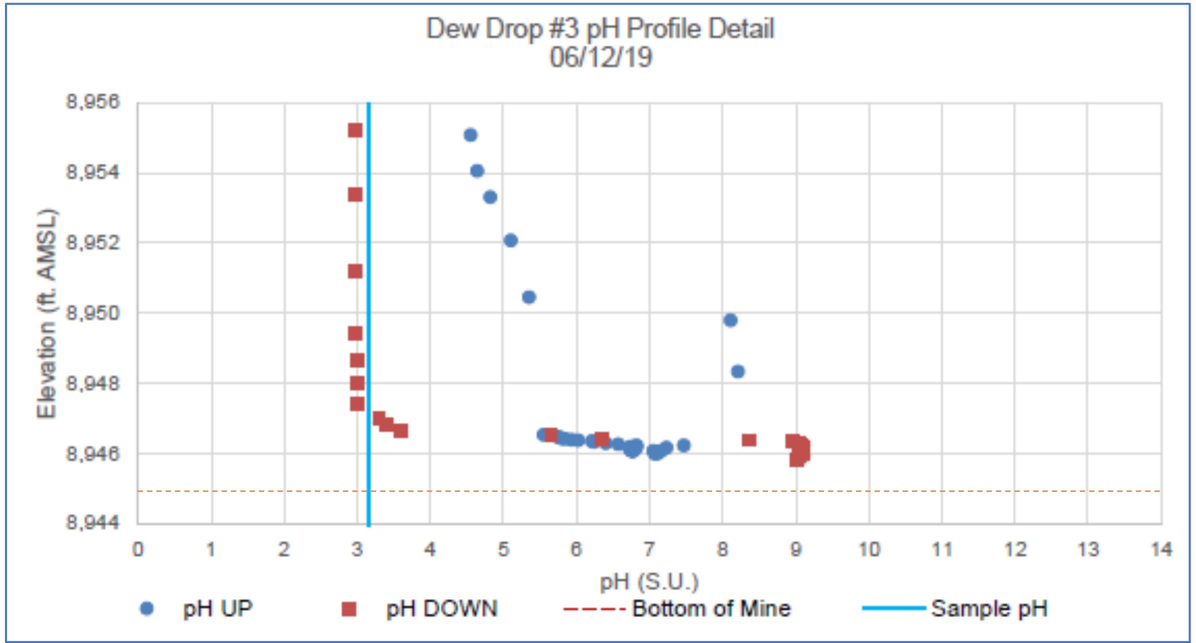
- Likely flushing/dissolution of acidic metal laden salts when subsurface wetted
- Typical phenomenon of spring flush in waste rock piles can increase metals
- Magnitude of change was unanticipated! Order of magnitude or more
- Was AMD generation still significant contributer as well?

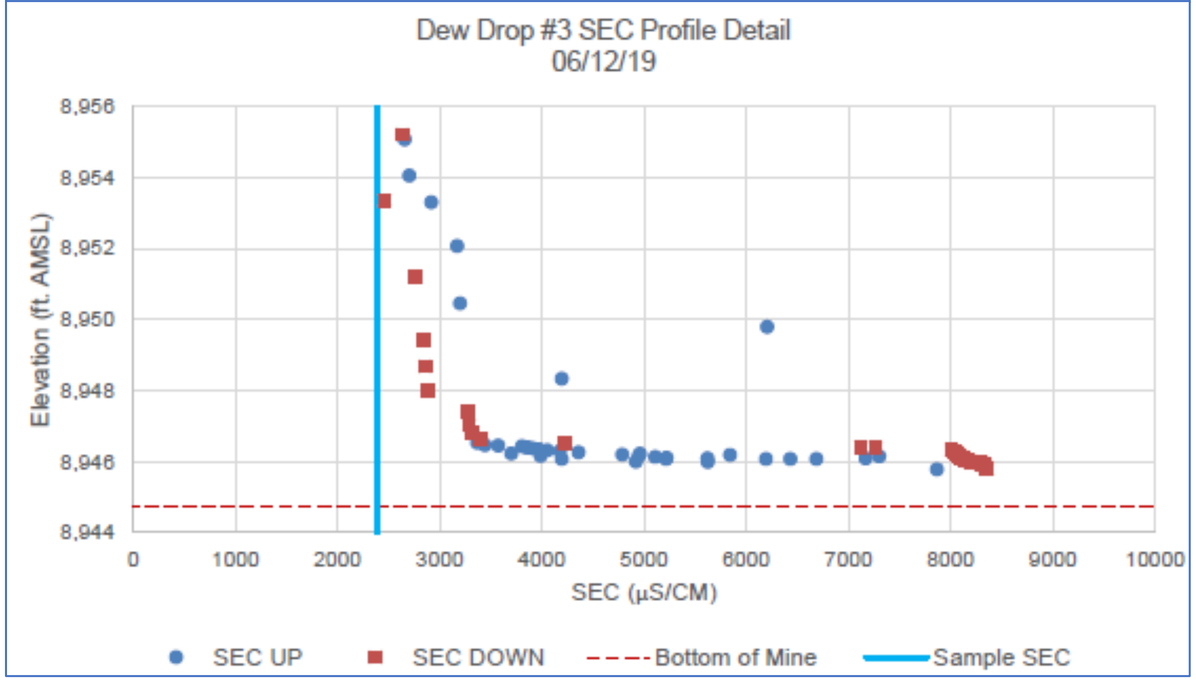
Problem Solving

- EPA Emergency Response mobilized a temporary external lime treatment system to manage the mine pool level and allow discharge of treated water

Problem Solving

- Added NaOH into Tunnel
- Increase recirculation rate in attempt to mix the NaOH
  - Detected increase of Na at Bulkhead sampling port, but
  - Blob of high pH & conductivity at bottom of tunnel
  - Limited success for mixing
- Current Objective:
  - Bring mine pool back to historic levels & corresponding historic water quality
  - Time to re-evaluate approach





Current Conditions

- Metals concentrations did decrease over time
- Flows may have increased from historic or possibly past flow information (20 gpm) was lower than typical?
- This week at historic mine pool level (less than 3 feet)

mg/L	Maximum Pre-Remedy Conc. 2014-2016	Maximum after Valve Closure Fall 2018	Recent Conc. Aug 2019
Al	10	140	**13**
Cd	0.014	0.77	**.079**
Cu	5.4	57	**6**
Fe	24	830	**170**
Mn	5.0	130	**26**
Zn	2.2	140	**16**
pH	2.6	2.4 (1.8)	**3.7**
Water Level	3 feet	151 feet	**34 Feet**

Next Steps: Re-evaluate In-Tunnel Treatment Approach

- Considering carbon addition
- Re-Evaluating recirculation and mixing capabilities in a mine tunnel system
- Consider external treatment needs while implementing in-tunnel treatment in order to manage water levels
- **The potential cost savings of In-tunnel treatment over external active treatment is worth continuing to work on the challenges presented

Is there a light at the end of the tunnel for AMD water sources?

Next Steps: Opportunity to use Forensics to Create a Predictive Tool

- What site specific information can we use to be predictive of future water quality upon flooding of mine workings?
  - Develop geochemistry model using existing data and sulfur isotope sampling to determine if dissolution of acid salts were main contributor to increasing metals or if oxic or anoxic pyrite oxidation was a significant driver?
  - Does a closer examination of minerology, porosity, and flow paths provide predictive information?
  - Are pre-flooding differences between high and low flow pH and metals concentrations indicative of changes that may occur upon flooding?
    - Ideally sufficient data would be available from several sites pre-and post flooding to determine if this is an adequate predictor

Concluding Thoughts & Questions

- Not all mine sites are the same, one solution does not fit all
- Characterize the mine system and surrounding area to the extent feasible
  - Groundwater and mine system hydrology
  - Geology & minerology
  - Existing water quality & loading
- Establish reasonable goals for the bulkhead
  - Flow control, preventing “burps”, temporary storage, or plugging a pathway?
  - Water may come out somewhere else, is that good or bad?
  - Where are you trying to reduce metals loading?
  - Are there lines of evidence that can predict water quality changes after flooding?
  - Will lower/controlled flows make passive treatment a feasible option?
  - Maintenance generally required, what will be long term fate of bulkhead?
  - Bulkhead effectiveness may require years to establish.