# Long-term Passive Treatment of Gold Mine Effluent Using a Natural Wetland

BC-MEND ML/ARD WORKSHOP 2023

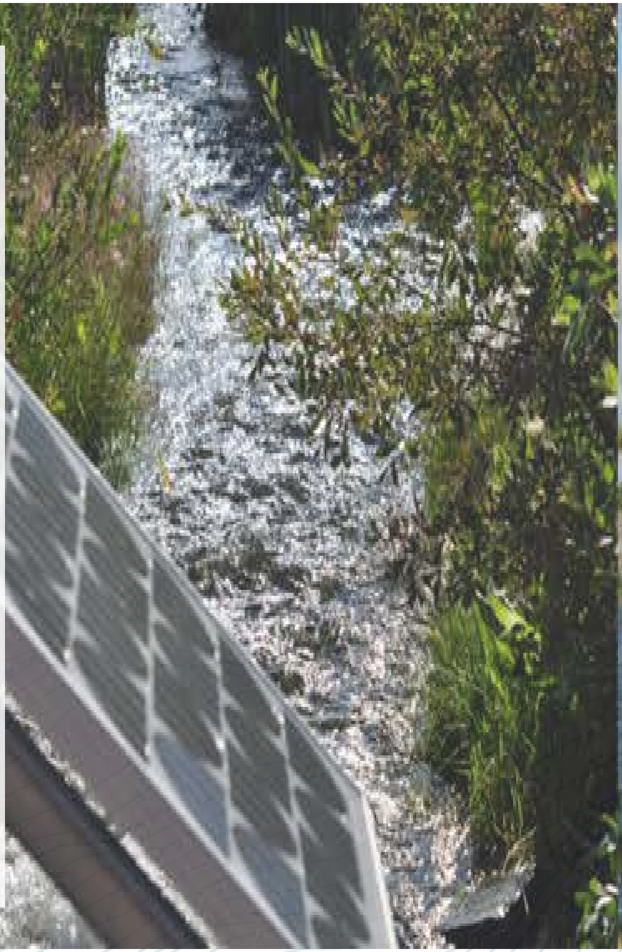
**Lorax Environmental Services Ltd.**: Cheng Kuang, Gladys Oka, Alan Martin

**Newmont**: Shane Matson, Steven Uchtenhagen, Felix Abanto, Hugh Davies, Kristin Pouw, Doris Pilar Achircano Condori, Stephanie Thibeault

# Outline

MUSSELWHITE MINE
(THUNDER BAY, ONTARIO)

- Mine facility
- Wetland cultural significance
- Wetland features
- Wetland performance
- Concluding remarks



# Musselwhite Mine

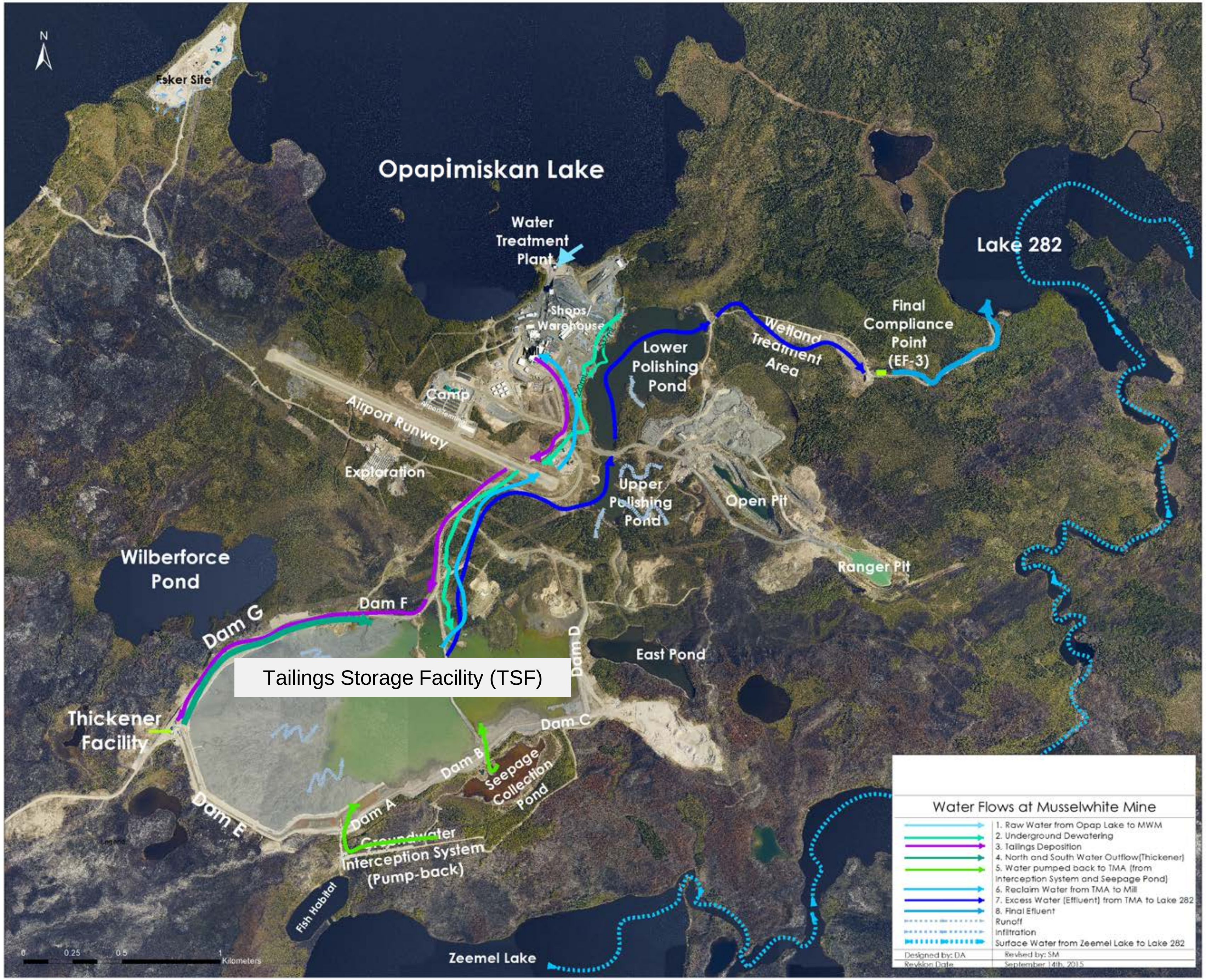
Commercial gold production commenced in 1997, with current life-of-mine until 2033.

215 ha Tailings Storage Facility (TSF)

- 1997-2010: Slurry tailings
- 2010-current: Thickened tailings

## Site Water Balance:

- Majority of site water is collected and stored in the TSF. Inputs to the TSF include:
  - o Process water from mill
  - o Underground dewatering
  - o Precipitation
  - o TSF seepage (captured via seepage collection pond and groundwater interception system)
  - o Treated sewage effluent
- 75% TSF water is pumped back to mill (reclaim).
- Excess water is pumped to a two-stage polishing pond system with gravity flow to the treatment wetland, and ultimately the receiving environment (Lake 282).



# Wetland Cultural Significance

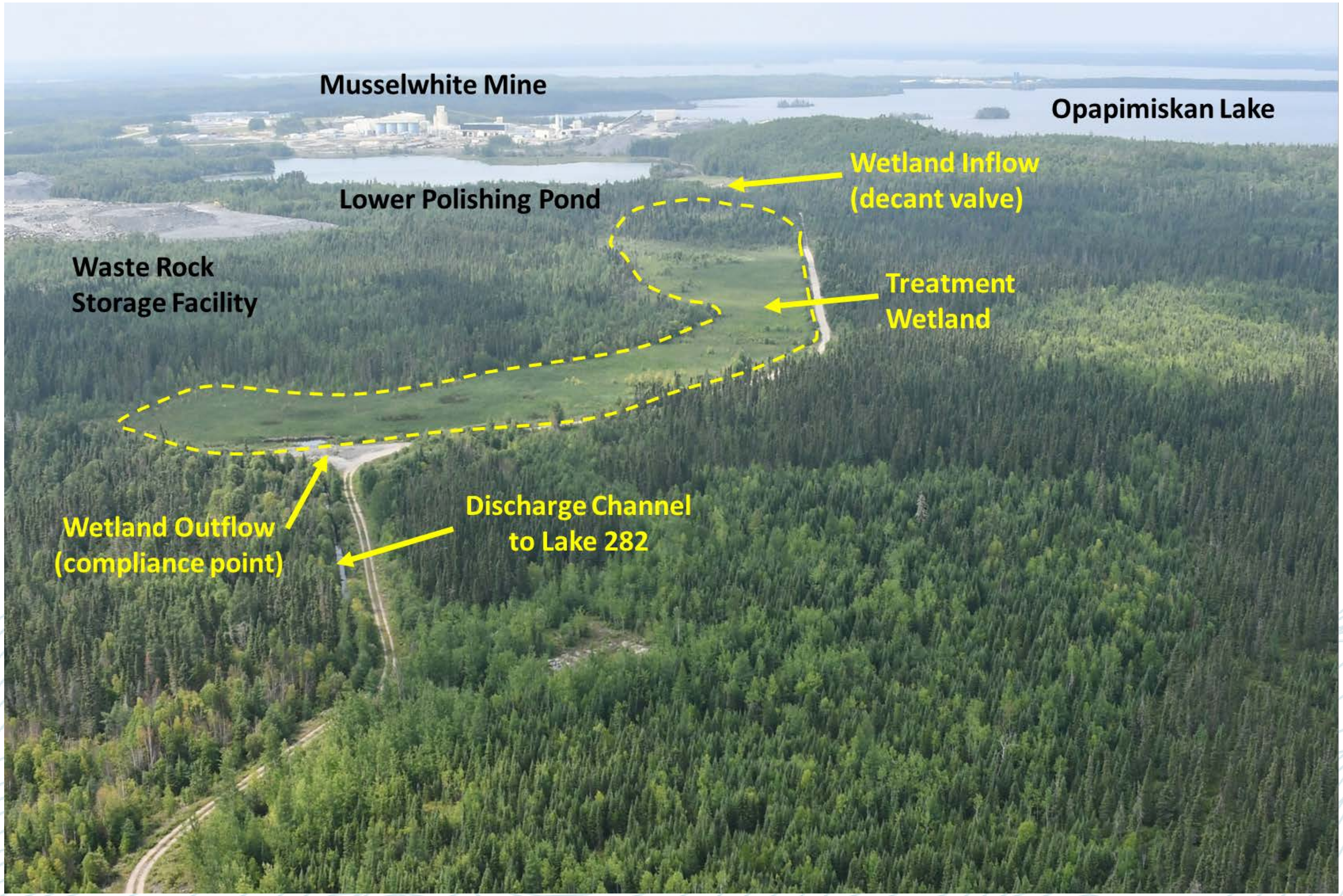
- Inflow to the wetland serves as the location for the annual opening and closing ceremonies with local Indigenous communities.
- Ceremonies mark the successful beginning and end of the discharge season.
- Located at the base of Spirit Hill.
- Attended by site employees and community members.
- 2 of 4 signatory communities live downstream of the wetland as well as several other communities onward to James Bay.
- Community members invited to open and close the decant valve after blessing of the water.
- Ceremonies have been integral part of building and maintaining strong community involvement and contribution to environmental stewardship.

# Wetland General Features

*Wetland Outlet at EF-3 (Photo taken on September 14, 2022)*

- Wetland vegetation comprised predominantly of cattails (>80%) and common horsetails.
- Other vegetation includes sedges, aquatic grasses, and trees/shrubs.
- Water depths in the wetland generally range from 0.10 to 0.41 m (mean of 0.26 m).
- Estimated average hydraulic retention time (HRT) of 24 hrs based on estimates of wetland storage volume and measured flow rates.

# Treatment Wetland




**6 ha wetland (natural, pre-existing)**

Major Inflows:

- Polishing pond decant (EF-1)
- Precipitation
- Runoff
- Groundwater inflows (negligible)

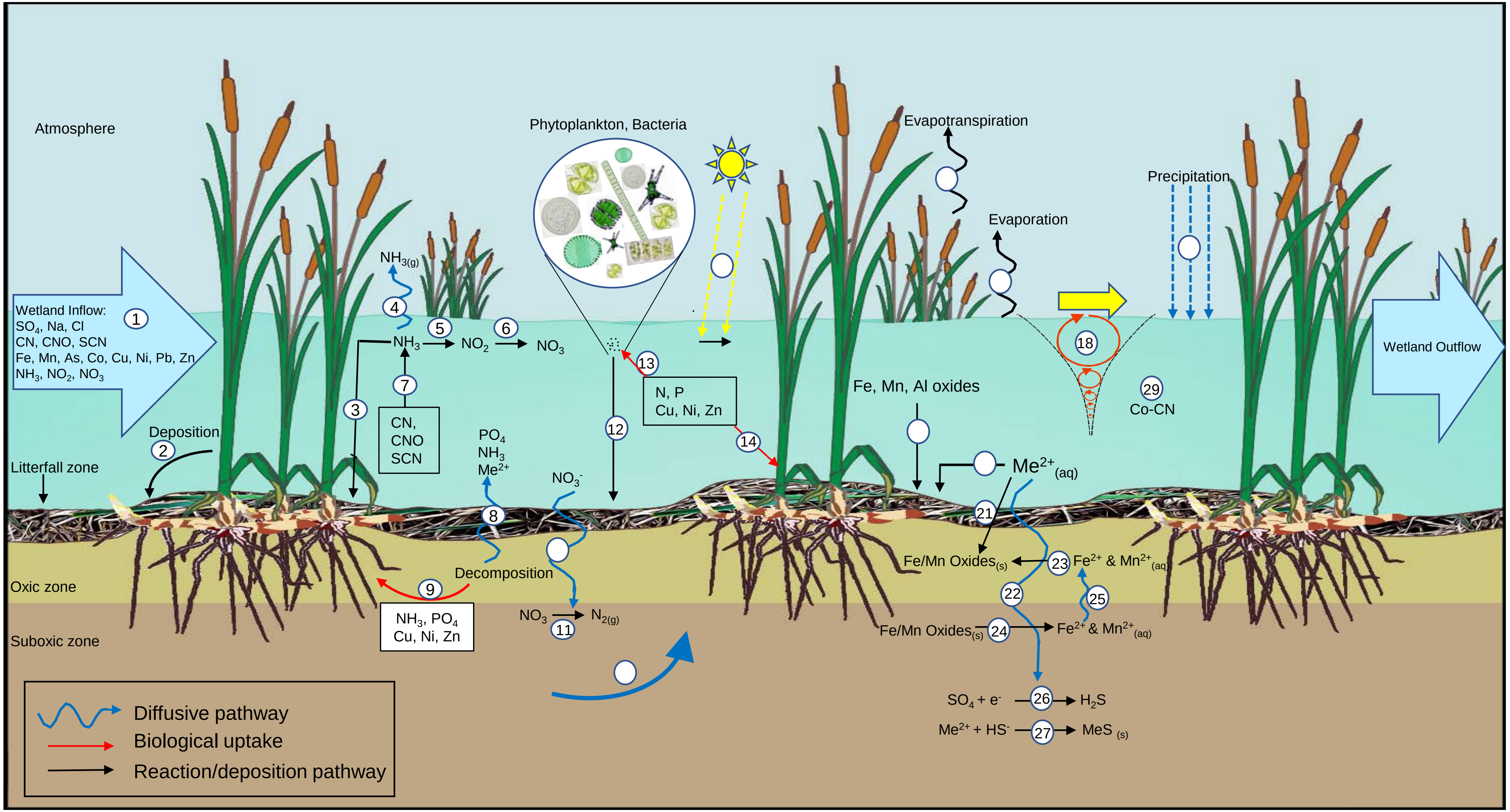
Major Outflows:

- Surface discharge (EF-3) to Lake 282 (through a Palmer-Bowlus flume into a constructed rip rap channel)
- Evaporation
- Groundwater losses (negligible)

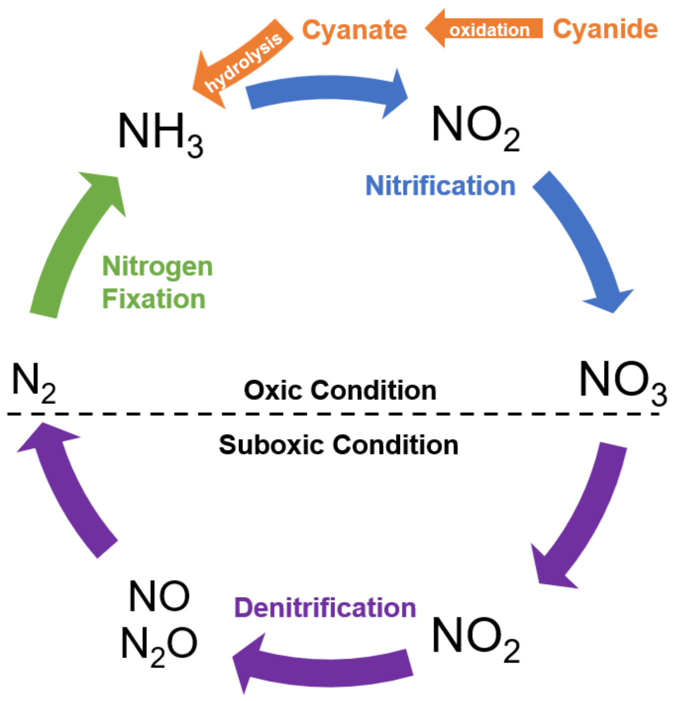
# Wetland Treatment Performance

- The Musselwhite Mine has utilized a wetland to treat effluent since operations commenced in 1997.
- The wetland operates seasonally during ice-free periods (typically from May through October).
- Typical treatment rate: 1.7 – 2.2 $Mm^3$/year
- In the last 25 years of operation, there have been no failed acute or chronic toxicity tests observed at the wetland discharge (EF-3).
- Ammonia represents the primary potential constituent of concern (PCOC).
- Other PCOCs include nitrate, nitrite, cyanide, sulphate, arsenic, chloride, cobalt, copper, iron, nickel, lead, and zinc, and pH.
- A wetland performance assessment was conducted by Lorax to:
  - Determine the primary mechanisms controlling constituent removal
  - Quantify removal efficiency for PCOCs
  - Provide recommendations for monitoring and management

# Wetland Biogeochemical/Physical Conceptual Model



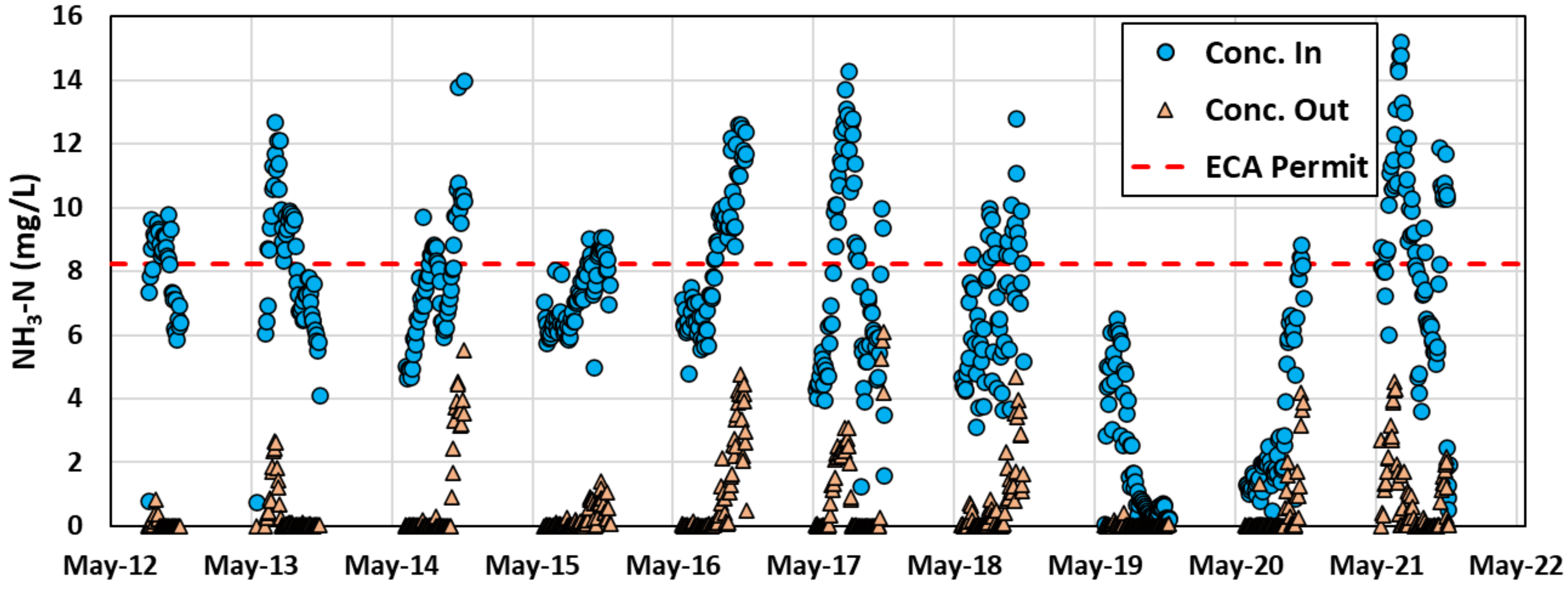
# Nitrogen Species




*Major transformations in the nitrogen cycle and its link to cyanide species. Figure modified from Bernhard (2010).*

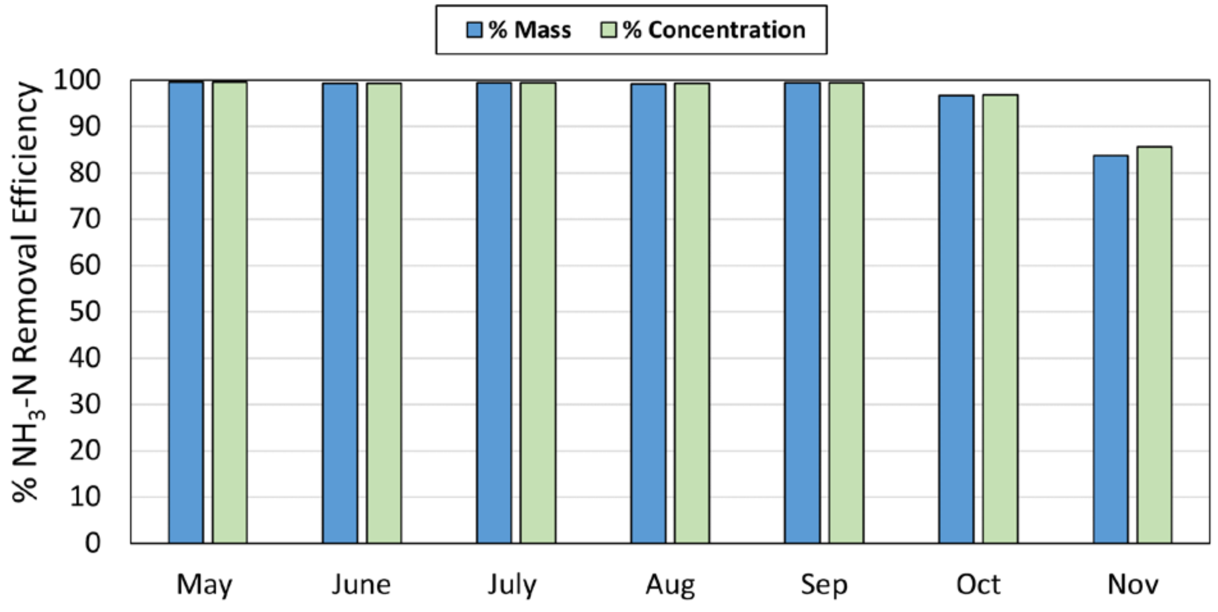
- Within the cyanide destruction process (INCO $SO_2$/Air), free and weak-acid dissociable cyanide species are oxidized to cyanate, which then hydrolyzes to ammonia.
- Ammonia released from blasting residues and treated sewage also contribute to the wetland input loading.
- In oxygenated waters (wetland surface water), $NH_3$ will oxidize to $NO_3$, with $NO_2$ being an intermediate product of nitrification.

# Ammonia Inflow and Outflow Concentration (2012-2021)




- Inflow $NH_3$ concentrations range from 0.02 – 15 mg-N/L.
- Outflow $NH_3$ concentrations range from 0.002 – 6.1 mg-N/L.
- Examination of conservative tracers (e.g., Na) demonstrate negligible dilution within the wetland. Hence, the observed declines in $NH_3$ must relate to non-conservative processes.
- Un-ionized $NH_3$ comprises a small fraction (<10%) of the total $NH_3$ in the wetland at the observed effluent pH (median of 7.1) and temperature (median of 13 °C).

# Ammonia Removal Efficiency (2012-2021)




*% Removal by mass = (Load$_{in}$ – Load$_{out}$) /(Load$_{in}$) x 100*

*% Removal by concentration = ([C]$_{in}$ –[C]$_{out}$)/[C$_{in}$] x 100*

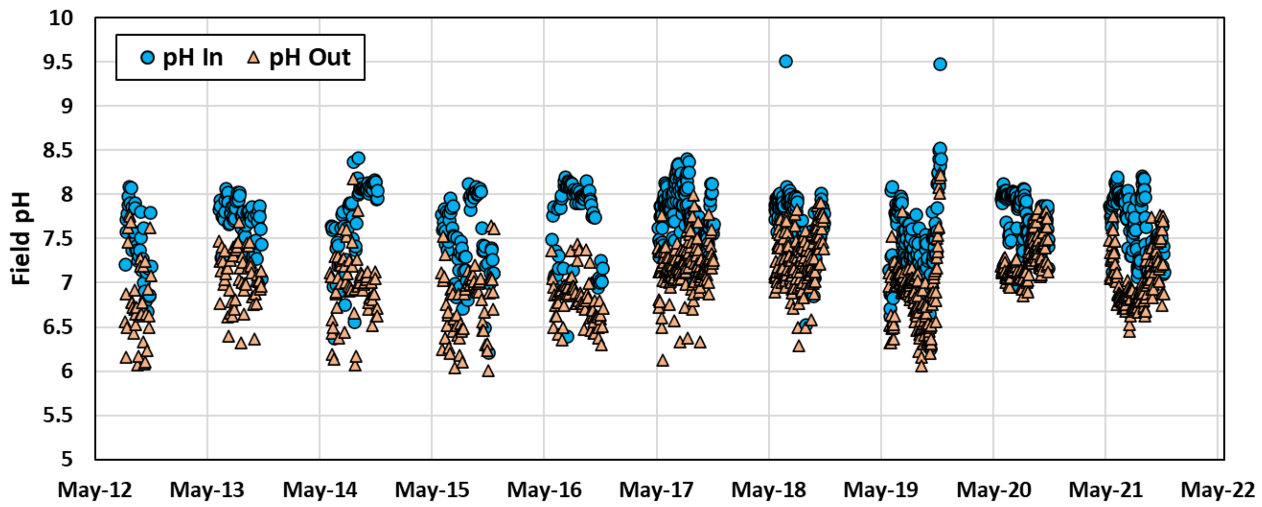
- Ammonia removal efficiency (expressed as %) was calculated by concentration and mass.
- Monthly median $NH_3$ removal efficiency calculated for the treatment season (May – October) is consistently above 90% (for both concentration and mass).
- Ammonia removal efficiency is affected by water temperature and $NH_3$ concentration in the wetland inflow.
- Poor correlation is observed between ammonia removal and HRT.

# Ammonia Removal Mechanisms

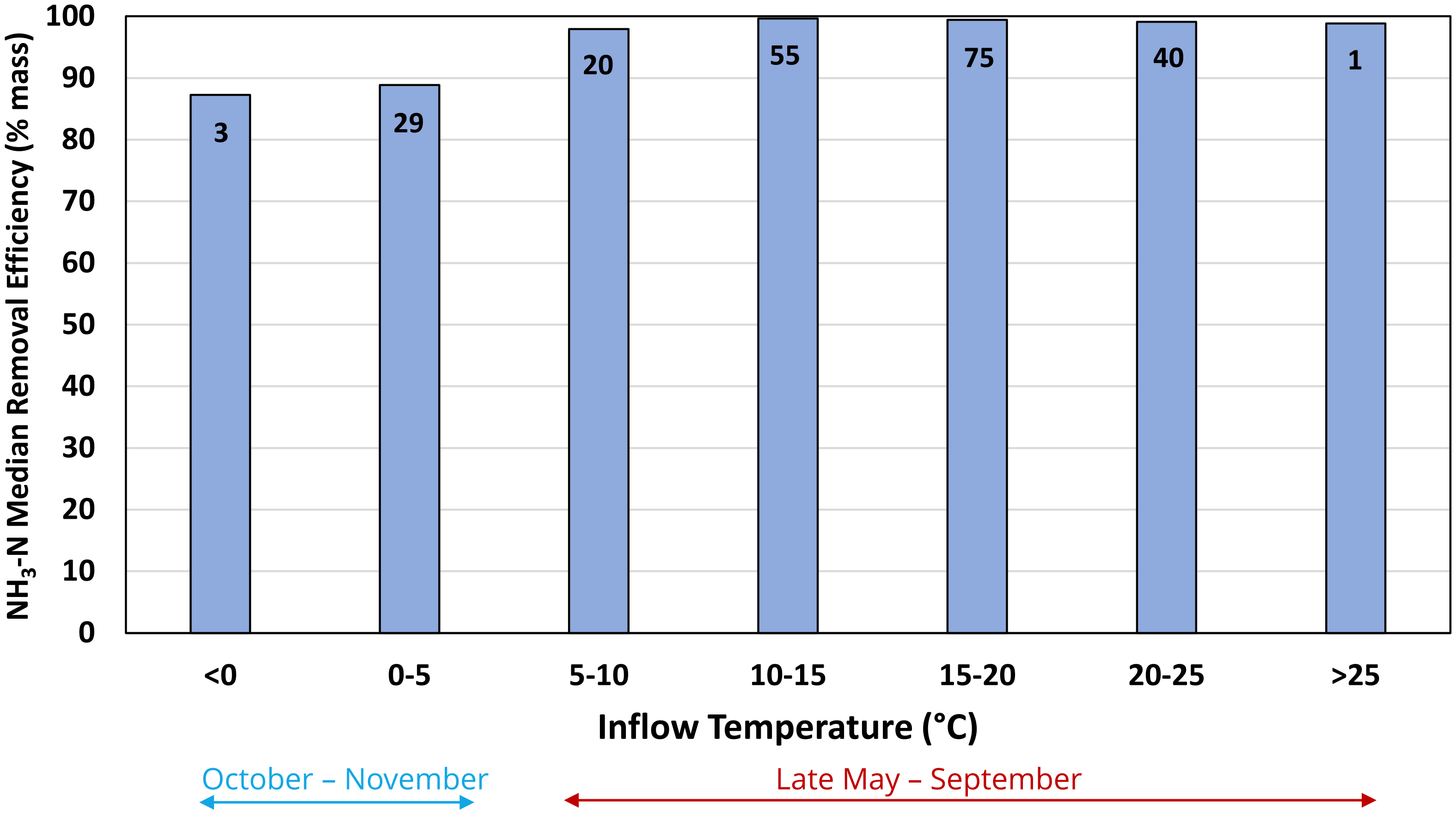
- Key mechanisms relating to ammonia removal are predicted to include:
  - o Nitrification
  - o Biological uptake
  - o Adsorption (e.g., organics, clays)
- The occurrence of nitrification is supported by declines in pH from inflow to outflow.

$$NH_4^+ + O_2 \Rightarrow NO_3^- + H_2O + 2H^+$$

- Volatilization assumed to be minor given wetland pH and low predicted concentration of un-ionized $NH_3$.



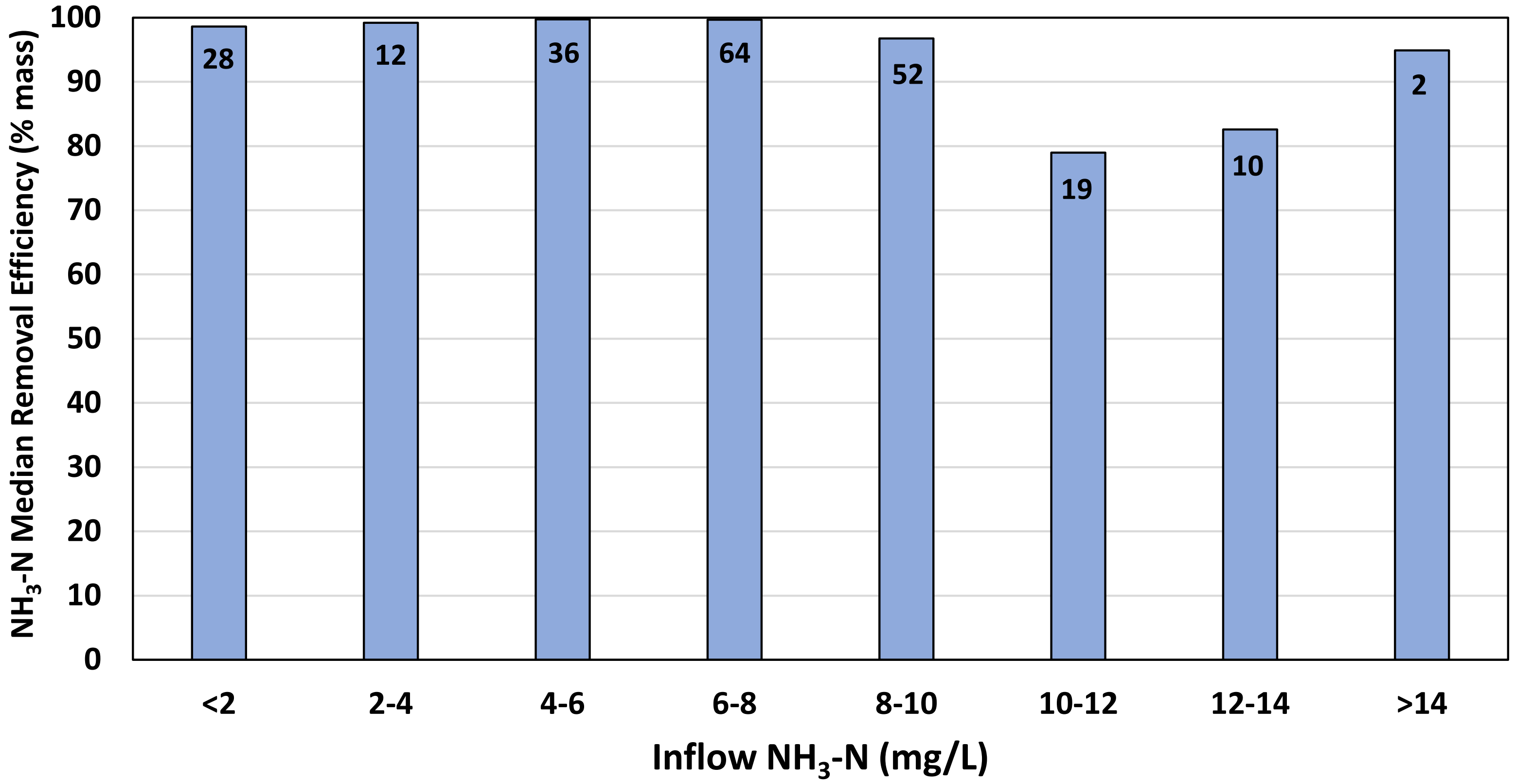
# Influence of Temperature on Ammonia Removal




*Note: The number of samples within each internal is shown in the bar graphs.*

- Several removal mechanisms for $NH_3$ are facilitated by biological processes (e.g., plant/algal uptake, bacterially-mediated processes), which will exhibit temperature-dependent kinetics.
- Moderately lower $NH_3$ removal rates observed at temperatures <5°C.

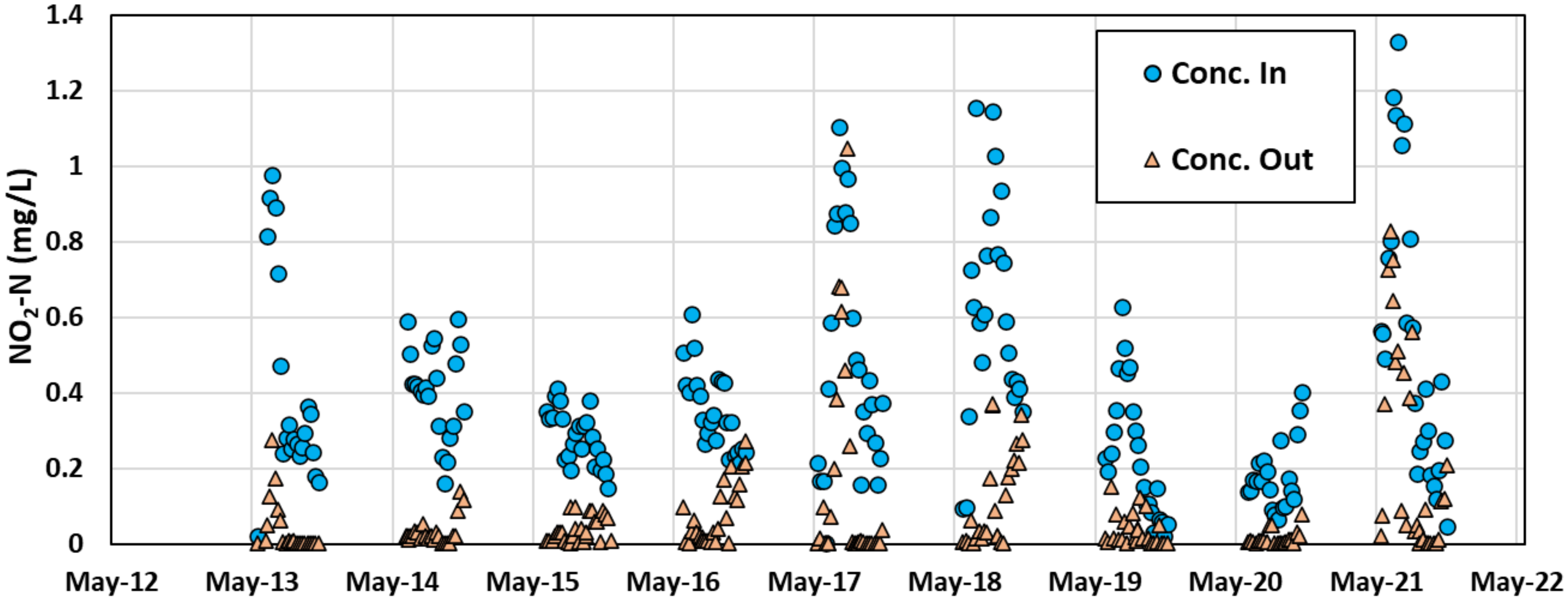
# Influence of Inflow Concentration on Ammonia Removal




*Note: The number of samples within each internal is shown in the bar graphs.*

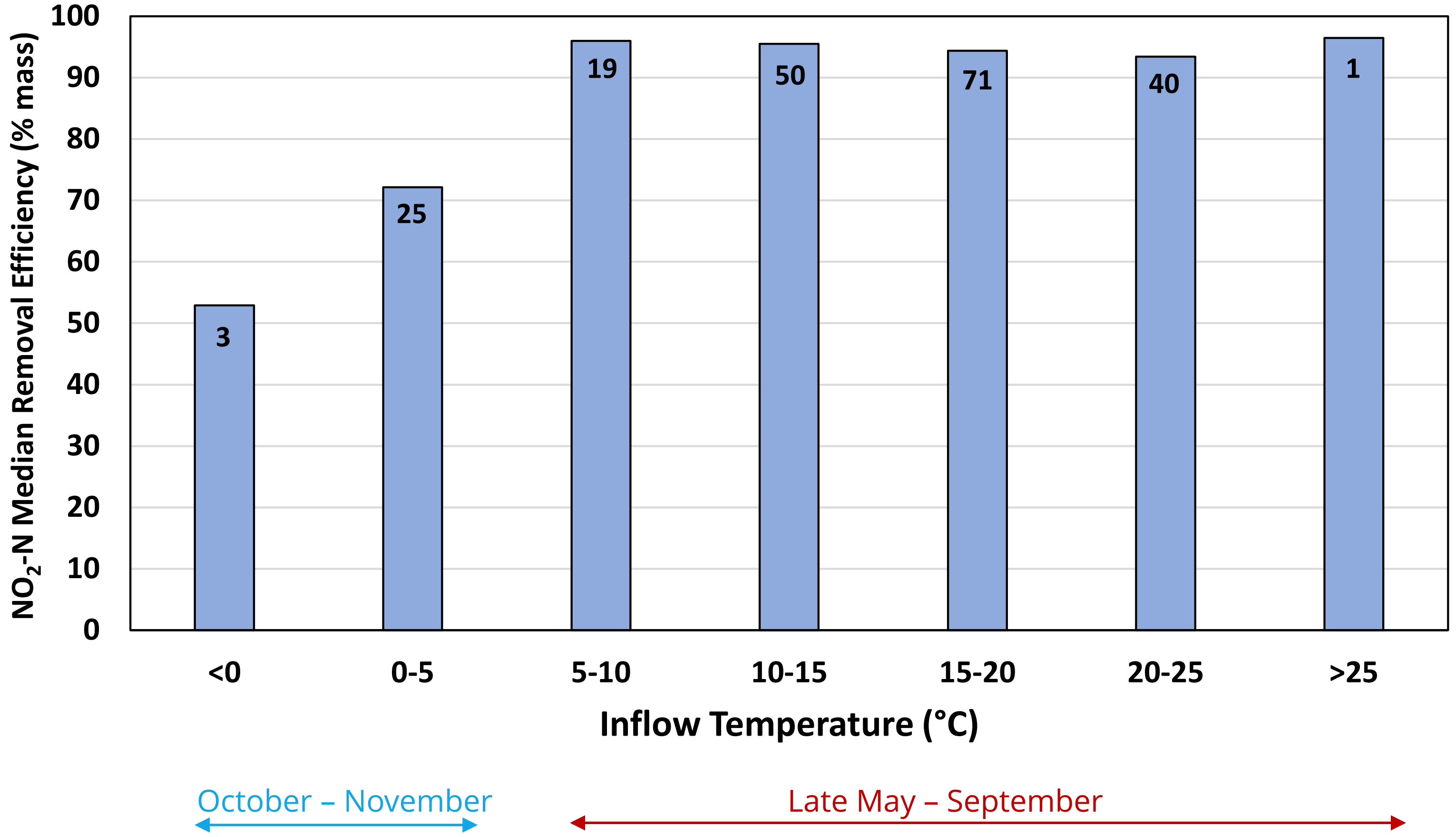
- Inflow $NH_3$ concentration is governed by the proportion of mine-contact water from the TSF versus non-contact flows reporting to the wetland from surrounding catchments and meteoric water.
- At inflow $NH_3$ concentrations >10 mg-N/L, a notable decline in removal efficiency (to <80%) is observed.

# Nitrite Inflow and Outflow Concentration (2012-2021)




- Inflow $NO_2$ concentrations generally range from 0.1 – 1.2 mg-N/L.
- Outflow $NO_2$ concentrations are generally <0.5 mg-N/L.
- Declines in $NO_2$ concentrations within the wetland may reflect nitrification in the oxic water column, or denitrification in suboxic sediment porewater.
- Support for a nitrification pathway is provided by a decrease in pH and an increase in $NO_3$ from inflow to outflow.

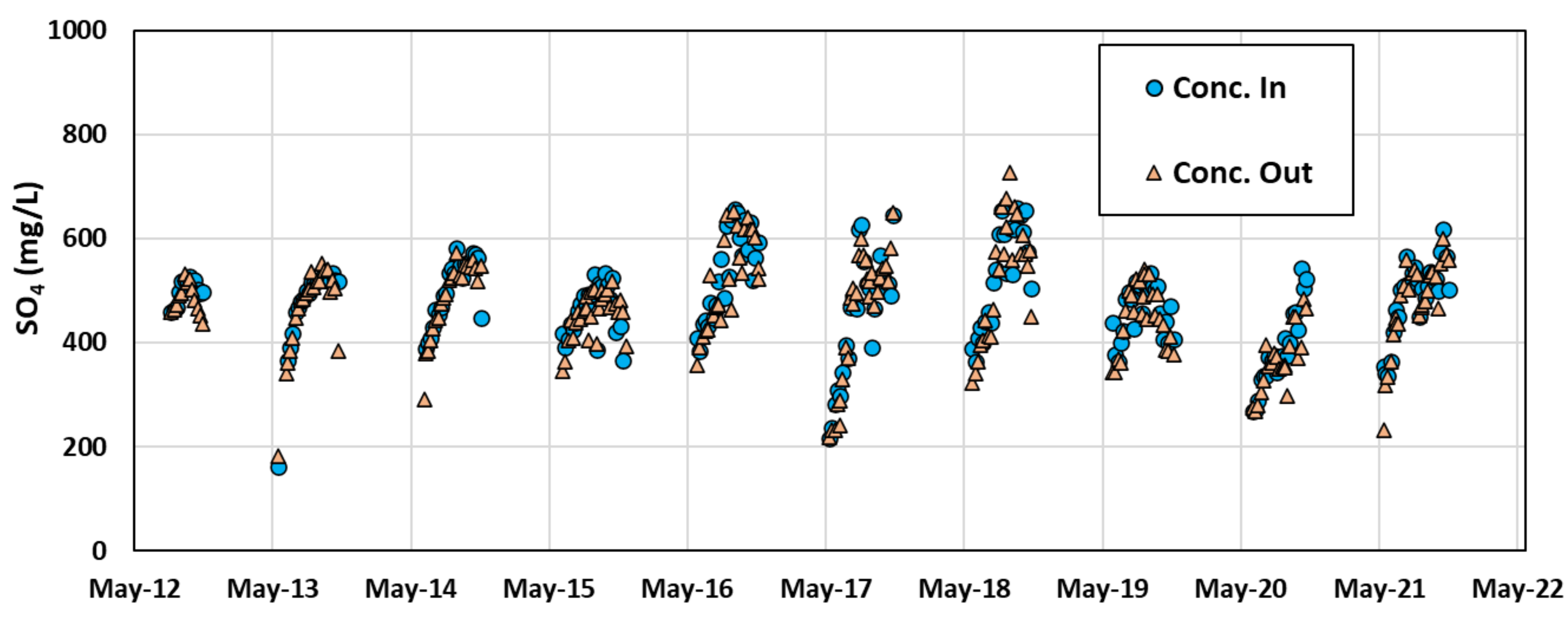
# Influence of Temperature on Nitrite Removal




*Note: The number of samples within each internal is shown in the bar graphs.*

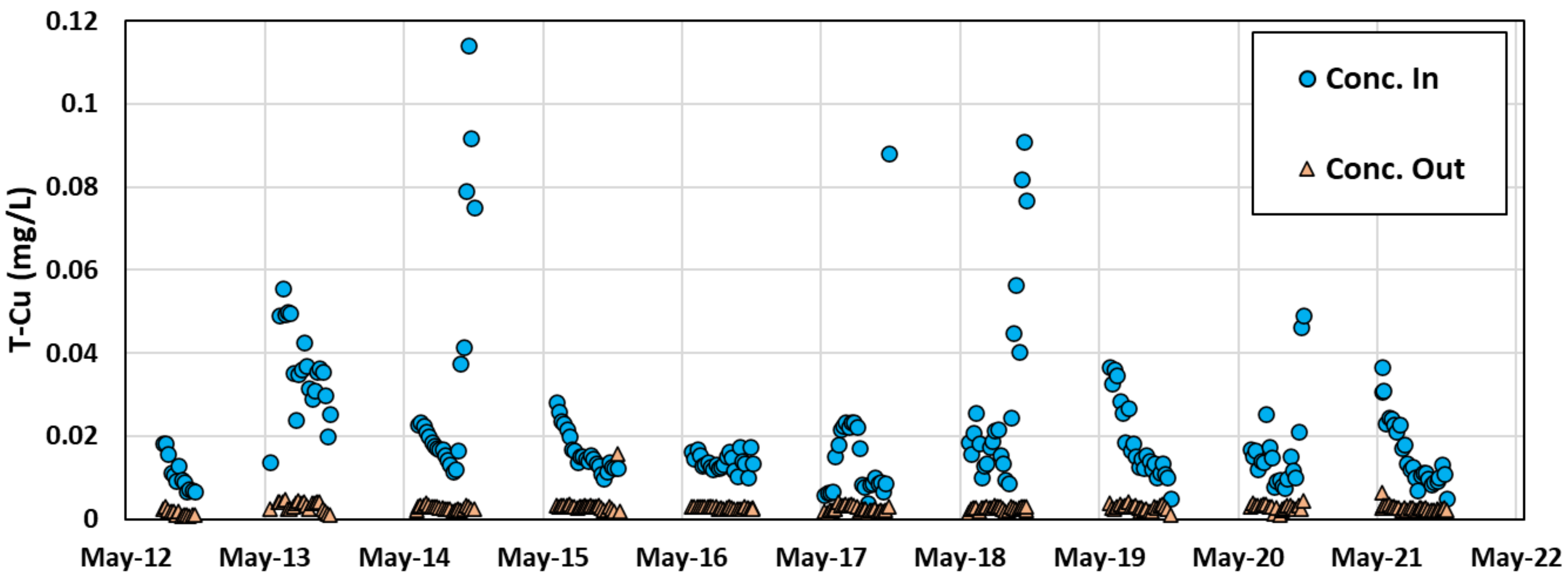
- Similar to $NH_3$, lower $NO_2$ removal rates were observed at colder temperatures (<5°C), typically during October and November.

# Sulphate Inflow and Outflow Concentration (2012-2021)



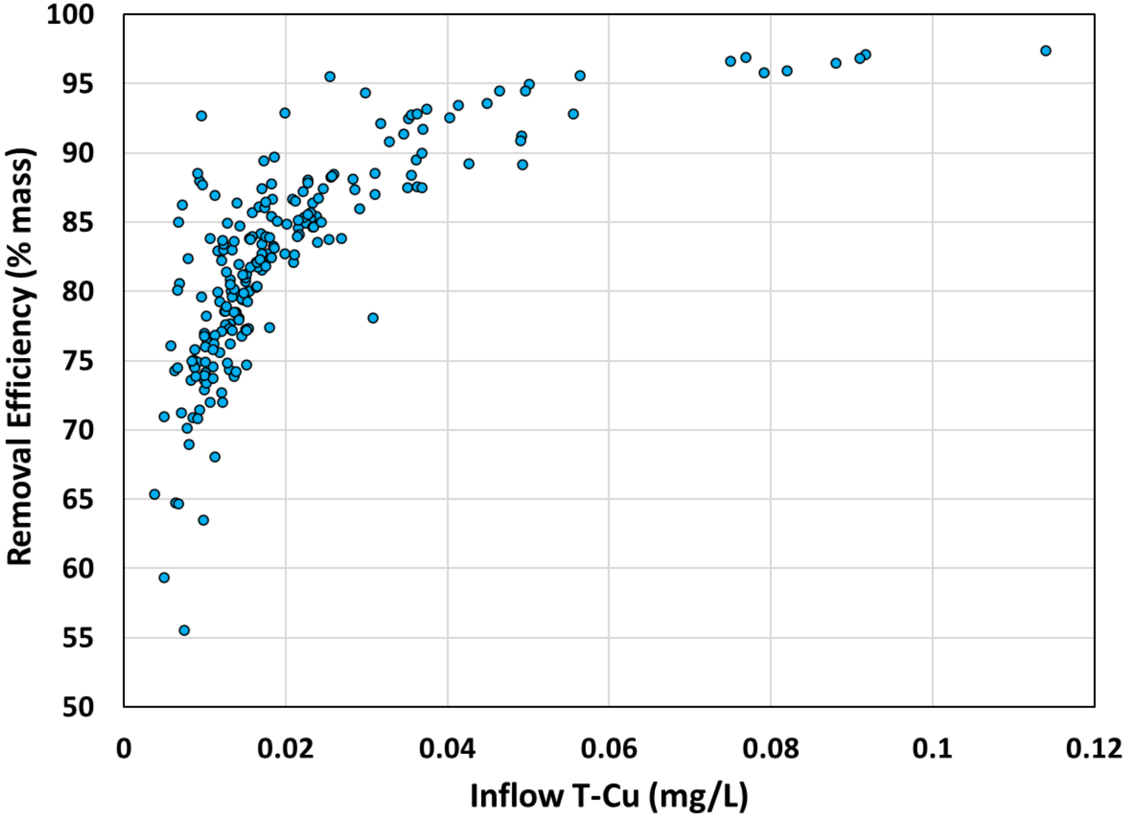

- Sulphate concentrations measured at the inflow (median = 494 mg/L) closely mirror those at the outflow (median = 429 mg/L), reflecting conservative behaviour of $SO_4$ as water flows through the wetland.

# Total Copper Inflow and Outflow Concentration (2012-2021)




- Dissolved values were not consistently collected. Based on available data, Cu is expected to be dominantly present as dissolved species.
- Total Cu concentrations in the wetland inflow show considerable seasonal and interannual variability, with values ranging from 0.004 to 0.11 mg/L.
- Effective removal of total Cu within the wetland is observed, with concentrations in the outflow generally decreasing to <0.005 mg/L.

# Total Copper Removal Efficiency (2012-2021)




- Removal efficiency for T-Cu ranges from 56% to 97% (median = 83%).
- Total Cu removal efficiency is governed by the inflow concentration.
- Invariant total Cu concentrations in the wetland outflow are observed over a range of inflow concentrations.
- This relationship indicates that the wetland has excess capacity for Cu treatment.

# Total Copper (2012-2021) – Removal Mechanisms

- Potential removal mechanisms for T-Cu include:
  - Sorption with Fe/Mn/Al oxides
  - Sorption with organic matter
  - Biological uptake (plants, algae)
- Diffusive flux calculations suggest that precipitation of Cu as secondary sulphides in reducing sediments is not important.

# Conclusions Relating to Wetland Performance

- The Musselwhite Mine has utilized a wetland to successfully treat effluent since the late 1990s.
- The wetland is viewed to be in a healthy state (no indications of mine-related adverse effects to vegetation) during a recent field survey (Minnow, 2021).
- Wetland performance was evaluated using monitoring data collected from 2012 through 2021. The results suggest that the wetland continues to function in an effective manner for the removal of $NH_3$ and trace elements, despite a relatively short HRT (~24 hrs).
  - Treatment performance for $NH_3$ is inferred to be linked to temperature and inflow concentration.
  - For key trace elements such as Cu, available data suggest that the wetland currently has excess capacity for treatment.
  - Other species exhibit conservative behaviour (e.g., $SO_4$).

# Implications for Wetland Management

- Optimize the timing of discharge through the wetland (e.g., in warmer months) to achieve optimal ammonia removal efficiency.
- Maximize water level while maintaining an optimal environment for wetland plants.
- Maximize flow path length and HRT of the wetland (i.e., prevent short-circuiting).

Newmont™

LORAX ENVIRONMENTAL

Thank you!