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Constructed Wetland Bioremediation of Chlorinated Organic Compounds in a Groundwater Capture and Reinjection System

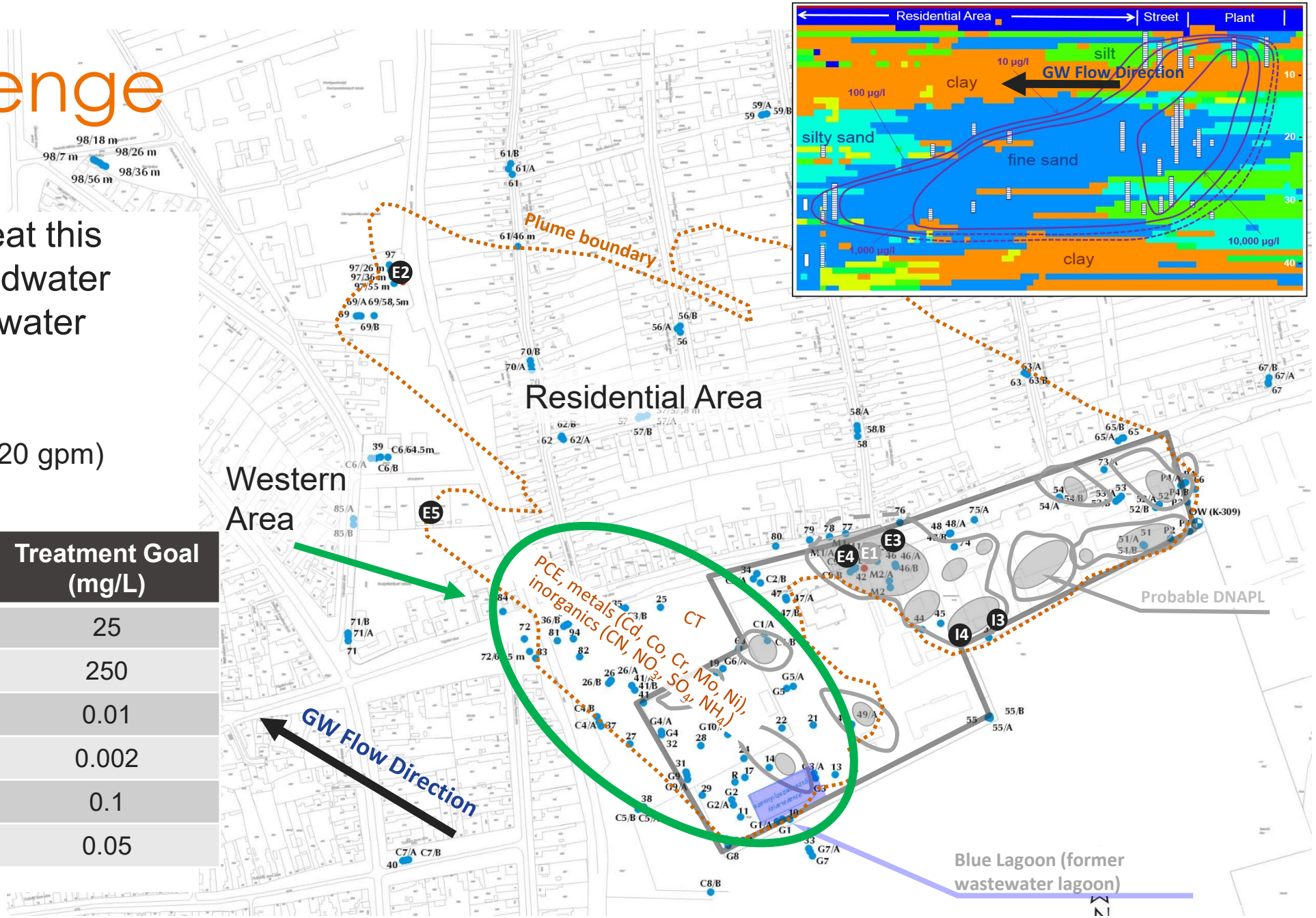
Stantec

Our Challenge

How to cost effectively treat this complex mixture of groundwater contaminants to drinking water standards?

Potential Flow Rate = 5 m^3/hr (20 gpm)

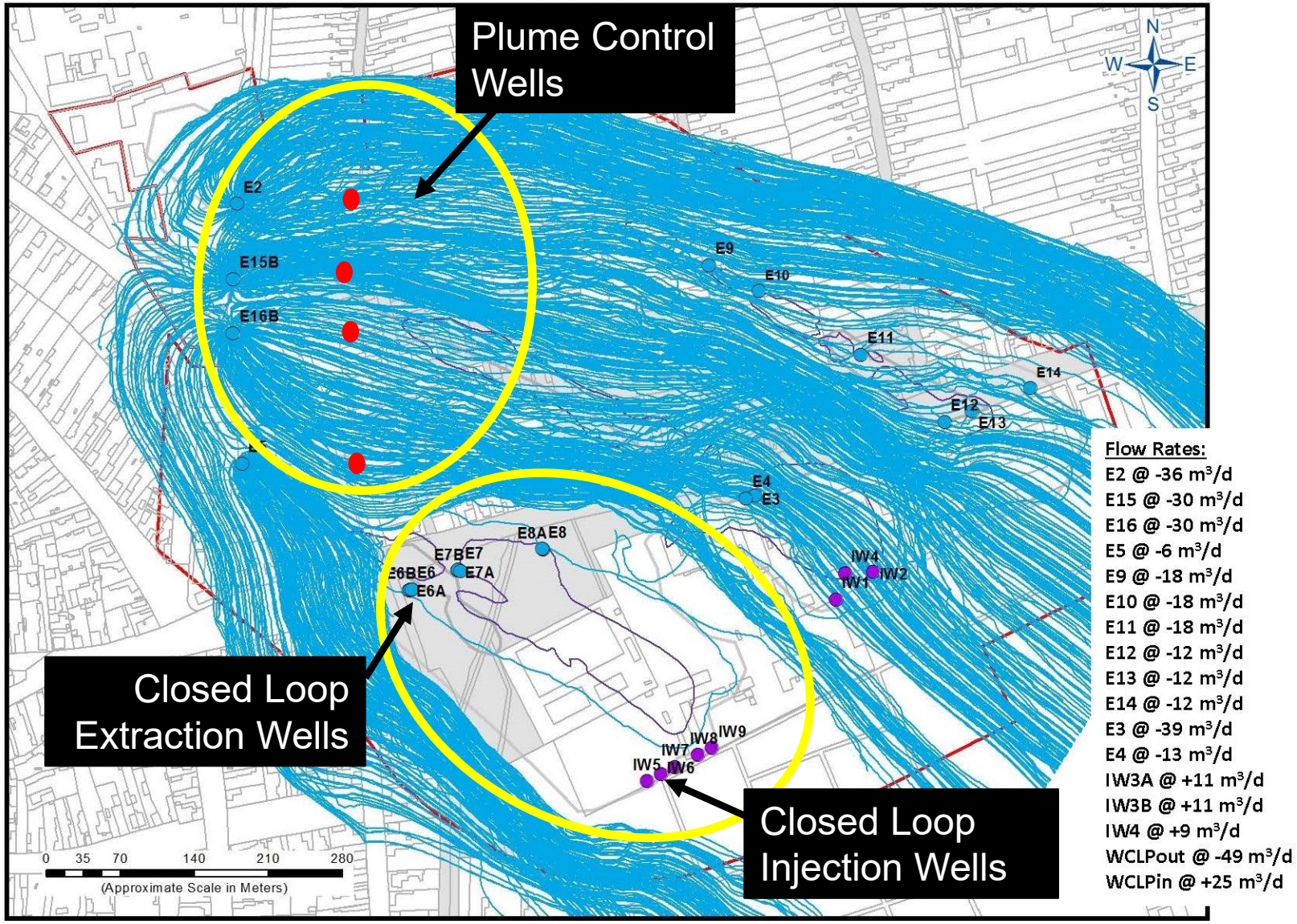
Compound	Influent (mg/L)	Treatment Goal (mg/L)
Nitrate	>1000	25
Sulfate	>350	250
Tetrachloroethene	21	0.01
Carbon Tetrachloride	4.7	0.002
Cyanide	1.4	0.1
Molybdenum	0.1	0.05



Source: Bernie Kueper and Associates

Technology Screening

- **Constraints:**
  - Halt plume expansion (regulation)
  - Plume not accessible (residences)
  - Technical Impracticability for clean up in the near term
- **Evaluated:**
  - In-Situ methods
  - Ex-Situ
  - Physical barrier
  - ✓ **Hydraulic control**



Bernie Kueper and Associates

Treatment Selection

Objectives:

- Effective for all contaminants
- Cost effective
  - Capital
  - O&M
- Sustainable
- Integrate with existing systems
- Separate from Plant Ops
- Passive

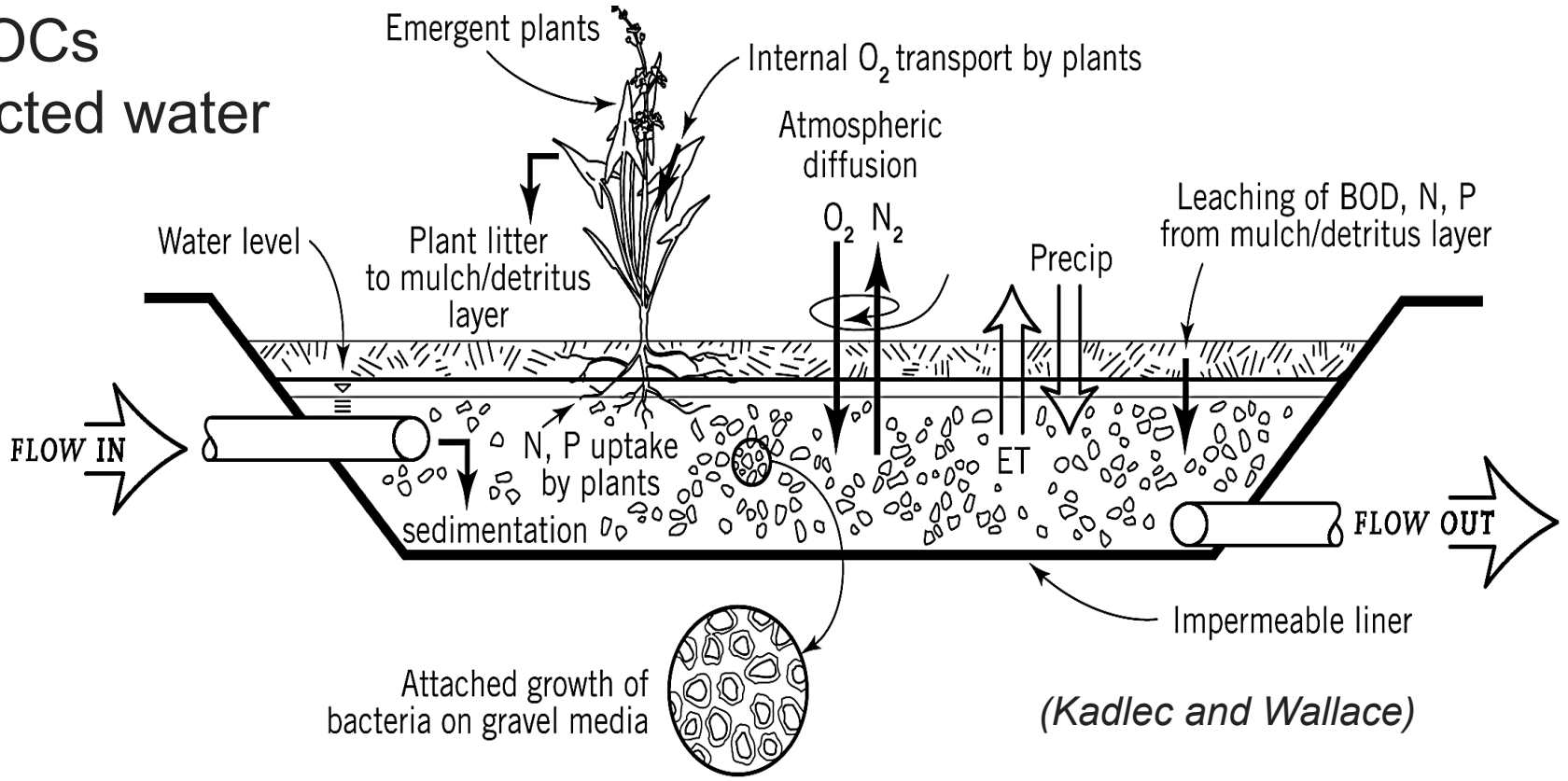
Options:

- Air stripper / RO
- Air stripper /cation exchange
- Biological reactor
  - Continuously stirred tank reactor (CSTR)
  - ✓ **Constructed wetland**

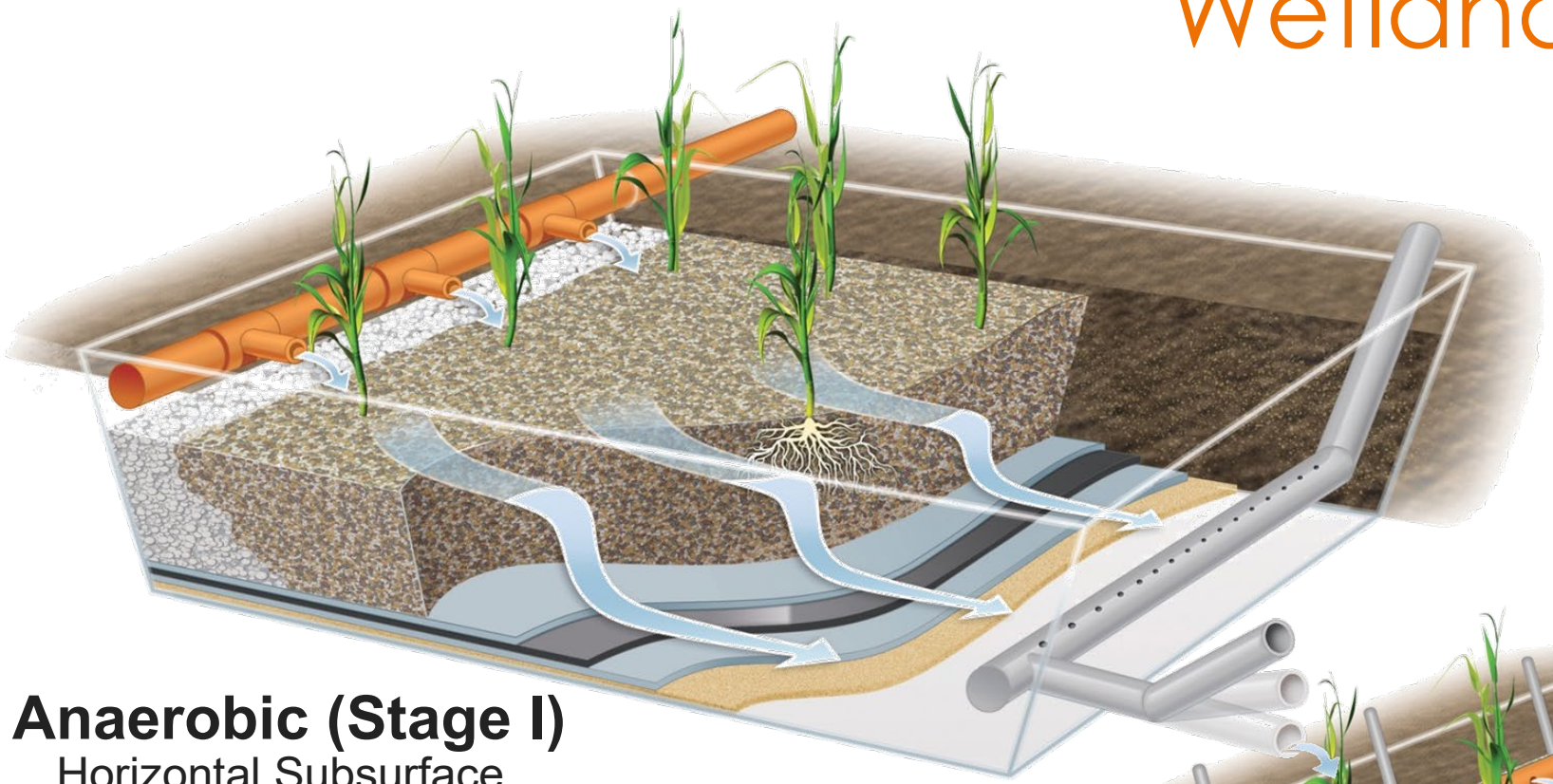
Wetland Treatment

Chosen because:

- Effective for Nitrate
- Potential to treat all COCs
- Potential to treat extracted water from other areas
- Sustainable
- Passive
- Low O&M



Wetland configurations



Anaerobic (Stage I)

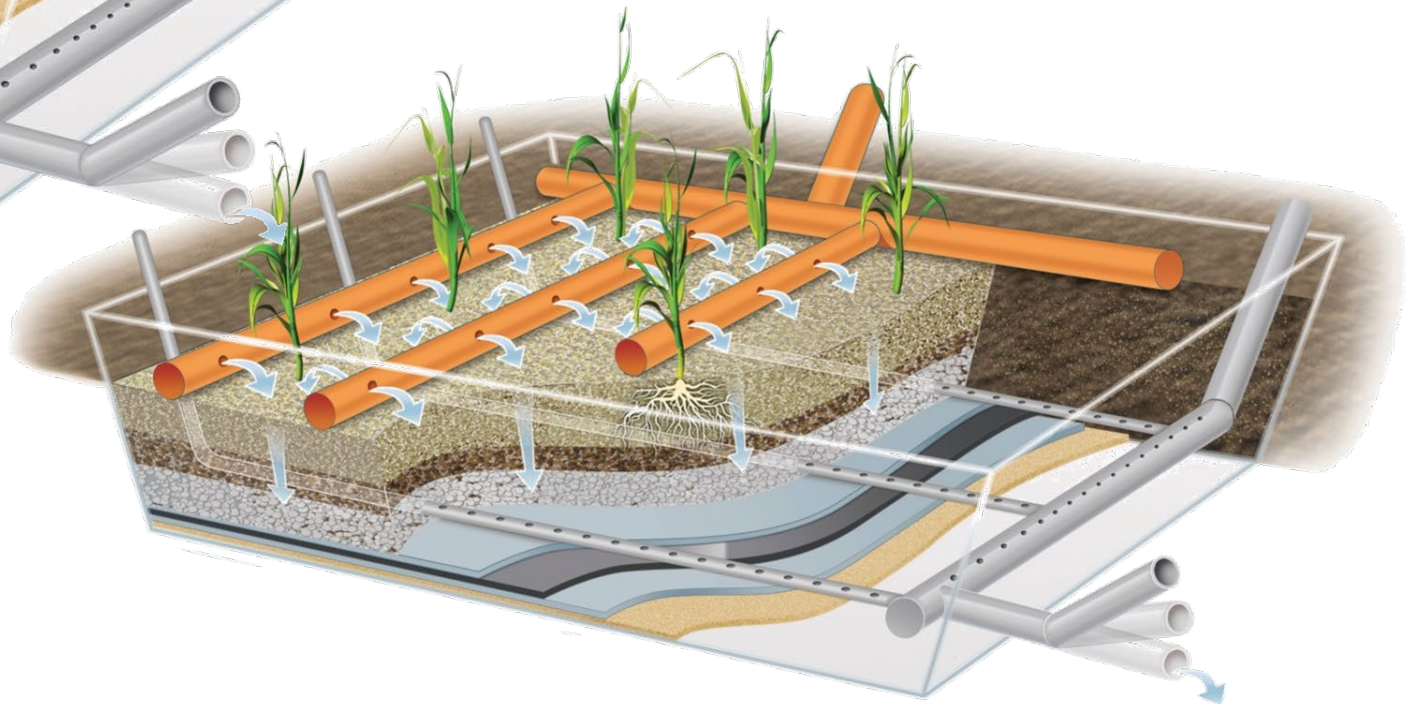
Horizontal Subsurface Flow Wetland (HSSF)

Bacteria + Carbon (wood) = reducing
Nitrate ➡ ammonia ➡ N_2
PCE ➡ TCE ➡ DCE ➡ VC
Cyanide ➡ Nitrogen + Carbon
Sulfate ➡ Sulfide (H_2S)
Molybdenum ➡ MoS_2 / MoS_4^{2-}

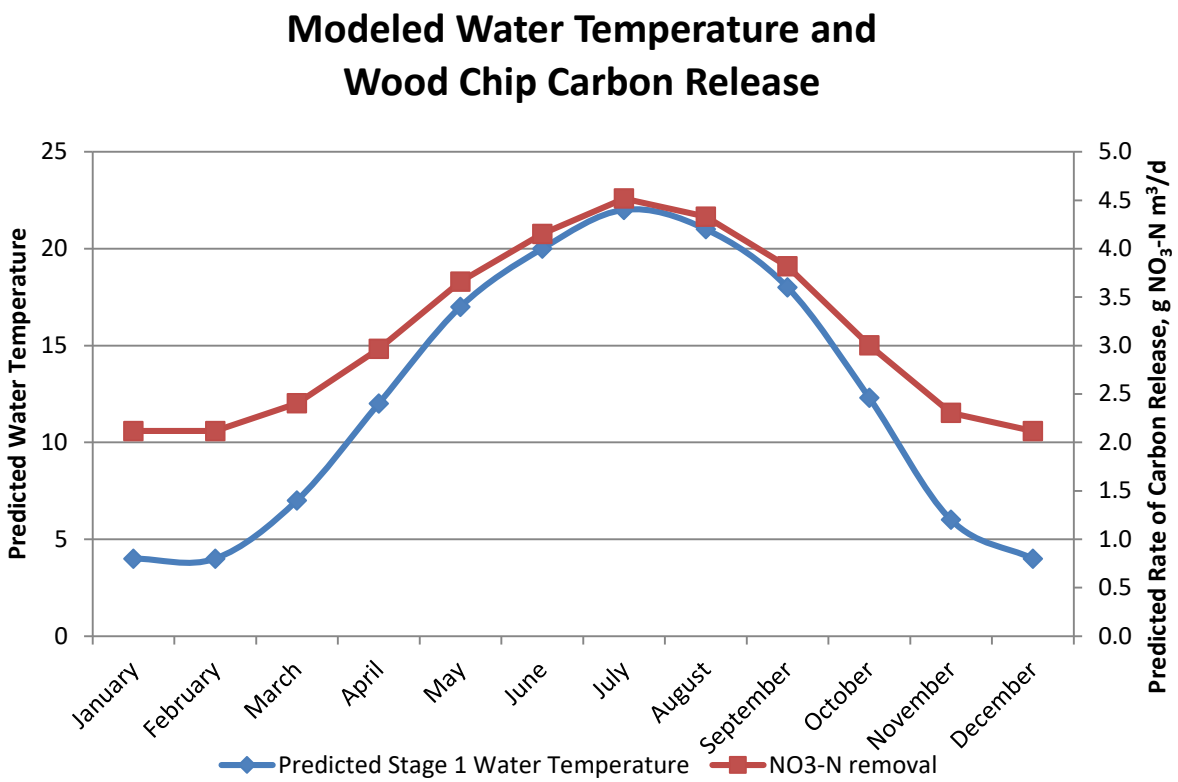
Aerobic (Stage II)

Vertical Flow Wetland (VF)
(Naturally Wallace)

Bacteria + oxygen to consume TOC
VC ➡ Ethene + Chloride
Plant uptake of Nitrogen



(Naturally Wallace)



Modeled Treatment Processes

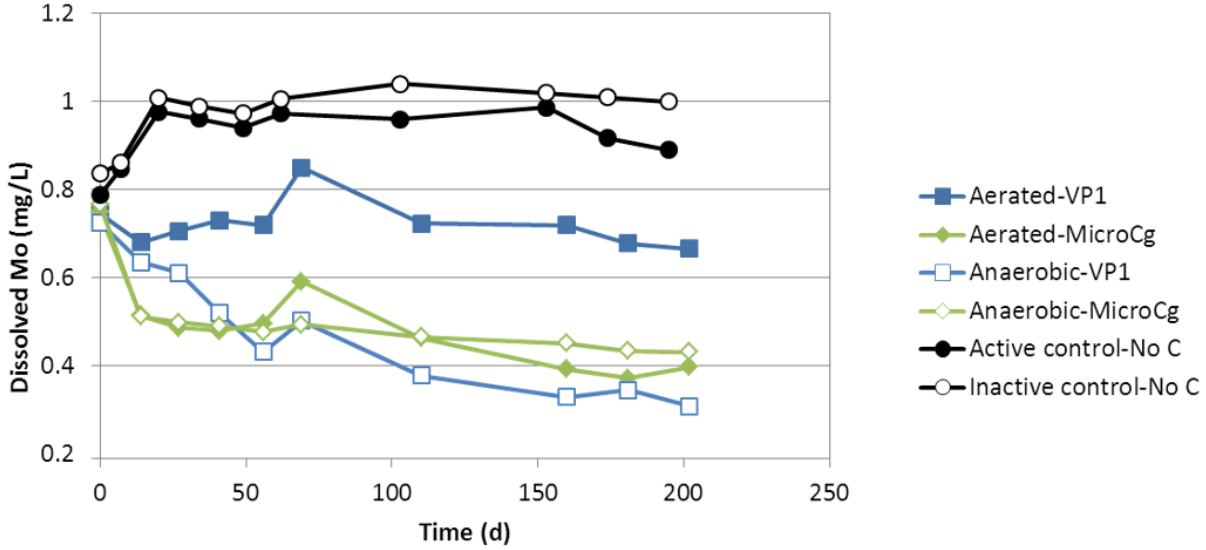
- Temperature vs. carbon release rate
- Climate (Mean, Warm/Dry and Cold/Wet)
- Evapotranspiration, Precipitation
- Nitrate/Sulfate reduction vs Carbon release VOC dechlorination (tank in series model)
  - Anaerobic for Stage I
  - Aerobic for Stage II
- CN reduction (tank in series model)

Mean Year

Influent	Rate Constant (1/day)	Mean Modeled Effluent Stage I (mg/L)	Mean Modeled Effluent Stage II (mg/L)
PCE	0.212	0.0001	0.0001
TCE	0.337	0.00001	0.0004
DCE	0.22	0.001	0.000001
VC	0.499	0.0000004	0.0000001
CT	0.334	0.0000001	0.0000001
CN	0.910	0.000000001	0.00000000001

Testing

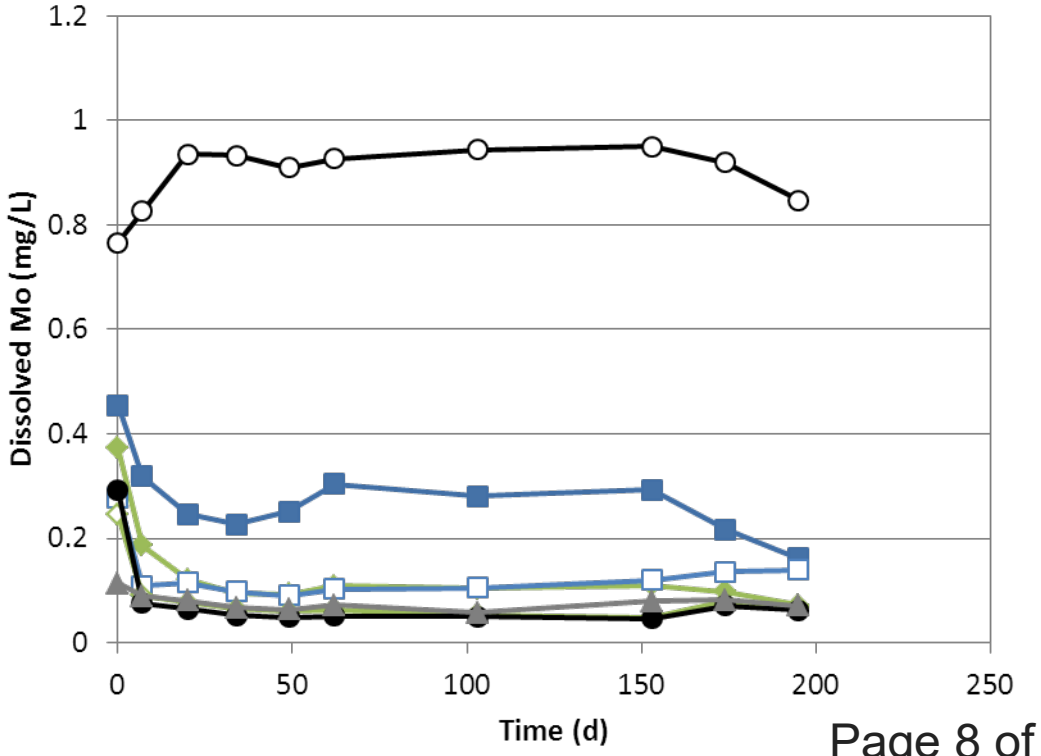
Pine Chip Testing - Moderate initial decline in dissolved molybdenum concentration in active & amended treatments (all that contain solid substrate)



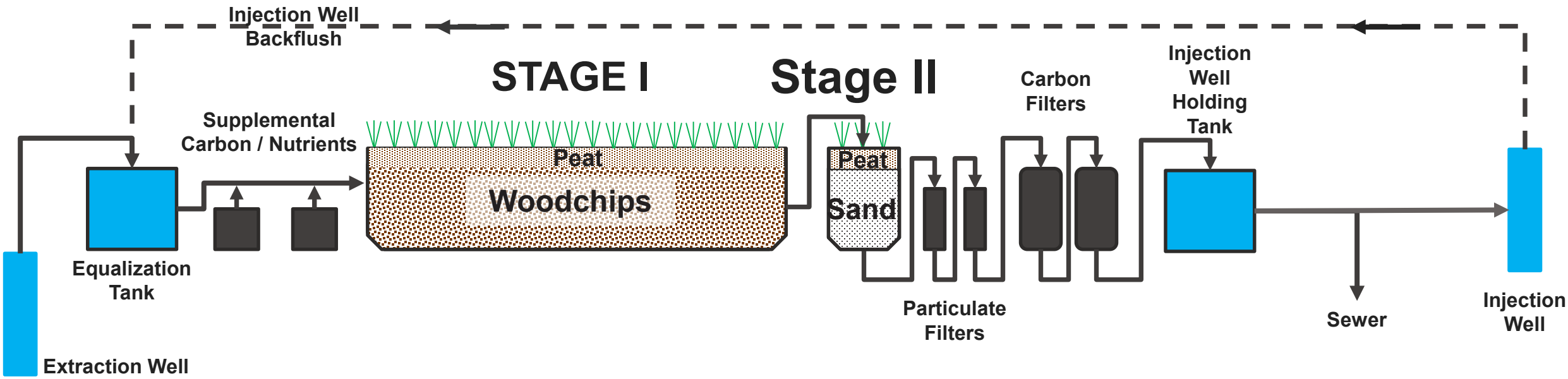
Testing (Completed by the team)

- Injection field testing (IW5)
- Hydraulic conductivity lab test (three wood chip sources)
- Molybdenum lab testing
  - Sorption in Stage I,
  - in combination with additional carbon source, and
  - precipitation in Stage II.

Poplar Testing - Apparent substantial physical interaction (adsorption) with poplar



Simplified Process Flow Diagram

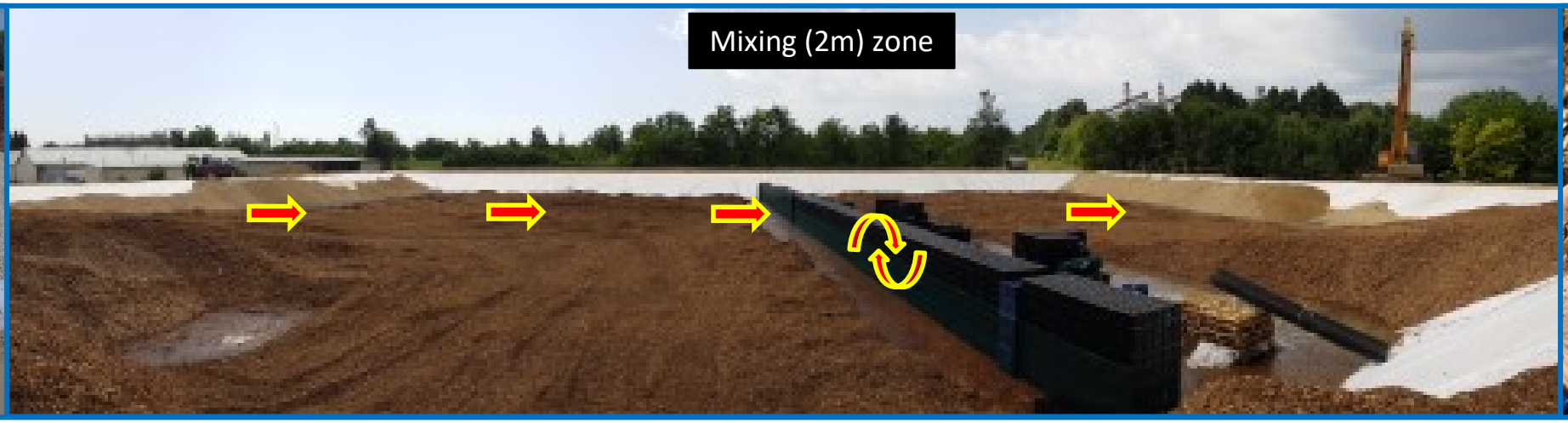


Design Elements

- Down gradient groundwater extraction (1.9 – 5.5 m^3/hr)
- Equalization tank (Applied vacuum)
- Supplemental Bio-available Carbon (BAC)/Nutrient Addition
- Stage I Horizontal Subsurface Flow Wetland (HSSF)
- Stage II Vertical Flow Wetland (VF)
- Peat – Odor control (Contingency vapor extraction, not shown)
- Particulate filters (10 µm/1 µm)
- Liquid Granular Activated Carbon (GAC)
- Injection Holding Tank
- Upgradient Aquifer Injection (1.25 – 3.75 m^3/hr)
- Sewer Discharge (1.75 – 4.25 m^3/hr)

Stage I – Horizontal Subsurface Flow Wetland

Gravel at wetland inlet / outlet



Mixing (2m) zone

Locally sourced Wood chips

Walkways

Mixing zone

Final Wetland w Peat and Roadways November 2017

Imported Peat

Stage I Sample Locations

Stage I (Anaerobic)
~85m by 60m
4,690m²

Q3.1
Stage I Effluent

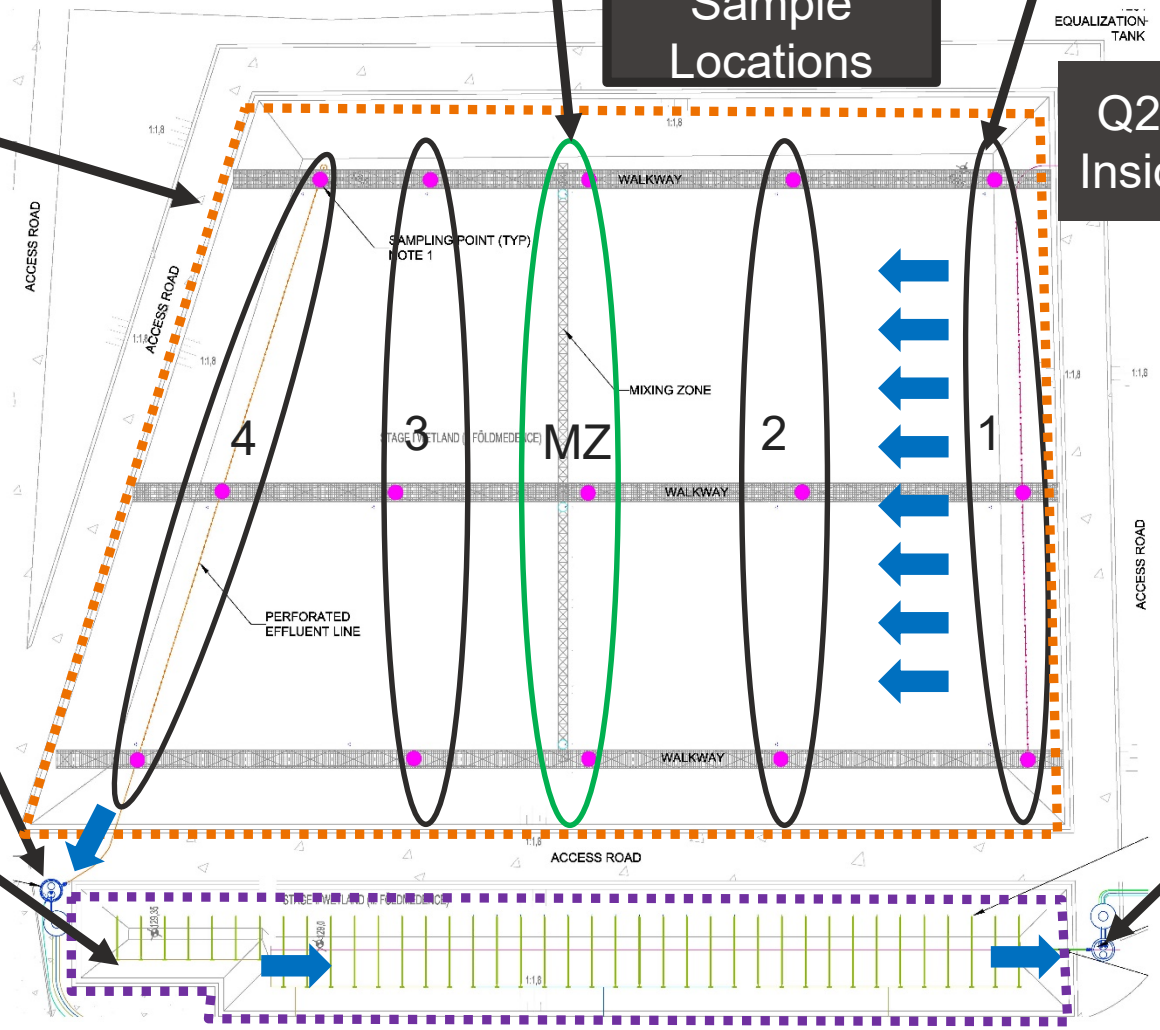
Stage II (Aerobic)
~85m by 12m
945m²

Mixing Zone Sample Locations

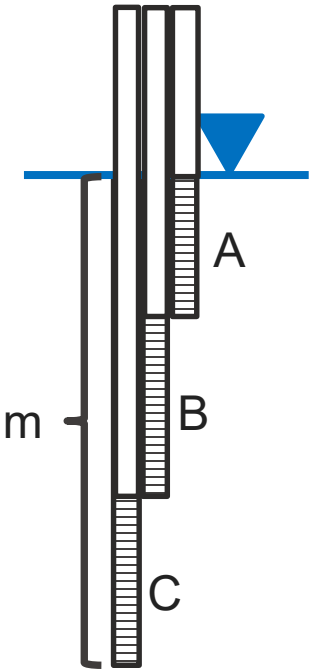
Sample Location Rows 1-4

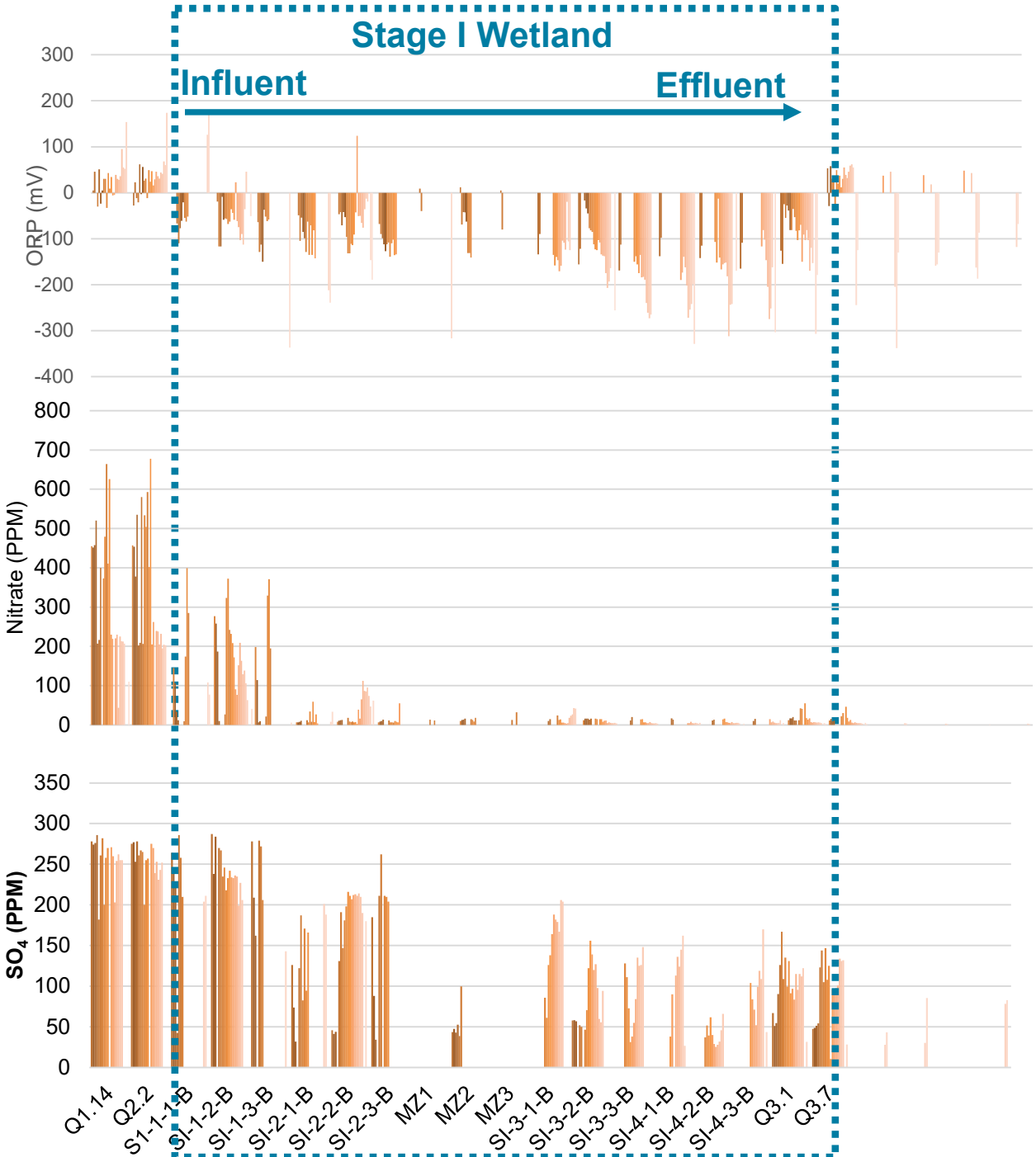
Q2.2 Influent Inside Building

Q3.7 Stage II Effluent



Sample points within Wetland



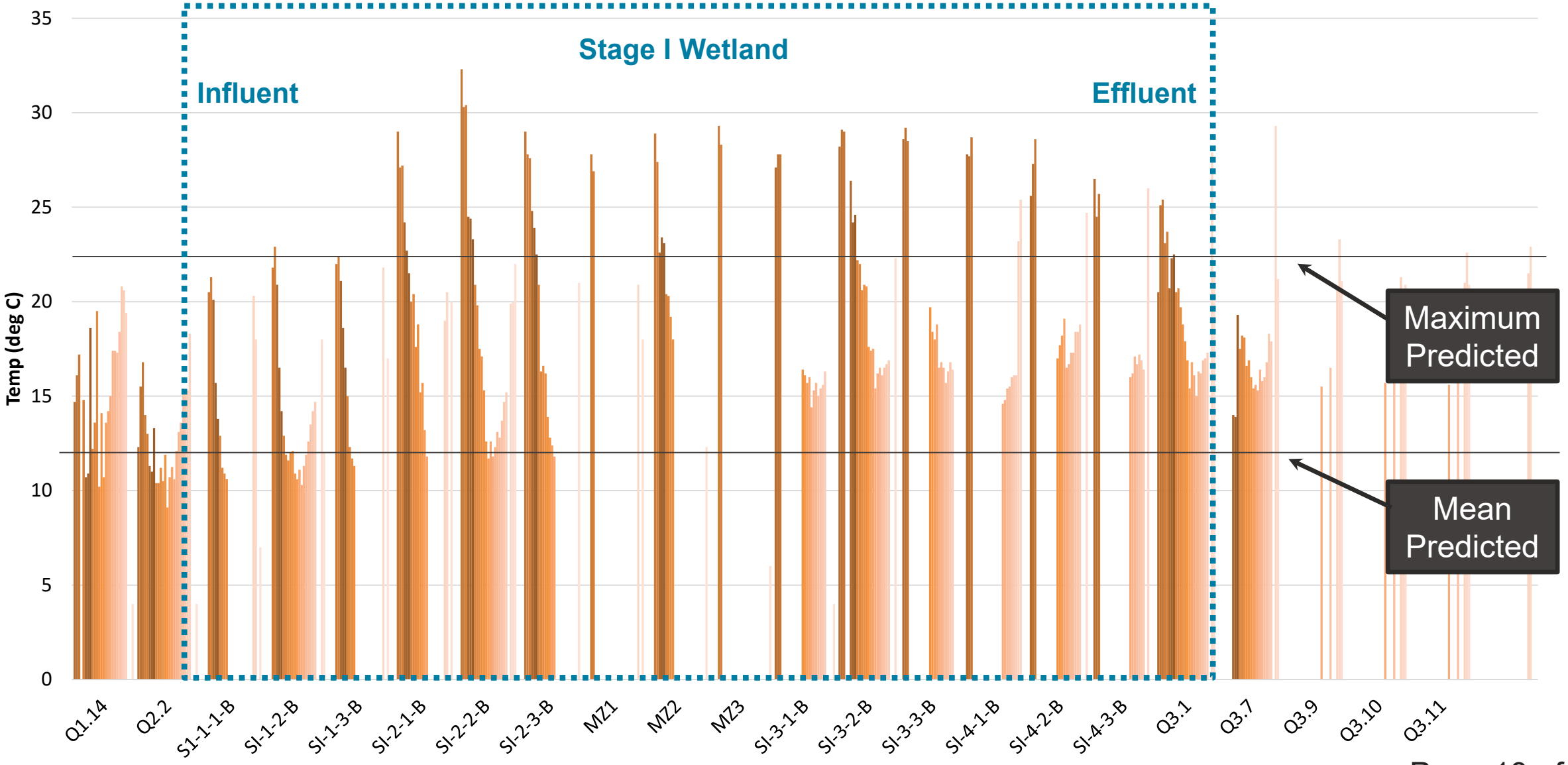


Inorganic and BOD Treatment

- Negative ORP consistently achieved in Stage I
  - Nitrate consistently reduced to below the discharge limits (>99.9% reduction in Stage I)
  - Sulfate consistently reduced to below the discharge limits (>40% in Stage I)
  - TOC/BOD effluent from Stage I reduced by 50% in Stage II Wetland.

Temperature

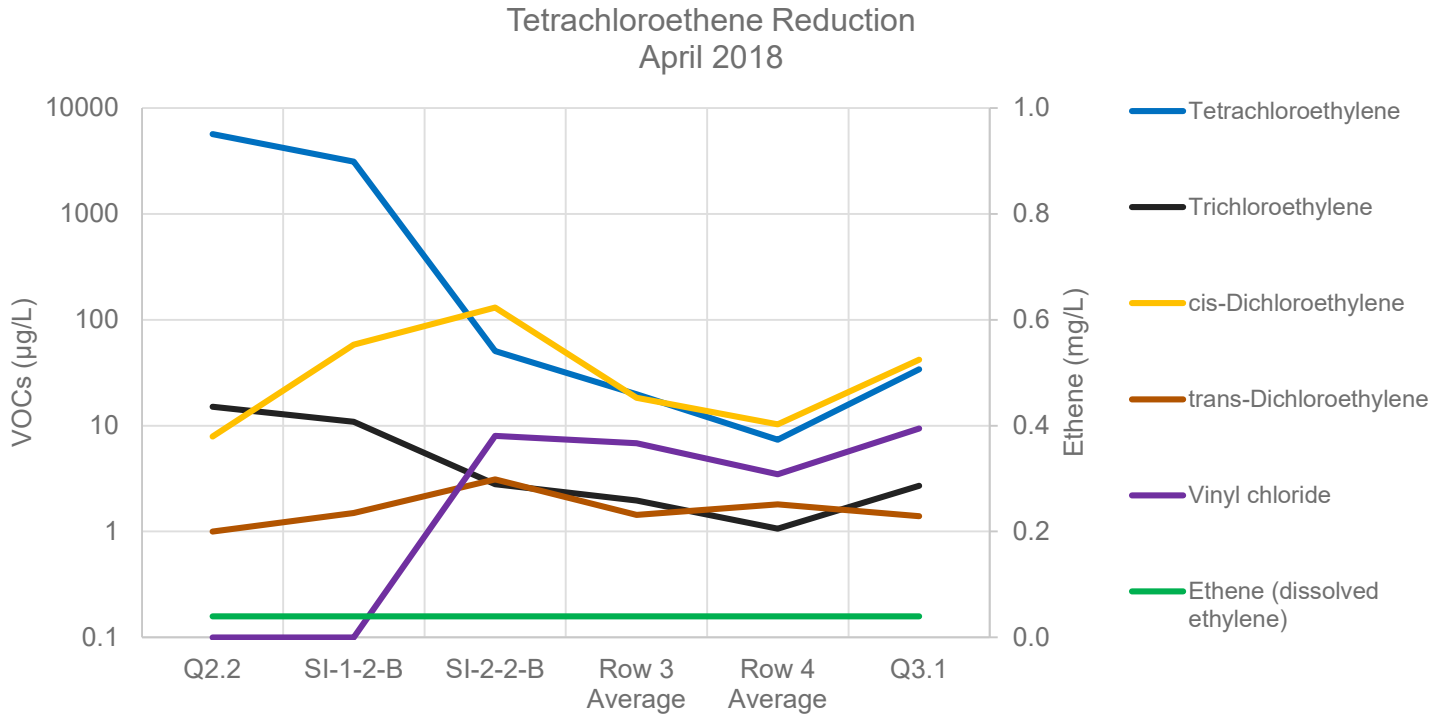
✓ Temp higher than predicted.

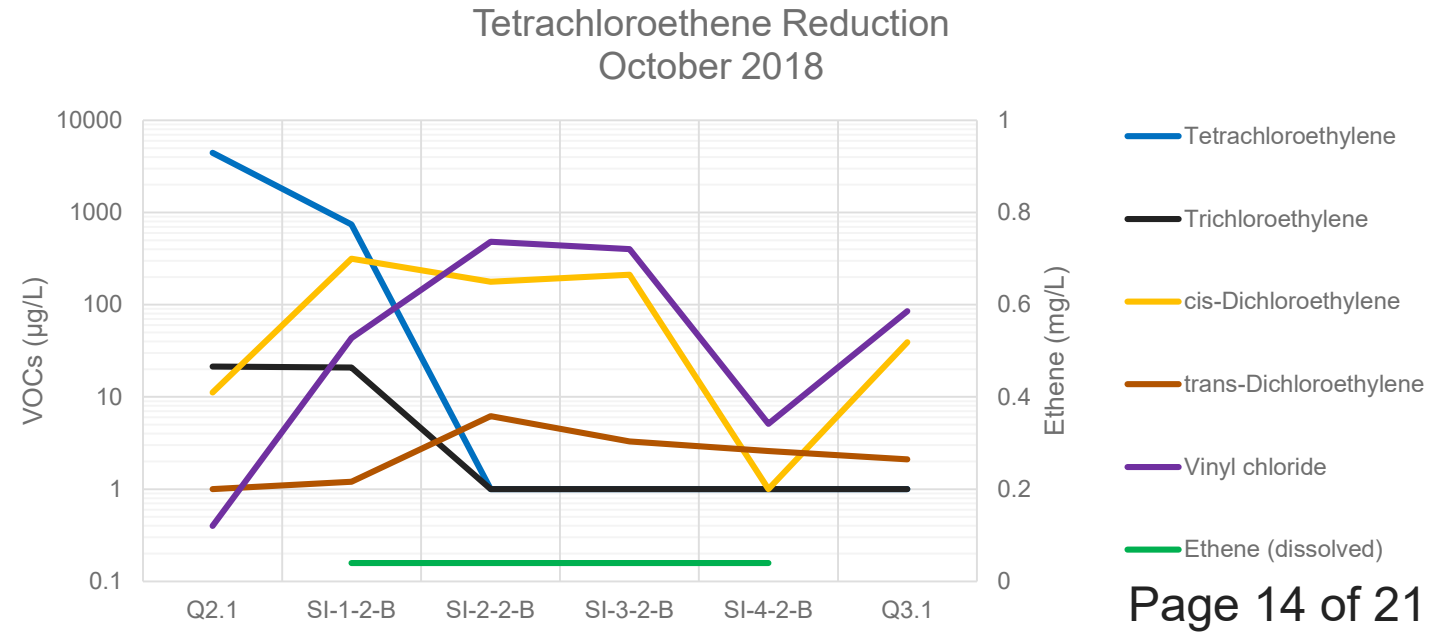


PCE Treatment

Stage I Wetland

- 99.4% mass reduction of PCE
  99.9% mass reduction of TCE
- Formation and subsequent
  98% mass reduction of cis-DCE
- Formation and subsequent
  99.8% mass reduction of VC
- No ethene (dissolved)
  measured (secondary axis)

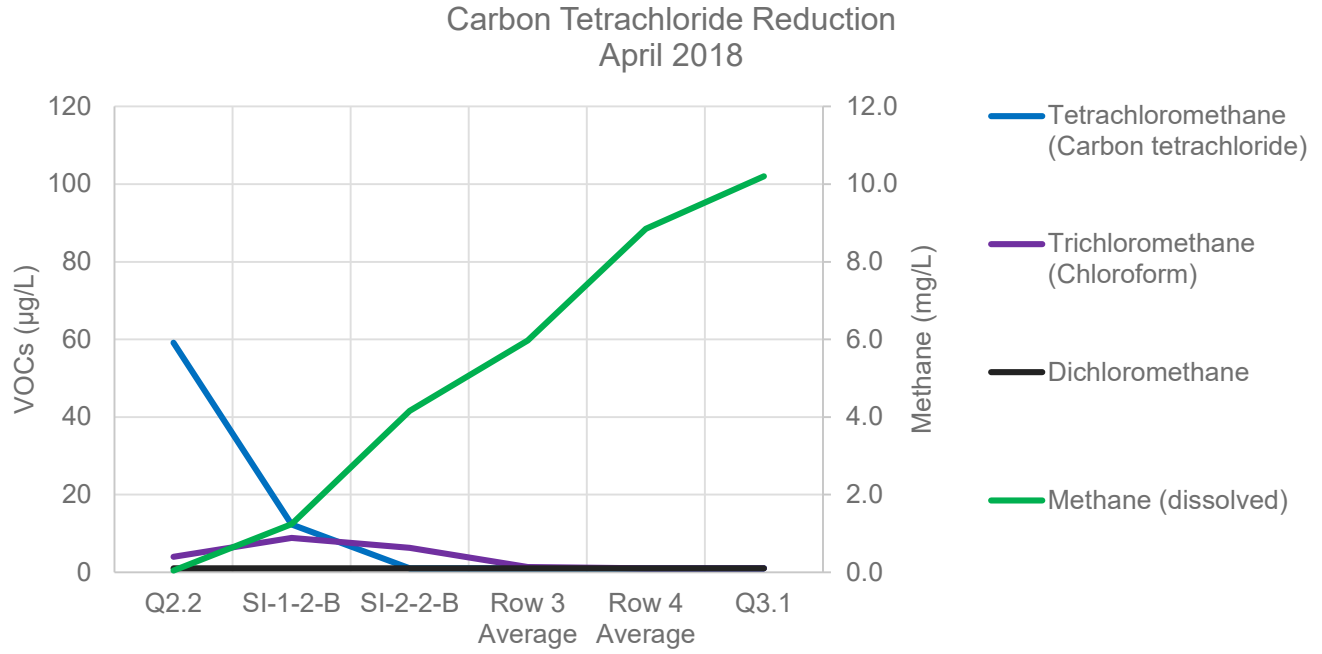


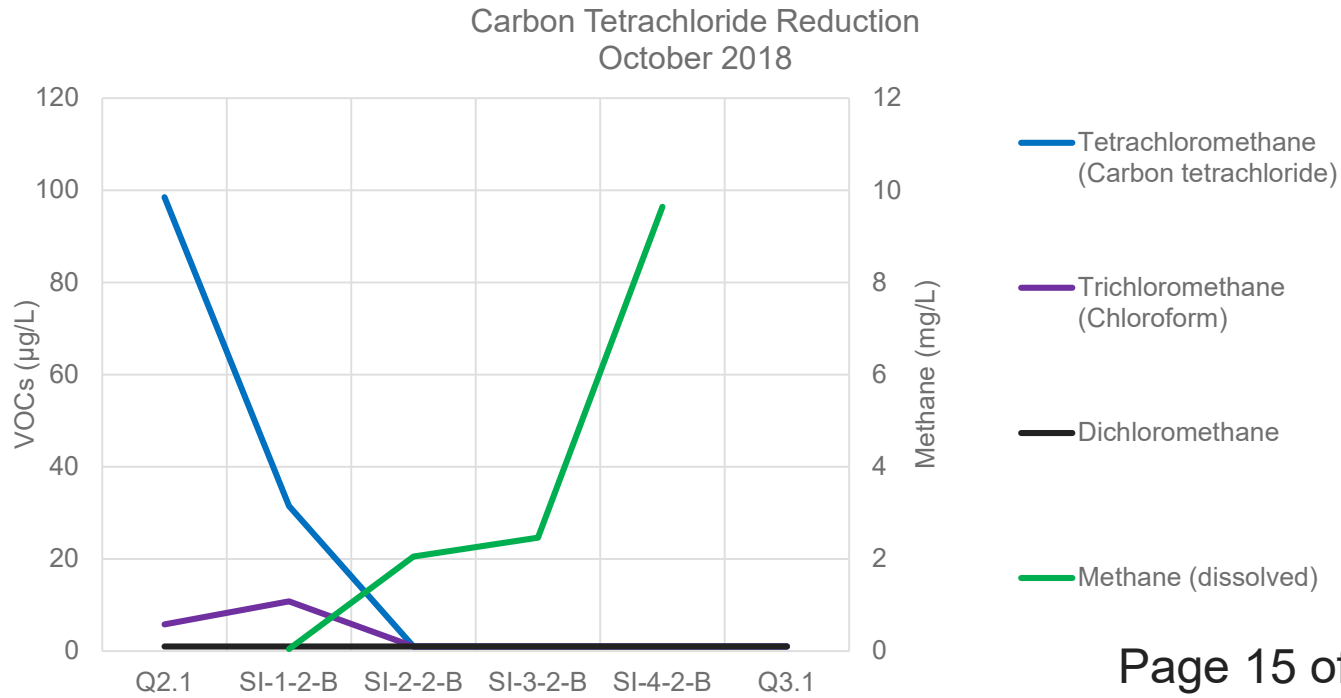


CT Treatment

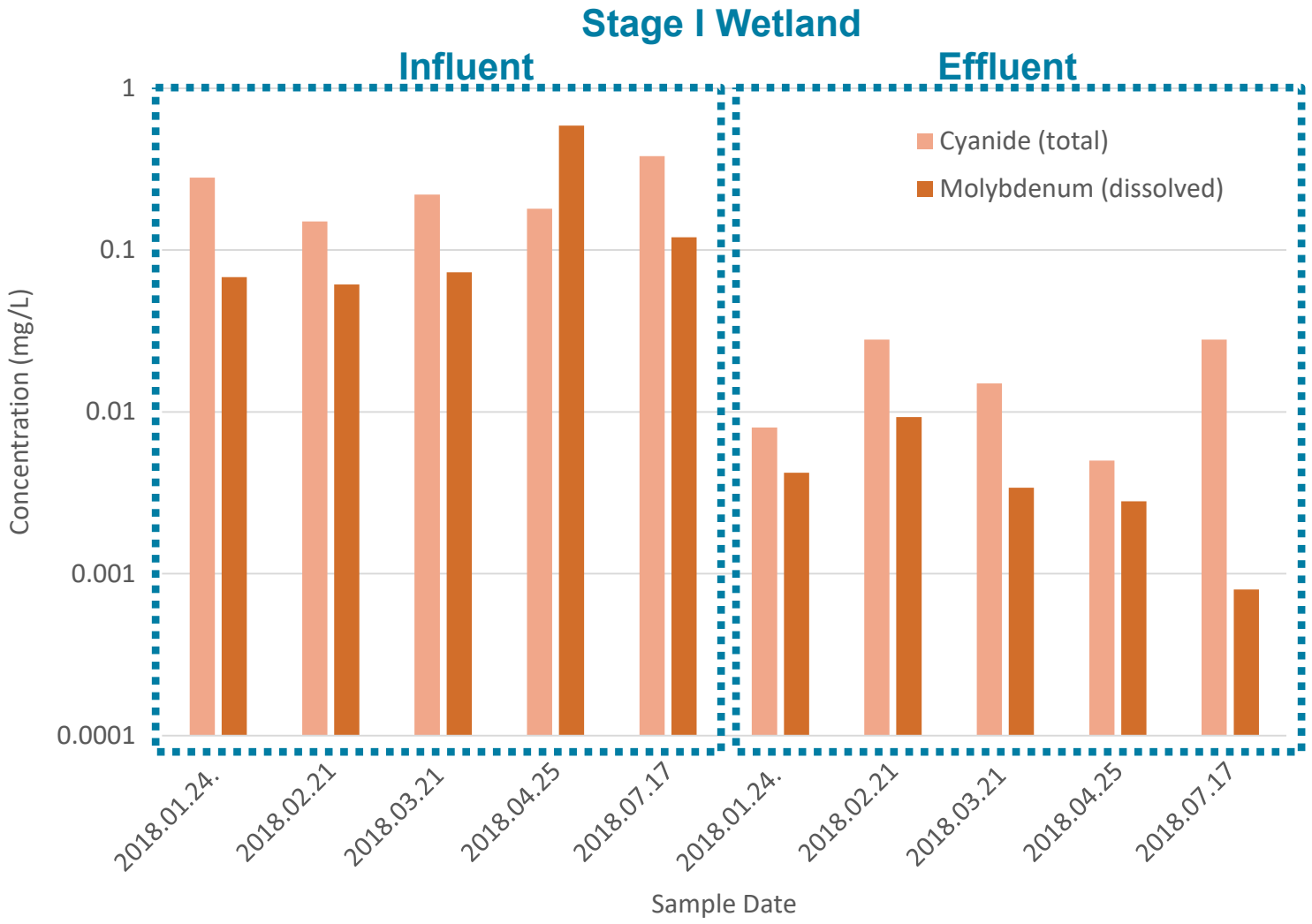
Stage I Wetland

- 98.4% mass reduction of CT
- Only reduction species observed was trichloromethane
- 92.4% mass reduction of trichloromethane
- Significant methane (dissolved) production observed (Secondary axis)





Cyanide and Molybdenum Treatment



Cyanide mass reduced by 93.1%

Molybdenum mass reduced by 97.7%

Stage II Performance

- Stage II less monitoring
- Initially aerobic
- Became anaerobic
  - Elevated TOC loading from Stage I
  - VOC and hydraulic loading from other system
- Oxygen deficient
- Optimization in progress

Calculated Average Removal Rate Constants (Stage I)

Volatile Organic Compounds	Mass Reduction (%)	TIS 1/day	Plug Flow 1/day
PCE	99.4	0.158	0.113
TCE	99.9	0.255	0.158
Carbon Tet	98.4	0.120	0.092

Inorganics	Mass Reduction (%)	TIS 1/day	Plug Flow 1/day
Cyanide	93.1	0.071	0.060
Moly	97.7	0.104	0.082
Nitrate	98.1	0.113	0.088

Tank in series equation (TIS)

$C_e=C_i\ (1+(kt/P)^{-P})$

Where:

C_* - Sink source (mg/L assumed to be zero)

t – Hydraulic residence time (day)

P – Hydraulic parameter (assumed to have a value of eight, typical for HSSF systems)

Plug flow equation

$C_e=C_0e^{-kt}$

Where:

C_e – Concentration effluent (mg/L)

C_0 – Concentration influent (mg/L)

k – rate constant (1/day)

T - time (day)

Measured vs. Modeled Rate Constants

Volatile Organic Compounds	Plug Flow Calculated 1/day	TIS Calculated 1/day	TIS (Modeled) 1/day
PCE	0.113	0.158	0.212
TCE	0.158	0.255	0.337
DCE	0.087	0.112	0.220
VC	0.135	0.201	0.499
Carbon Tet	0.092	0.120	0.334

- PCE and TCE dechlorination rates for system compares well with literature for both equations.
- DCE and CT rates an order of magnitude less than TIS calculated and modeled values
- If P is increased three orders of magnitude (P=1000) the TIS modeled and the calculated Plug and TIS rates align.
- TIS model is a better fit for faster than aquifer flow rate in the wetland.

Conclusions

- **Stage I is meeting design objectives**
  - **Nitrate removal exceeded expectations**
  - **Discharge goals achieved**
  - **Complete dechlorination of CT/no residual intermediates**
  - **Dechlorination of PCE is almost complete/DCE, VC residuals**
  - **Composite Mo removal rate constant determined.**
- **Bioaugmentation not necessary**
- **Peat effective for odor control**


Questions?