High Altitude Mine Site Wetland Demonstration Constructed Wetlands Treatment

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Background

- Development of water treatment system required by EPA

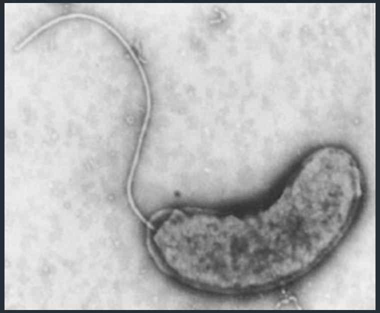
- Safety and logistical concerns were drivers to investigate feasibility of constructed wetland system
  - Extreme winter weather
  - Avalanche hazards
  - Limited local population base

- Regulatory support for wetlands/passive treatment
  - Keen interest by EPA, state and local groups
  - Resurgence in acceptability as viable technology
  - Need viable passive treatment alternatives at numerous orphan sites

SRB Biotreatment Overview

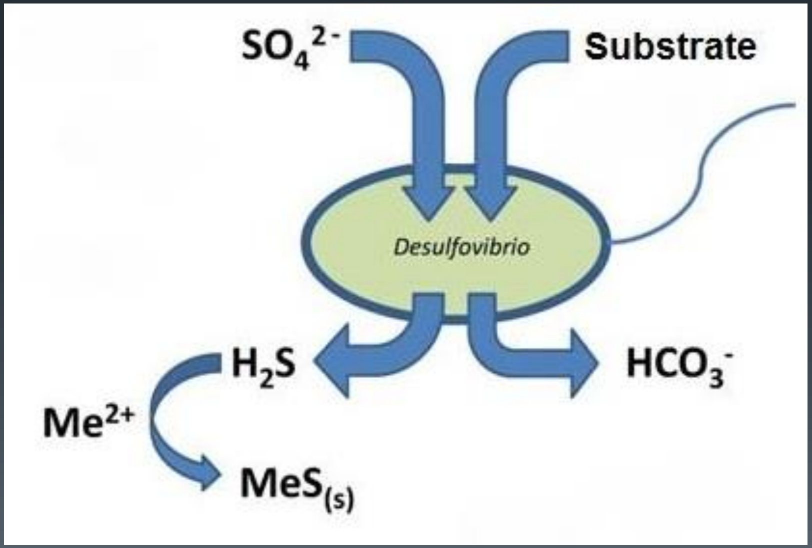
Microorganisms need three things:

- Energy Source (e^- donor) – Organics / Carbon
- Favorable environment - Anaerobic
- Nutrients and e^- acceptors – Sulfate and Micronutrients



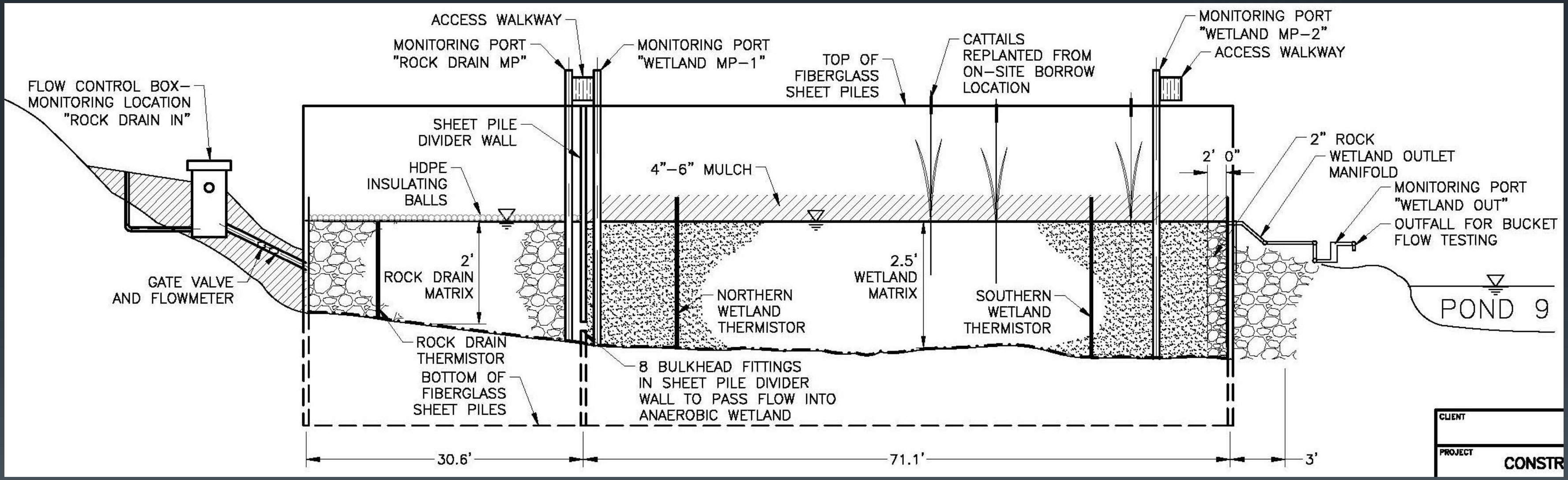
Sulfate Reduction Process

- Organics yield carbon and energy
- Sulfate (SO_4^{2-}) reduced to sulfide
- Metals bind with sulfide (MeS)
- Generates Bicarbonate (HCO_3^-)



Pilot System

- Feasibility testing initiated in 2012
  - 12 liter per minute (lpm) system
  - Aerobic rock drain followed by horizontal-flow anaerobic wetland
  - Operated December 2012-August 2014 with favorable results



AMEC, 2012

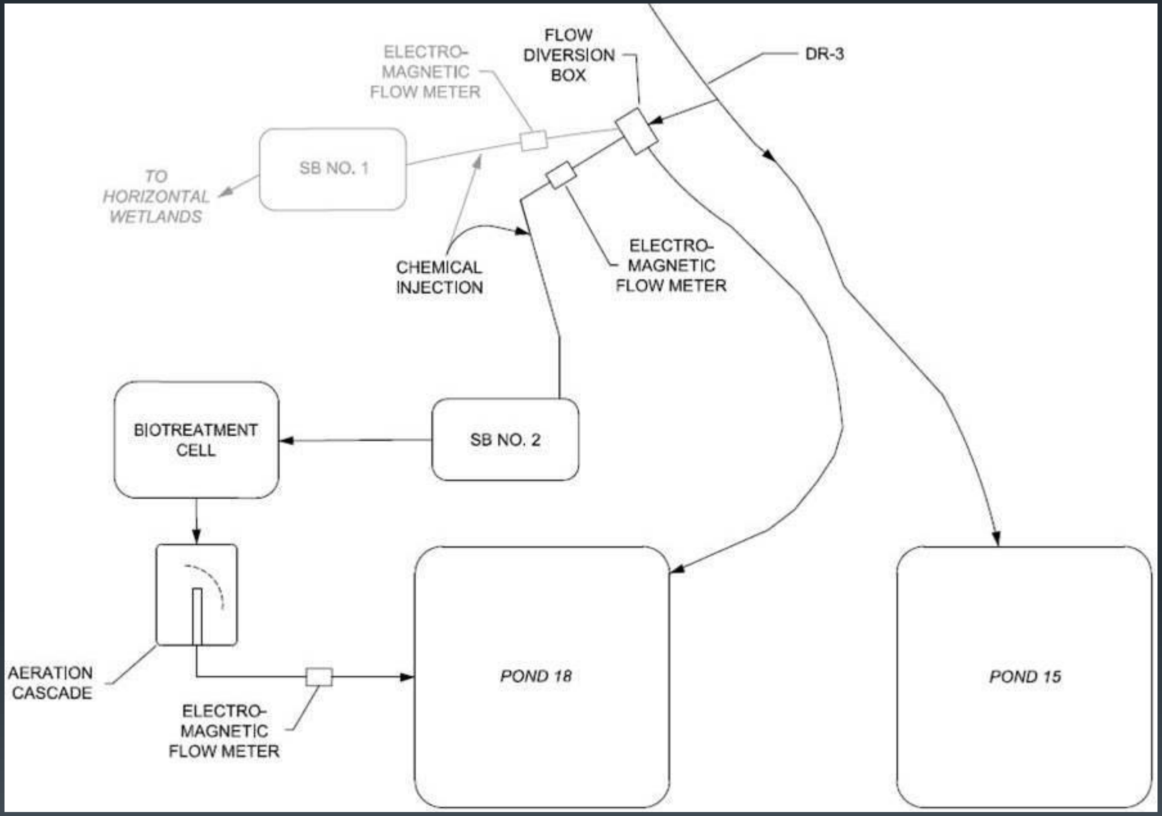
Wetland Demonstration Systems

- 2014 - Two parallel 115 lpm demonstration-scale systems constructed
  - Horizontal wetland treatment train (HWTT)
  - Vertical wetland treatment train (VWTT)

- 2015 – Enhanced Wetland demonstration (EWD)
  - Scaled-up to 2,100 lpm
  - Largely based on VWTT, plus Mn removal step after settling basin similar to pilot wetland rock drain

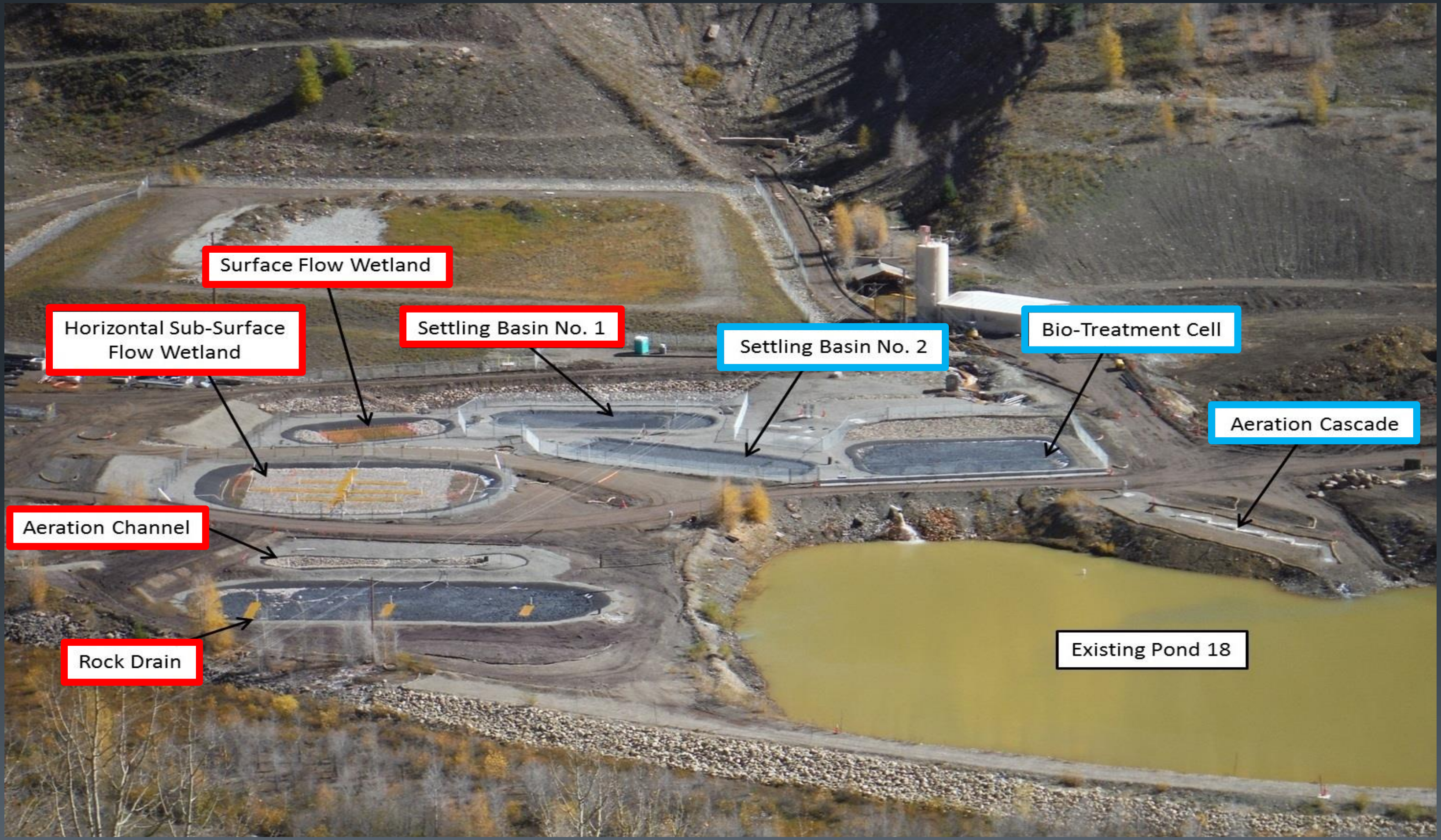
VWTT Overview

- <u>Components</u>
  - Coagulant addition (aluminum chlorohydrate)
  - Settling Basin (SB2)
  - SRB Biotreatment Cell (Biocell)
  - Aeration Cascade
- <u>Metals of Concern</u>
  - Cd
  - Cu
  - Fe
  - Mn
  - Zn



Wetland Demonstration Systems

VWTT (blue) and HWTT (red) Overview



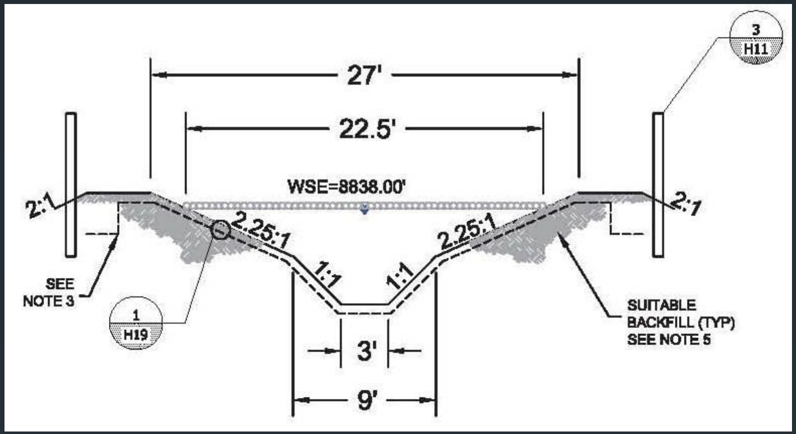
Wetland Demonstration Systems

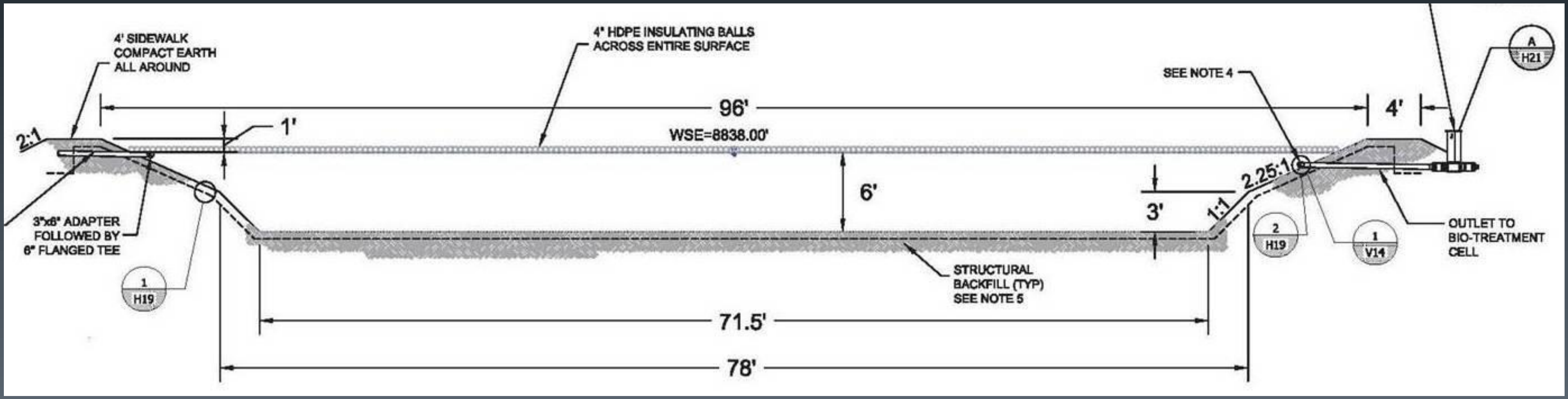
EWD overview

- EWD treatment performance consistent with VWTT treatment performance

VWTT Overview

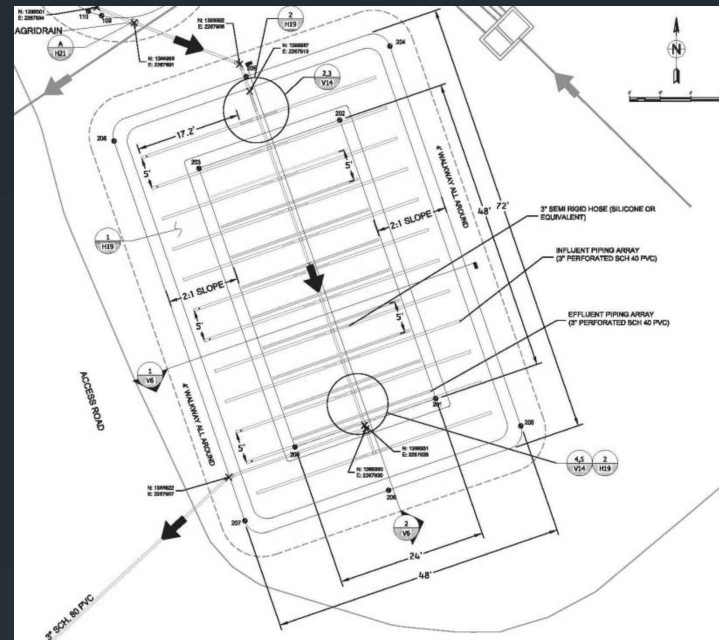
- Settling Basin No. 2
  - Al, Cu, Fe, Pb and TSS Removal
  - Volume: 140 m^3
  - Area: 191 m^2
  - Depth: 1.8 m
  - HRT: 20.5 hrs

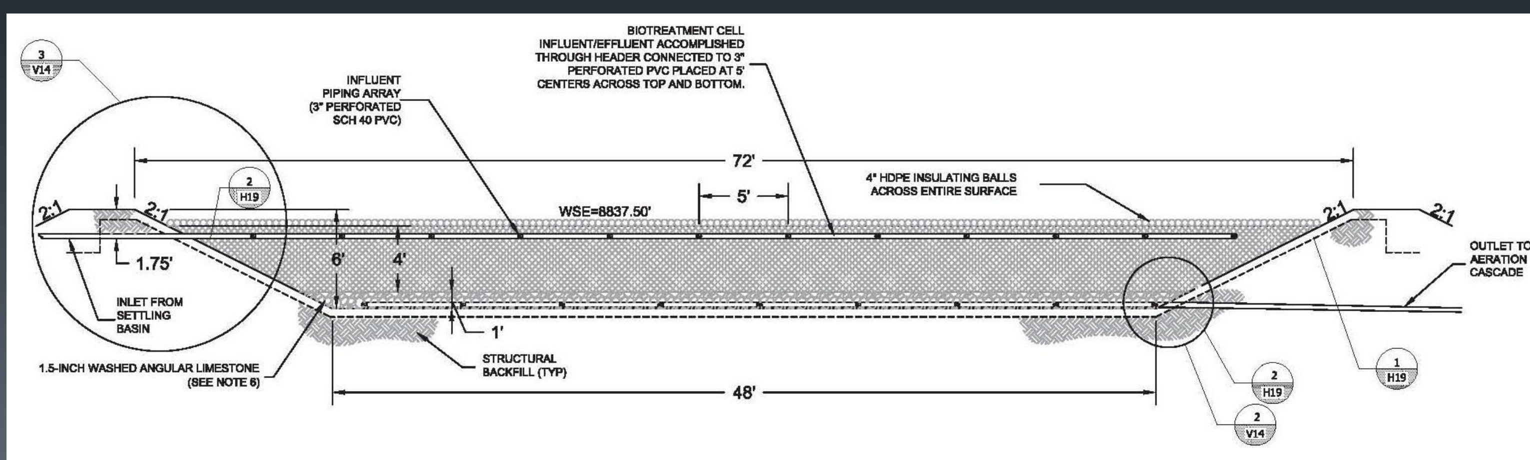




VWTT Overview

- <u>Biotreatment Cell</u>
  - Cd, Cu, Fe, Mn, Zn Removal
  - Volume: 272 m^3
  - Area: 278 m^2
  - Depth: 1.5 m
  - HRT: 12 hrs
  - Matrix: 65% wood chips, 25% wood shavings, 5% manure, 5% alfalfa



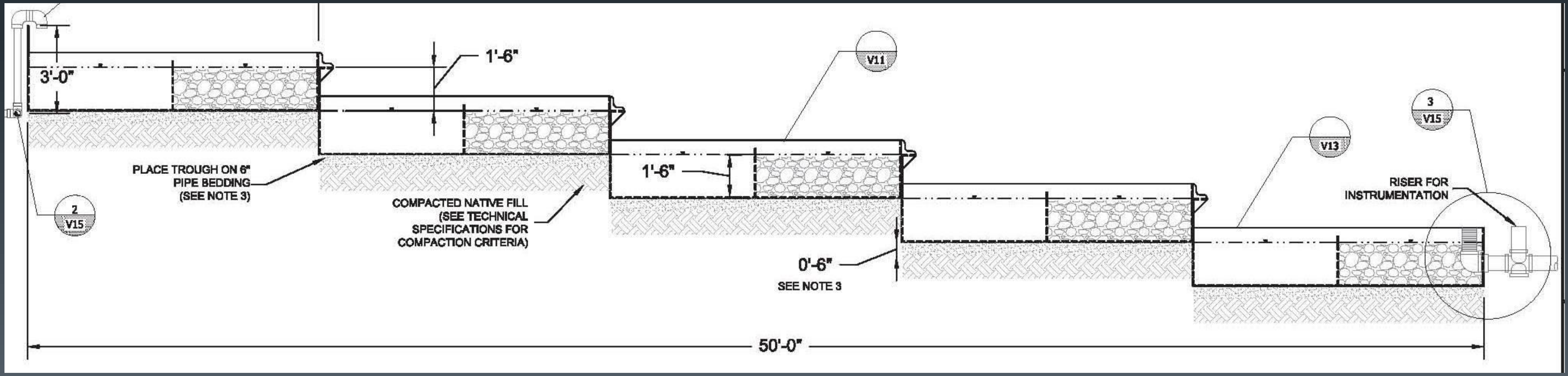


VWTT Overview

- <u>Settling Basin and Biotreatment Cell Outlet Control</u>
  - Agridrain^{TM} Inline Water Level Control Structure
  - “Weir in a box”

VWTT Overview

- <u>Aeration Cascade</u>
  - Sulfide and BOD Removal, Restore DO
  - 5 sequential drop troughs
  - Trough Length: 3 m
  - Trough Width: 0.6 m
  - Trough Depth: 0.6 m
  - Inter-trough drop height: 0.45 m
  - HRT: 28 min



VWTT Overview

- Hydraulic Conductivity
  - Hydraulic gradeline calculations indicate minimum required K of ~10^{-3} cm/s
  - Column test substrate falling head test results were ~10^{-1} cm/s
  - Hydraulic head can be manipulated via Agridrain weir slats, allows accommodation of K changes

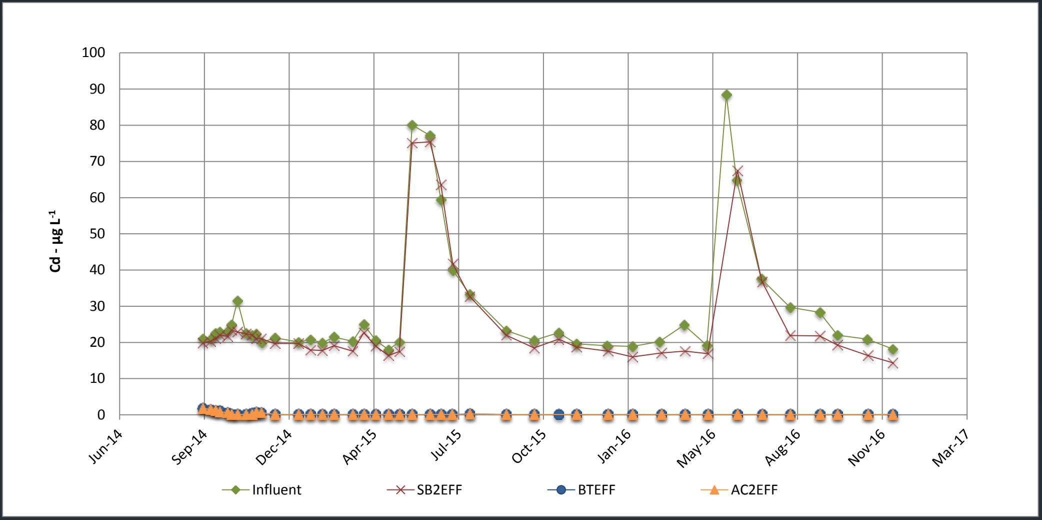
- Minimal Instrumentation
  - Water entering upstream side of Agridrain is representative of conditions in bottom of cell
  - Low short circuiting/preferential flow potential due to short flow path

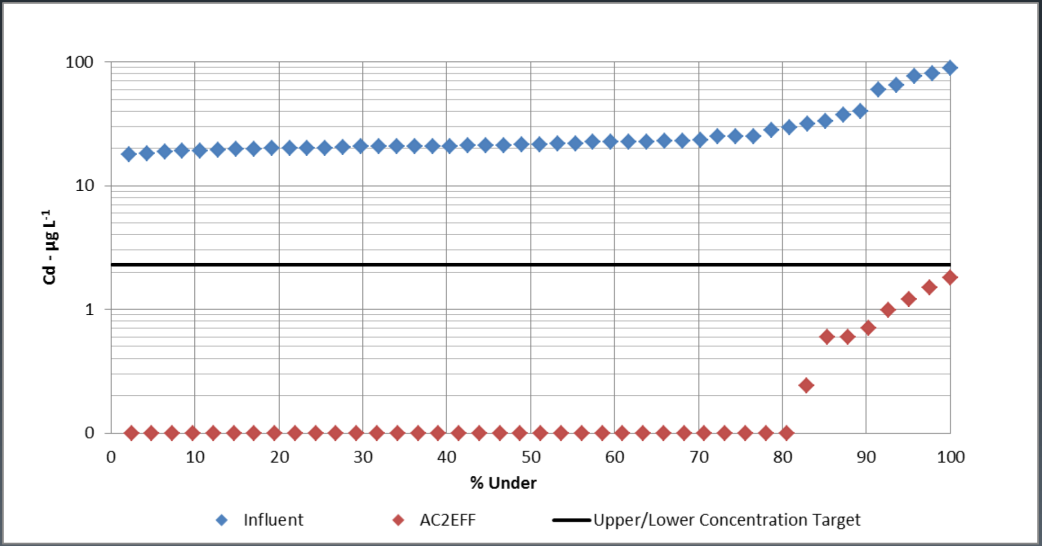
- Temperature/Freezing
  - Minimal heat loss through SB No. 2 and Biocell using HDPE insulating balls
  - REMC has successfully operated biotreatment cells at water temperatures below 4^{o} C

VWTT Overview

VWTT Results

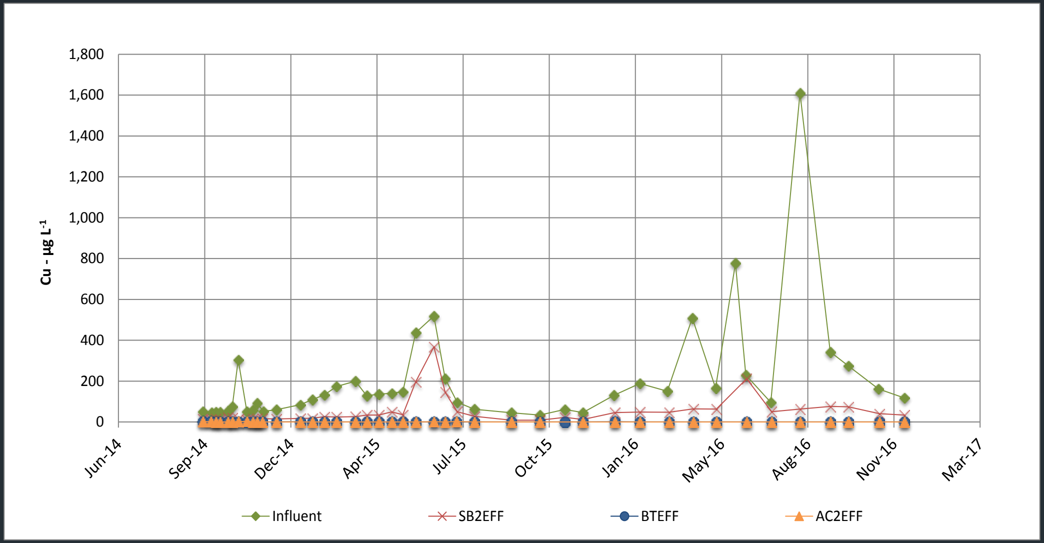
- <u>Total Cadmium</u>
  - Influent average: 22 µg/L
  - Influent max: 88 µg/L
  - 100% of effluent samples below concentration target
  - Avg. removal efficiency: >99%
  - Includes start-up period data
  - All effluent results non-detect (<0.5 µg/L) since December 2014

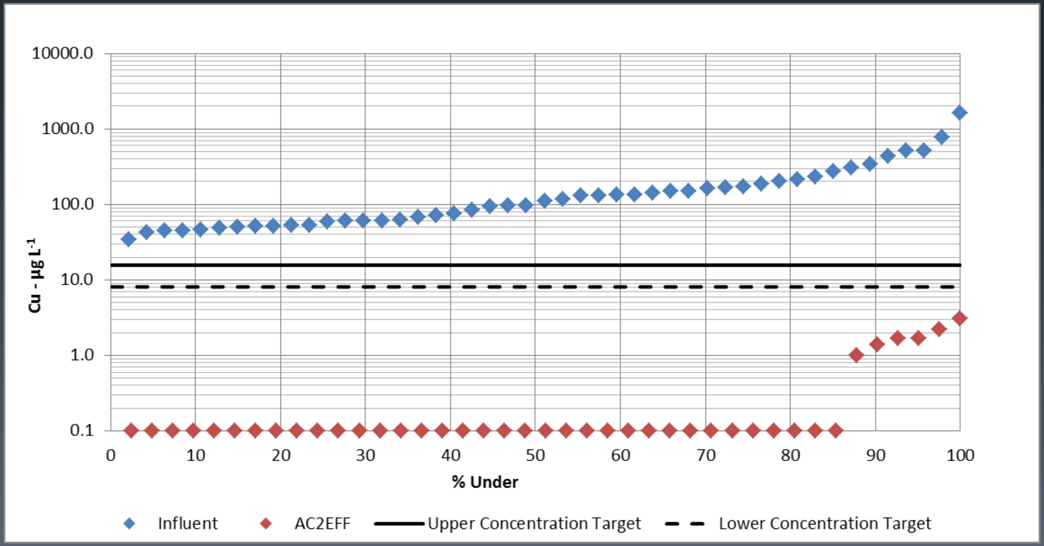




VWTT Results

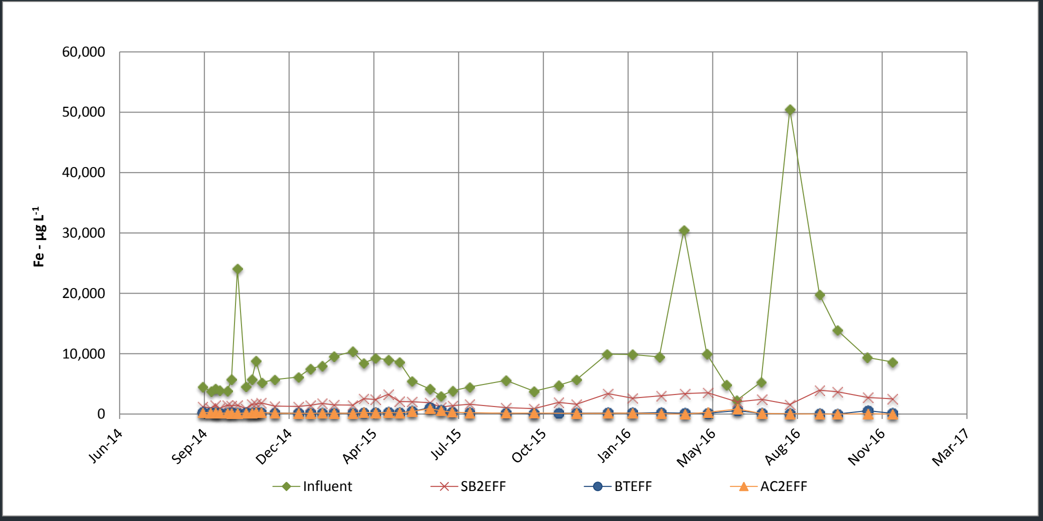
- <u>Total Copper</u>
  - Influent average: 133 µg/L
  - Influent max: 1,610 µg/L
  - 100% of effluent samples below all concentration targets
  - Avg. removal efficiency: >99%
  - Majority of load is particulate removed in SB2, possibly sorbed to Fe
  - Most results non-detect

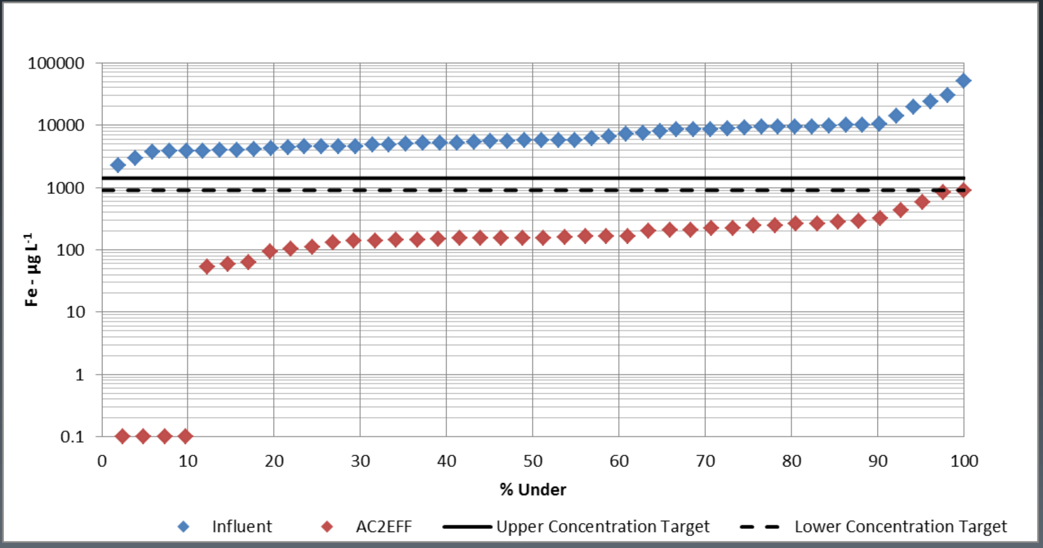




VWTT Results

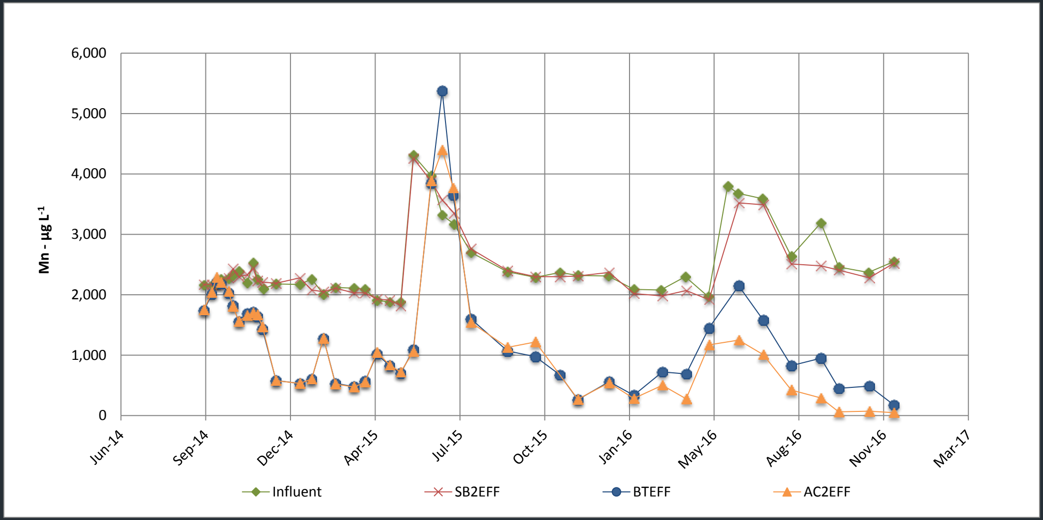
- Total Iron
  - Influent average: 9,400 µg/L
  - Influent max: 30,500 µg/L
  - 98% of effluent samples below lower concentration target
  - Avg. removal efficiency: 98%
  - SB2 effluent average: 1,800 µg/L
    - Insufficient iron removal to prevent solids loading to Biocell matrix
    - <500 µg/L is ideal
    - Residual iron primarily fine colloids, some dissolved Fe(II)

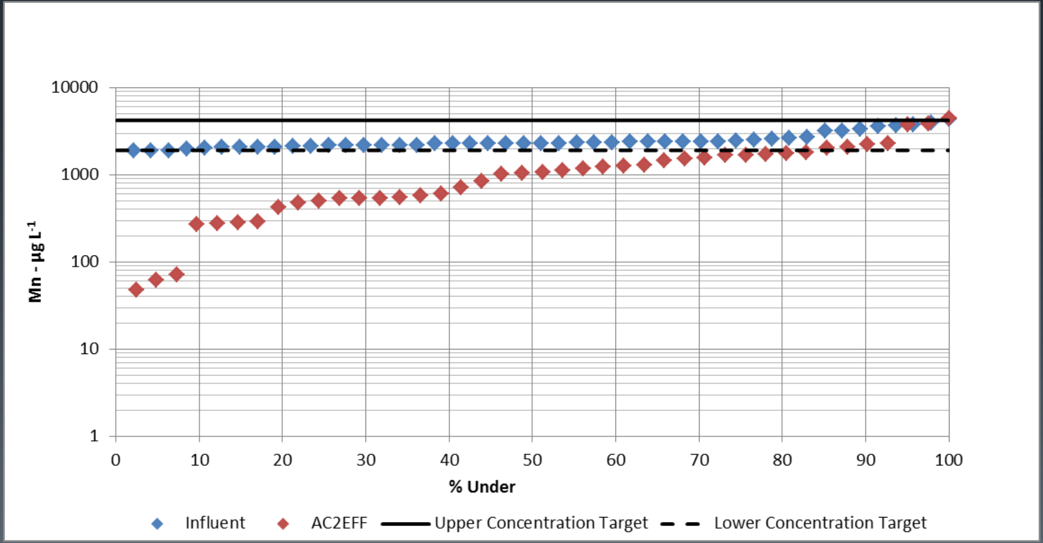




VWTT Results

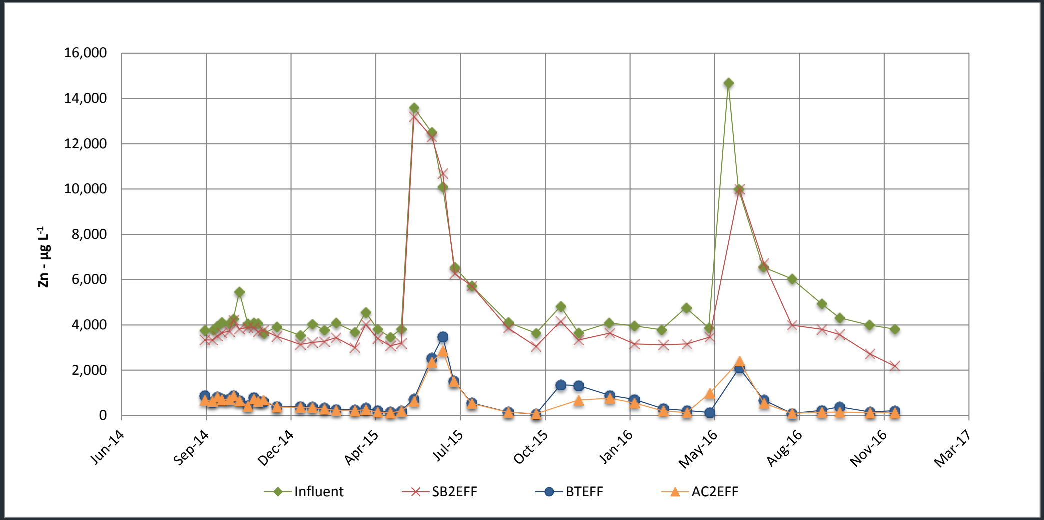
- Total Manganese
  - Influent average: 2,300 µg/L
  - Influent max: 4,310 µg/L
  - 83% of effluent samples below lower concentration target
  - Avg. removal efficiency: 54%
  - Mn removal not a design goal of the VWTT
    - Unexpected in anaerobic cell
    - September 2017 sampling indicates oxic removal in upper 15 cm of organic matrix
  - Additional Mn removal occurring in aeration cascade
    - Last 3 troughs
    - Rapid removal (minutes)
  - Ongoing investigation of Mn removal mechanisms

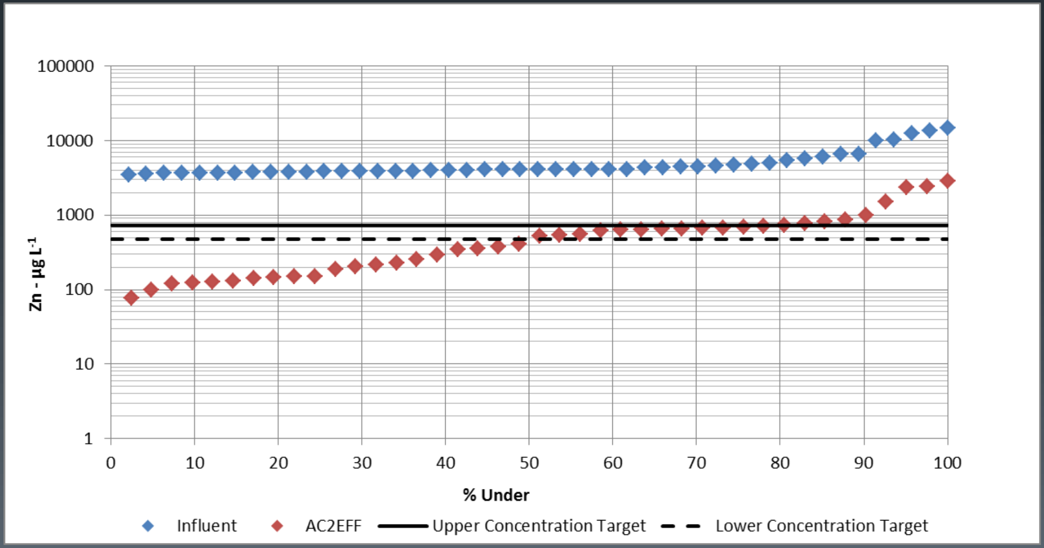




VWTT Results

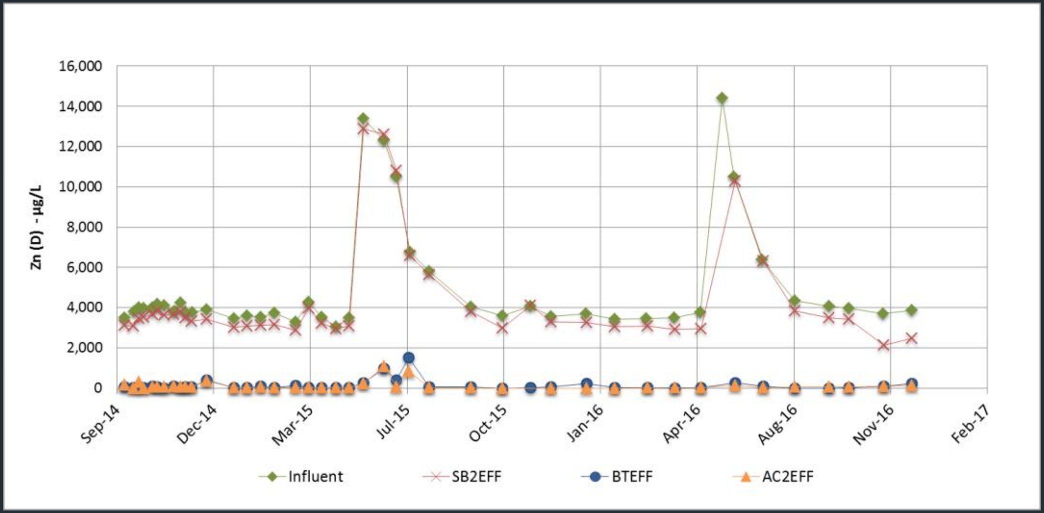
- Total Zinc
  - Influent average: 4,100 μg/L
  - Influent max: 14,700 μg/L
  - 49% of effluent samples below lower concentration target
  - 90% of effluent samples below 1,000 μg/L
  - Avg. removal efficiency: 89%
  - Includes start-up period data
  - Removal is seasonally variable
    - >90% during majority of year
    - 65-80% during freshet peak
    - Baseflow effluent concentrations are typically 100-300 μg/L
    - Peak freshet effluent concentrations 1,000-3,000 μg/L, but decreasing in magnitude each year

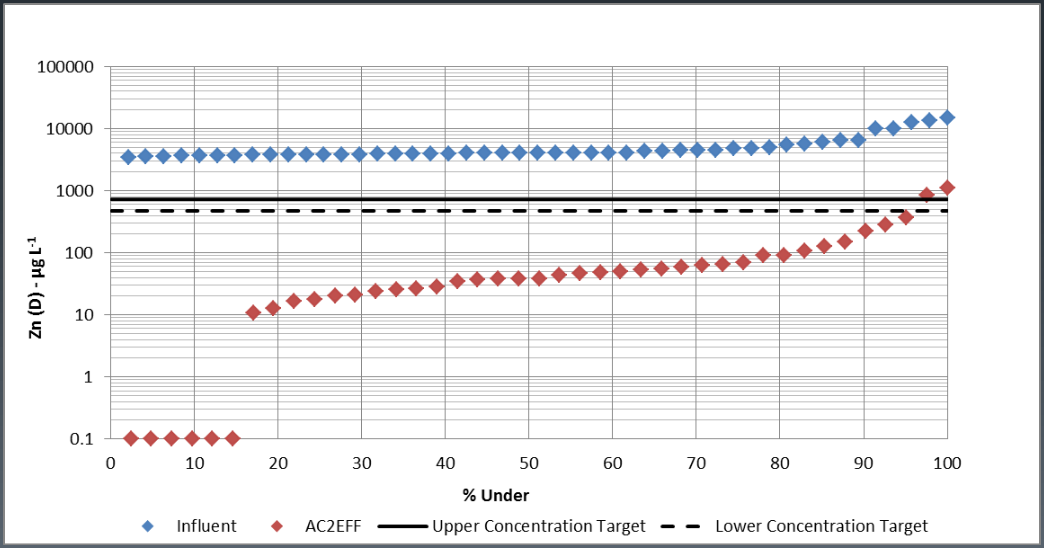




VWTT Results

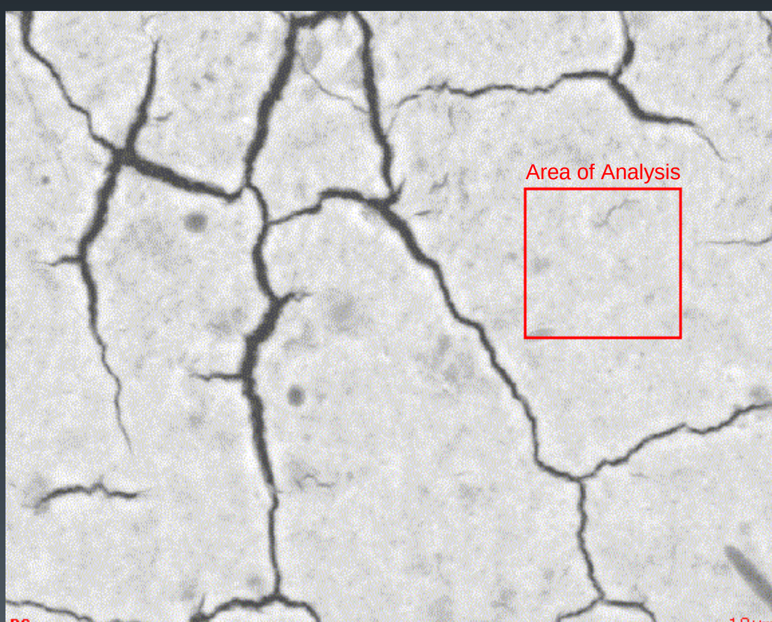
- Dissolved Zinc
  - Zinc removal appears limited by matrix capacity to filter precipitated ZnS colloids
  - 95% of effluent samples below lower concentration target
  - Avg. dissolved Zn removal efficiency: 98%

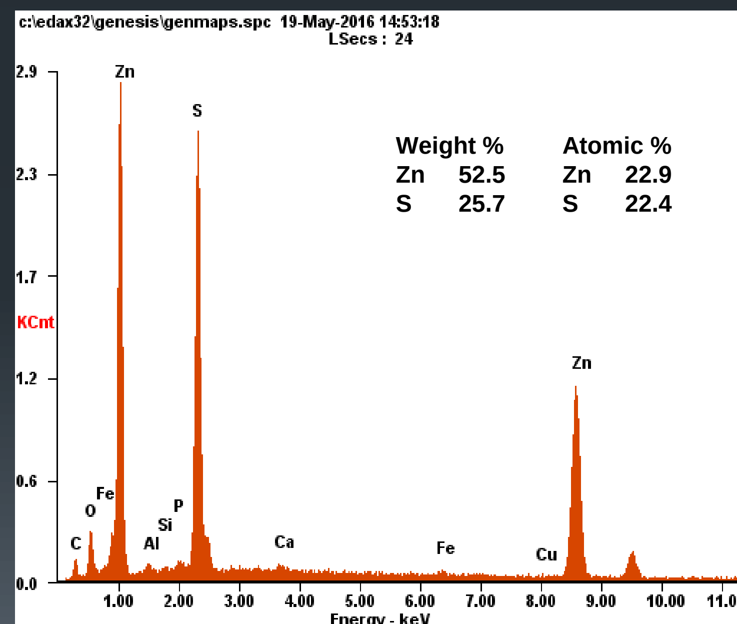




VWTT Results

- <u>Total Zinc</u>
  - SEM micrograph of Biocell effluent filter residue shows nearly pure ZnS
  - Lack of visible particles in SEM image indicates sub micron-sized ZnS particles in filter residue





Design Challenges

- High elevation location
  - 2,700 m above sea level
  - Maximum length of construction season is June 1-Nov 1
  - Snow depths can exceed 2 m
  - Multiple avalanche paths terminate at site
  - Winter temperatures commonly reach -30º C
    - Mine water temperatures are above normal from geothermal influence (19º C)
    - Insulating balls used to minimize heat loss

- Siting
  - Site is large (12 hectares), but most areas unsuitable for construction of treatment units
  - Near-surface groundwater is common
  - Limited hydraulic head available for gravity flow

Treatment Challenges

Iron/solids loading

- Influent solids load highly resistant to gravity settling
- Particle size analysis consistently shows that ~90% of particles are <1 micron
- SEM analysis of filter residue indicates presence of significant quantity of clay minerals.
- Avg. 2 mg/L iron in SB2 effluent. Filtered by Biocell matrix surface which impacts hydraulic conductivity.
- Removal of iron sludge from Biocell surface required in 2017
- Improving solids removal is current design focus.

Treatment Challenges

Freshet

- Annual drop in pH and increase in metals loading during spring runoff
- Influent pH drops by 1 s.u. on average
- Influent metals concentrations increase 2-5x
- Negatively impacts removal of iron, manganese and zinc
  - Iron
    - Total iron load shifts toward dissolved phase
    - Iron oxidation rate slows at lower pH
    - Reduces effectiveness of coagulant
  - Zinc
    - Breakthrough of total Zn in Biocell effluent
    - Biocell effluent dissolved Zn concentrations remain low
    - May be due to simple overload of filtering capacity, or change in ZnS particle size
  - Manganese
    - Mechanism unknown, but Mn(II) oxidation well known to be pH-dependent

Questions?