Nitrogen removal at cold-climate mine sites in northern Sweden

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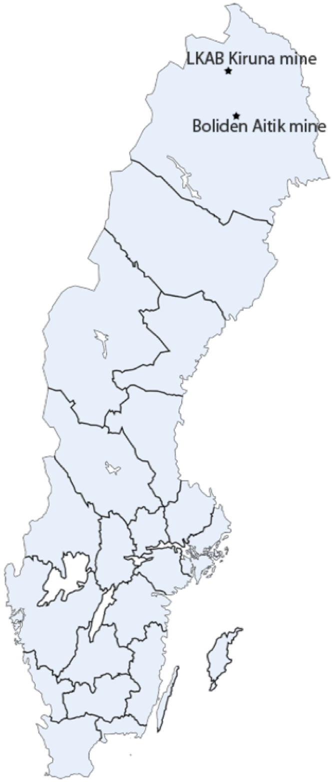
Background – the problem

Ammonium nitrate based explosives are a major nitrogen source in the mining industry

- Mining operations are characterized by large water volumes with moderately high N concentrations (<30 mg N/L)
- Active treatment for N removal is expensive and usually not feasible
- Passive or semi-passive removal methods should therefore be tested

Background – project WaterPro



In Sweden, WaterPro was coordinated with project *miNing*[1] at the Kiruna and Aitik mines in northern Sweden

Project *miNing* consisted of three sub-projects, each aiming to develop low-cost, passive or semi-passive treatment methods that require only a minimal amount of energy to maintain in operation:

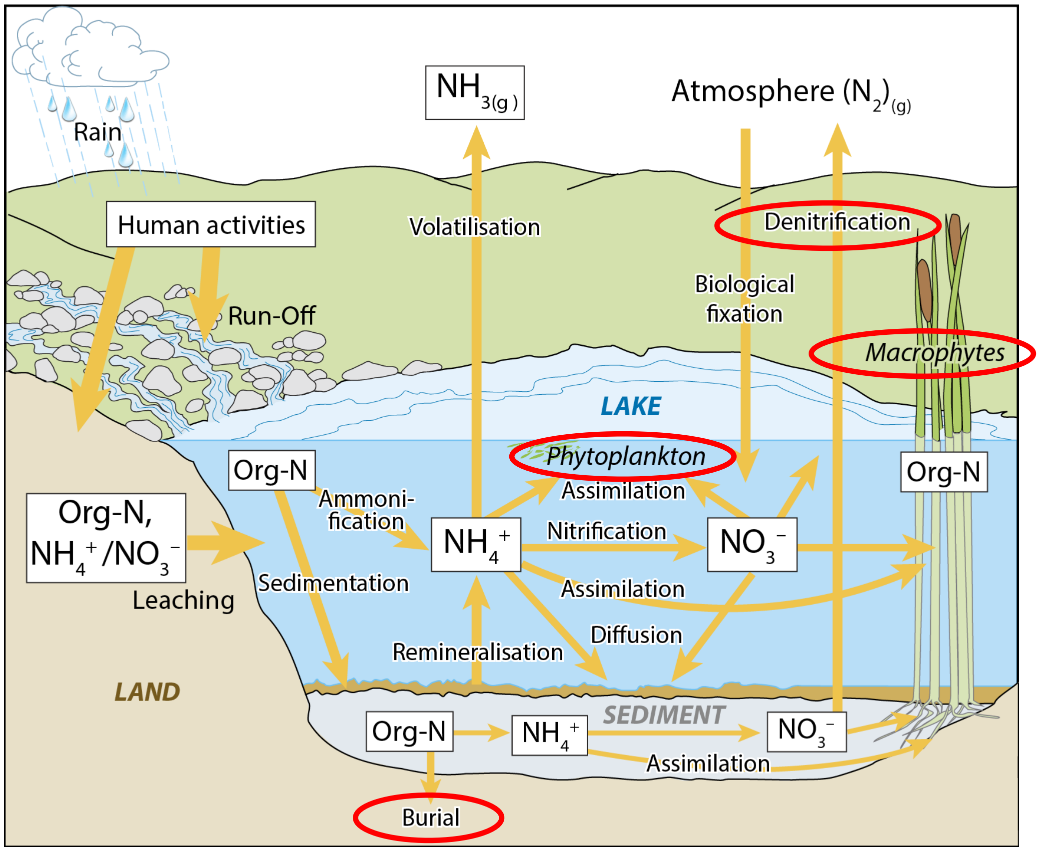
- Microbial denitrification in mine ponds
- A denitrifying bioreactor system for nitrate removal
- Wetland systems for nitrogen removal by macrophytes, algae, and denitrification

The Swedish part of WaterPro investigated denitrification in mine ponds

[1] **Project *miNing***: *Reduction of nitrogen discharges in mining processes and mitigating its environmental impact*
Project period 2013–2018. Coordinated by Swedish University of Agricultural Sciences

Background – nitrogen cycling in mine ponds

Nitrogen cycling in mine ponds is similar to that in lakes where permanent N removal occurs



Permanent nitrogen removal is possible trough:

- Denitrification in pond sediments
- Nitrogen uptake in phytoplankton (algae) and macrophytes followed by partial burial of nitrogen in sediments

Research question

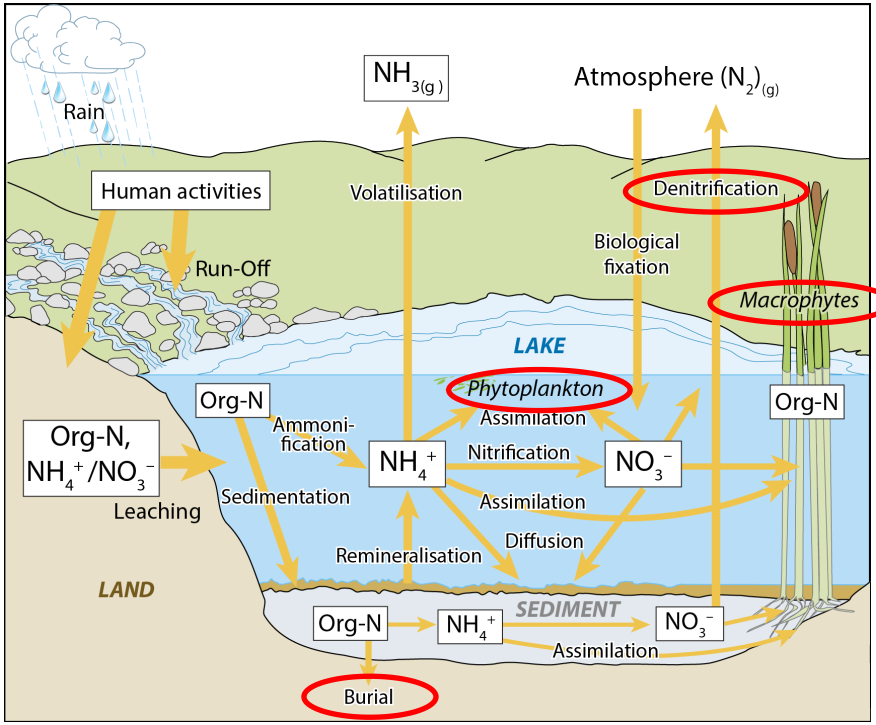
Can N removal in mine ponds be increased so that ponds can be used as passive N removal systems?

Laboratory studies showed that:

- Denitrification in the Kiruna pond sediment was carbon-limited
- Phytoplankton was an efficient carbon source for driving denitrification

Hypothesis for the pond study

- Phytoplankton can be used as a natural carbon source to increase denitrification in ponds
- Phytoplankton growth and denitrification can be increased by phosphorus fertilization of mine ponds

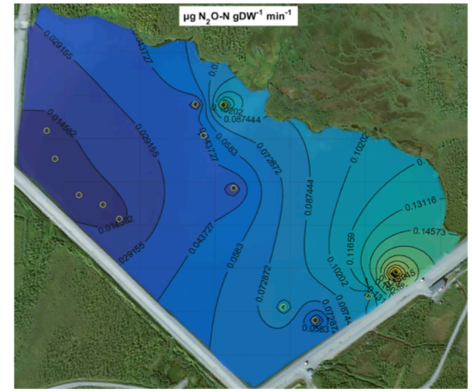


Work done – methods

Field work in the mine ponds at Kiruna

- Water and sediment chemistry
- Potential denitrification activity (PDA)

PDA in the Kiruna clarification pond sediment



Field work in mesocosms at Kiruna

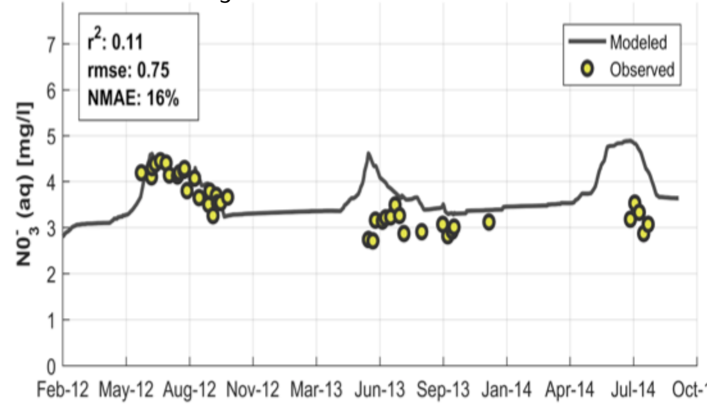
- Nitrogen removal from pond water
- Potential denitrification activity


Mesocosms at the Kiruna mine

Computer modelling of nitrogen cycling

- Modelling of N transformations in mesocosms and ponds

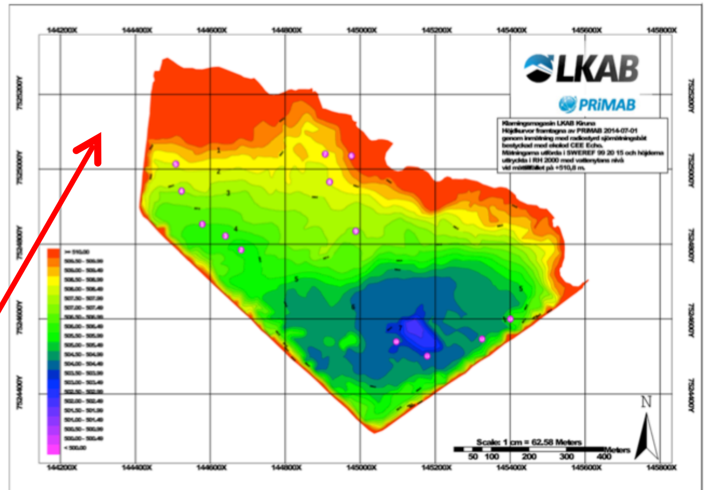
Modelled NO_3 concentration at the Aitik mine



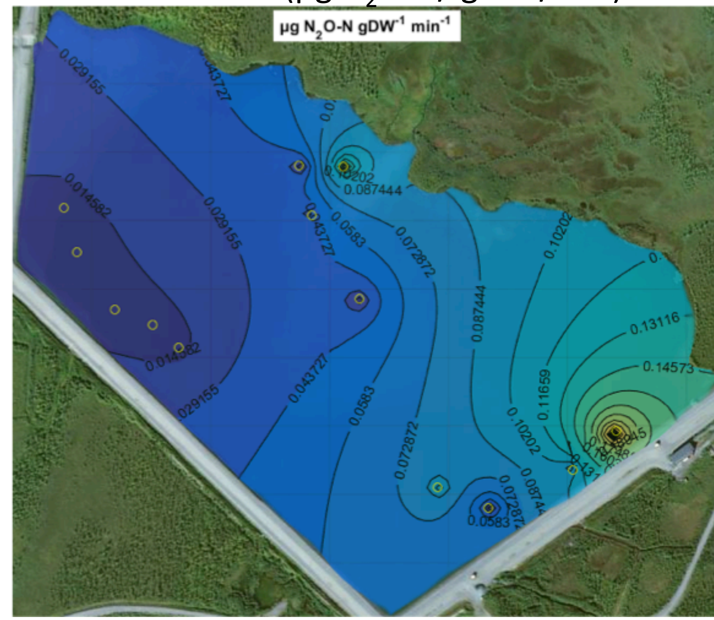
Results – field work in the clarification pond, Kiruna

Kiruna ponds

Bottom topography and sediment sampling stations



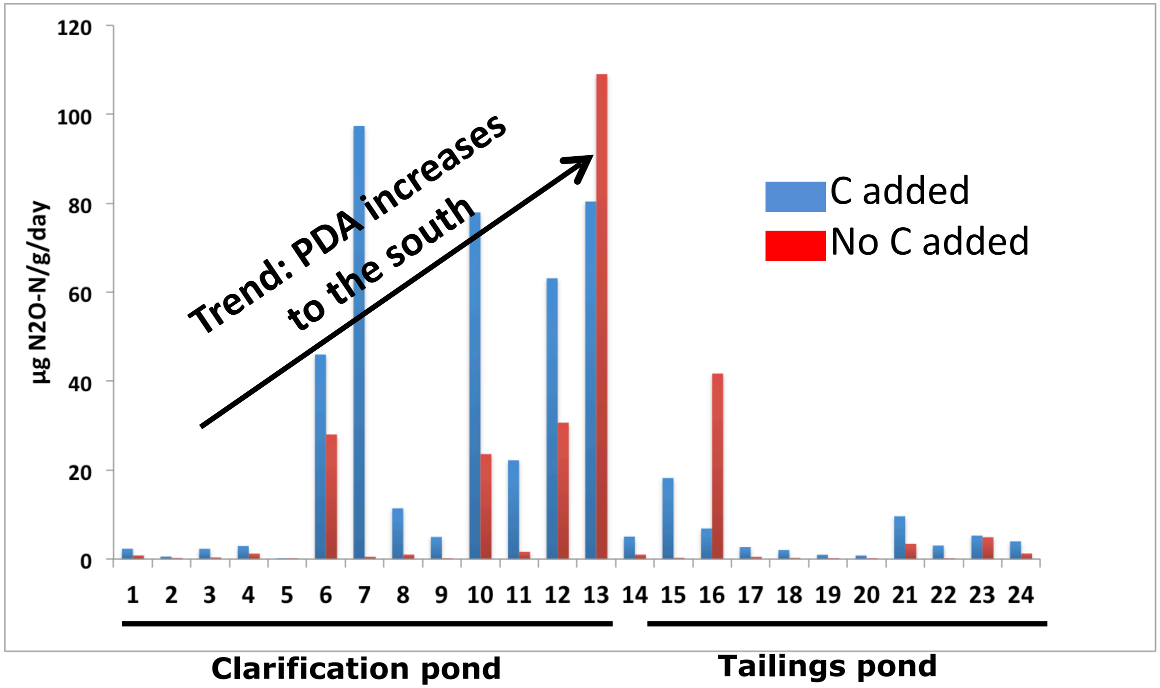
Potential denitrification activity in pond sediment (µg N_2O-N/ g sed/min)



- The clarification pond collects tailings that have not settled in the tailings pond before the mine water is released into the receiving waters
- Water and sediment were sampled in the clarification pond

- Potential denitrification activity (PDA) was measured at a number of stations in the pond
- PDA is higher in the southern, deeper part of the pond

Potential denitrification activity (PDA) in pond sediments



Clarification pond

PDA in clarification pond sediments is higher than in the tailings pond sediments

PDA in pond sediment (0–2 cm):
0.094 g N/m² d (no C added)
0.20 g N/m² d (with C added)

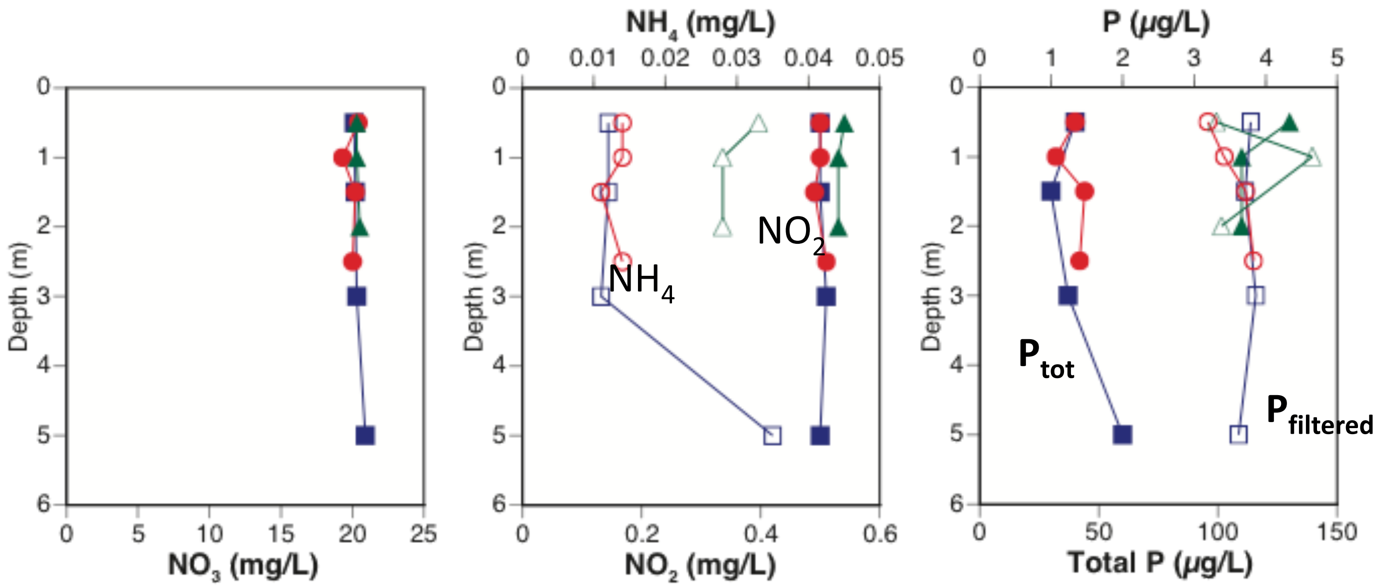
0.094 g N/m² d corresponds to ca **5 tonnes of N/90 days** (three month summer period) or a N removal rate of **0.1 %/day**

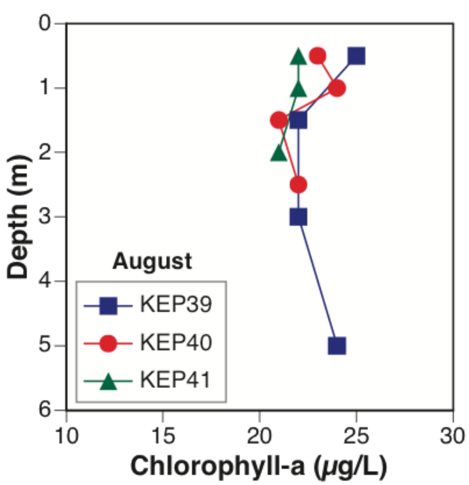
Adding carbon to pond sediment may approximately double denitrification in the pond from 5 to 10 tonnes of N per 90 days, or from 0.1 to 0.2 %/day

Hypothesis: Phytoplankton carbon can be increased through phosphorus fertilization

Results – field work in the Kiruna pond

Vertical profiles of N, P and Chl-a concentrations

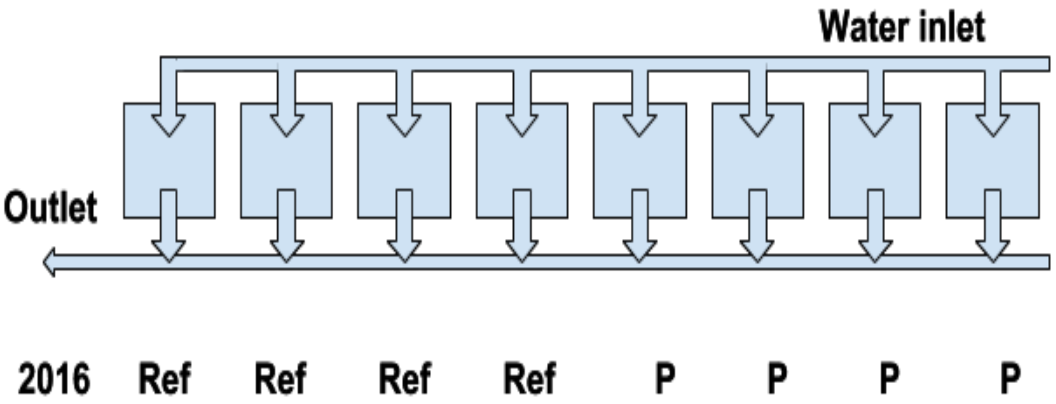




- Nitrate is the dominating N species (~20 mg/L)
- Filtered P (<0.2 µm) is 3–4 µg/L (bioavailable?)
- Total P is ~50 µg/L
- Chl-a is 20–25 µg/L

Mesocosm study – experimental design

- Mesocosms fed with water from the clarification pond were used to simulate conditions in the pond if phosphorus fertilization is used to stimulate phytoplankton growth
- Mesocosms: 1000-L containers filled with 0.3 m of tailings and circulating pond water
- Four mesocosms fertilized with P / four reference mesocosms with no P added

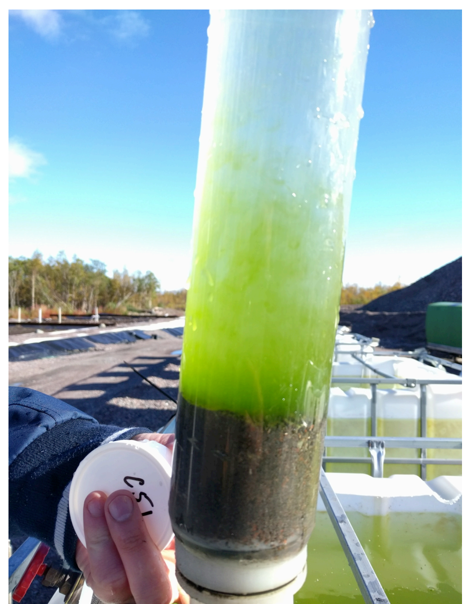


Potential denitrification activity in mesocosm sediments

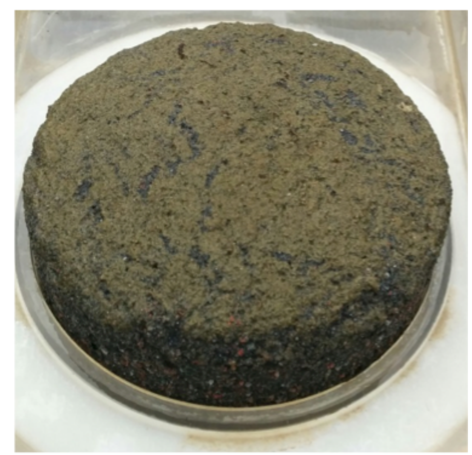
- Measured on surface sediment (0–2 cm) from four reference and four phosphorus fertilized mesocosms
- Three replicates from each mesocosm
- Potential denitrification activity (PDA) measured with / without additional C at 15 °C

Sediment in reference mesocosm

Algae growing in fertilized mesocosm



Sediment in fertilized mesocosm with layer of algae

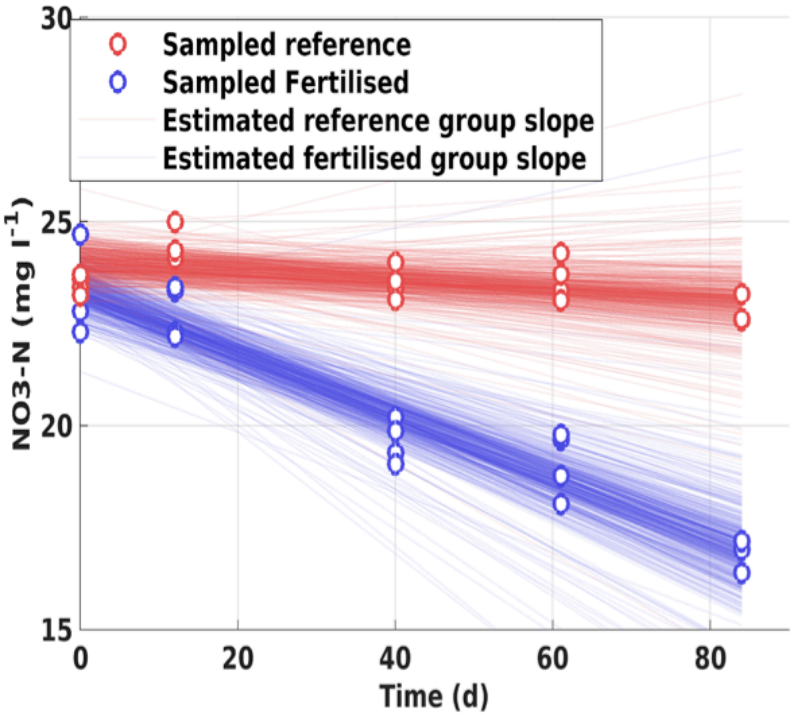


Results – mesocosm study

Nitrate removal in mesocosms

- Nitrate concentrations in fertilized mesocosms decreased from 23 to 17 mg NO3-N/L after 86 days (June to September)

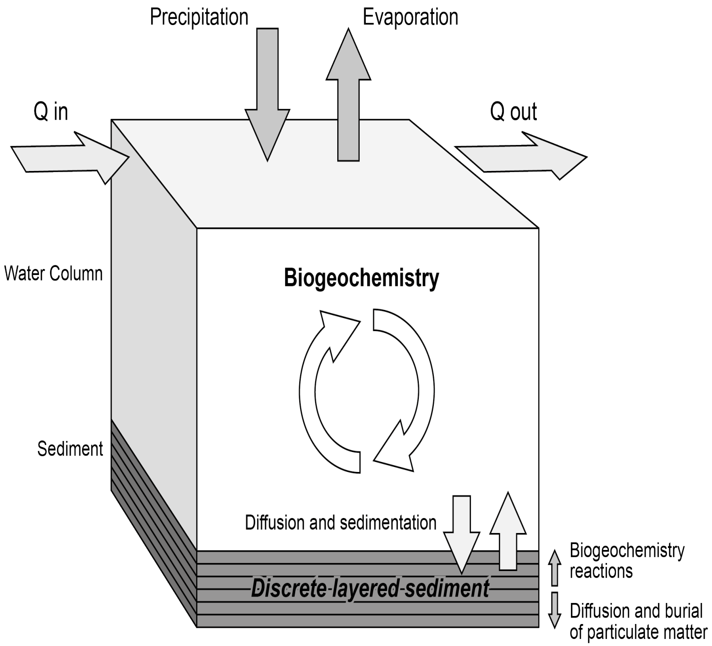
- Nitrate decrease is caused by anaerobic denitrification in tailings, and possibly also aerobic denitrification in the water column



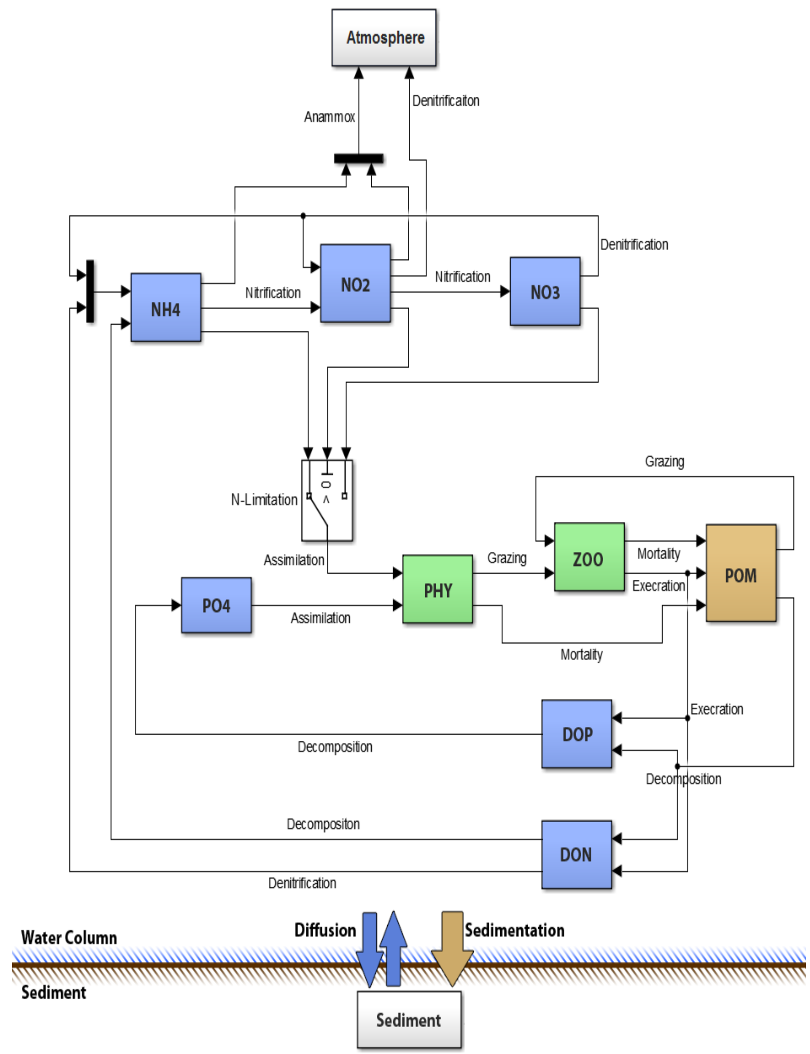
Red: Reference mesocosms with no P added (lines are statistically generated)

Blue: Mesocosms with P added (lines are statistically generated)

Biogeochemical model – conceptual model



Model with 10 state variables

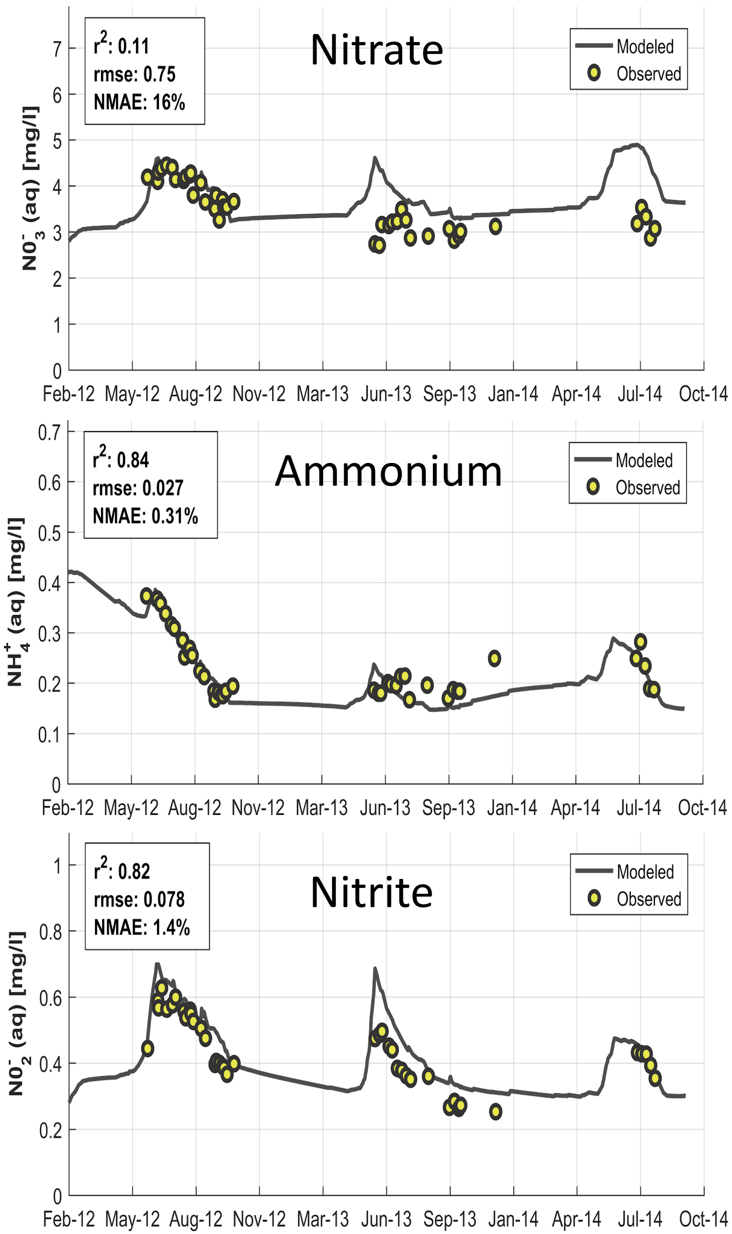


- Biogeochemical reactions calculated in water column and sediment
- Precipitation, evaporation, ice formation, and water flow are included

Results – biogeochemical modelling at Aitik

Pond concentrations 2012–2014

- Based on monitoring data from the mining company Boliden Mineral AB
- Ammonium and nitrite accurately modelled with $r^2 > 0.8$
- Nitrate shows less satisfactory r^2 (0.11), and modelled NO_3 increases with time
- Allowing for aerobic denitrification in the water column improves model accuracy for nitrate ($r^2 = 0.54$)

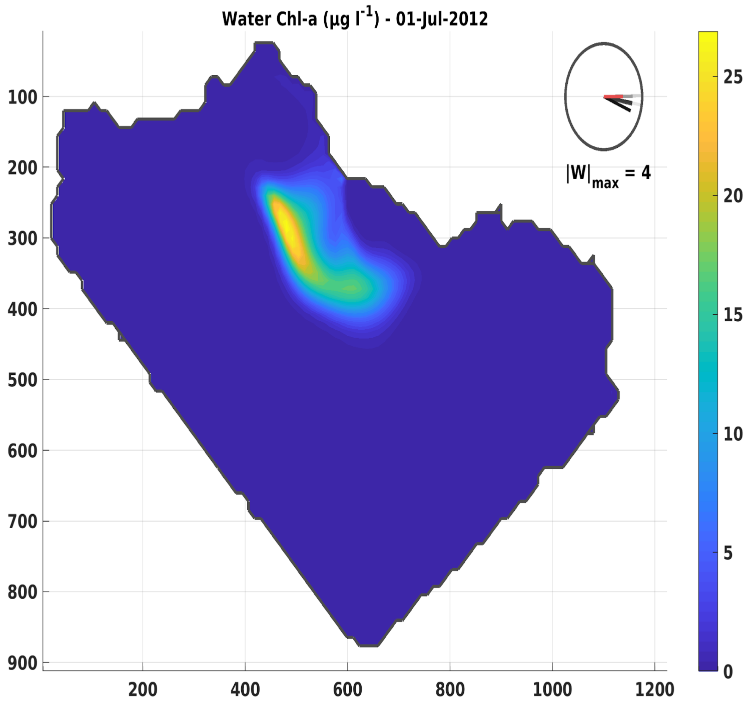


Results – biogeochemical modelling at Kiruna

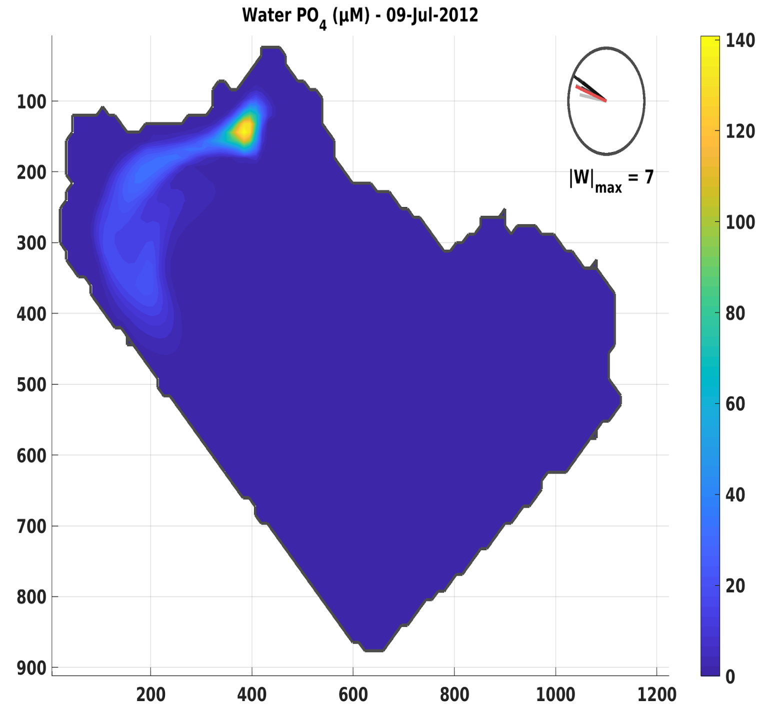
- Testing P fertlization at full scale in the pond would be controversial. Biogeochemical modelling was therefore used to test the effect of P fertilization on nitrate removal

- 4.5 kg of P was added *in the model* on six occasions during summer in the northern part of the pond

Modelled increase of Chl after first addition of P



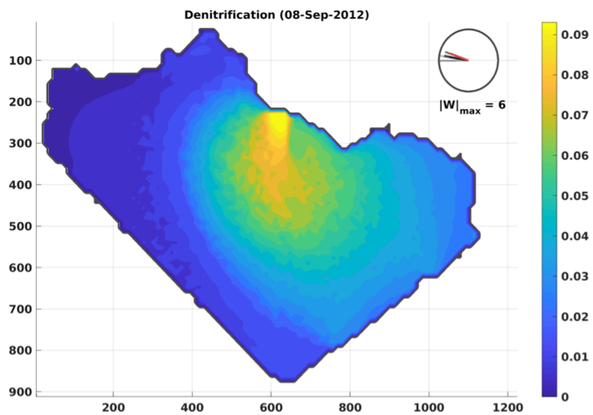
Modelled increase of PO_4 after second addition of P



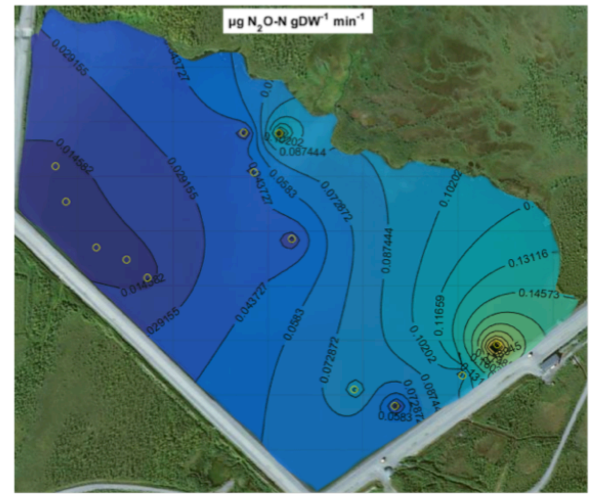
Results – biogeochemical modelling at Kiruna

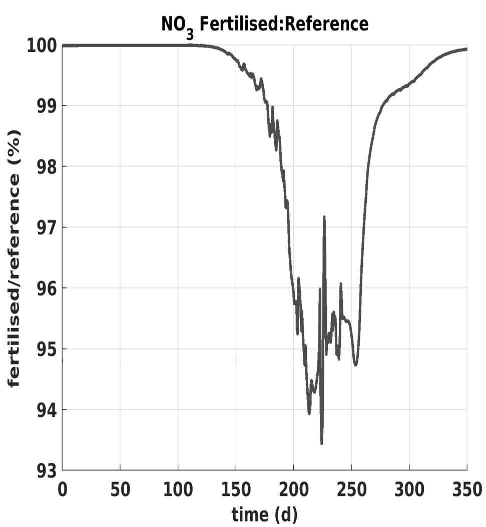
Modelled potential denitrification activity (PDA) is approximately similar to measured PDA in pond sediment

Modelled PDA



Measured PDA





After P fertilization, modelled NO_3 decreased by about 5% (100 to 95 conc units)

Considering the recirculation of pond water back into the process, NO_3 decrease over time can be expected to be higher than 5%

Algae as a carbon source in mine ponds
Risks and disadvantages

- Fertilization with phosphorus

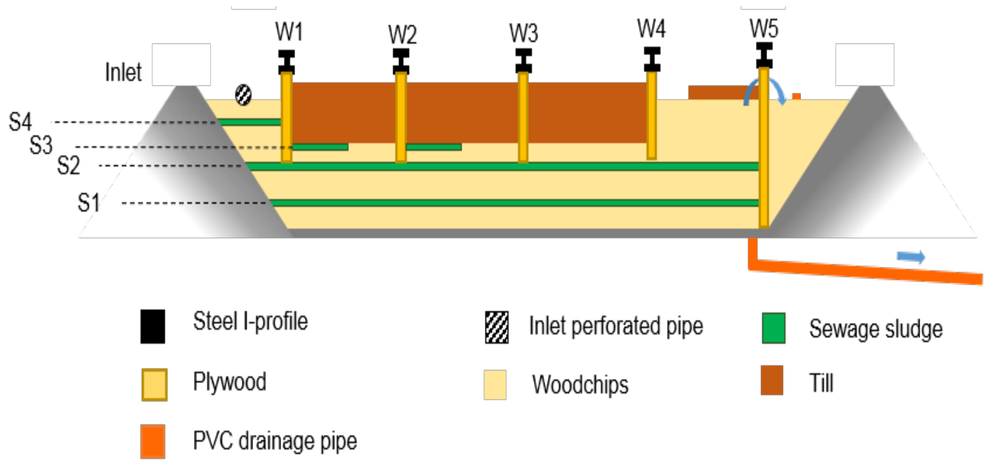
  – To some extent added P will be retained in mine ponds, but receiving waters may still be eutrophicated

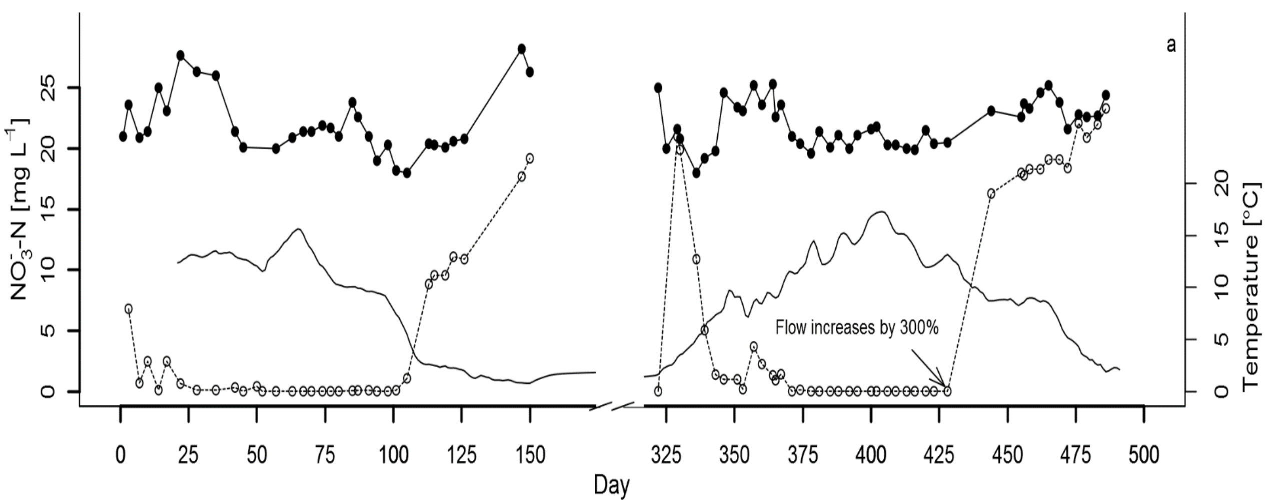
- Production of ammonium (NH_4), dinitrogen oxide (N_2O) and methane(CH_4)
  - NH_4 a nutrient and toxic to biota
  - N_2O and CH_4 are greenhouse gases

- Quality of process water recycled from ponds
  - Higher concentrations of NH_4, Chlorophyll, and dissolved organic carbon

Denitrifying woodchip bioreactor at the Kiruna mine
A subproject in project *miNing*

- Pilot-scale denitrifying bioreactor constructed in fall 2014 at LKAB's Kiruna mine
- Operations started June 2015
- Hydraulic residence time of ca 2 days until day 429
- Generally complete removal of nitrate unless < 5°C and/or HRT < 1 day





EIT Raw Materials project NITREM
A continuation of the bioreactor project

- An upscaling project financed by European Institute for Innovation and Technology (EIT) Raw Materials initiative for period 2018 – 2020.

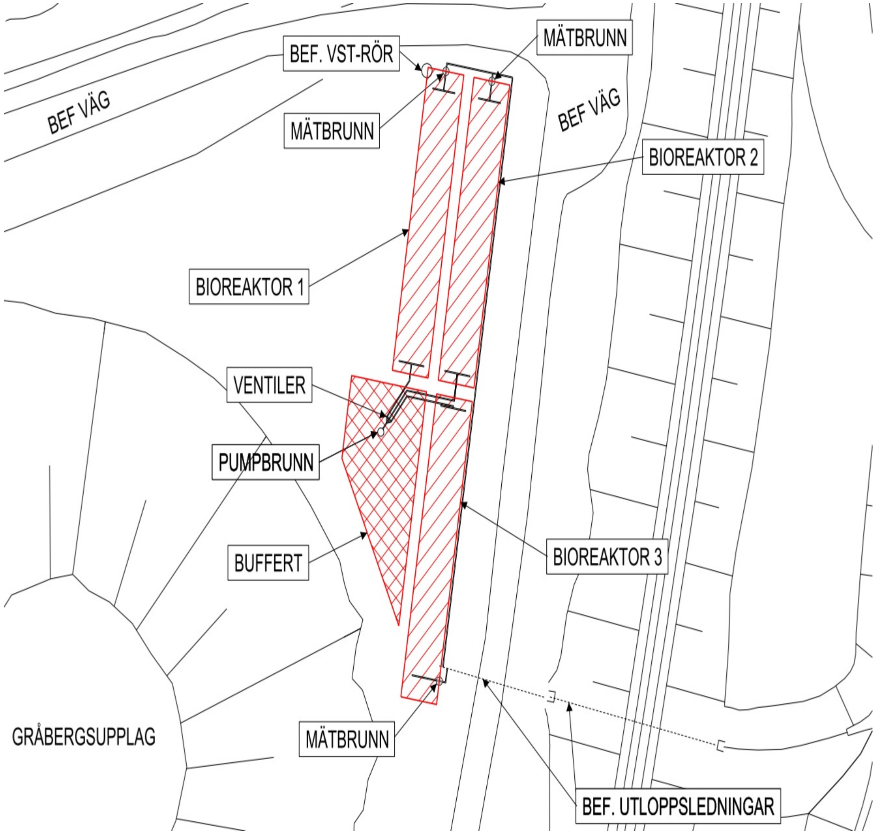
- ”NITREM establishes a service for the passive removal of nitrogen from waste rock leachate with a bioreactor technology, in conjunction with long-term waste rock management. Technology development has been driven by EUs Water Framework Directive and will enable the industry to meet current and future discharge requirements. The outcome is a low cost and low maintenance technology that is ready for market introduction and customer testing.”

eit RawMaterials
Connecting matters

nitrem

Biroeactors at Kiruna site
Installation completed fall 2018

- Water reservoir (*buffert)* collects groundwater seepage, which consists almost exclusively of leachate from waste rock dump (*gråbergsupplag*)
- Water pumped from a pumping chamber (*pumpbrunn*) through gate valves (*ventiler*) to the bioreactors.
- Water discharges from each bioreactor through a 1600 mm diameter) monitoring chamber (*mätbrunn*) and further to a drainage ditch (*Bef. Utloppsledningar*)
- Performance will be evaluated through all of 2019 and 2020



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Connecting matters

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Conclusions

- Denitrification in pond sediments is carbon limited, and increases when algae production increases in the system

- The denitrification activity increased by a factor of two after carbon addition to pond sediments, suggesting a possible additional removal of ca 5 tonnes of N/year in the Kiruna pond if carbon is not limiting denitrification

- Nitrate concentrations in P fertilized mesocosms decreased from 23 to 17 mg NO3-N/L after 86 days (June to September)

- Modelling of the Kiruna pond indicated an increase in potential denitrification activity (PDA) that was similar to PDA measured in the pond sediment

- A question that remains to be answered is how much of the added PO_4-P (6 x 4.5 kg in model) that actually will be discharged from the pond, potentially resulting in eutrophication of the receiving waters

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