Dynamic modelling of chemical recovery of 1000 Norwegian Lakes

Heleen de Wit

Global Biogeochemical Cycles

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Changing Water Chemistry in One Thousand Norwegian Lakes During Three Decades of Cleaner Air and Climate Change

Heleen A. de Wit, Øyvind A. Garmo, Leah A. Jackson-Blake, François Clayer, Rolf D. Vogt, Kari Austnes, Øyvind Kaste, Cathrine Brecke Gundersen, Jose Luis Guerrerro, Atle Hindar

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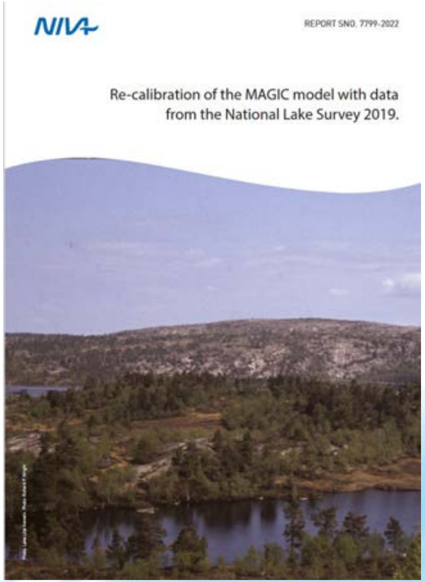


Kaste et al. 2022
https://hdl.handle.net/11250/3040570

Outline

- What are dynamic and steady-state models?
- Results of a steady-state modelling exercise - ANC
- Recap: the ThousandLakes show an unexpected increase in Ca (and ANC)
- Dynamic modelling with Magic of the unexpected changes in Ca
- Lessons learned, which questions remain?

Dynamic models and steady-state models

- Steady-state refers to a single point when the system is at equilibrium while dynamic refers to a trajectory where history matters
  - Steady state modelling of chemical recovery: you can describe the STATE, but you don't know how long it takes before you get there
    - Such models are usually simpler to run and require less data, but leave some key questions open (when the target ANC is reached, interannual variation)
  - Dynamic modelling of chemical recovery: taking into account processes that delay and affect chemical recovery
    - Such models are more complicated to run and require more information, and considerable effort to calibrate
    - Such models can answer when the target ANC may be reached

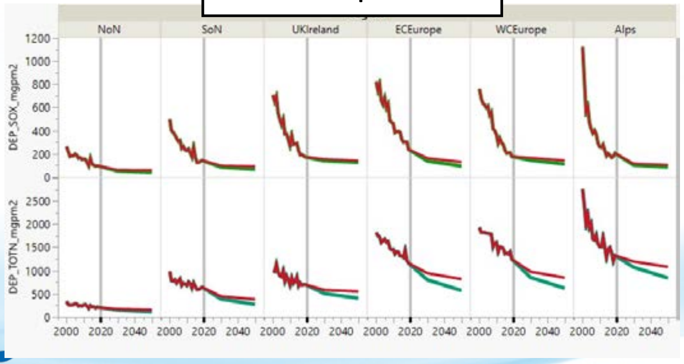
Which factors delay (accelerate) chemical recovery?

- Variation in deposition
  - Wet years, more S and N deposition than in dry years, all else being equal
  - Seasalt deposition (acidifying)
  - Deposition of Saharan sand (counteracts acidification)
- Catchment processes
  - Depletion of soil base cation stores because of decades of enhanced mobilization and leaching by acid deposition
  - Sulfate adsorption in soils, sulfate retention in wetlands, and their release
  - Increases in DOC (‘browning’), which add weak acids and thereby compensate (a little) for reduction in strong acids
  - Weathering

Steady-state modelling of chemical recovery with ICP Waters sites (GP review)

- Projected deposition from EMEP for 2030 and 2050
- Steady-state modelling (SSWC) of water chemistry

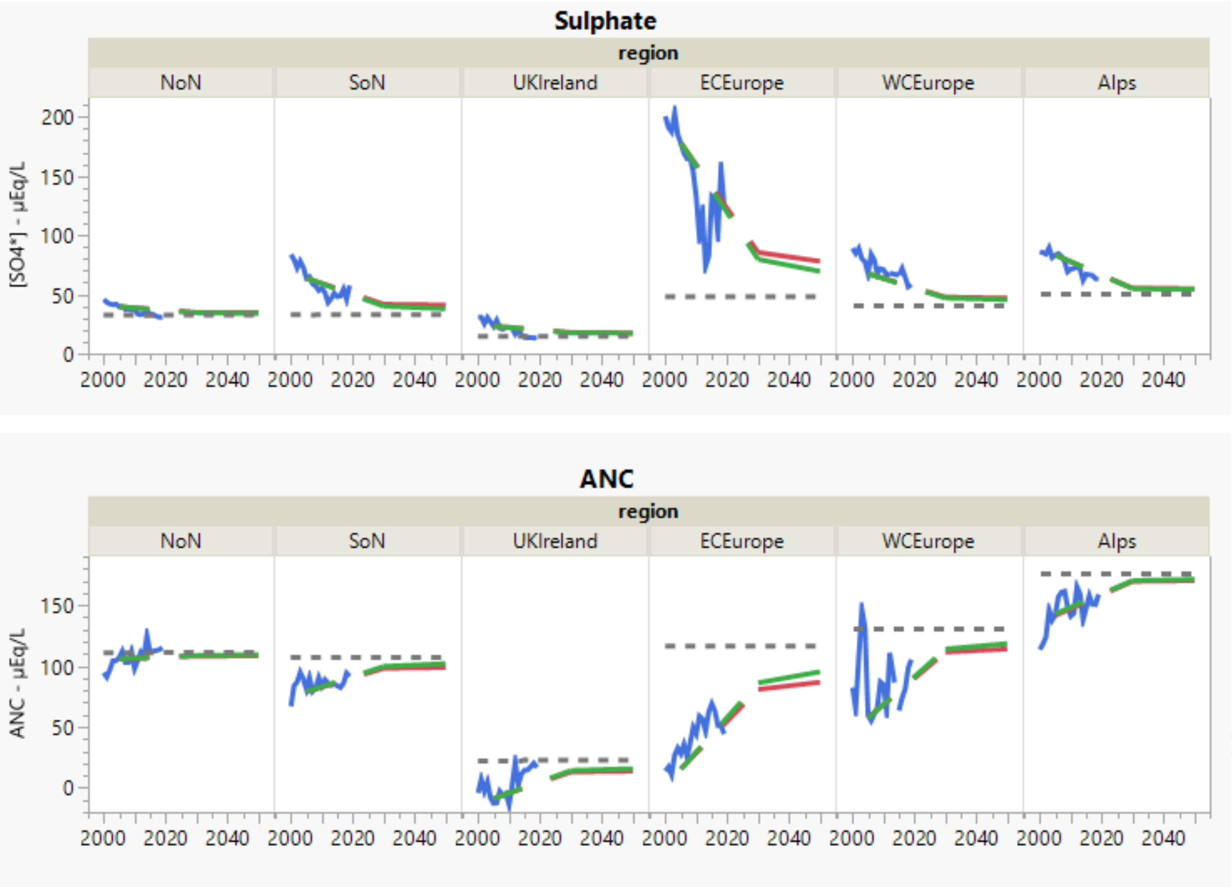
EMEP deposition



Baseline scenario

Maximum feasible reduction

Sulphate and ANC



Measured SO4

Estimated pre-acidification SO4

Modelled SO4 with baseline deposition scenario

Modelled SO4 with ‘maximum feasible reduction’ deposition scenario

Conclusions from steady state model

- Comparison between data and model output:
  - Long-term trends in recovery are described quite well, but not the interannual variation
- Further reduction of S and N deposition leads to chemical recovery, but not to pre-acidification water chemistry
- Climate change and interannual variability in weather will have greater effects on ANC as acid deposition declines, with unknown consequences for biological recovery
- Actual chemical recovery may take longer than predicted by steady state models

ThousandLake survey:
Expected and unexpected change

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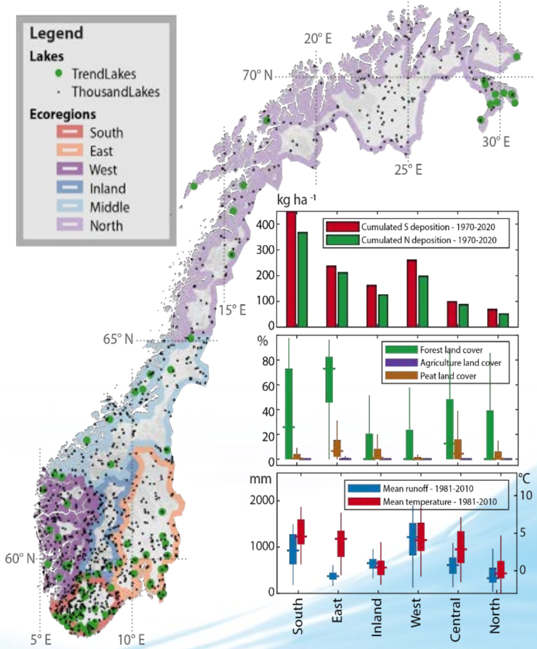
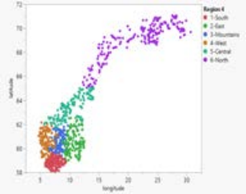
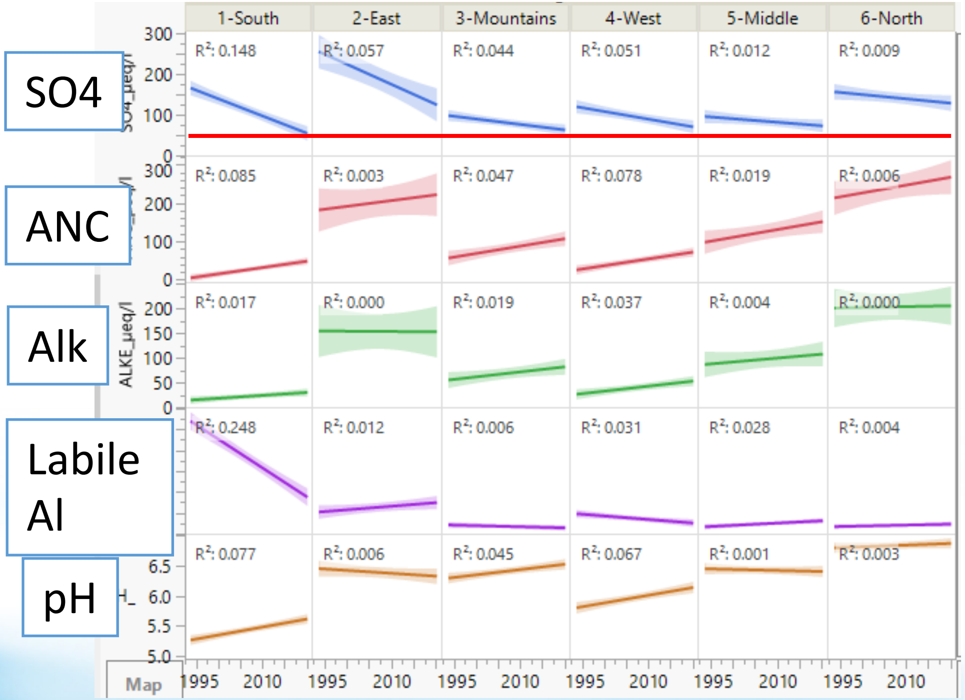




Expected change (difference 1995-2019)



Strong decrease in sulfate (40%) especially in southern Norway

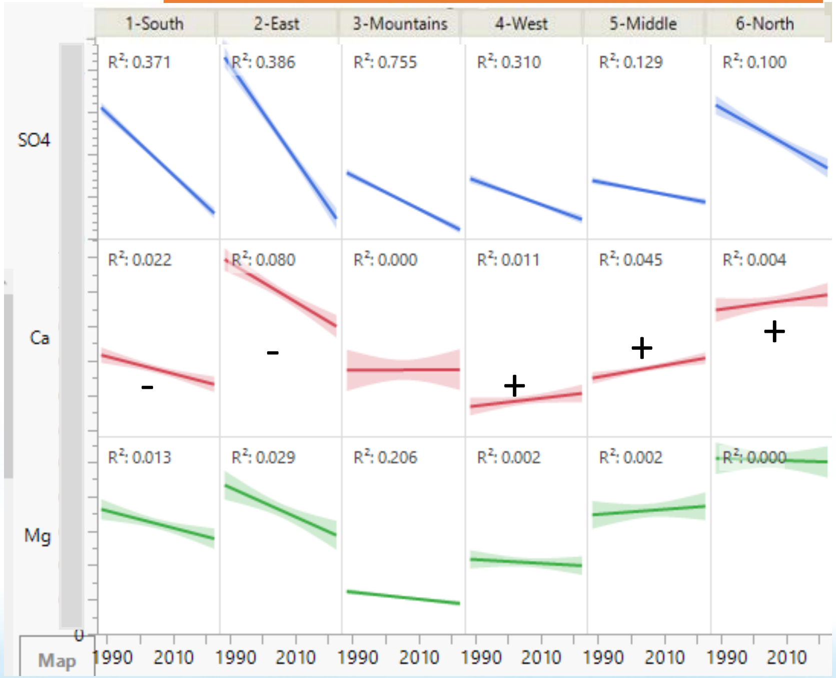
- Decrease in S deposition 60 to 70%
- What is the ‘baseline SO_4’?

Strong recovery

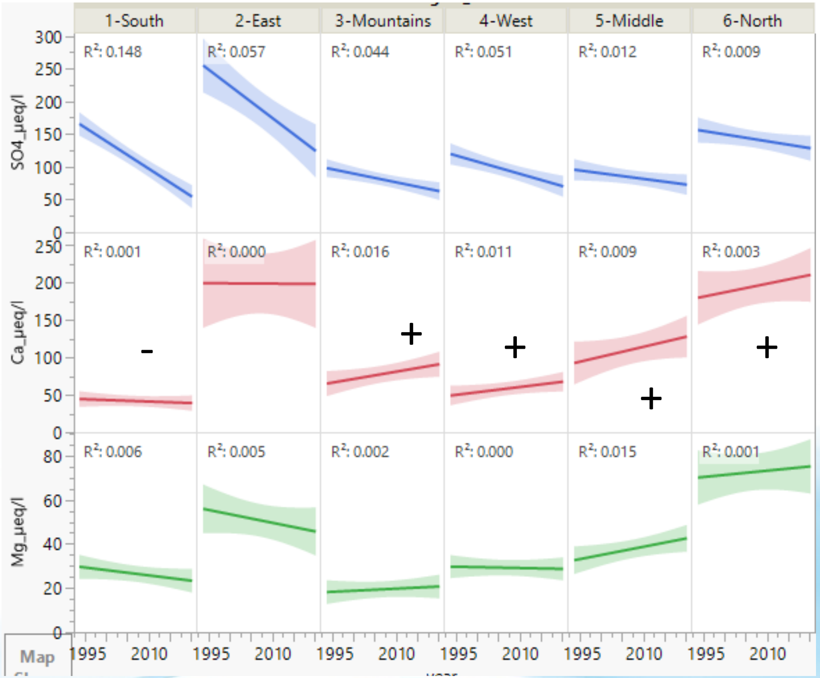
- Decrease in labile Al, increase in ANC, alkalinity, pH

Unexpected positive trends in calcium

TimetrendLakes (acid-sensitive)



ThousandLakes (all of Norway)



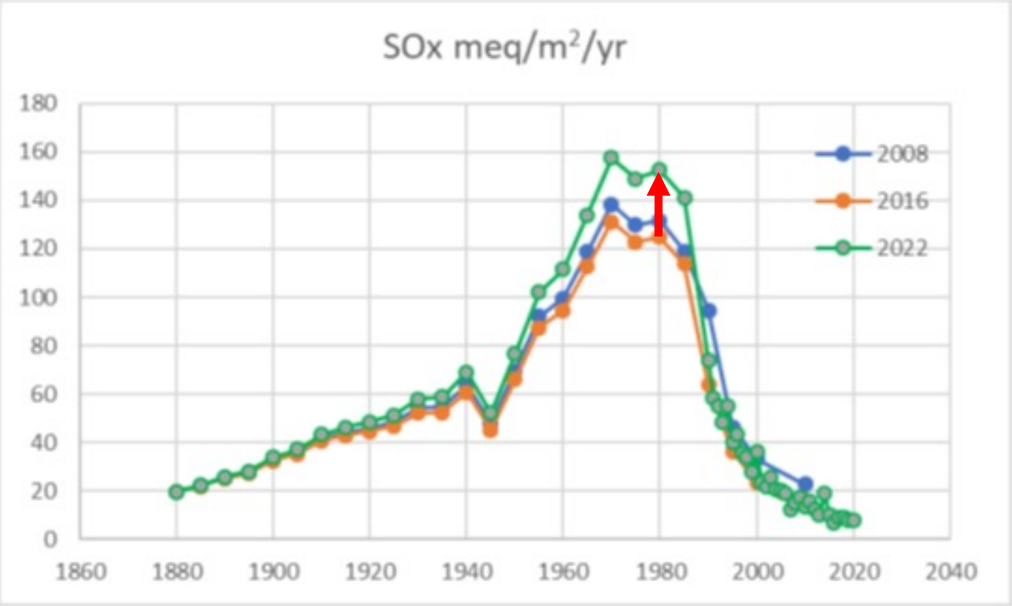
Using MAGIC to describe change in water chemistry in ThousandLakes

- Magic - widely applied dynamic model to describe and predict acidification and recovery of surface waters from acid deposition (Cosby et al. 1995)
- Dynamic model that includes description of soil chemistry, hydrology, weathering, and leaching.
  - A (simplified) representation of state of the art knowledge of catchment processes that drive surface water acidification and recovery
- See Kaste et al. 2022 (NIVA report 7799-2022)

Approach

- Use deposition from EMEP
- Calibrate Magic
  - Using only 1995 data; describe 1995 and 2019
  - Using only 2019 data; describe 1995 and 2019
  - *Using both years*
- Compare model output with 1995 and 2019 data
- Identify sensitive model parameters

Note: EMEP estimates of time series of deposition change with time (are re-assessed regularly)



Estimates of S deposition used to calibrate MAGIC by Larssen et al. (2008), Austnes et al. (2016) and this study (2022). Estimates for lake Lille Hovvatn, located in southernmost Norway

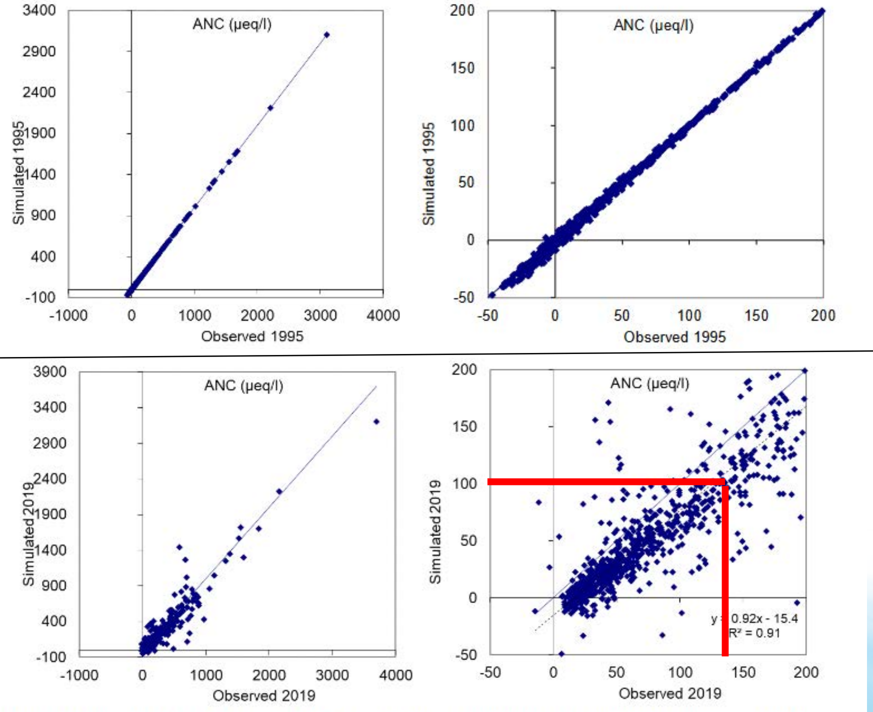
- Magic calibrated using 1995 dataset
  - 1995 ANC is described well
  - Simulated ANC < observed ANC in 2019
  - Simulated Ca < observed Ca in 2019
  - Mg is ‘ok’

All lakes

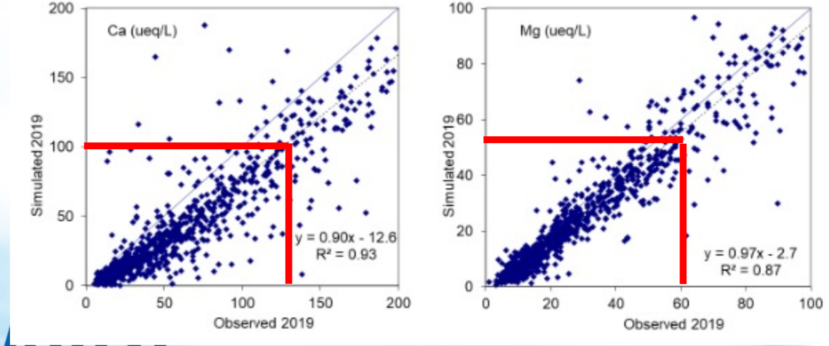
Acid-sensitive lakes only

1995

2019



Acid-sensitive lakes only



Kaste et al. 2022

Lessons learned / new questions

- Magic is good at describing chemical recovery, especially in acid-sensitive, acidified lakes
  - But the success of the model is dependent on choices made during model calibration
- Magic doest not capture upward change in Ca (mostly appearing in slightly less acidified lakes)
  - Reminder: nobody knows for sure what drives the unexpected increase in Ca!
- How important is this for prediction of chemical recovery?
  - simulation of ANC depends on good simulation of Ca
  - Background concentrations of Ca and SO4 (in non-acidified conditions) are difficult to quantify but important when S deposition becomes lower and lower
- 'New' questions:
  - Are weathering rates increasing (perhaps under climate change)? Is chemical recovery more rapid than we thought?
  - Are changes in weak acids (organic acids) properly described in dynamic models?
  - Are we missing some key processes in the dynamic models?
  - How do dynamic models perform compared with state-state models?

NIVA

Thank you

- Colleagues Øyvind Kaste, Magnus Norling, Kari Austnes, Dick Wright (Magic modelling)
- Norwegian Environment Agency for funding ThousandLake Survey and Magic modelling project

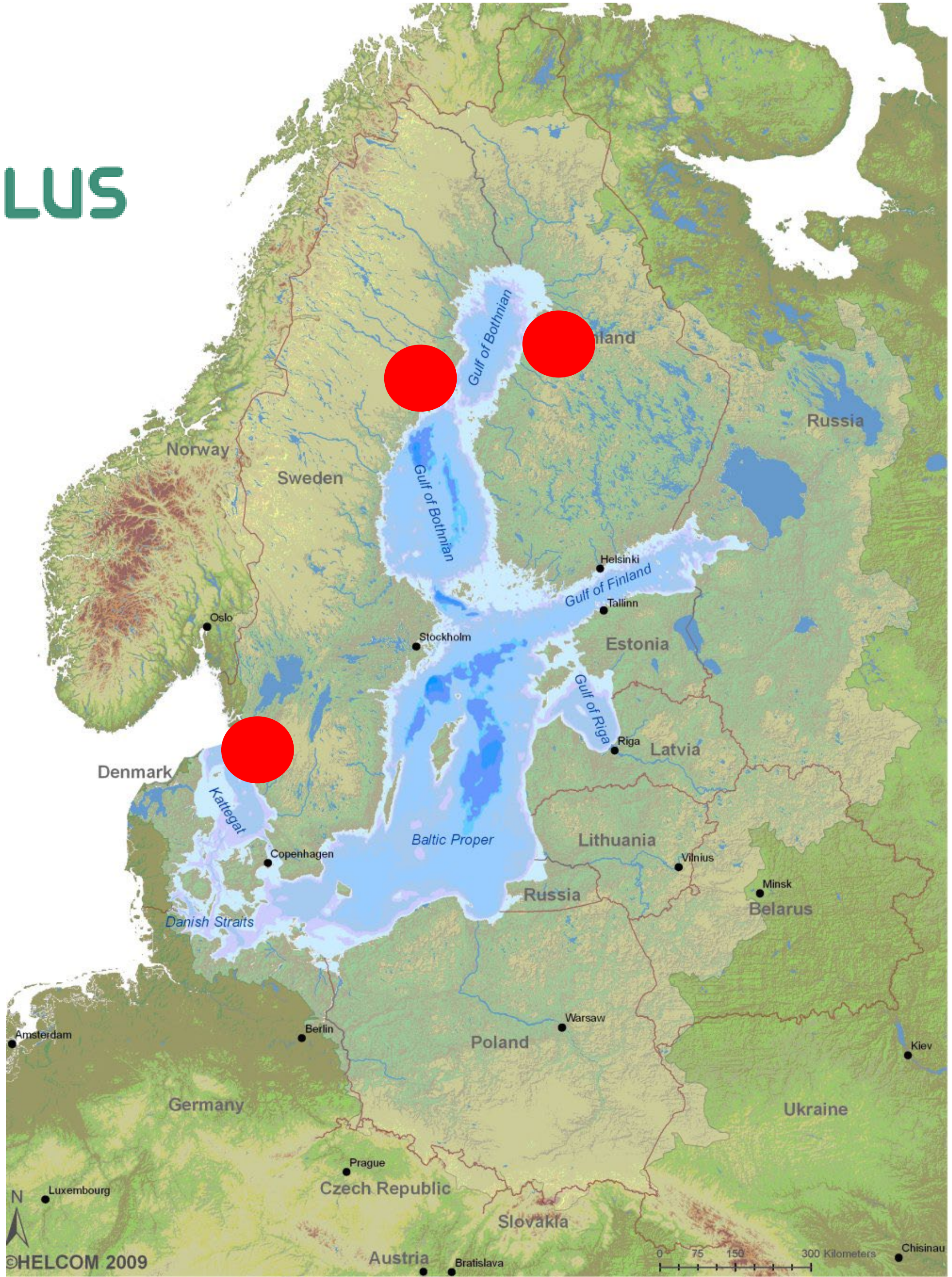
Norwegian Environment Agency

NIVA

Modelling Streamwater Nitrogen at the Gårdsjön IM site

eLTER PLUS

BIOWATER



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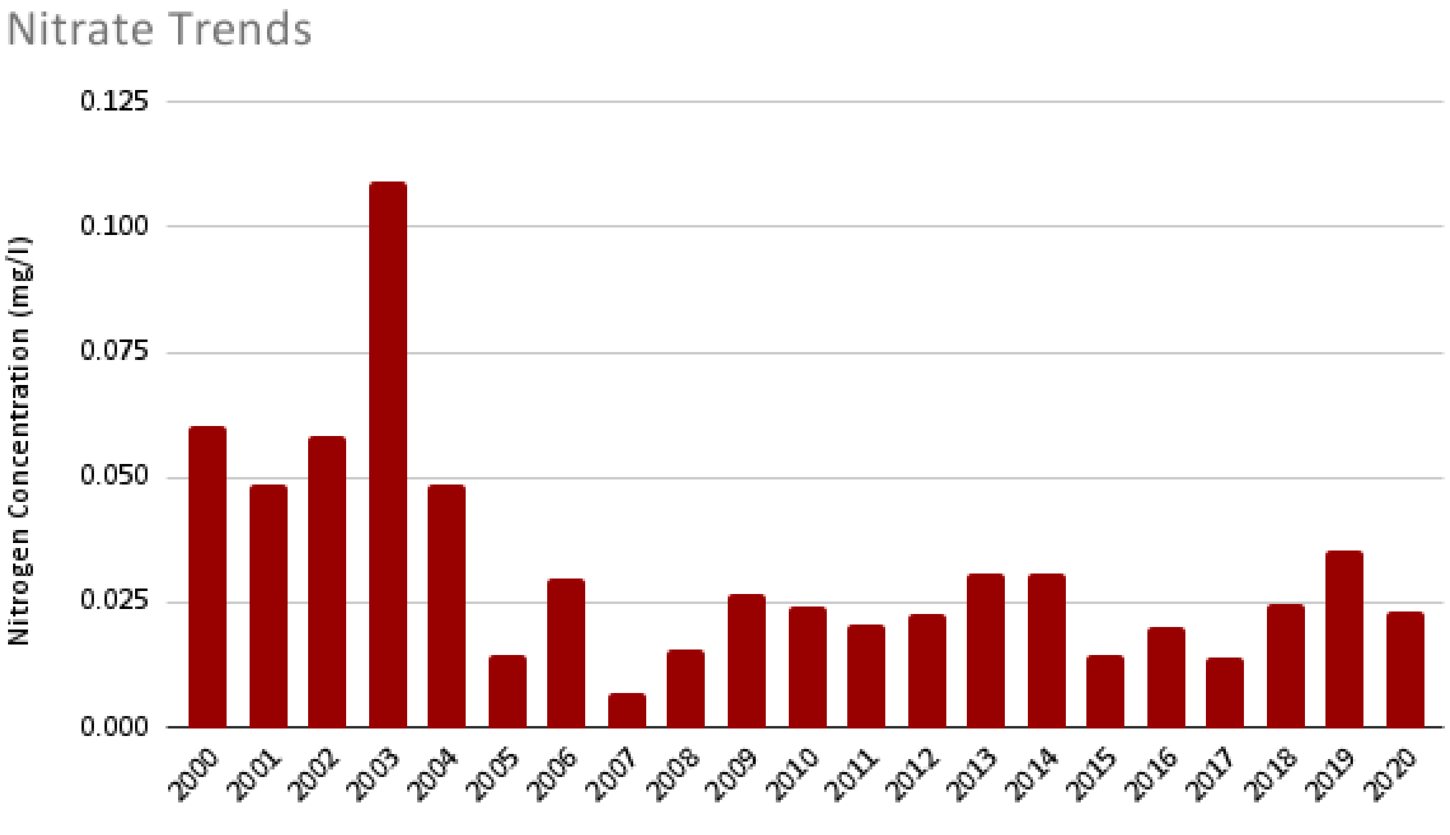
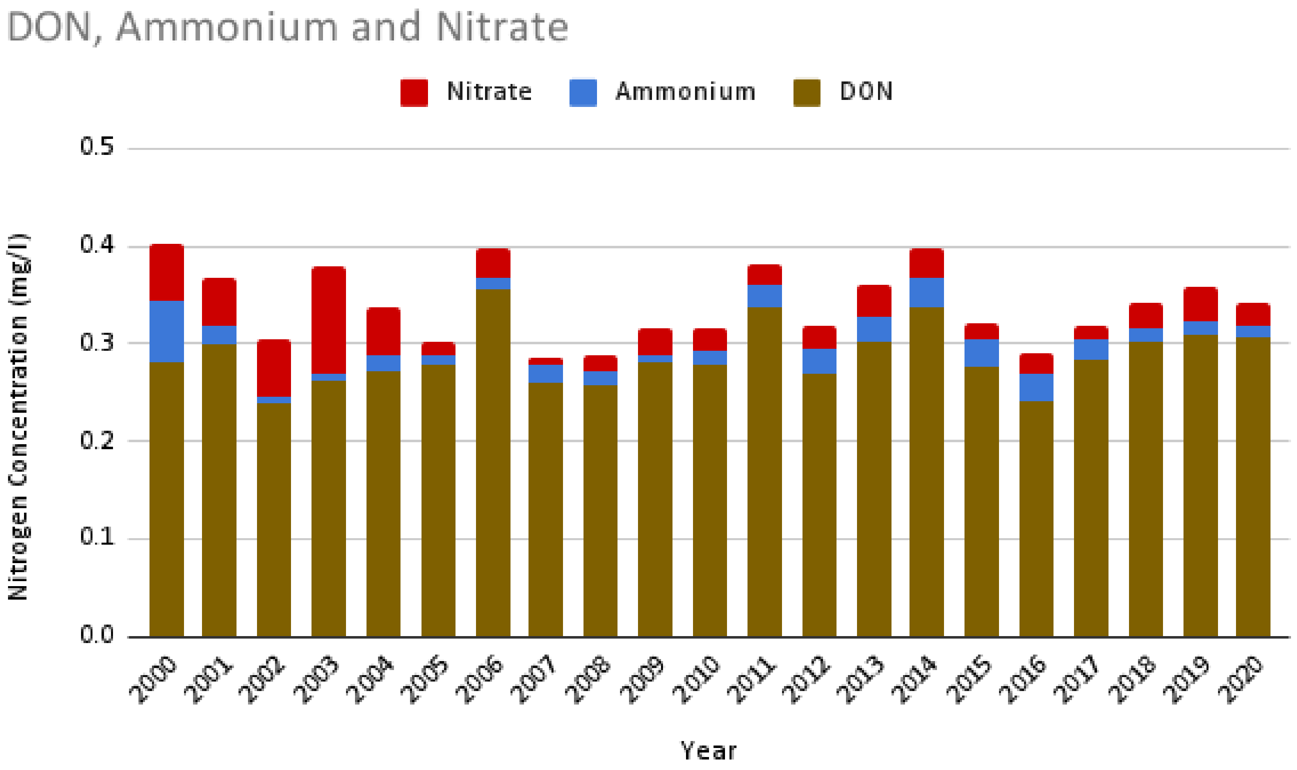
People to Thank

- Dan Butterfield
- Jill Crossman
- Dolly Kothawala
- Hjalmar Laudon
- Ahti Lepistö
- Nikos Nikolaidis
- Katri Rankinen
- Ryan Sponseller
- Paul Whitehead

Does the world really need yet another catchment-scale nitrogen model ?

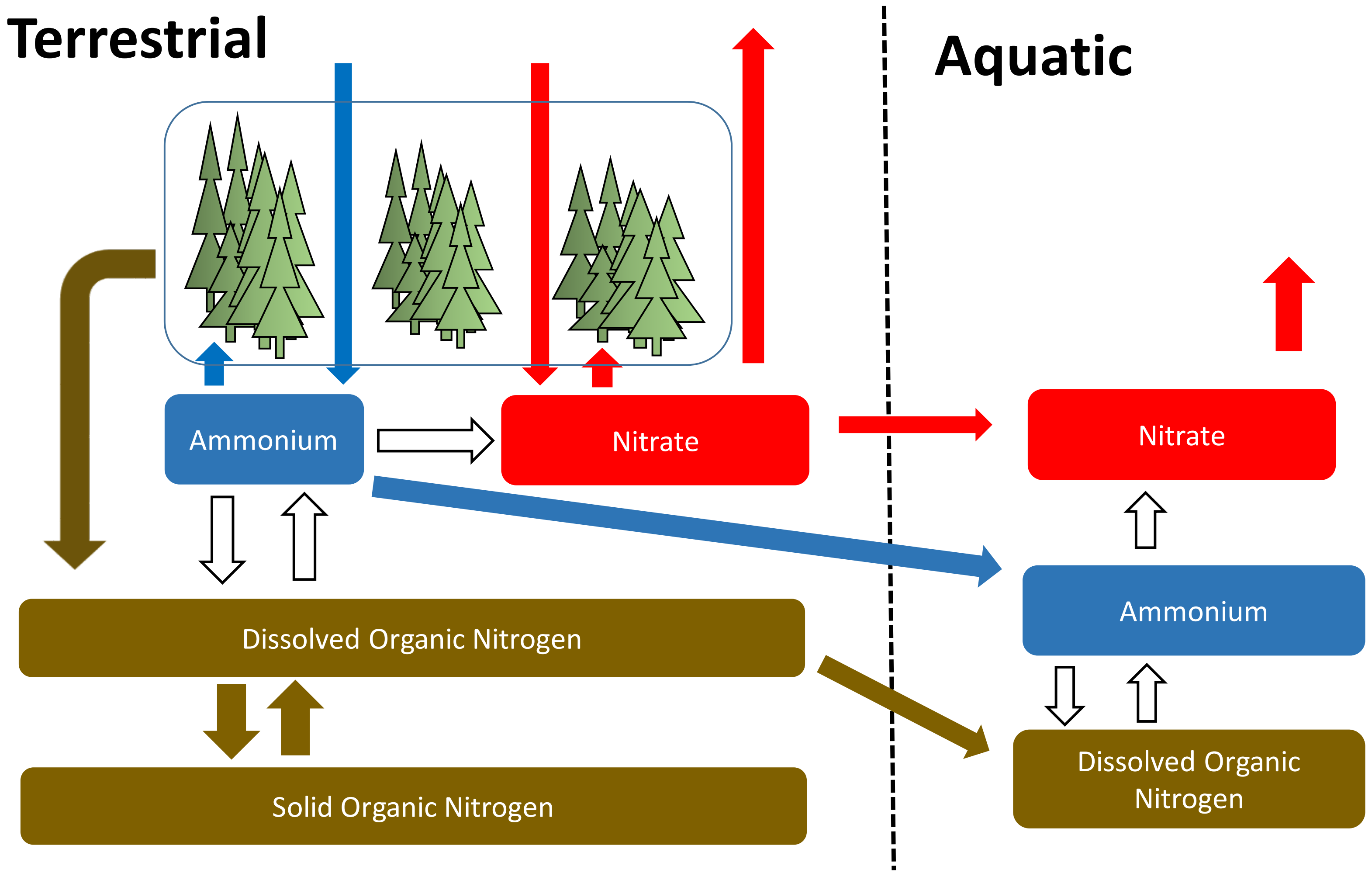


Does the world really need yet another catchment-scale nitrogen model ?



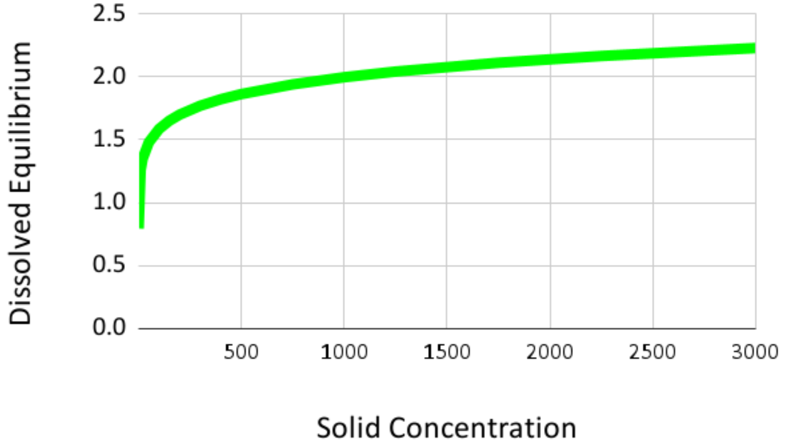
Project Goals

- **Model Solid and Dissolved Organic Nitrogen Mass Balances**
- Incorporate full hydrological model
  - Improved AET and PET representation
  - Couple snow dynamics to soil temperature
- Simulate weather-dependent plant N uptake


Terrestrial
Aquatic
Ammonium
Nitrate
Dissolved Organic Nitrogen
Solid Organic Nitrogen
Nitrate
Ammonium
Dissolved Organic Nitrogen

“Too much complexity is the route to premature failure”

“… as simple as possible but no simpler”

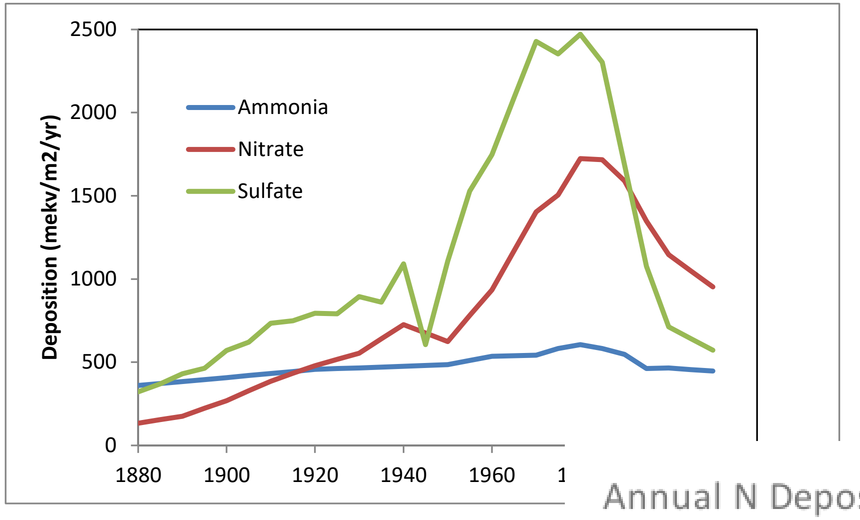


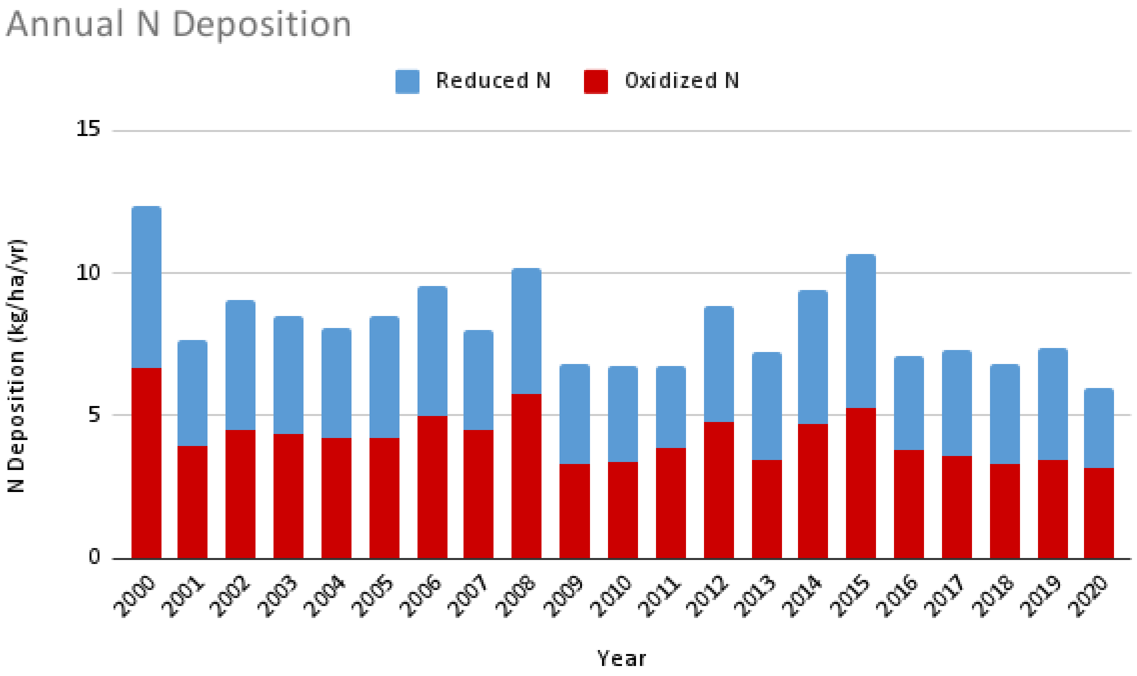
- DOM has some fundamental similarities
- Environmental behavior of DON is close enough to DOC that we can transfer insights from modelling the latter
- DOM concentrations have a maximum value

Is climate the noise in the recovery signal?

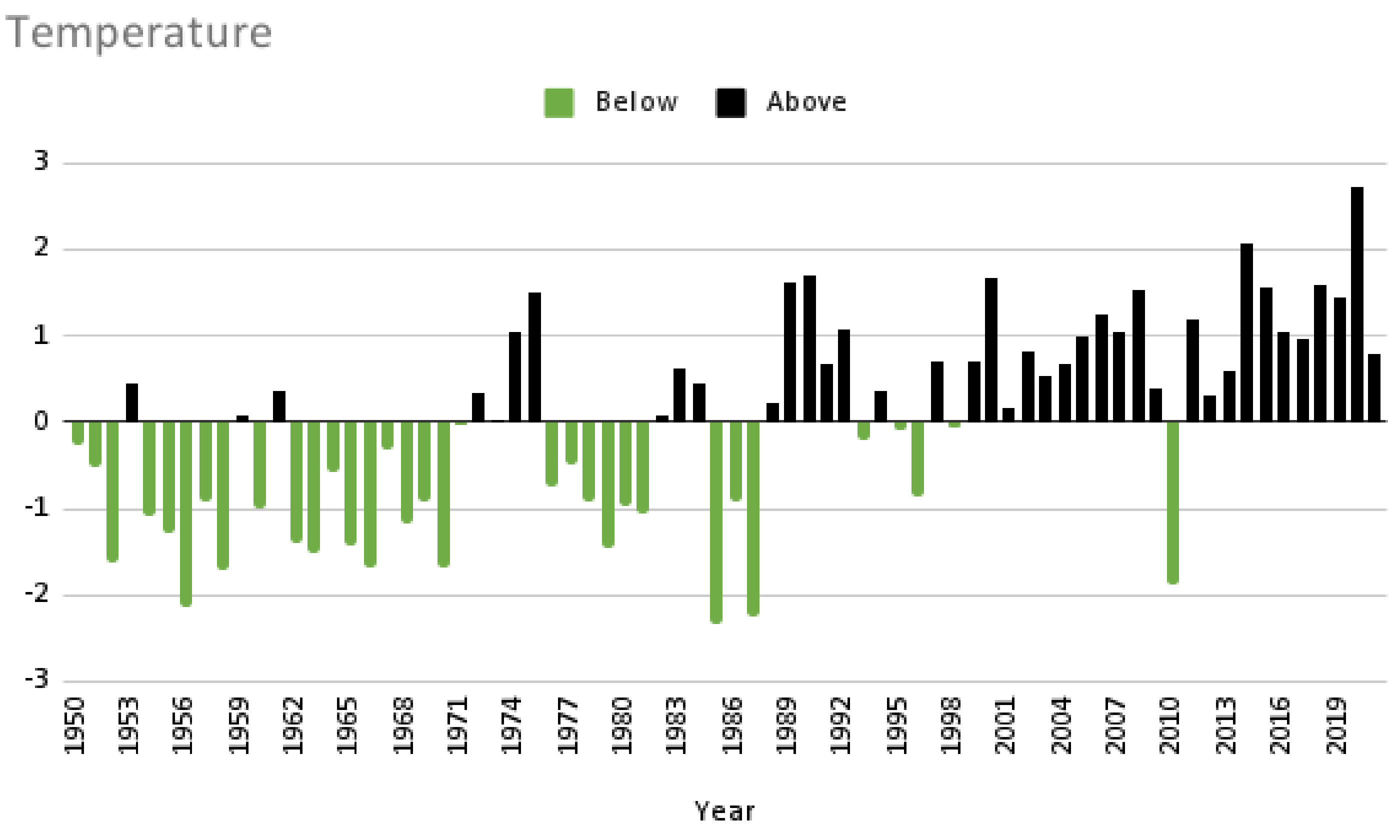
Is recovery the noise in the climate signal?

Is climate the noise in the recovery signal?





Or is recovery the noise in the climate signal ....



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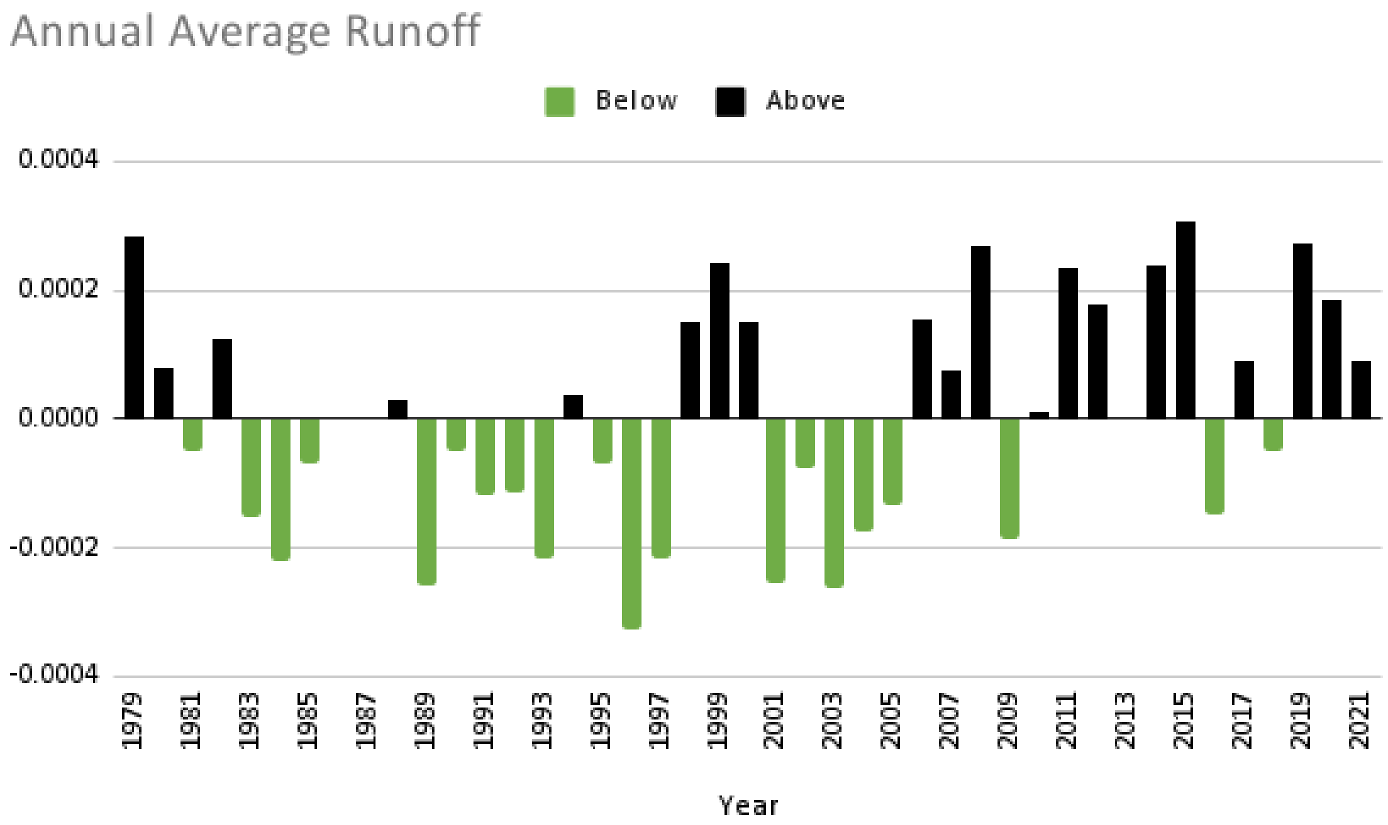

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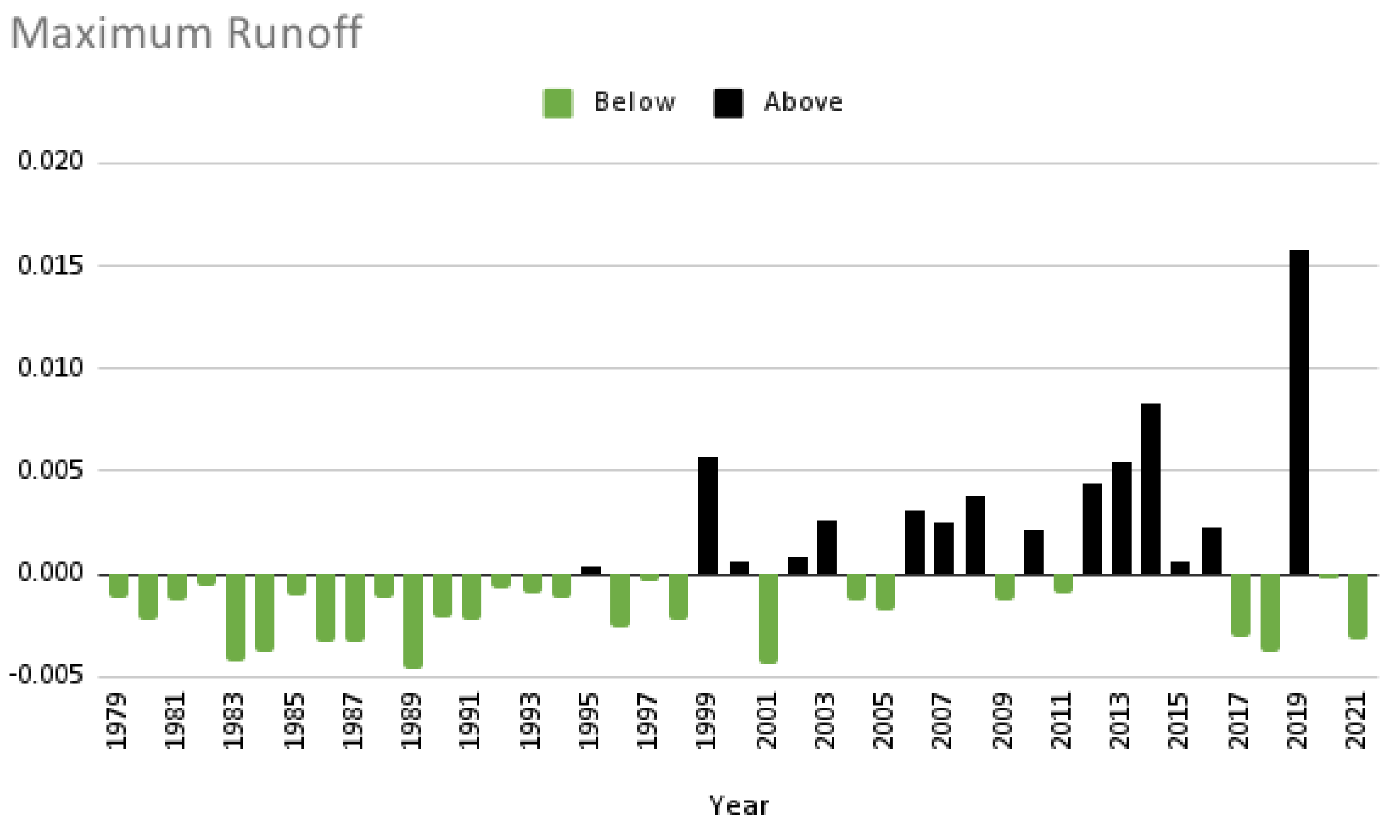
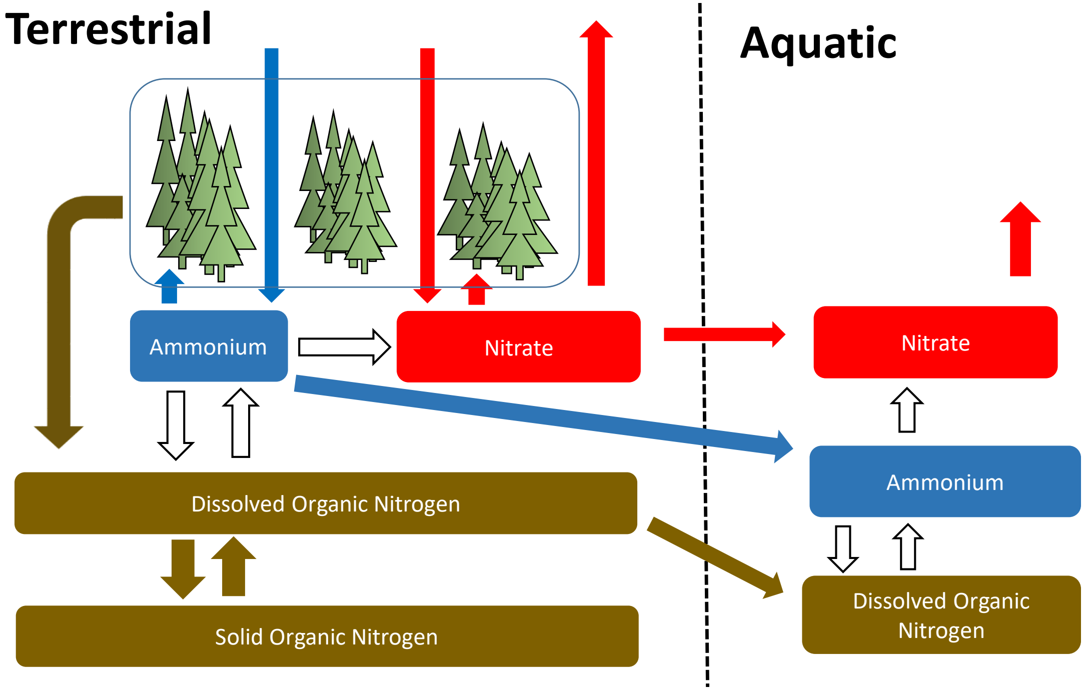
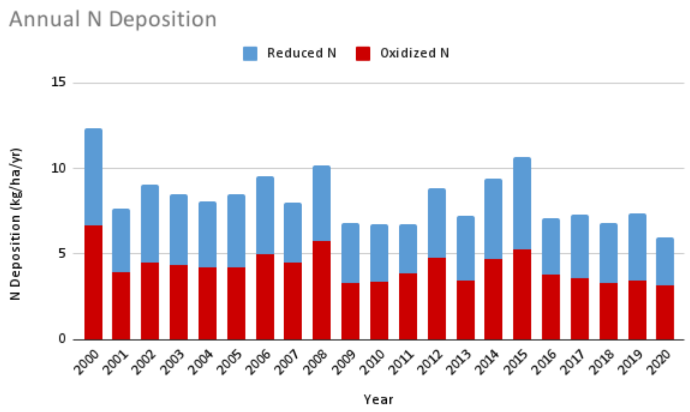
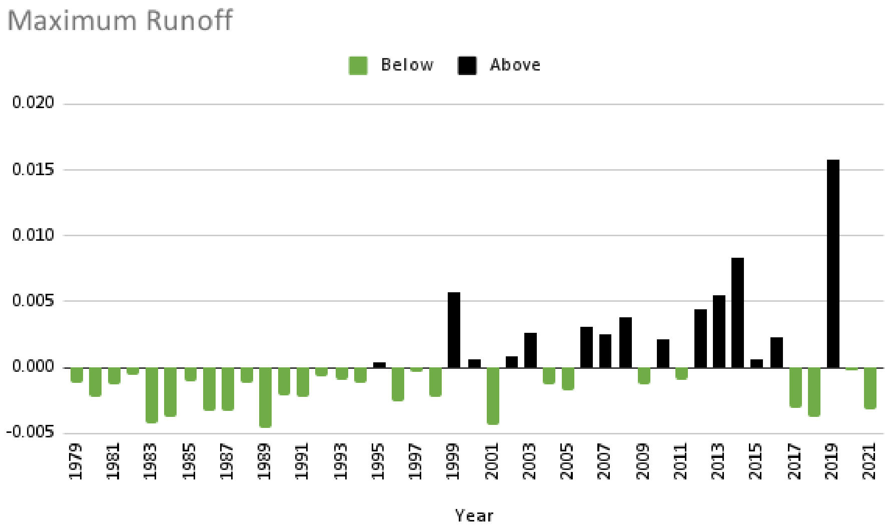
Or is recovery the noise in the climate signal ….

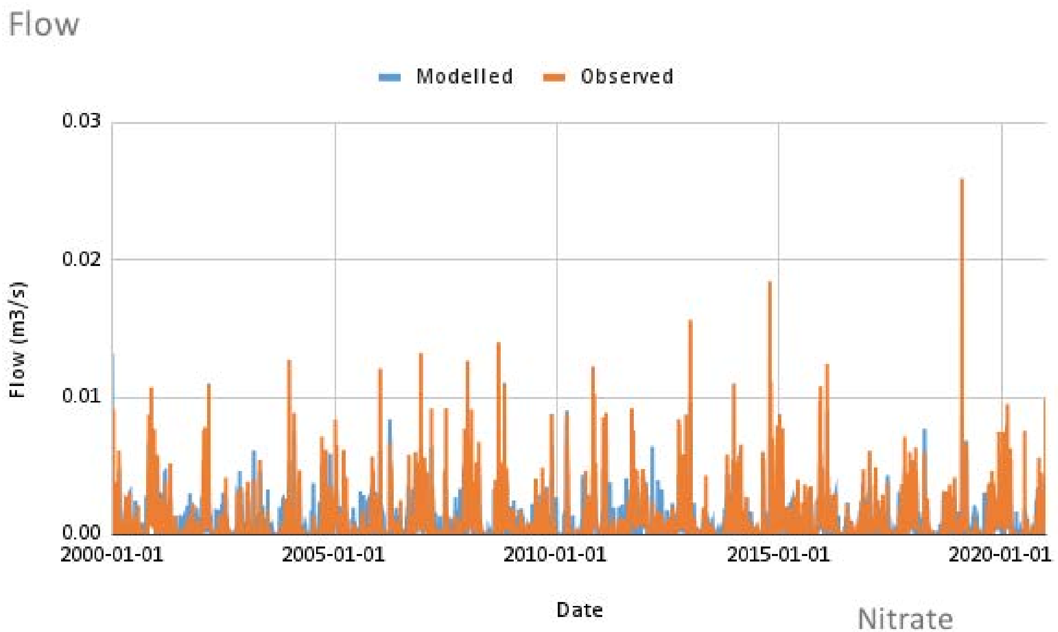


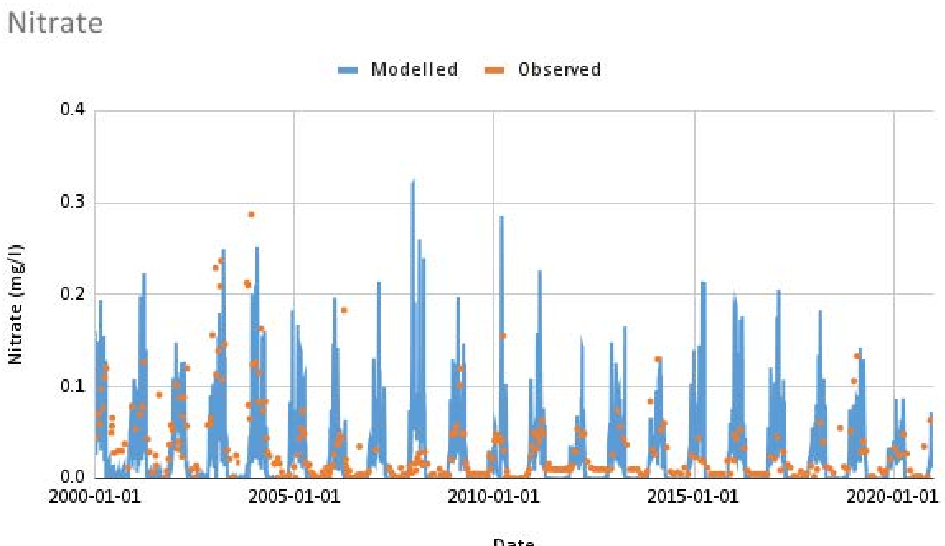

Terrestrial
Aquatic
Ammonium
Nitrate
Dissolved Organic Nitrogen
Solid Organic Nitrogen
Nitrate
Ammonium
Dissolved Organic Nitrogen


Annual N Deposition
Reduced N
Oxidized N
N Deposition (kg/ha/yr)
0
5
10
15
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020
Year

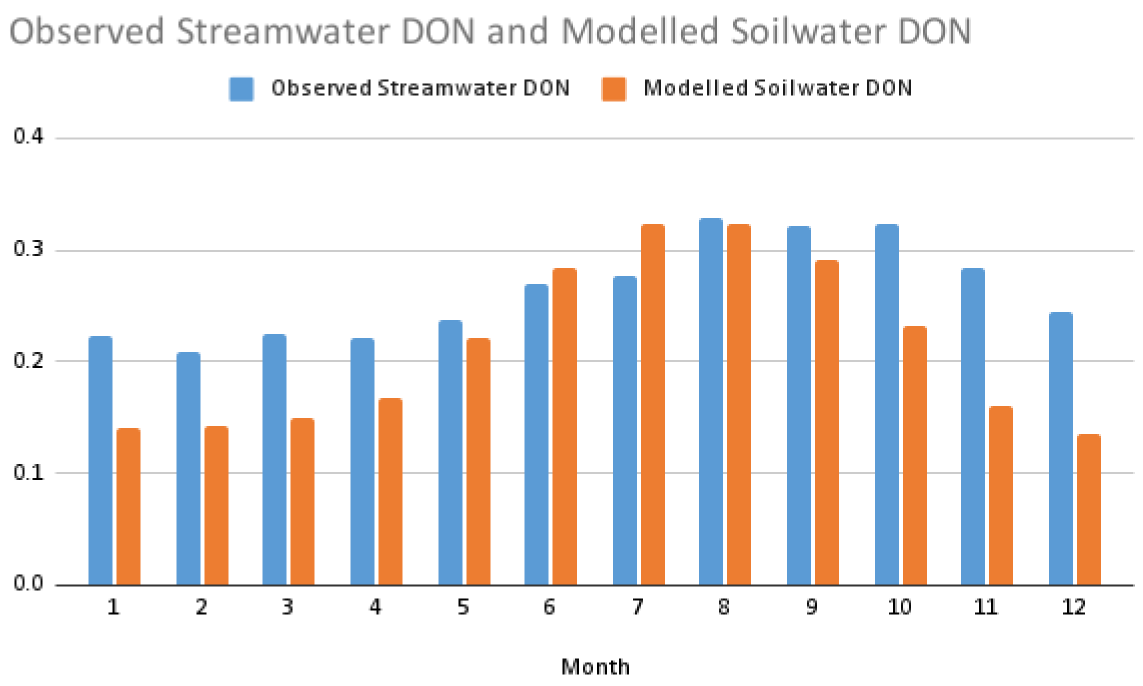

Maximum Runoff
Below
Above
0.020
0.015
0.010
0.005
0.000
-0.005
1979 1981 1983 1985 1987 1989 1991 1993 1995 1997 1999 2001 2003 2005 2007 2009 2011 2013 2015 2017 2019 2021
Year

Preliminary Results





Preliminary Results



Conclusions

- It is possible to model organic nitrogen at a catchment scale
    - However, more work is needed
- Long term data collected by IM site staff and managers offer a unique possibility to test process understanding
    - Headwater sites are typically harder to model than larger river systems
- Models may give us insights into possible future conditions
    - But there will always be surprises

SLU

Thank you for your attention!