Use of Constructed Wetlands to Remove Metals in Drainage from a High Altitude Mine System, SW Colorado: Horizontal Flow Wetland System

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Overall goal of presentation

- Present system design
- Indicate performance (metal removal) in 2015 and 2016
- Show what we learned

Pilot-scale trial

- Pilot-scale wetland comprised:
  - rock drain: 9.3 x 4.3 x 0.6 m
  - wetland: 21.7 x 4.3 x 0.7 m
- Flow rates ranged from 3.8– 23 L/min
  Nominal retention times (HRT)
  - rock drain: 8 – 42 hours
  - wetland: 24 – 120 hours
- Trial conducted over 1 year period
- Monitored metal removal, hydrogen sulphide production
- Post-trial tear-down investigation for rock drain and wetland

Pilot-scale trial – summary of findings

- Cadmium, manganese and zinc were removed to very low levels
  - Mn removed in rock drain to < 700 µg/L
  - Cd removed in anaerobic wetland to < 1.0 µg/L
  - Zn removed in anaerobic wetland to < 150 µg/L
  - Mn removed as an oxide, cadmium and zinc removed as sulphides
- Good treatment performance at low water temperatures (5-6 °C)
- Surprising finding that sulphate was removed well when flow rates decreased

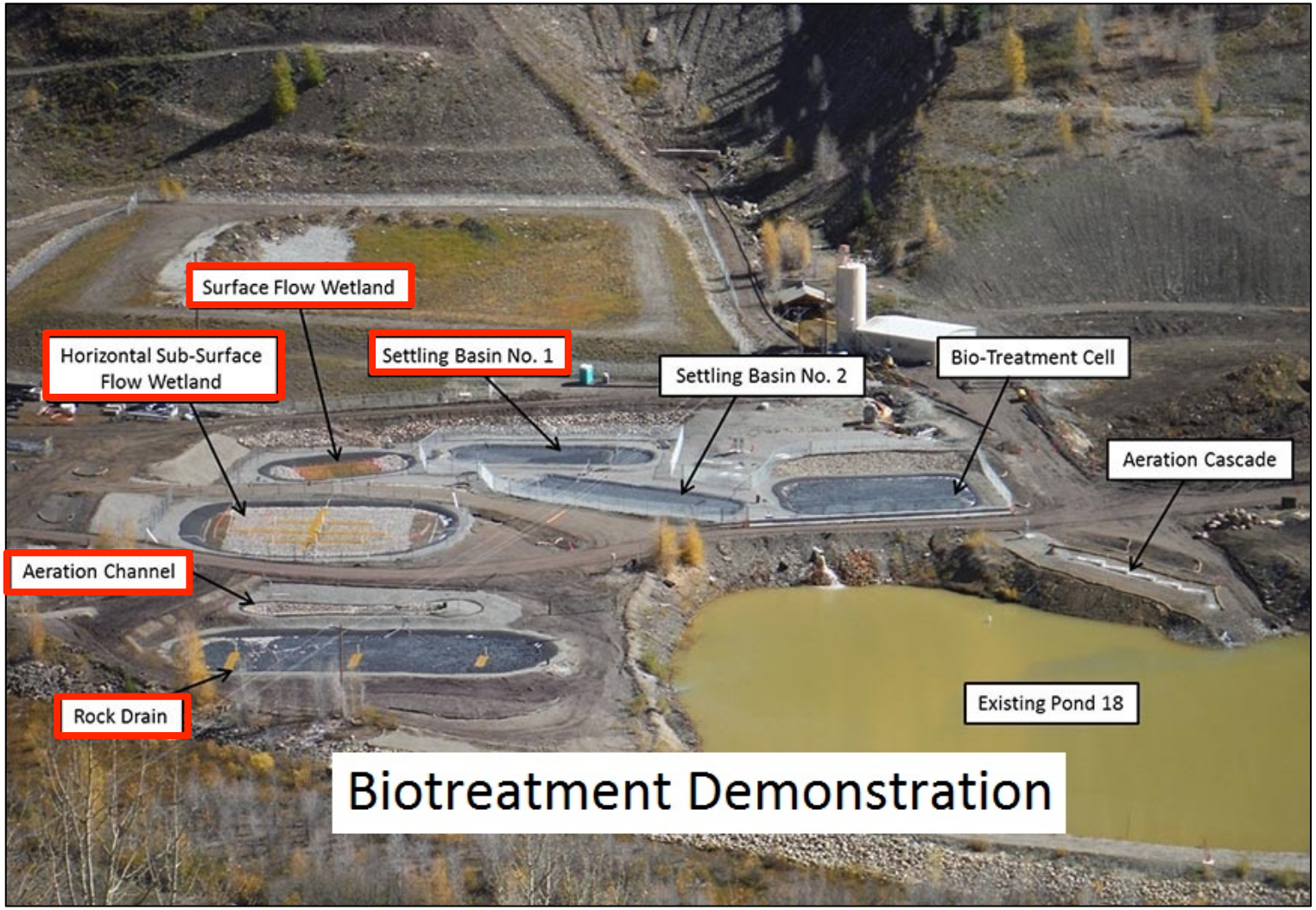
Site characteristics imposing constraints on design

- Space constraints
  - Gentle slope from portal to end of property
  - Elevated groundwater table
- Geothermal heat inside mountain warms water, but cold weather during winter months
- Snow pack on mountain peak means significant freshet during spring melt

System design criteria & trial objectives

- Remove incoming iron to < 0.5 mg/L
  - Use settling basin + coagulant at 17 hour HRT, surface flow wetland
- Remove cadmium to < 1.0 µg/L and zinc to < 500 µg/L
  - Anaerobic wetland with 17 hour HRT
- Remove manganese to < 2,000 µg/L (aim for <500 µg/L)
  - Rock drain with limestone bed with 15 hour HRT
- Operate year-round
  - Evaluate temperature effect
  - Evaluate performance during freshet
- Compare horizontal-flow with vertical flow system
- Evaluate remote monitoring via telemetry

Horizontal Wetland Treatment Train



Treatment Units – Settling basin for iron removal

- Design flow rate: 115 L/min
- Surface area: 150 m^2
- Depth: 1.8 m
- Nominal HRT: 17.6 hours
- Target iron levels: < 3 mg/L

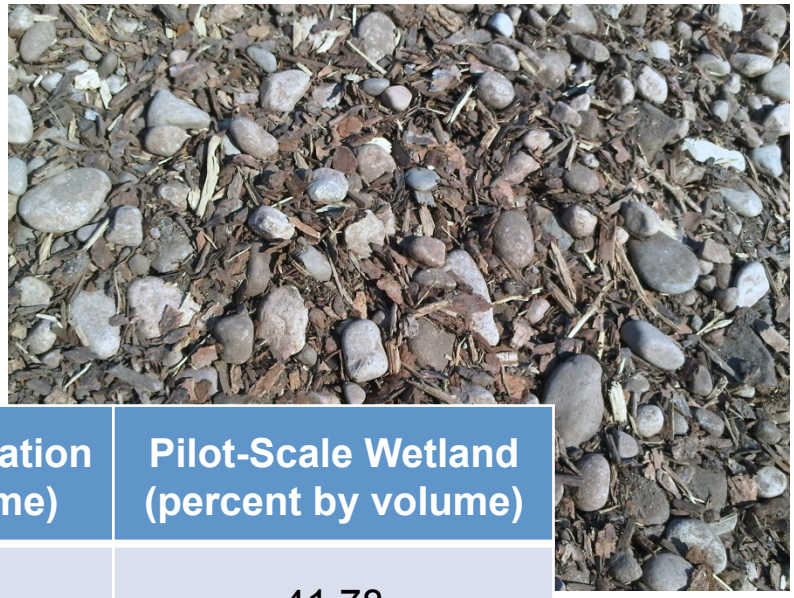
Surface flow wetland for iron removal

- Design flow rate: 115 L/ min
- Surface area: 125 m^2
- Depth: 1.8 m
- Nominal HRT: 6 hours
- Target iron levels: < 0.5 mg/L

Subsurface horizontal flow wetland for cadmium & zinc removal

- Design flow rate: 115 L/min
- Surface area: 300m^2
- Bed depth: 0.45m
- Volume: 350 m^3
- Nominal HRT: 17.2 hours
- Target cadmium levels: < 1.0 µg/L
- Target zinc levels: < 500 µg/L

Subsurface wetland matrix composition



Material	Wetland Demonstration (percent by volume)	Pilot-Scale Wetland (percent by volume)
Washed, rounded, granite rock – 1.5 inch nominal diameter	60	41.78
Wood chips – 1-inch to 2-inch nominal diameter	35	46.42
Manure	4.6	11.61
Sulfur prills	0.38	0.08
Sulfate-reducing bacteria	*added from pilot-scale wetland cell matrix*	0.09

Aeration channel for BOD & sulphide removal

- Design flow rate: 115 L/ min
- Surface area: 1.7 m^2
- Depth: 23 cm
- Nominal HRT: < 30 minutes
- Target oxygen levels: > 5.0 mg/L
- Target H_2S levels: < 0.1 mg/ L

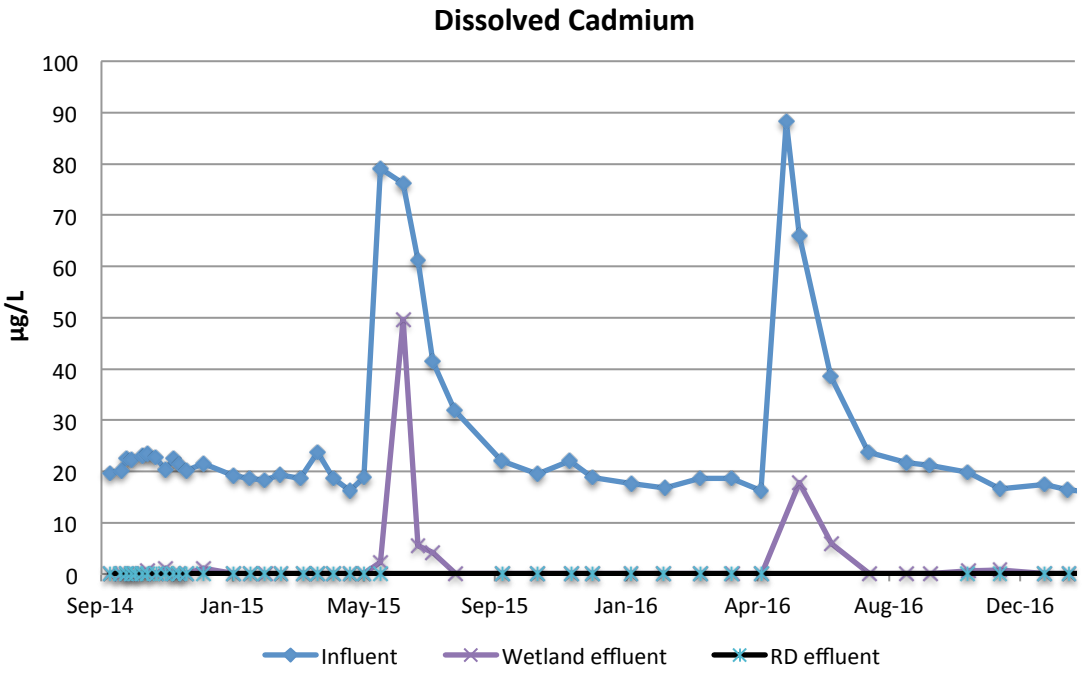
Note air spargers

Rock drain for manganese removal

- Design flow rate: 115 L/min
- Surface area: 348m^2
- Depth: 1.2 m
- Nominal HRT: 15.7 hours
- Target manganese levels: < 2.0 mg/L (aim for < 0.5 mg/L)

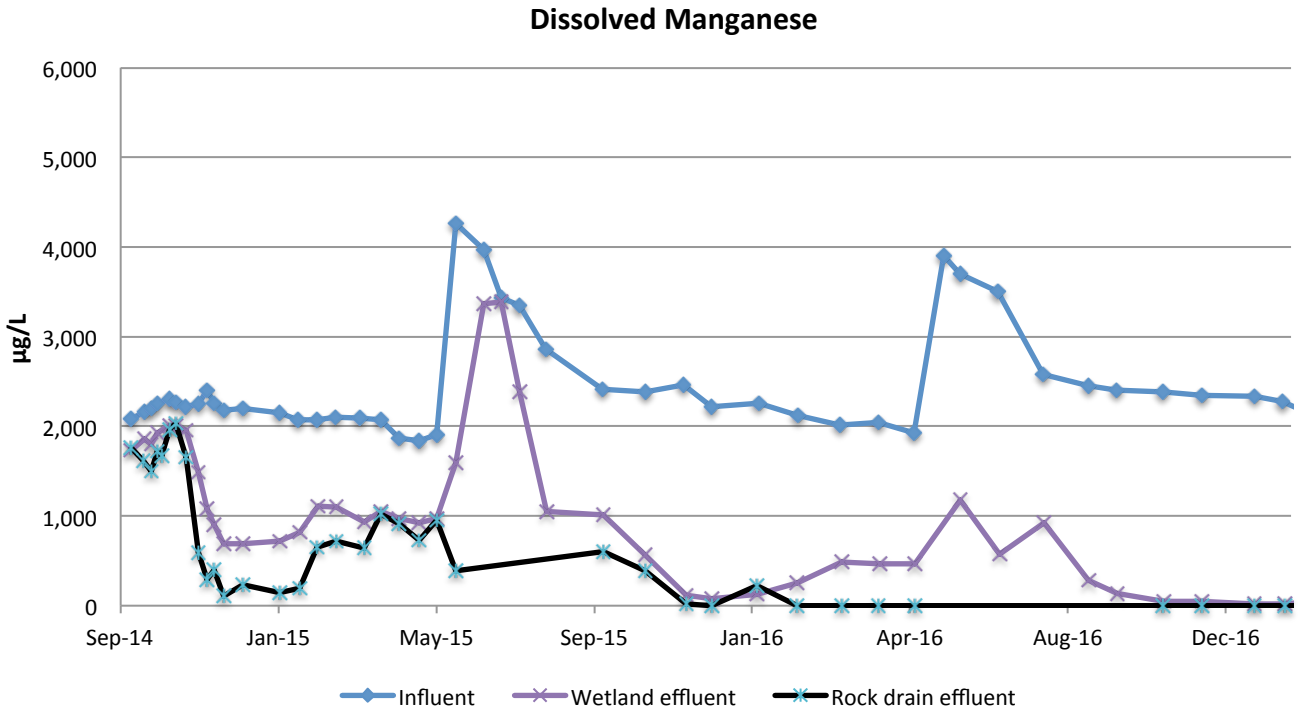
Cadmium removal

- Generally, influent cadmium was 20 µg/L, > 80 µg/L during freshet
- Wetland effluent was < 0.5 µg/L except during freshet
  - Poor removal associated with lower pH (discussed later)
- Rock drain effluent was < 0.5 µg/L year-round (adsorption onto manganese oxides)



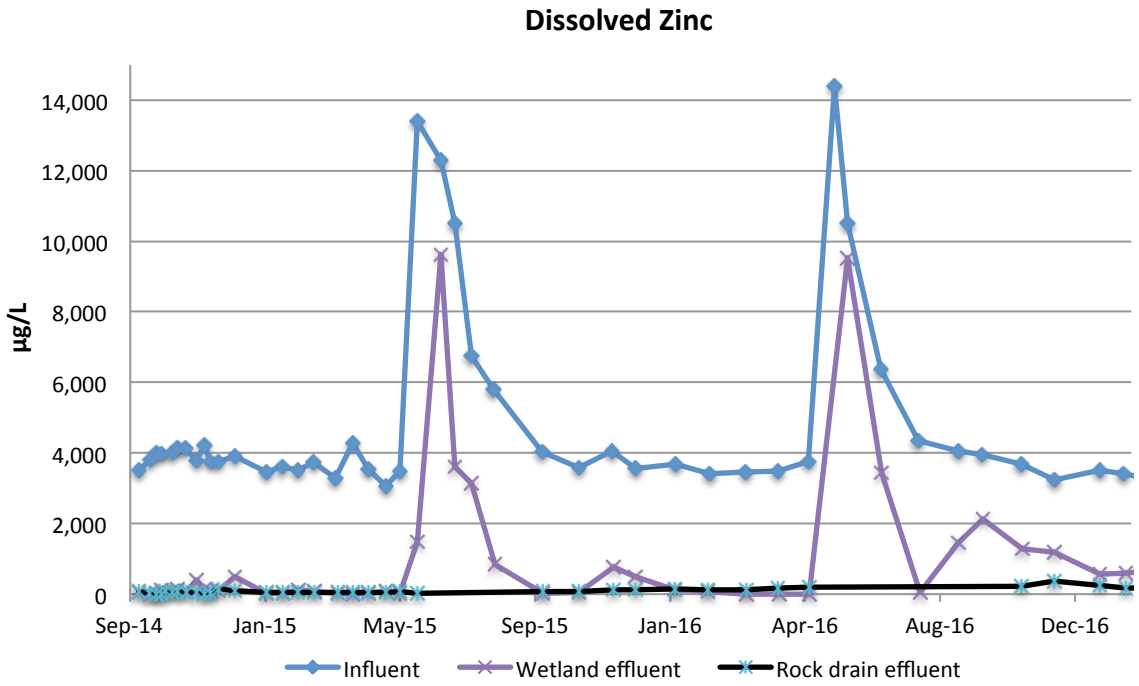
Manganese removal

- Influent manganese was 2,000 µg/L (baseline), peaking at 4,000 µg/L (freshet)
- Wetland effluent was initially 1,000 µg/L, improved over time
  - Unexpected removal associated with aerobic "transition zone"
- Rock drain removal improved with time, effluent < 50 µg/L throughout 2016



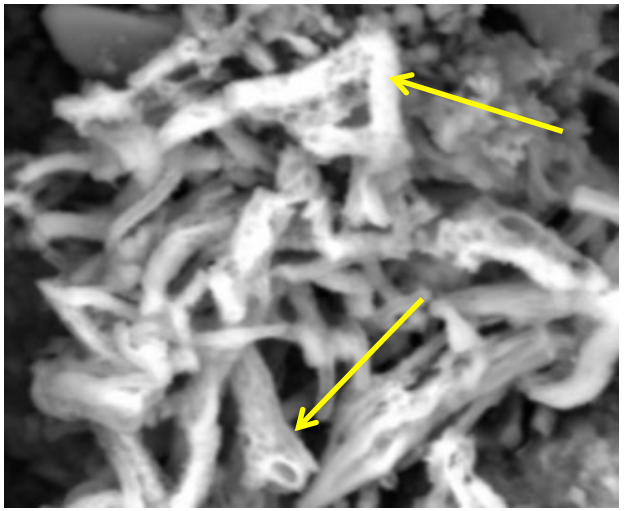
Zinc removal

- Influent zinc was 4,000 µg/L (baseline), peaking at 14,000 µg/L (freshet)
- Wetland effluent was usually < 500 µg/L, except for freshet
  - Zinc removal failed during freshet due to acidic pH (discussed later)
- Rock drain effluent was < 150 µg/L throughout 2015-2016



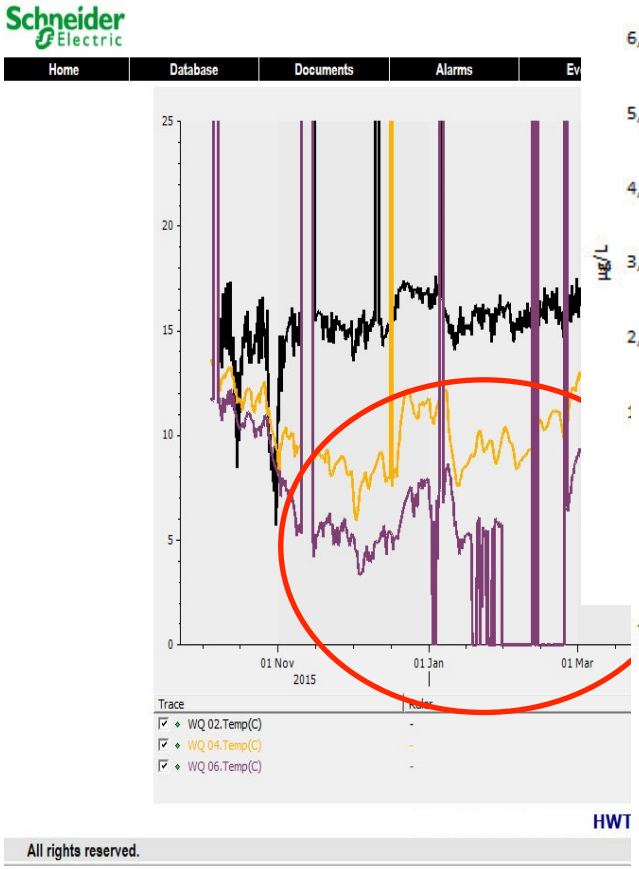
Investigation of manganese removal in Rock Drain

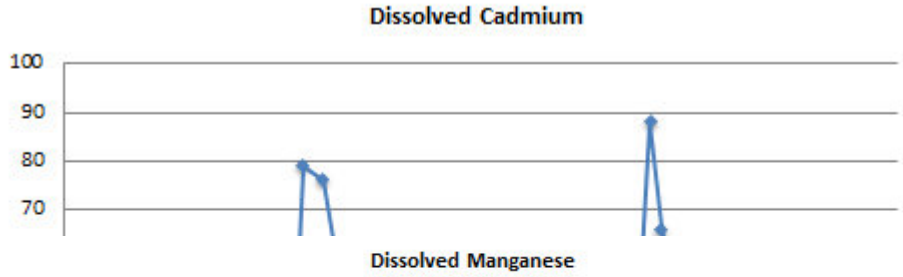
- Microbial oxidation of dissolved manganese responsible for its removal in rock drain
- Manganese oxides have high capacity to adsorb metals. In RD, they also retained arsenic, cadmium, lead and zinc
  - Zinc was present at 0.4 moles/ mole Mn!
- Rock drain located downstream provides insurance for continued metal removal if units upstream fail

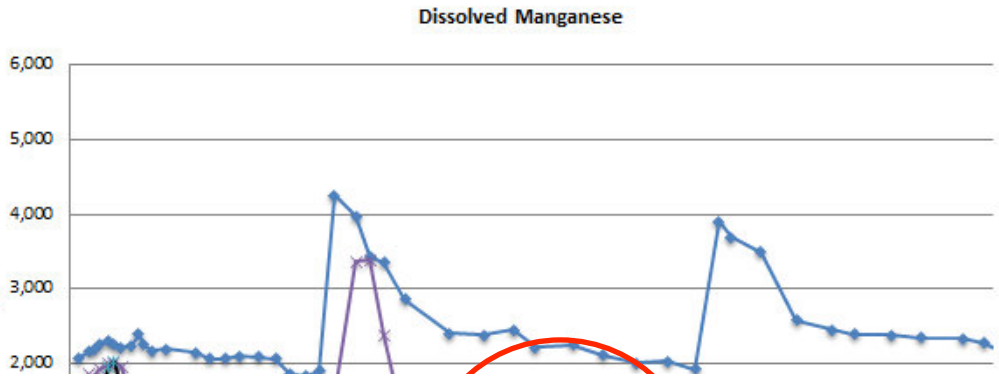


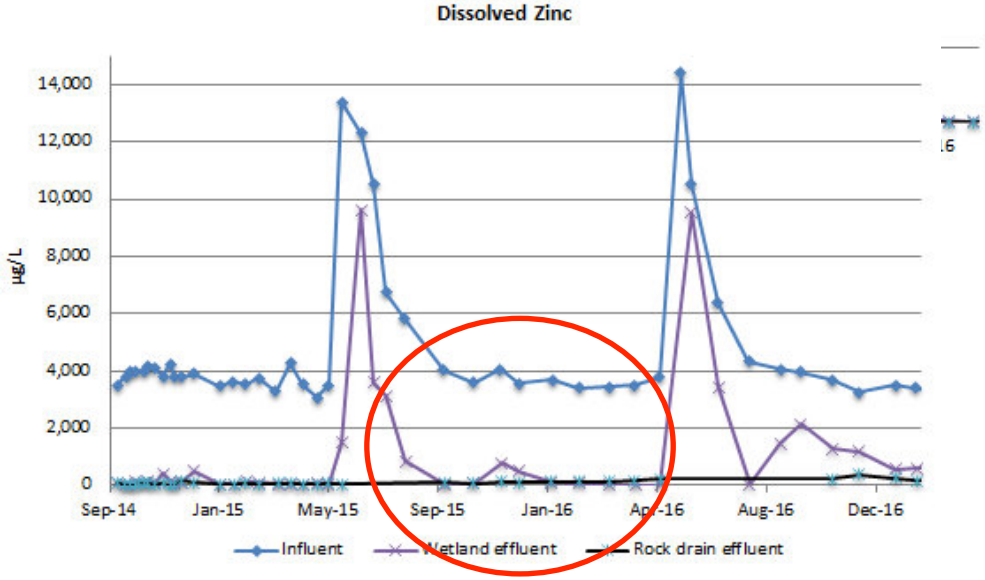
System Performance – Effect of Temperature

- Water temperature decreased to 5
- During that time, sulphide levels i
  2-3 mg/L and metal removal was



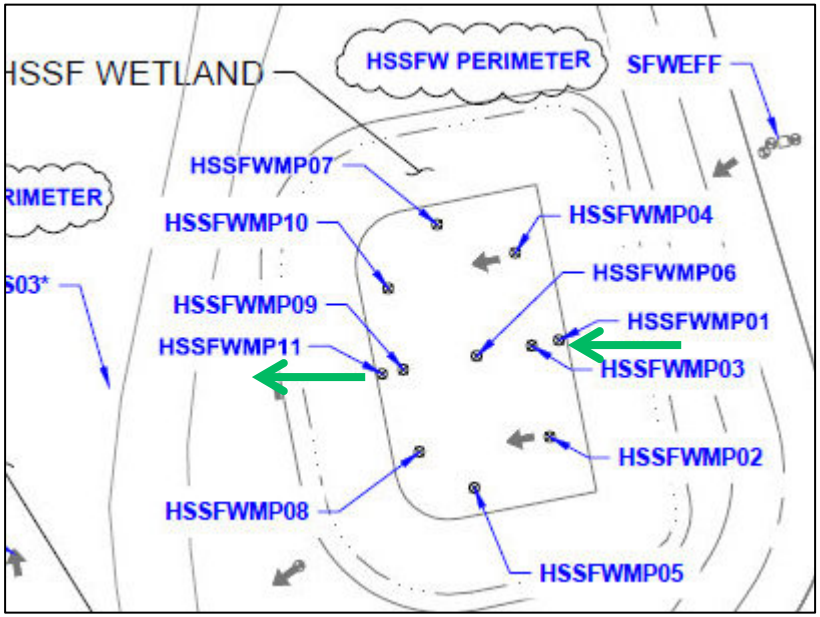






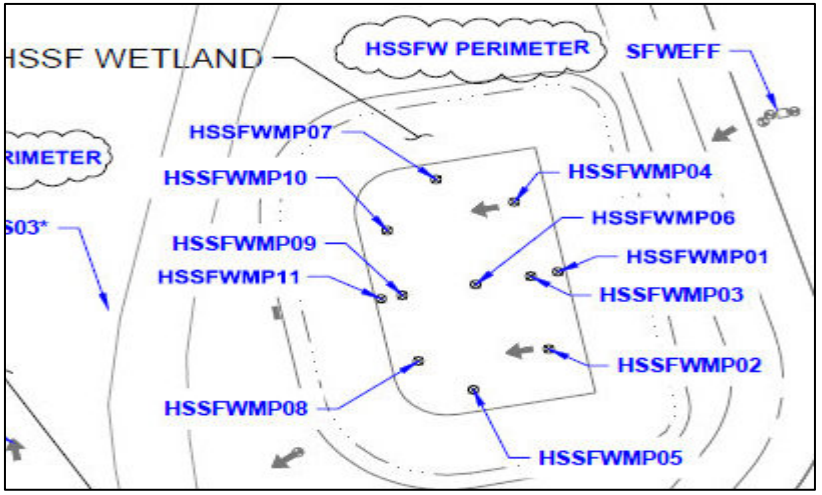
Wetland Transition Zone

- Network of sampling stations were installed in the horizontal flow wetland
- Regularly monitored for pH, ORP
- Discovered a significant “transition zone” between aerobic inflow and anaerobic zone of sulphide production



Transition Zone

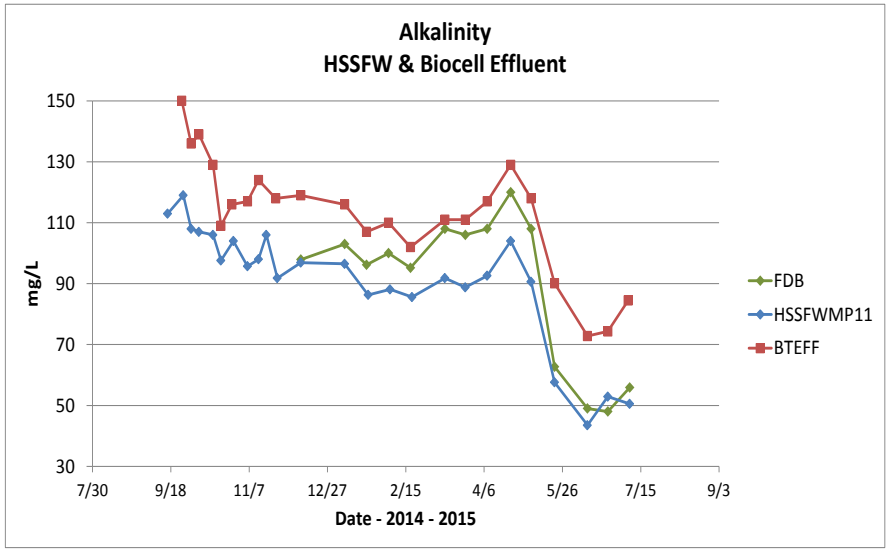
- Transect by inlet always has higher ORP than transects further in
- During freshet, the oxic zone expands towards the outlet; SRB activity declines
- *Manganese removal in wetland only occurs within the oxic transition zone*

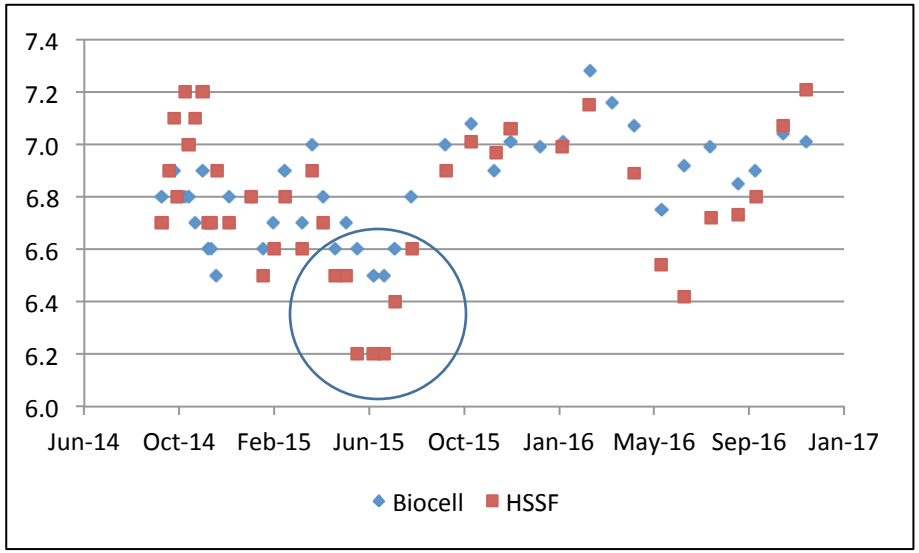


	18-Feb-15	23-Mar-15	20-Apr-15	18-May-15	08-Jun-15	06-Jul-15	27-Jul-15	09-Sep-15	13-Oct-15
INLET									
WMP 1	-67	97	3	122	153	23	63	57	34.7
WMP 2	-17	103	-6	82	58	6	44	-85	-204
WMP 3	3	99	25	125	88	21	54	14	-12.9
WMP 4	13	101	24	91	101	23	57	38	-16
MIDDLE									
WMP 5	-257	-180	-280	-197	23	-167	-177	-141	-224
WMP 6	-166	-84	-202	-139	-2	-128	-92	-190	-180
WMP 7	-196	-107	-160	-84	69	-39	-208	-199	-203
OUTLET									
WMP 8	-254	-186	-271	-230	47	-67	-187	-202	-253
WMP 9	-256	-164	-243	-144	65	-25	-167	-214	-263
WMP 10	-267	-196	-284	-234	-44	-211	-216	-226	-258
WMP 11	-227	-131	-179	-111	69	70	-21	-181	-203

Comparison with Vertical flow system

- Metal removal was comparable in both systems, except during freshet
- Vertical wetland always produced more alkalinity than horizontal wetland, likely due to higher organic matter content
- During freshet, water pH decreased more in horizontal than vertical wetland, resulting in lower SRB activity and poorer metal removal.

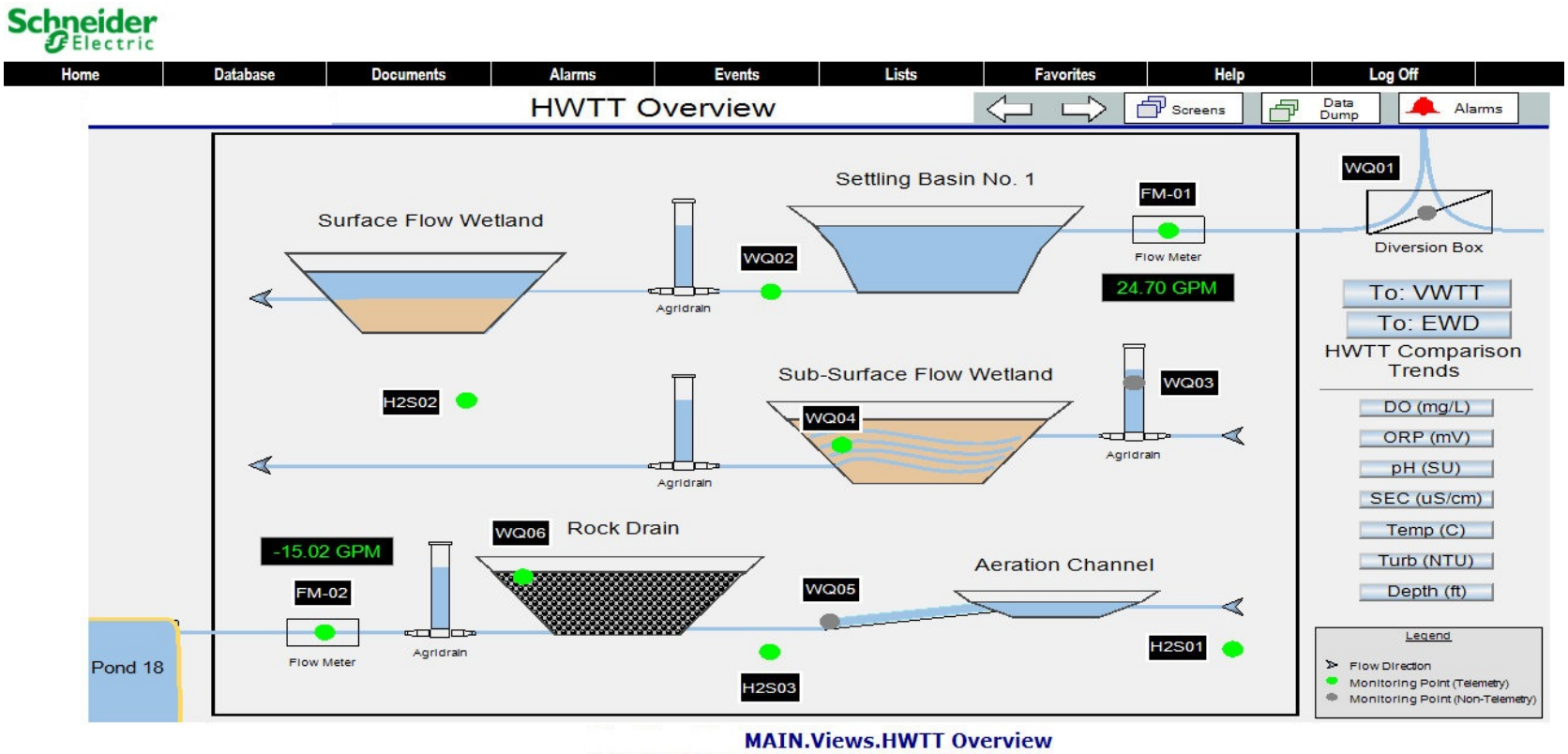




During freshet, minimum pH was 6.2 in horizontal vs 6.5 in vertical biocell

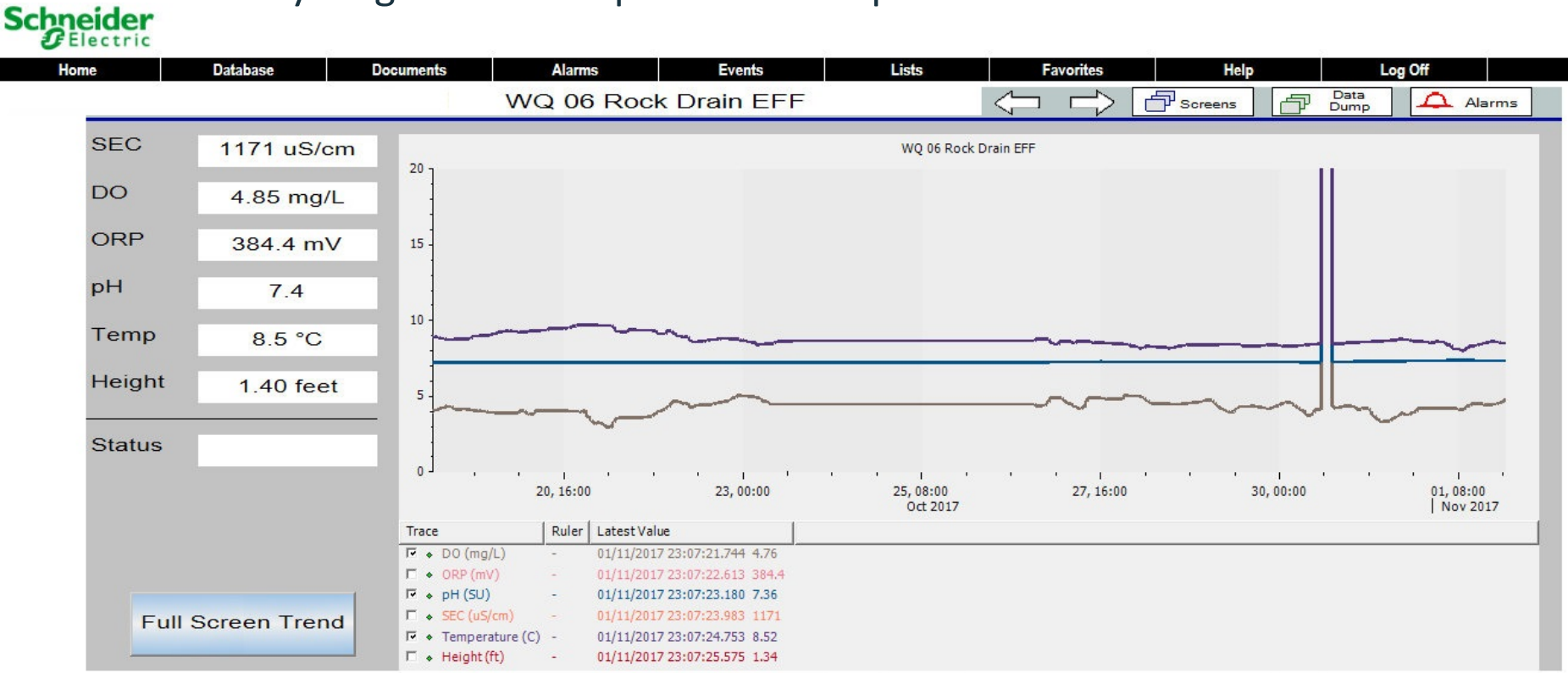
Instrumentation

- Entire demo-scale system was instrumented, connected to remotely-accessible data logger and SCADA
- Water quality parameters are available anywhere in real time



Instrumentation

- Example of screen providing status of rock drain parameters
- This enables remote monitoring, control of operation (raise or lower water elevation, adjust pH, add reagent, etc)
- Early stages in development and implementation



Current User: asobolewski

Conclusions

- Cadmium, manganese and zinc were removed to low levels year-round in a horizontal flow wetland + rock drain
  - Cadmium and zinc were primarily removed as sulphides in anaerobic wetland
  - Manganese is primarily removed in rock drain
  - Surprising amount of manganese removed in oxic “transition zone” of the wetland & metals removed on manganese oxides
- Low temperatures had no discernible effect on treatment performance
- Treatment performance deteriorated during freshet due to decreased SRB activity at low pH. Threshold is pH 6.3-6.4.
- Vertical flow system performance was less impacted by freshet; higher organic content in matrix maintained higher internal pH, SRB activity
- Remote monitoring and operation via telemetry was implemented, provides tremendous opportunities for improved operation of these systems at closure

Questions?