Impacts of climate change and land-use use change on water availability and water quality

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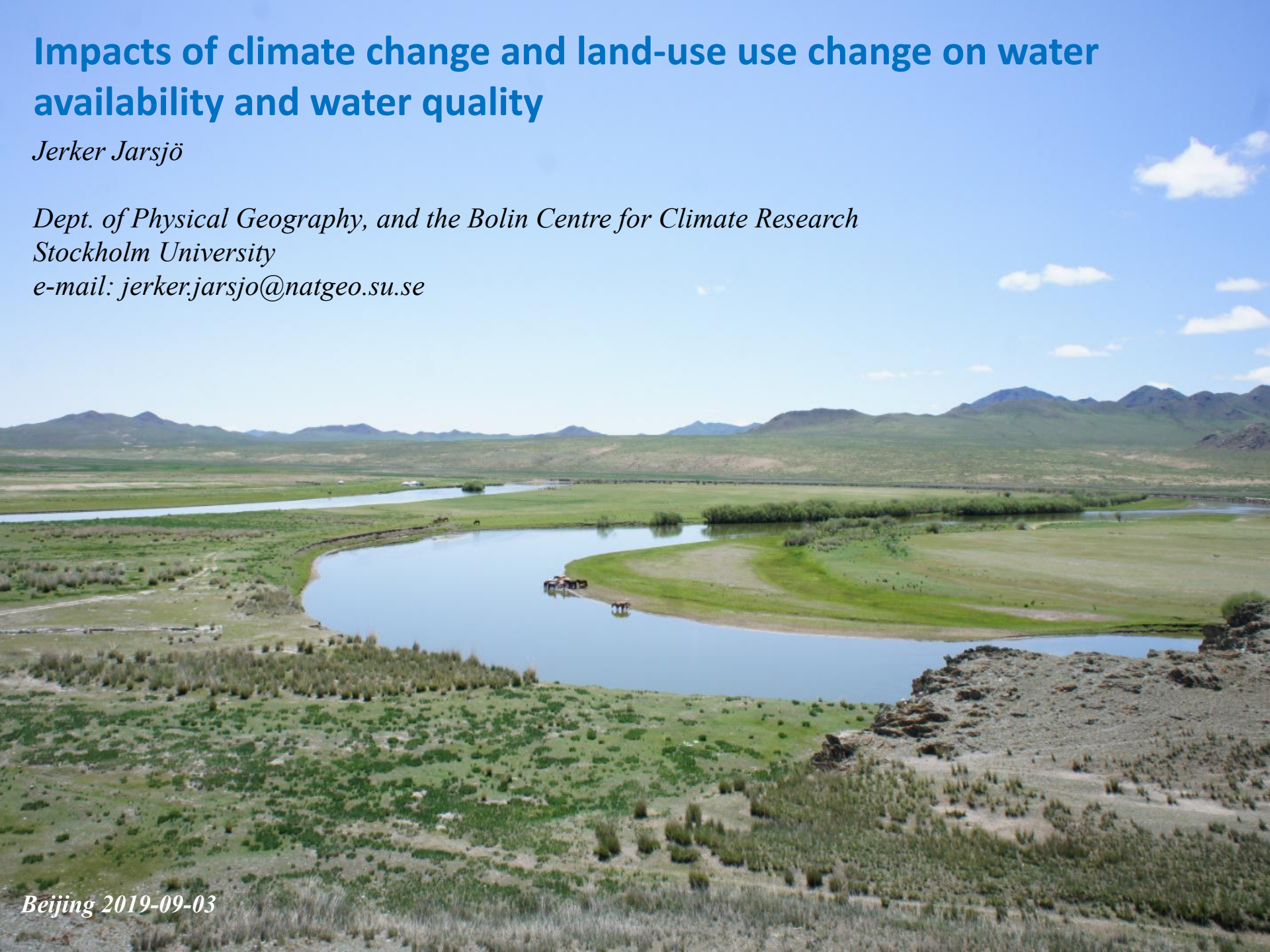

Beijing 2019-09-03

Stockholm University

Department of Physical Geography, Stockholm University:

- One of the major departments within the Faculty of Science at Stockholm University
- Has approximately 150 employees and educates 1000 students annually
- Main research disciplines are Climatology, Ecological Geography, Geographical Data Processing, Geomorphology, Glaciology, Hydrology, Remote Sensing, Tropical Geography, and Quaternary Geology
- Education is oriented towards geography and geosciences, including hydrology and environmental protection.

On-going research – global change* & water resources

*Main focus on impacts of **climate change and land-use change**

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Presentation outline

1. **Water balance quantification in the Lake Baikal basin**
2. **The extreme case: Water resources of the Aral Sea drainage basin**
3. **The eutrofication problem in the Baltic Sea drainage basin**
4. **The use of wetlands in mitigating impacts of global change* (*primarily climate change and land use change)**

1. Water balance quantification in the Lake Baikal basin

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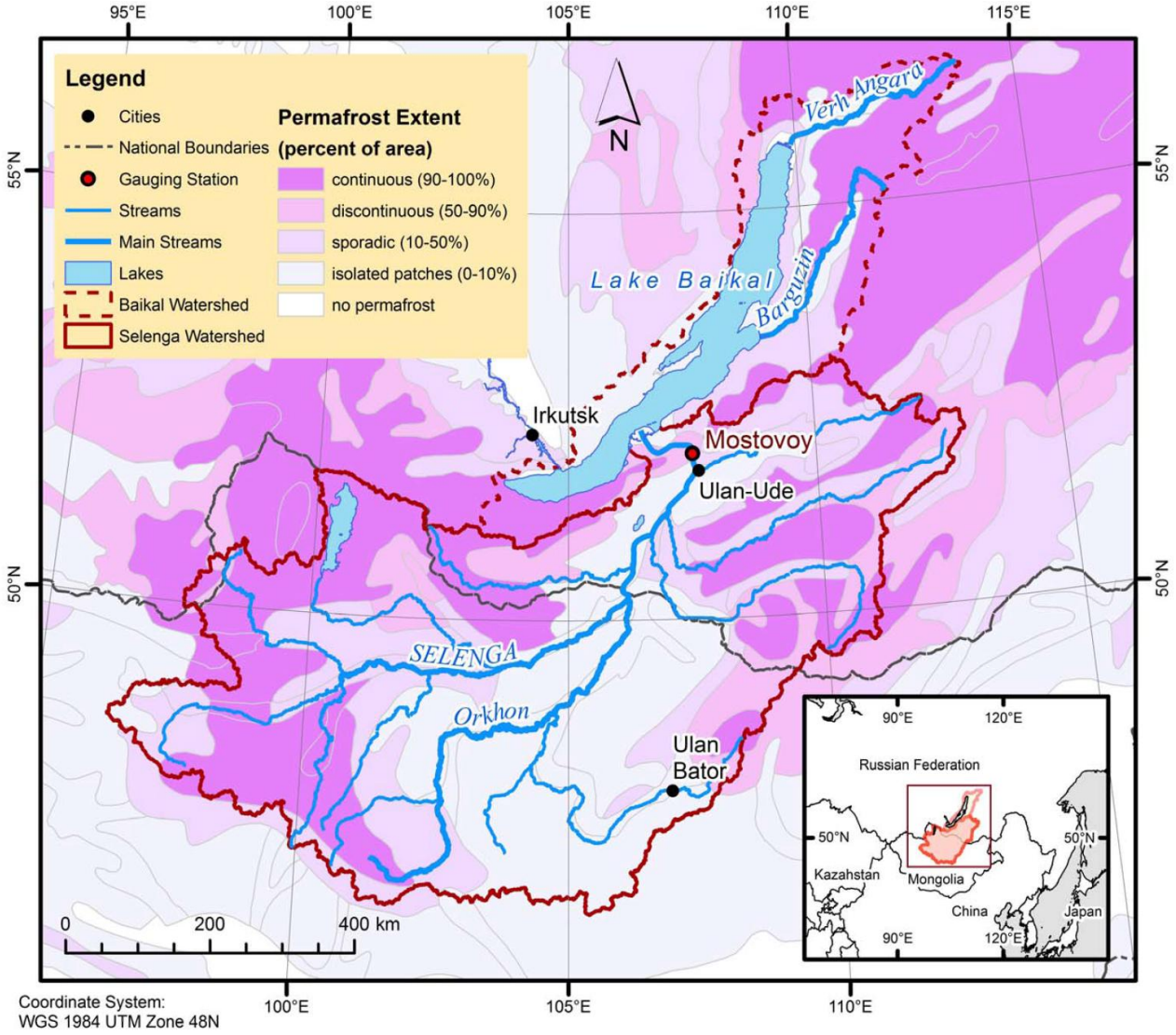


- *Area 477,000 km^2
- * Permafrost domination
- * Drains via the Selenga delta into Lake Baikal
- * Unique ecosystems in Lake Baikal and the Selenga River delta
- * Essentially unregulated

Background – study area

On-going changes in ambient conditions:

*Pollution spreading in the Selenga river Basin

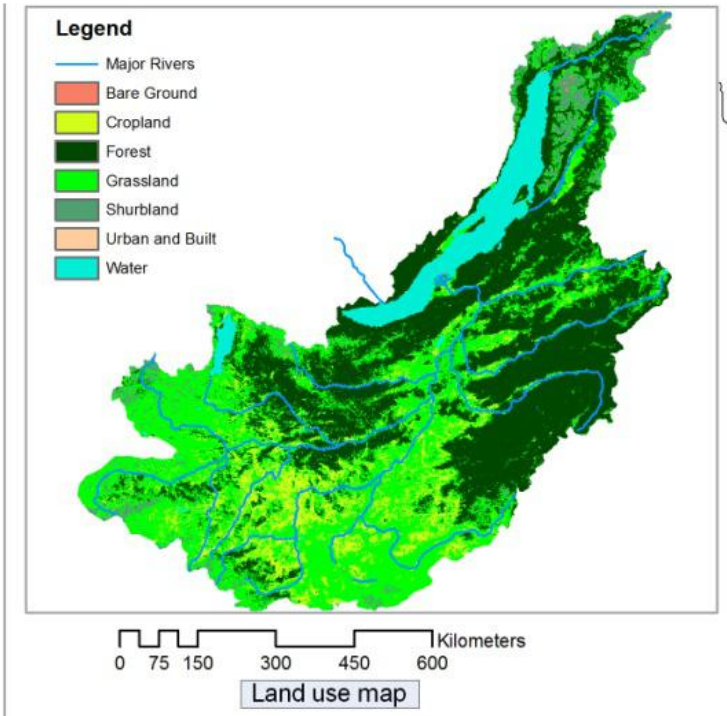
-Heavy metals from mining

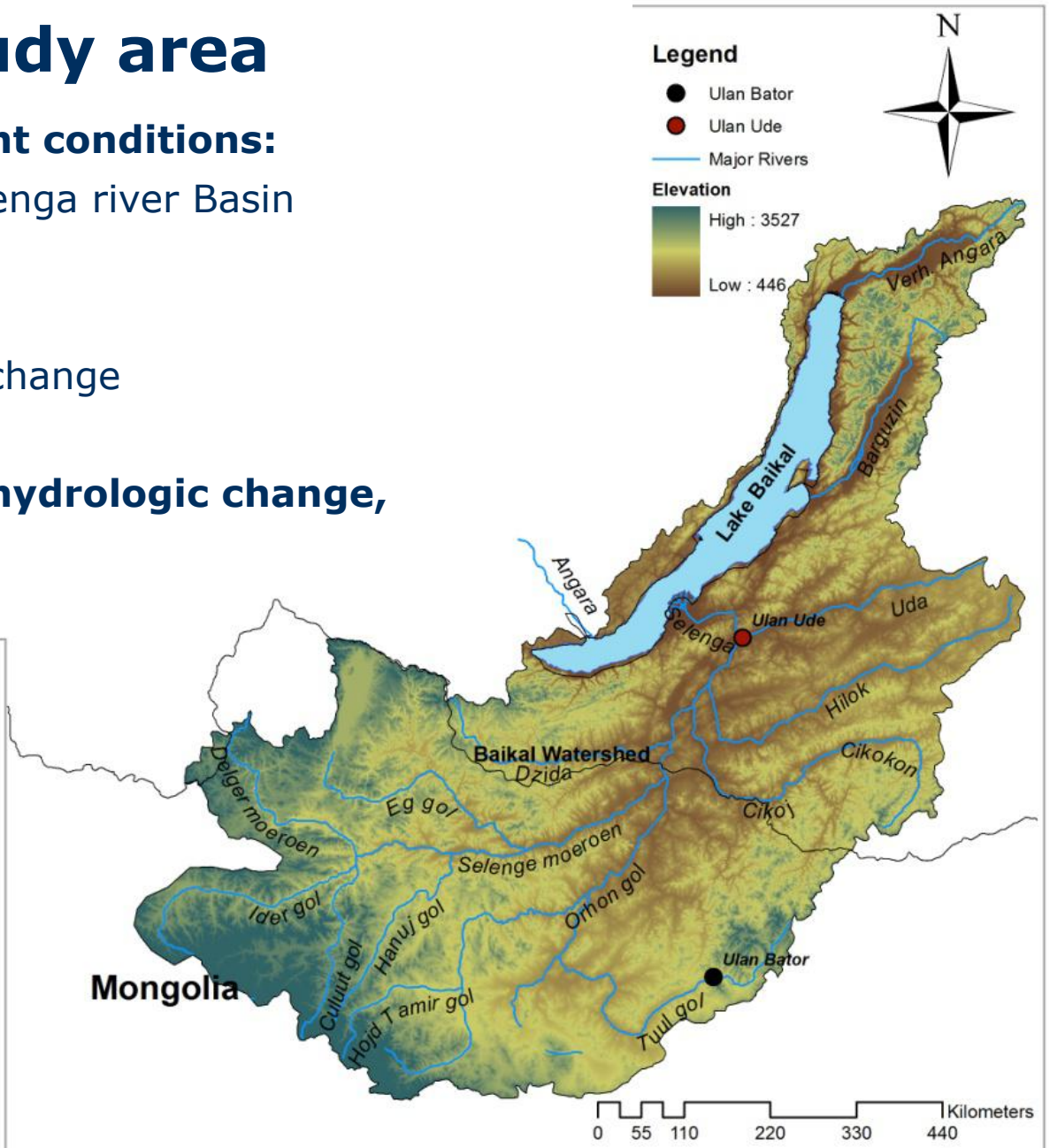
-Nutrients from agriculture

*Land-use change, water-use change

*Climate change

→ Many possible drivers of hydrologic change, complex feedbacks





Main questions

(i) What are the historical hydro-climatic trends and their possible causes?

(ii) Can CMIP5 climate models reproduce observed trends?

(iii) Are projected trends of different CMIP5 models consistent? Do they link to observed trends so far?

(iv) Which are the main implications of the projected trends?

Methods

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- Spatially distributed T and P data from the gridded CRU 3.10 dataset (40 measurement stations)
- Daily Q data from the Mostovoy station
- ET estimated by water balance closure
- Synthesis of output from CMIP5 climate models (22 models gave necessary output; emission scenario RCP 8.5)
- -> long term mean values of hydroclimatic parameters for 1961-1990, 2010-2039, 2070-2099.

Historic hydro-climatic evolution

Average annual temperature

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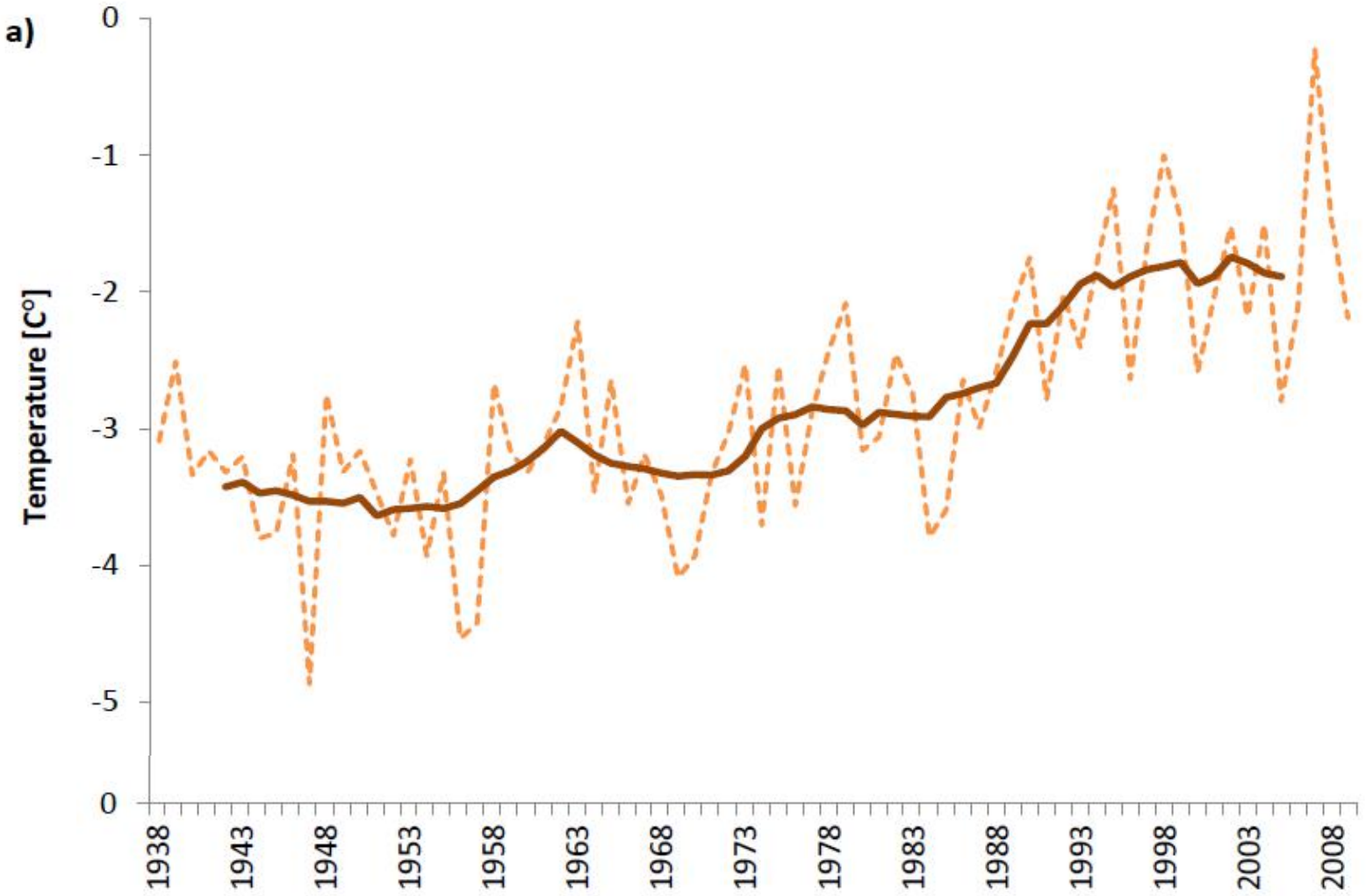

Historic hydro-climatic evolution

Water balance components of basin

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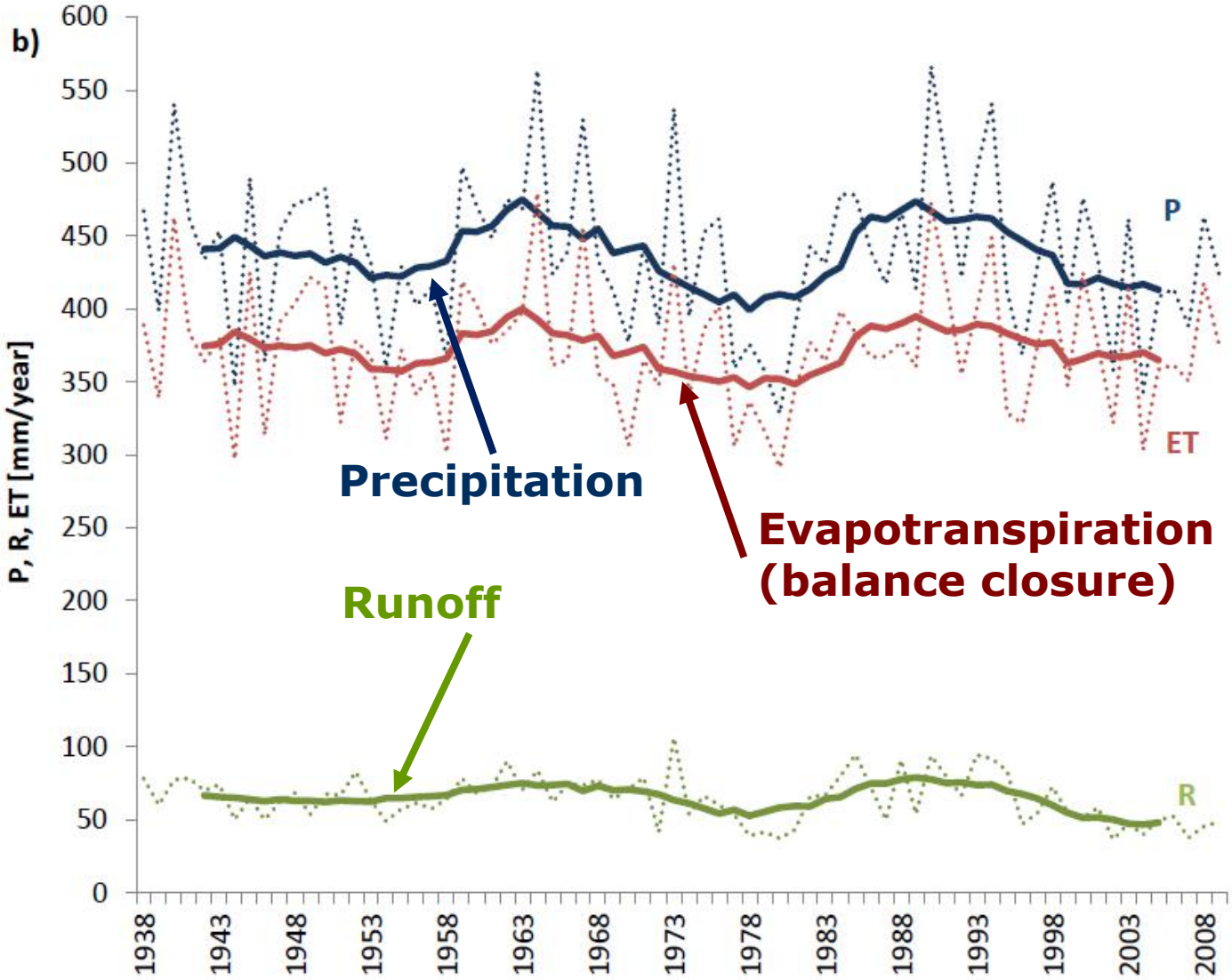

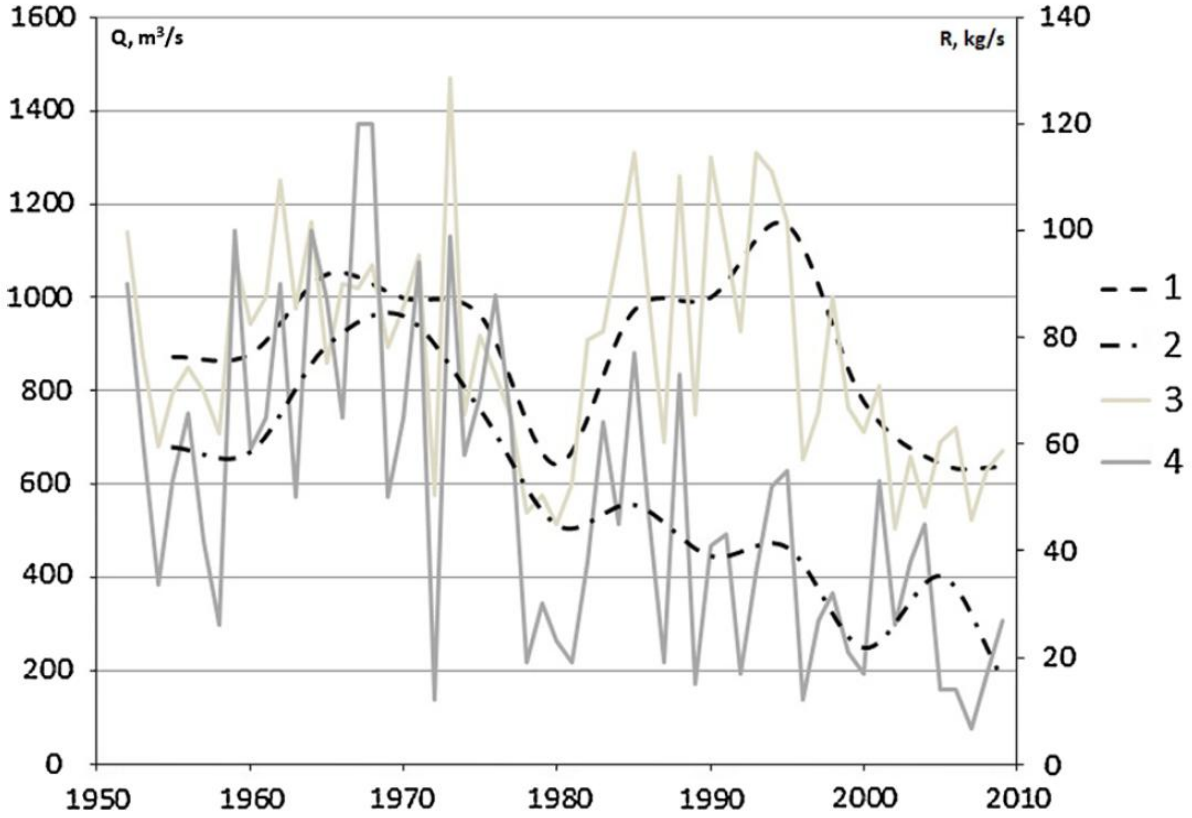

Fig. 4 Temporal changes in water and sediment discharges in the downstream Selenga River (Mostovoy gauging station, 50 km downstream of Ulan-Ude); 5-year running average of *1* water discharge *Q* and *2* sediment discharge *R*, and annual average *3* water discharge and *4* sediment discharge (data from Potemkina 2011)

Ensemble mean projections CMIP5

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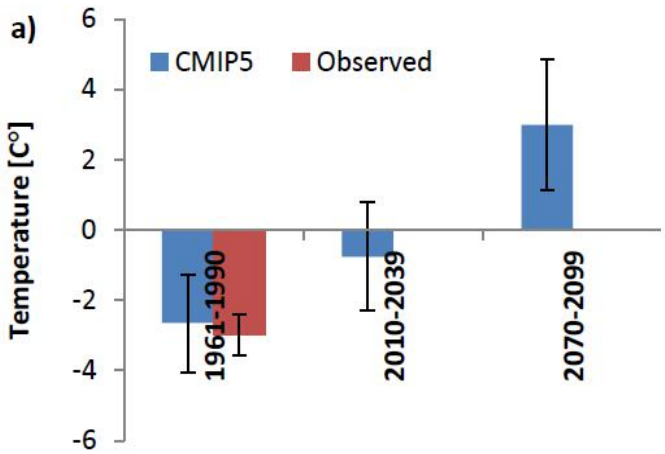

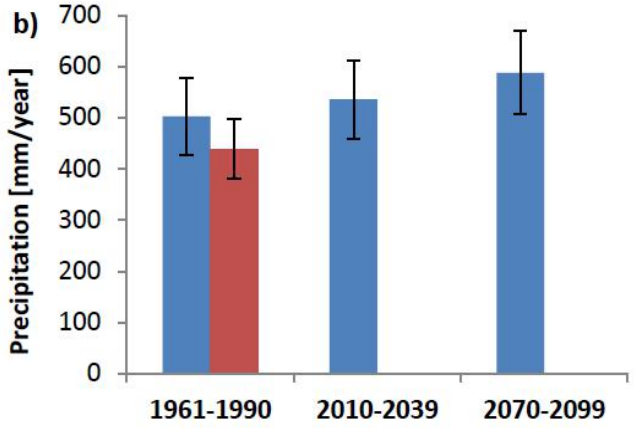

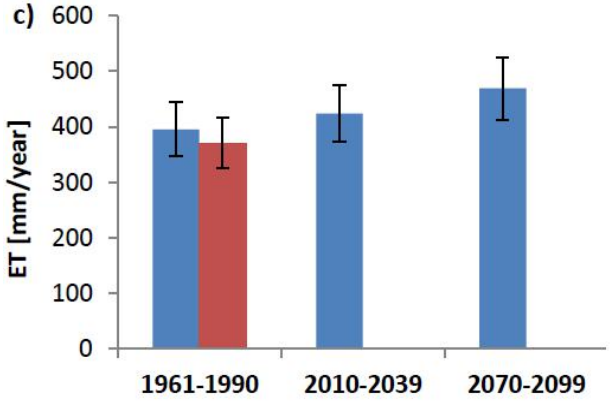

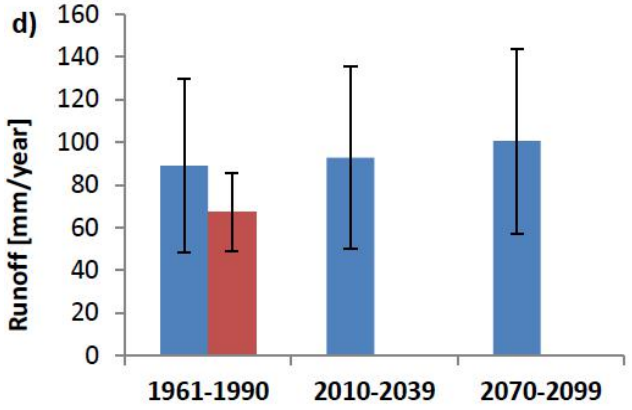

Historical discharge characteristics

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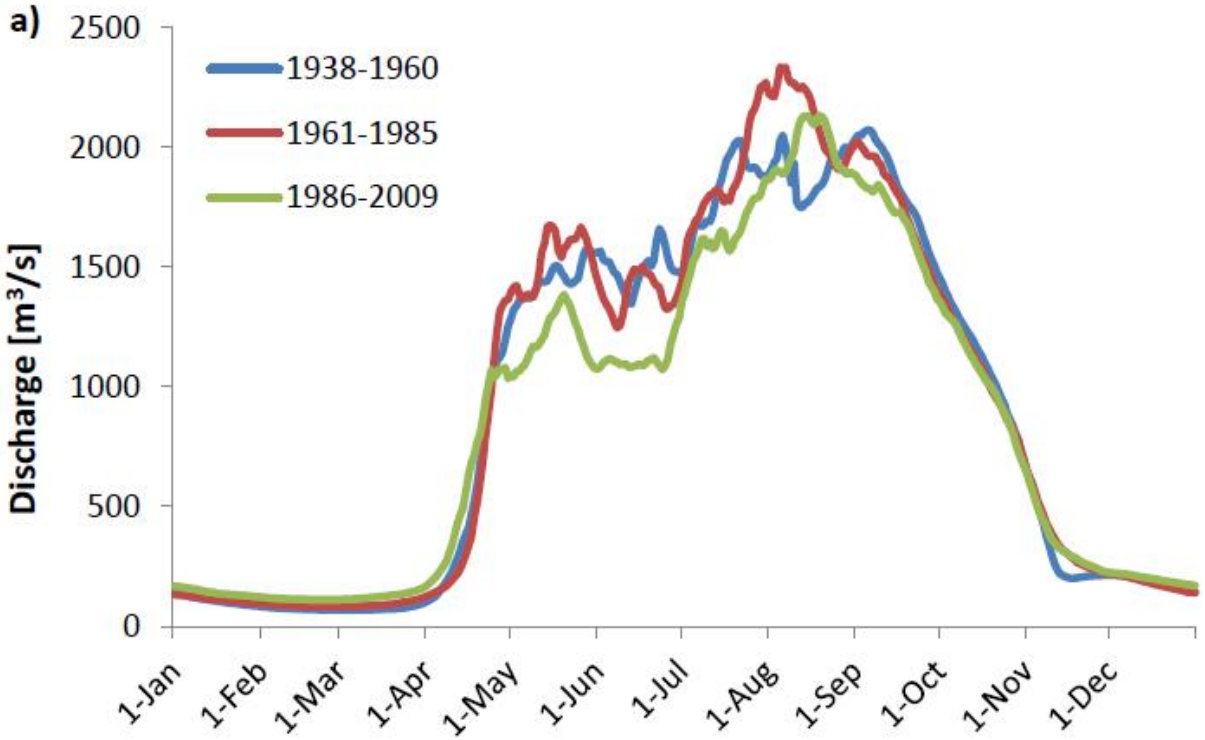
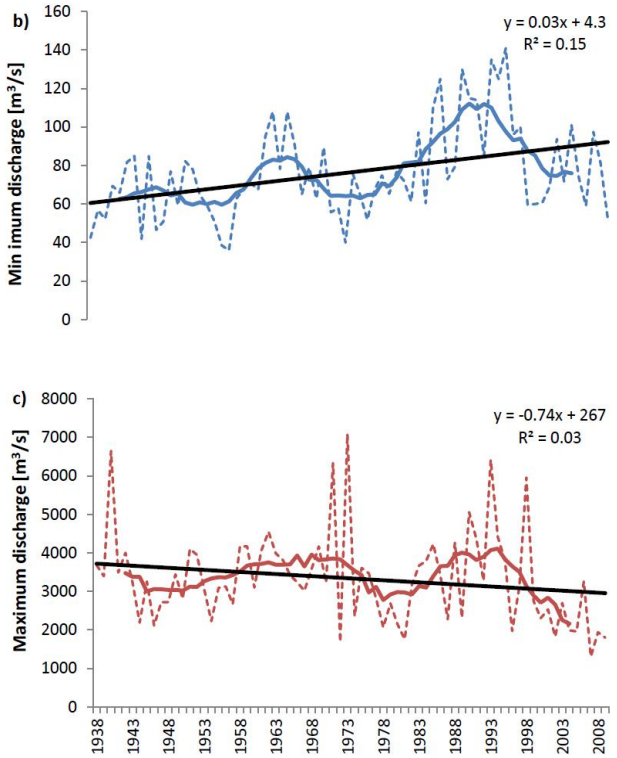
Seasonality

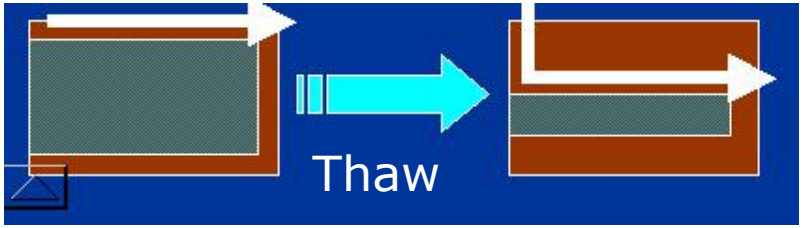


Min – Max

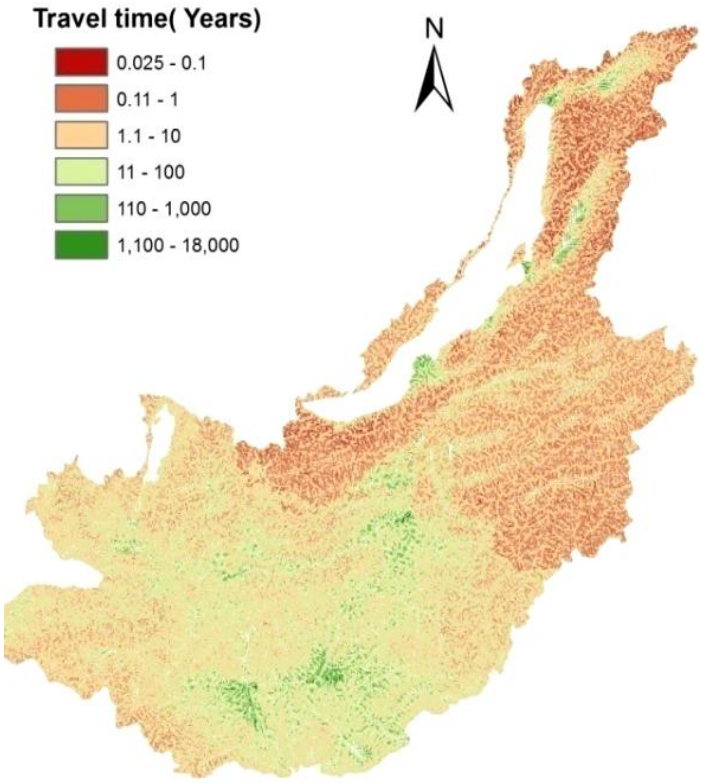


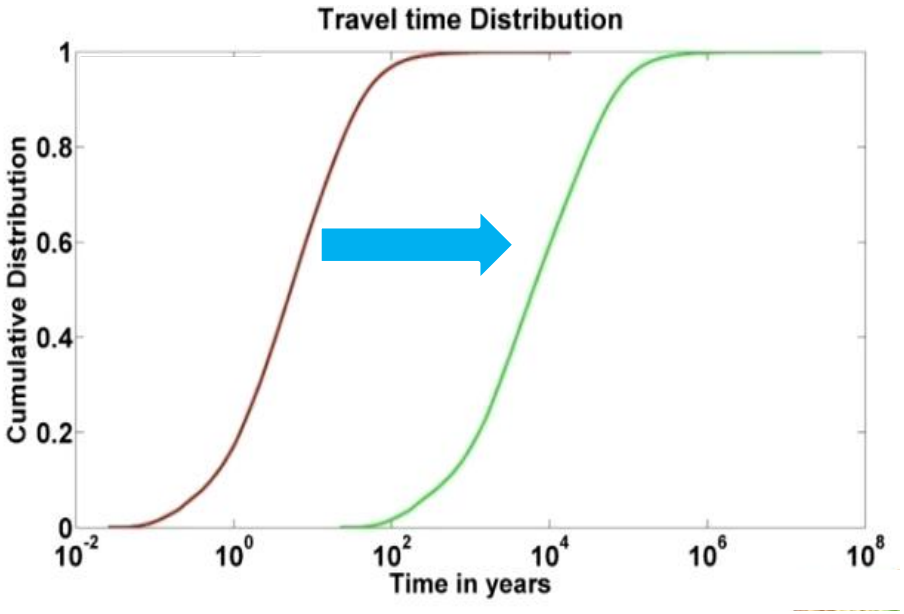
Implications:

Hydrological signals of permafrost thaw



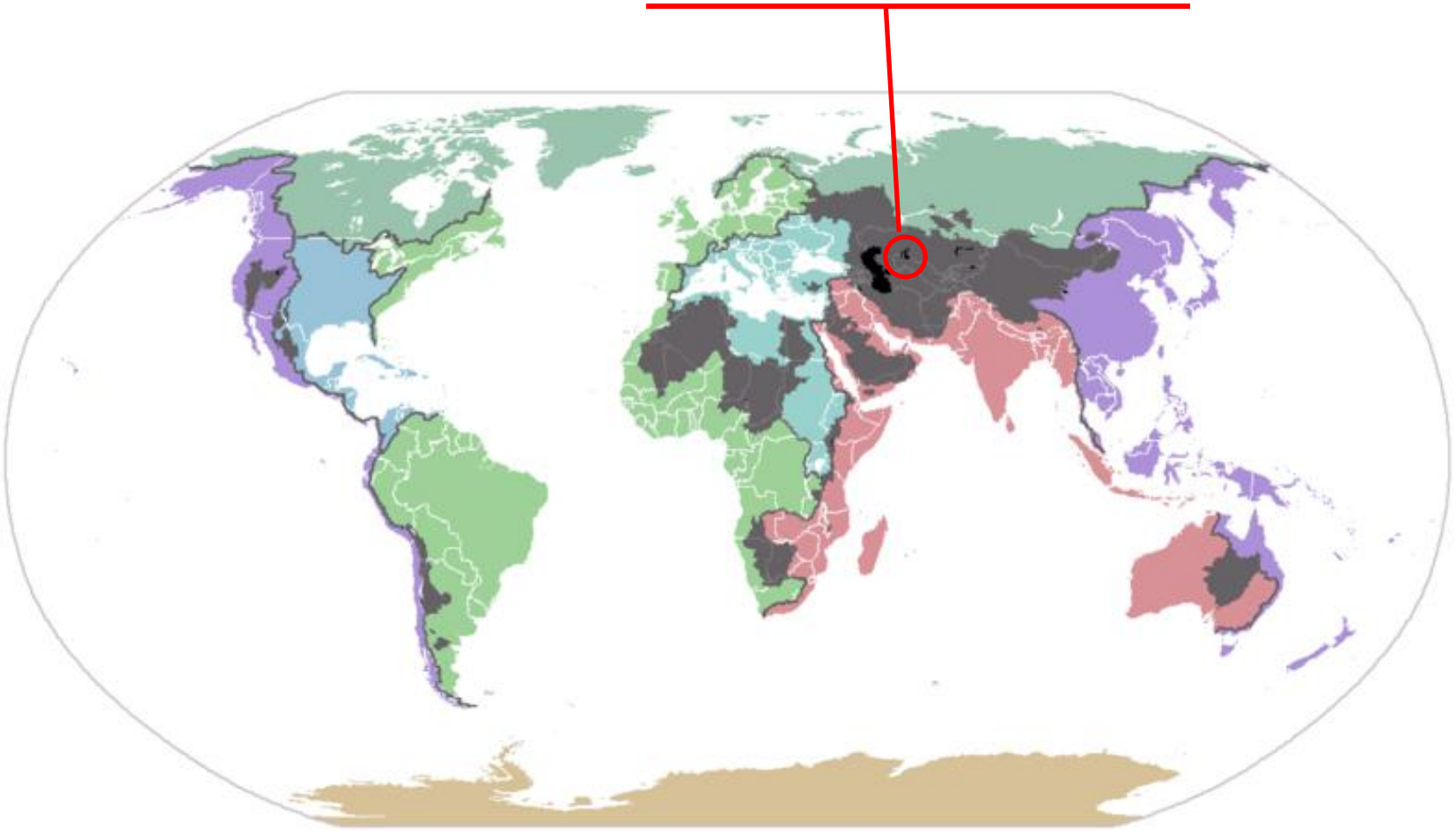
→ Decreased max flow
Increased min flow





2. The extreme case:

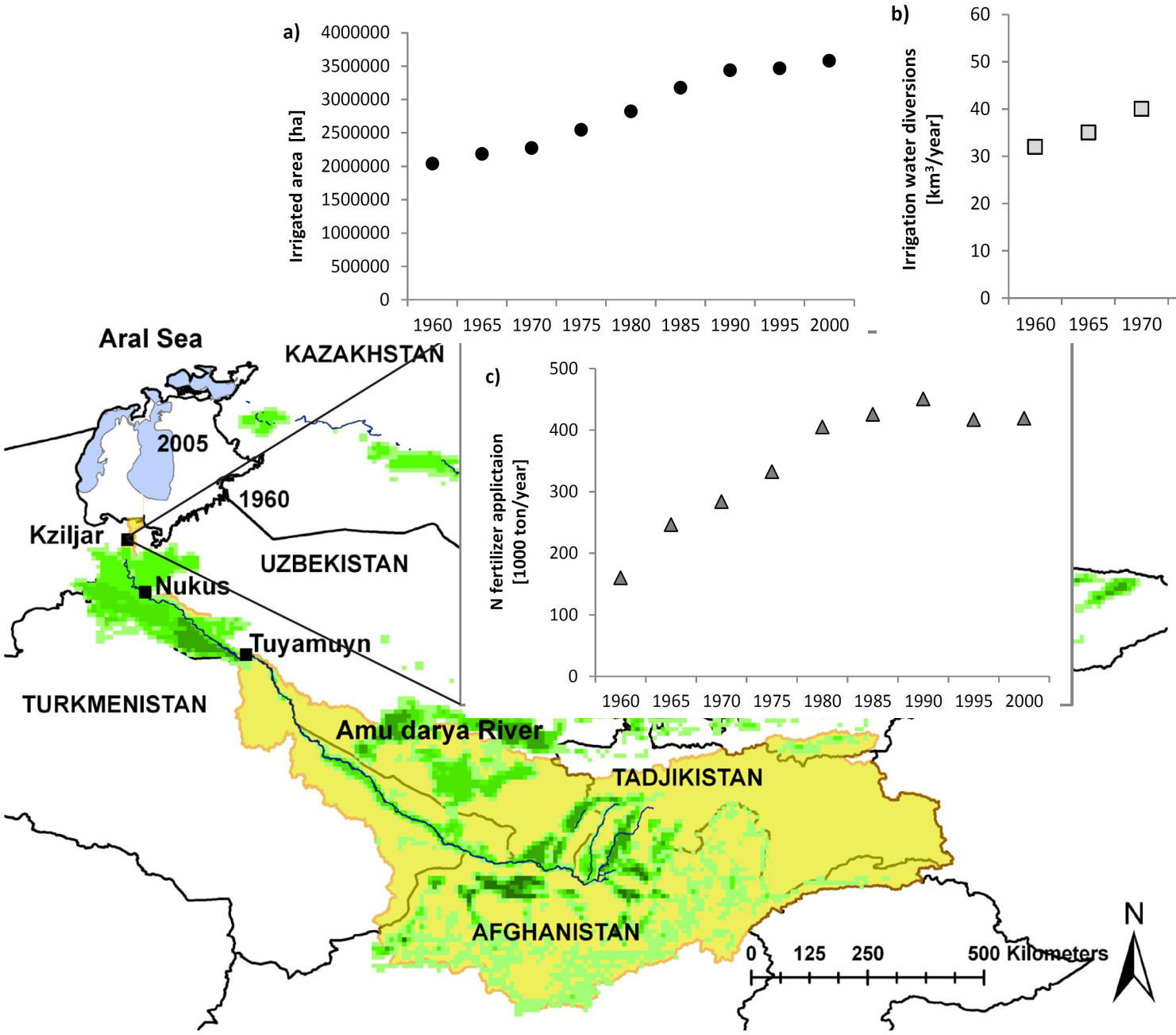
Water resources in the Aral Sea drainage Basin



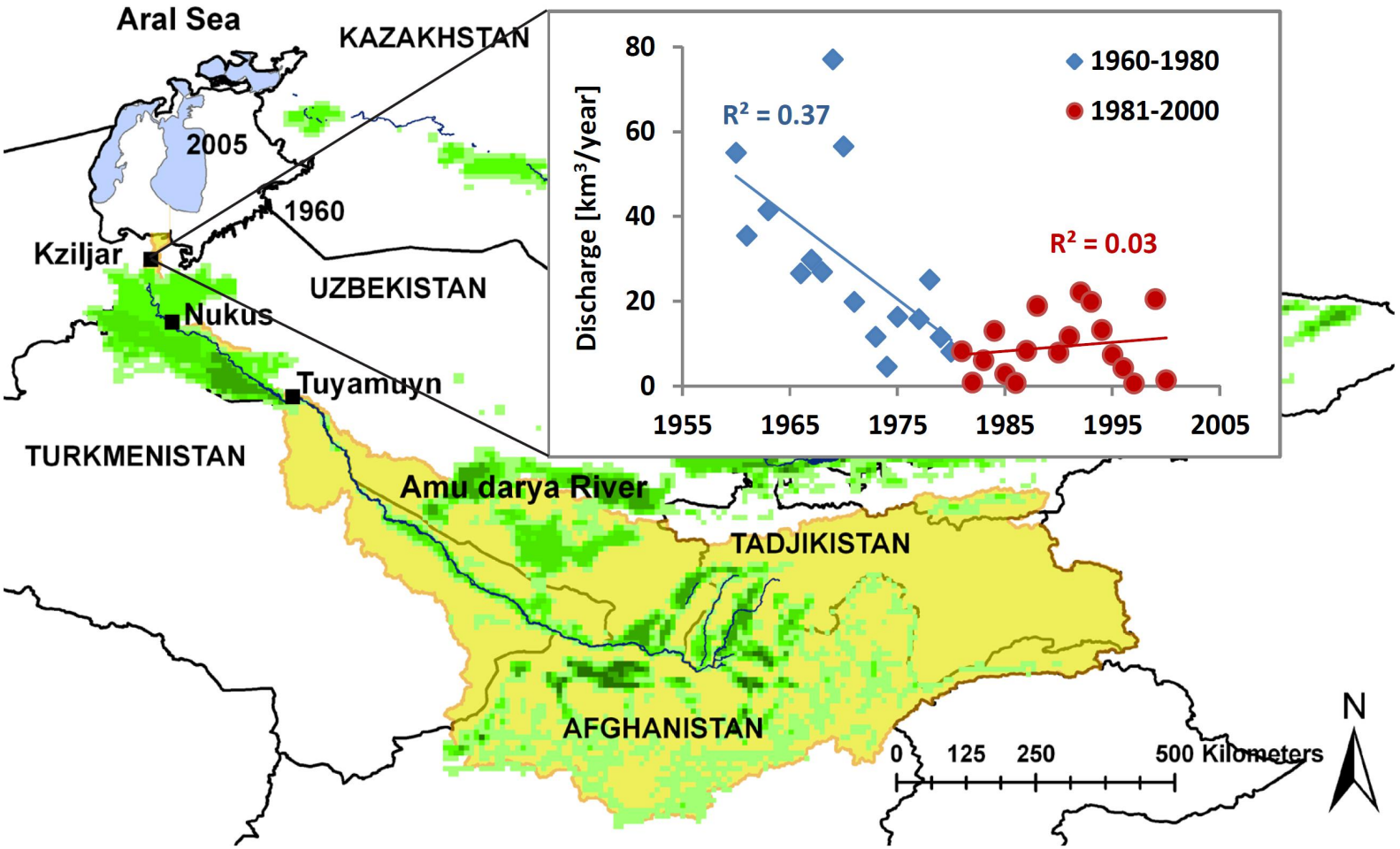
Present environmental & hydro-climatic changes → Changed transport and attenuation of chemicals?

Example of agricultural intensification

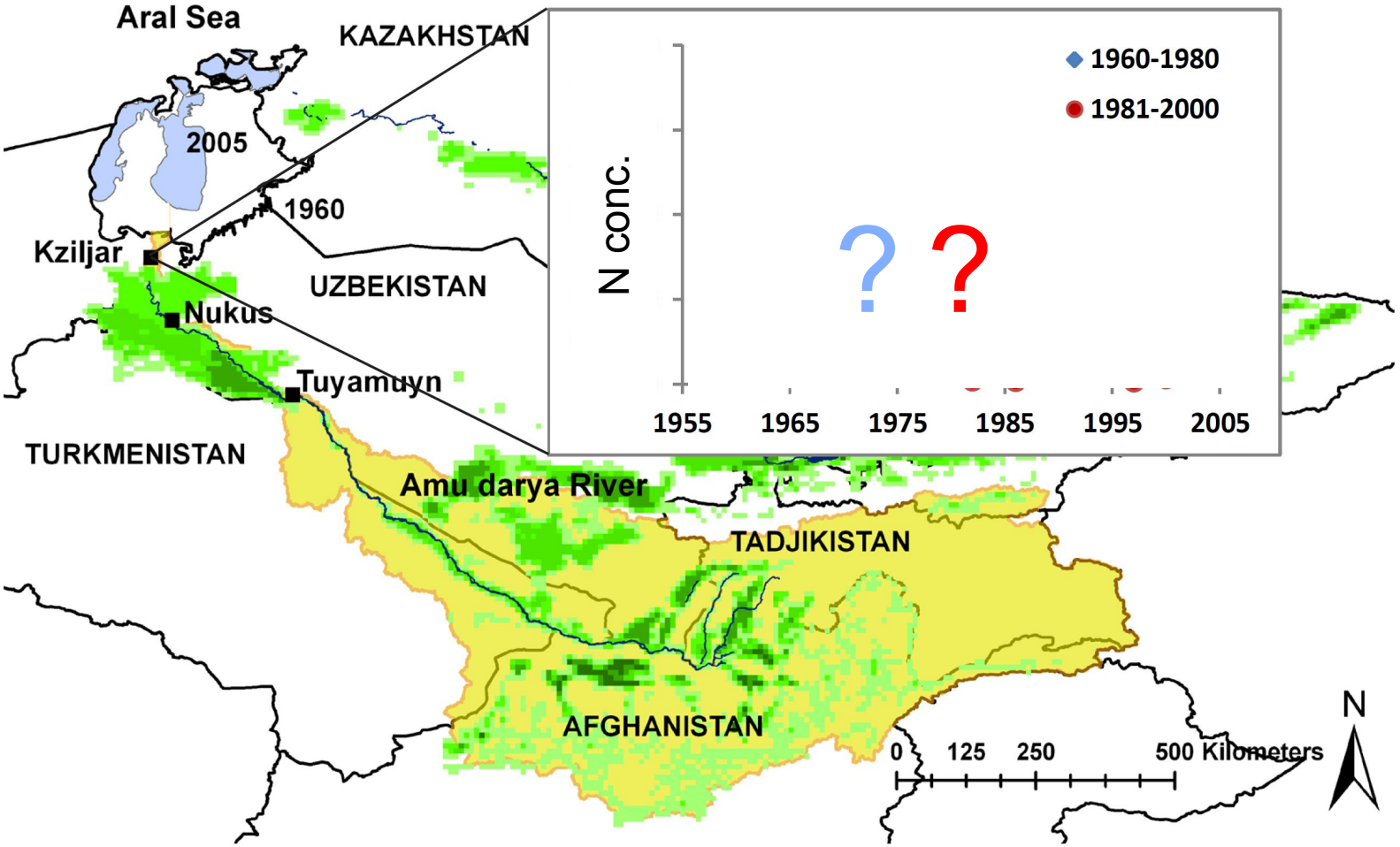
Example of agricultural intensification (under climate change)



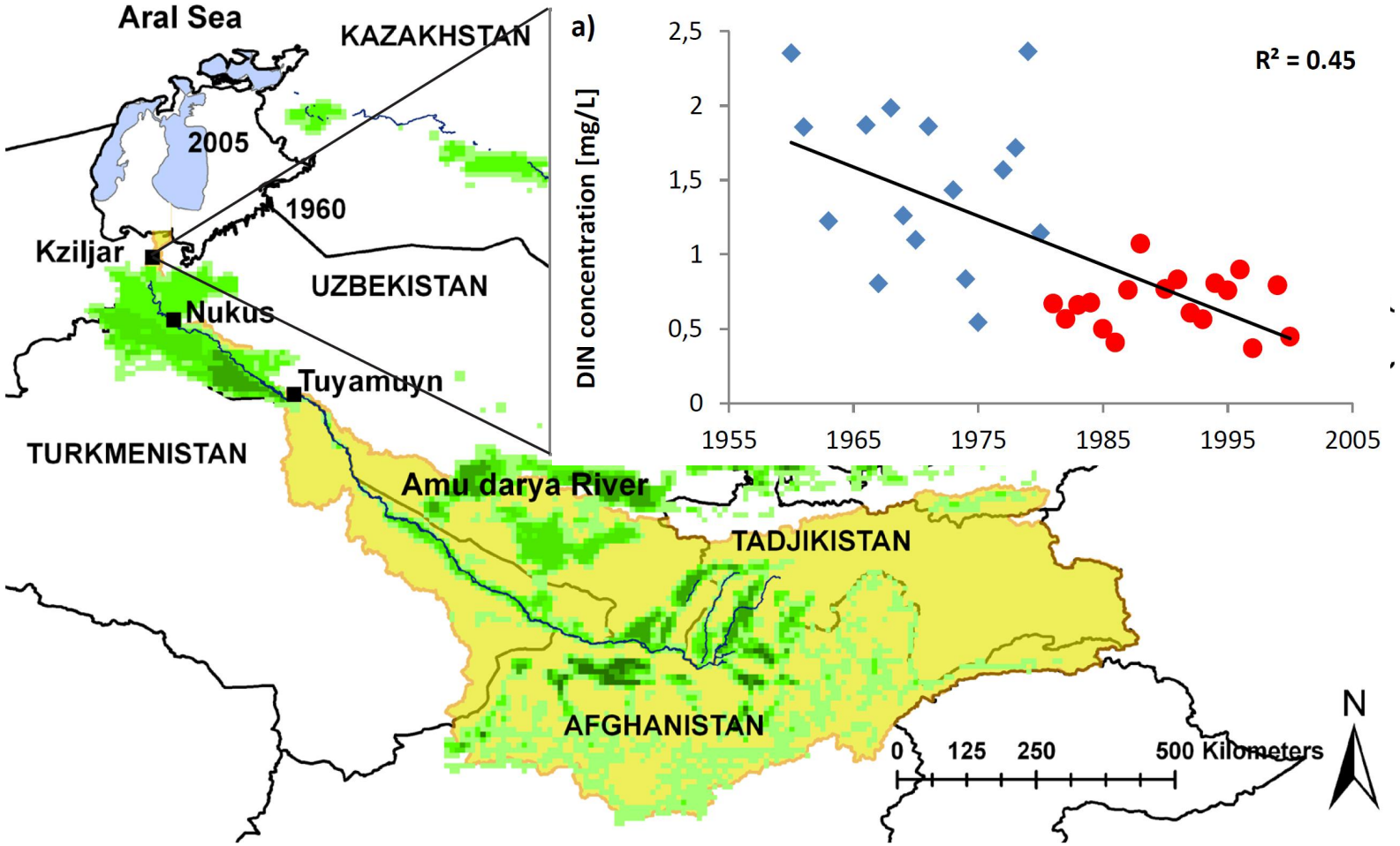
Resulting discharge change



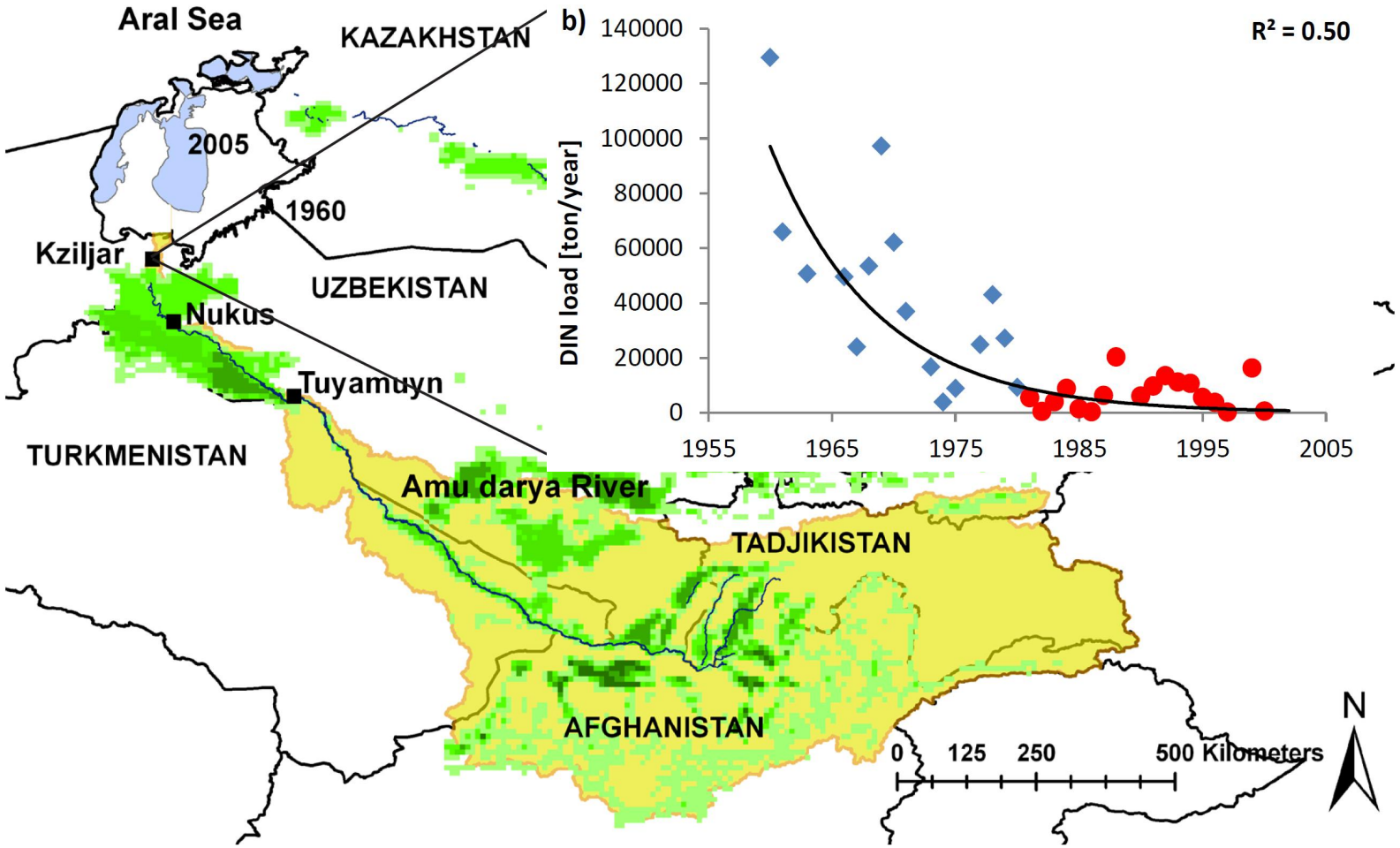
How would plots of nitrogen concentration and mass load (at the outlet) look like?



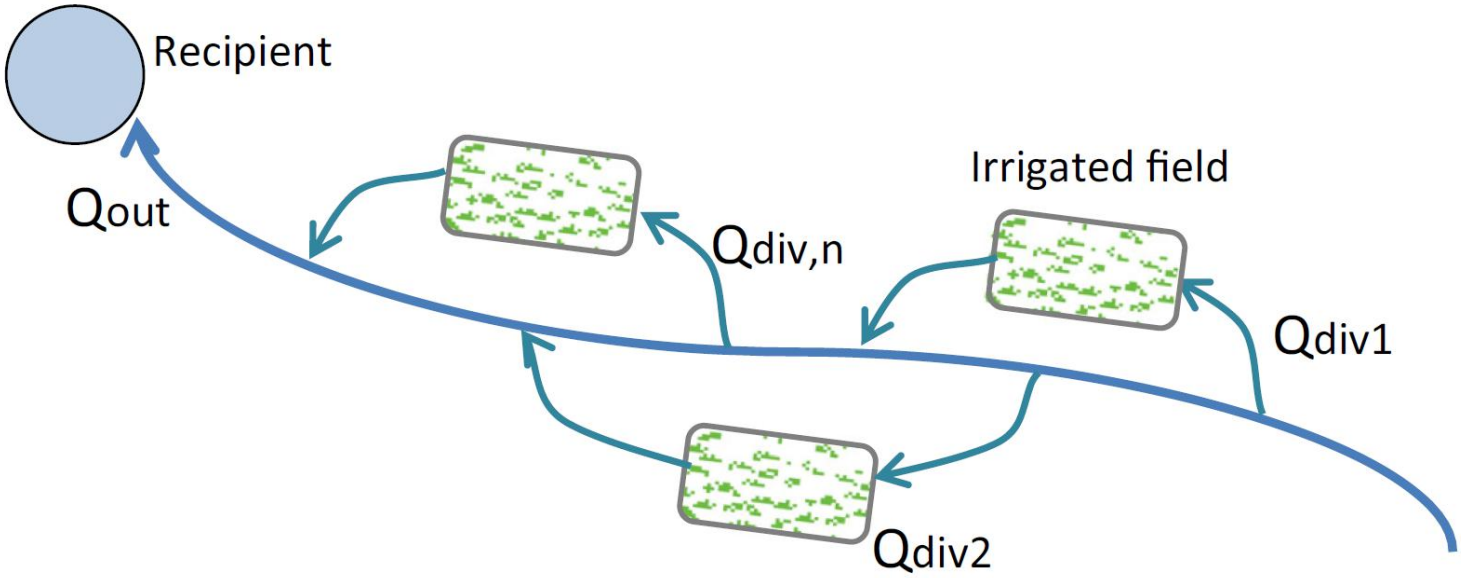
Resulting N (DIN) concentration change at the river outlet



Resulting N (DIN) mass load change at the river outlet



Which mechanism can cause such decreased concentrations and mass loads?



→ Filtering by diversion and re-circulation of river water

3. The eutrofication problem in the Baltic Sea drainage basin

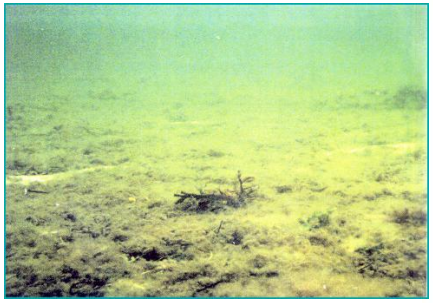


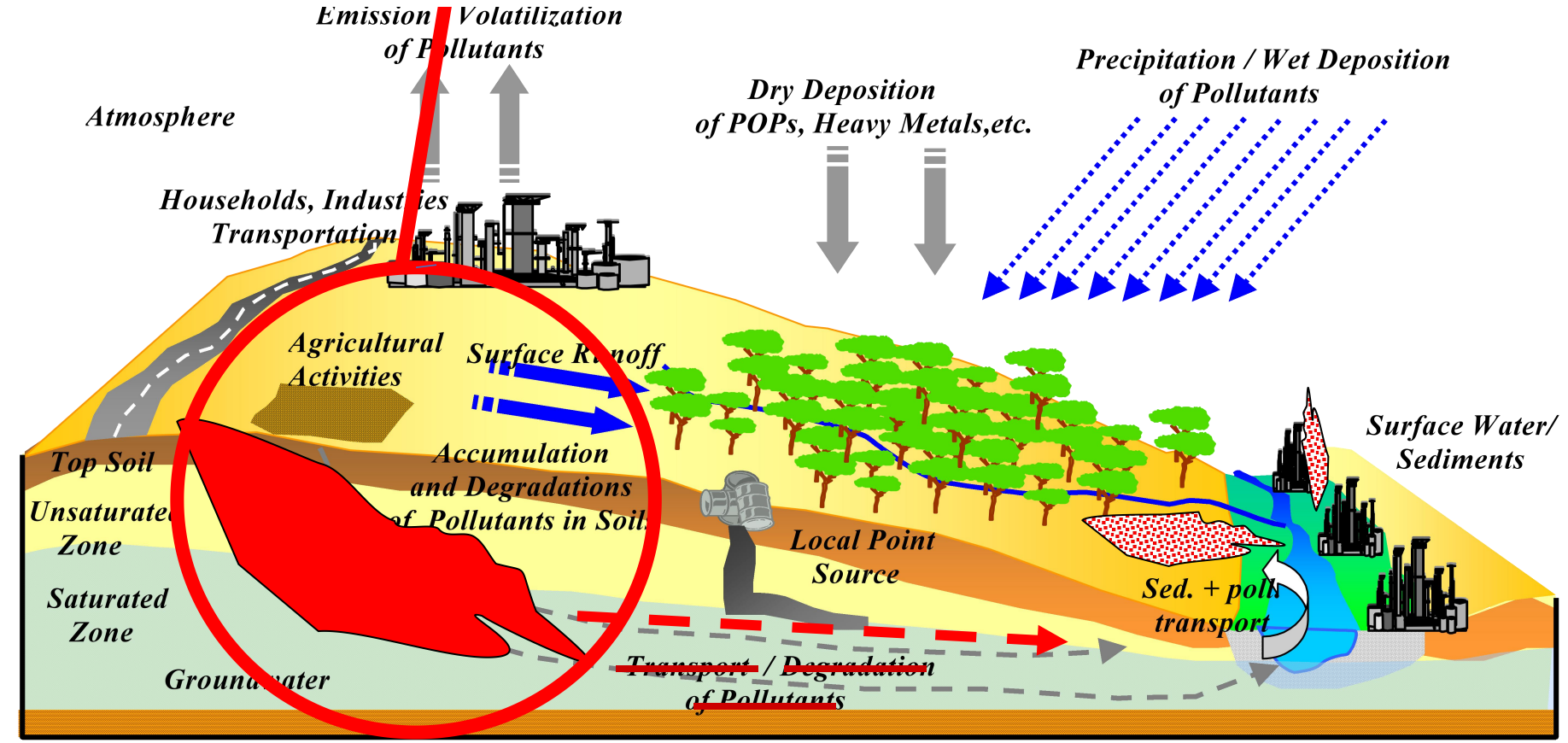
Figure 1. The new delineation of the Baltic Sea Drainage Basin (BSDB) with 634 drainage subbasins greater than 6 km^2.

Background: Pollutants in the water cycle

Baltic Sea problem:

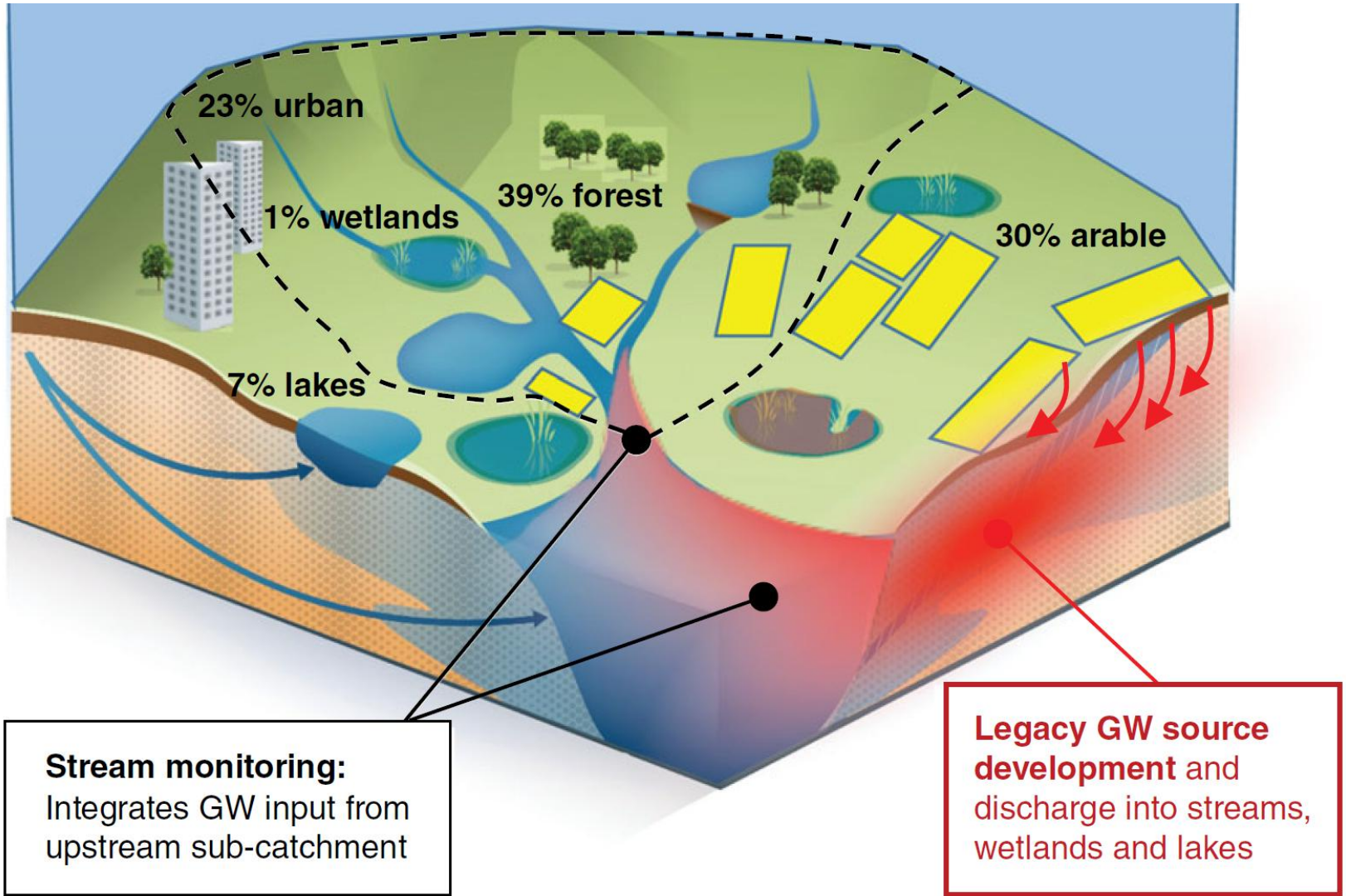
Focus on N and P from agriculture

Need to reduce inputs!

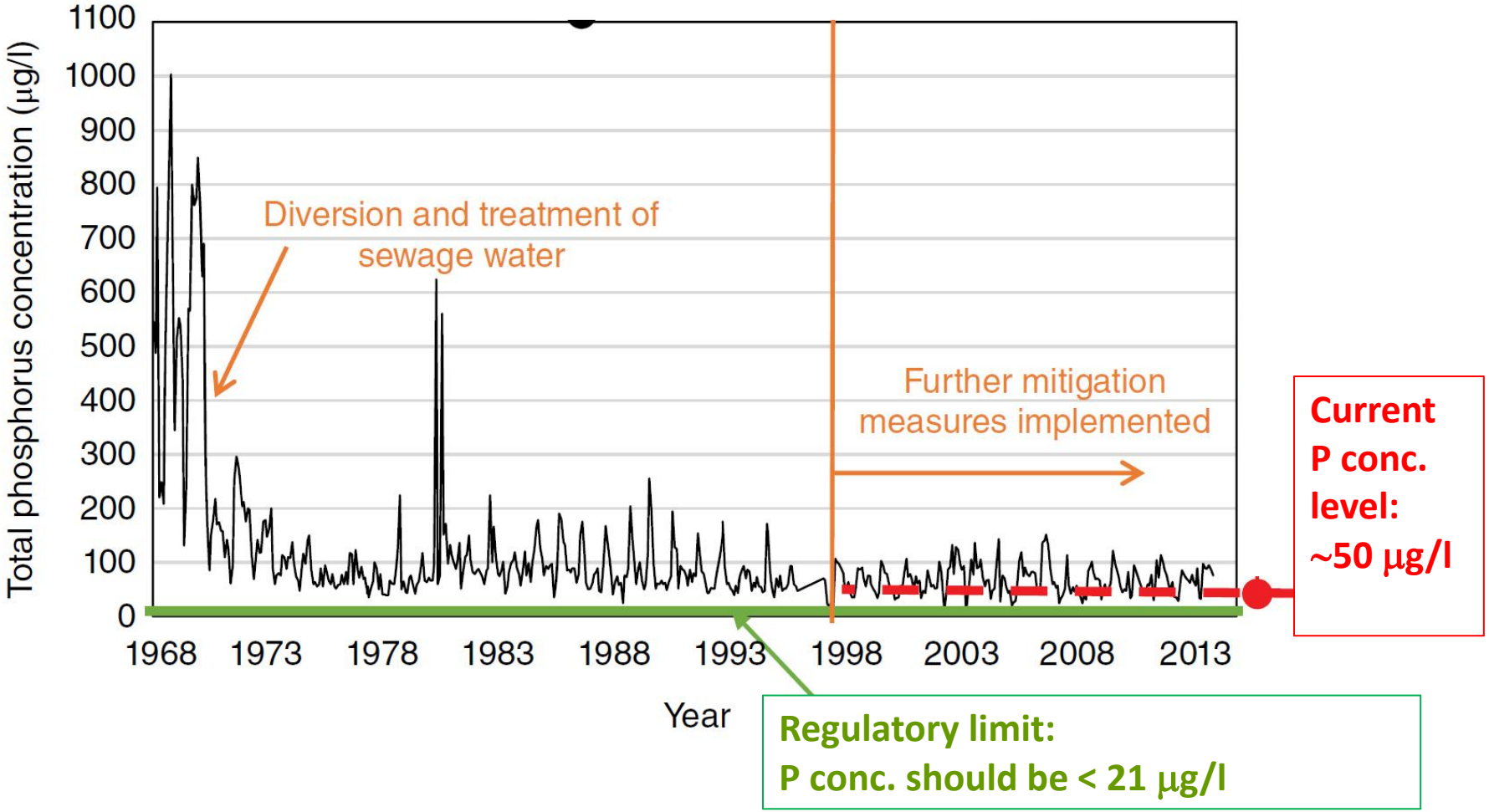


“Contaminant legacy” research questions:

- What is the impact of already contaminated, slowly moving groundwater?
- How much N and P is stored there?



P conc. in example stream 1968-2013

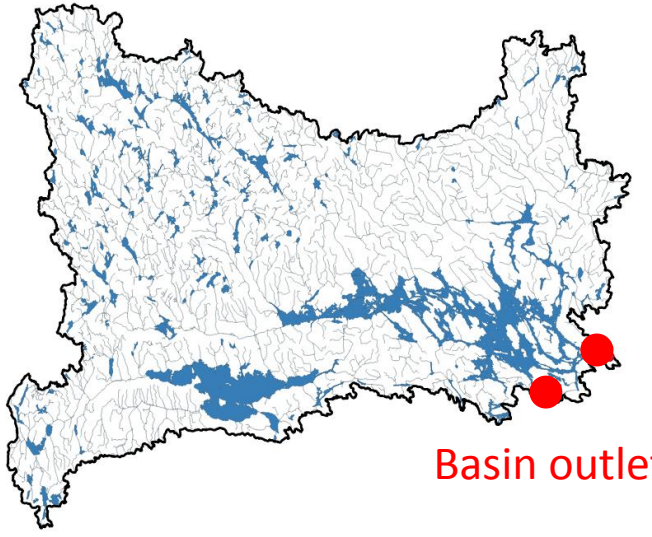


→ **HOW** and **WHEN** can we meet the **concentration limit**?
Depends on the storage in soil/groundwater (the "legacy")!
Need to do a mass balance to quantify this storage

Case study Norrström drainage basin, Sweden

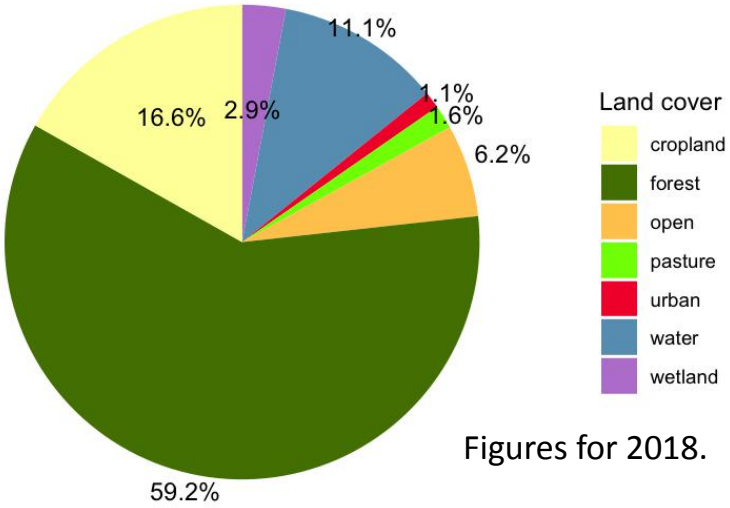
- How much N and P is stored in the soil/ groundwater?

→ Do a long-term mass balance of N and P storage in soil/ groundwater:
STORAGE = Input from agriculture MINUS discharge in streams



Two major lakes in the basin
- Hjälmaren (SW)
- Mälaren (SE), at the outlet

Norrström:
Land cover / Land use



Figures for 2018.

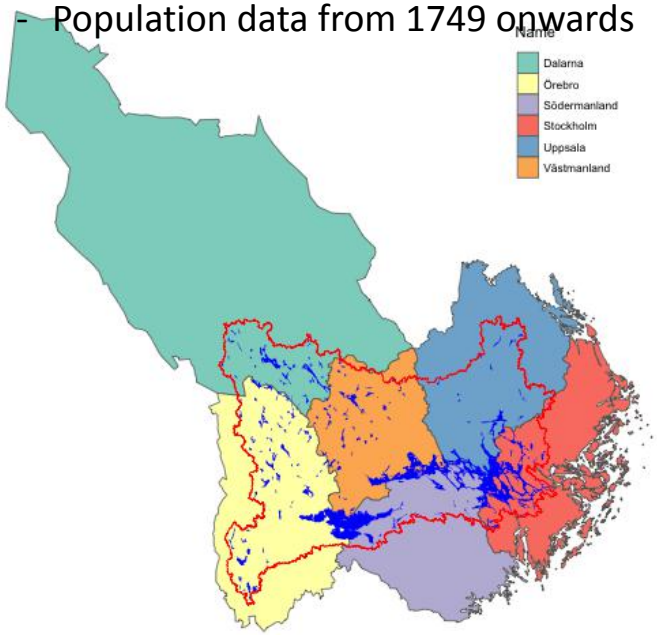
- The natural land cover is mixed forest. Much of it is now managed production forest.
- Only a small part of the landscape is suitable for agriculture.
- The extent of agricultural land peaked around 1920 and has been receding since then.

Data sources regarding **input (loading of N,P)**

Official statistics from the Swedish Board of Agriculture (”Jordbruksverket”) and Statistics Sweden (“Statistiska Centralbyrån”).

Counties

- Cropland areas from 1860s onwards
- Crop productions from 1913 onwards
- Population data from 1749 onwards

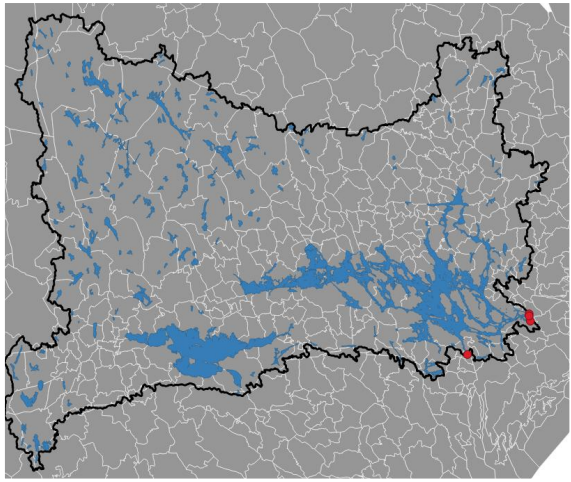


Municipalities

- Cropland areas from 1981 onwards
- Population data from 1950 onwards

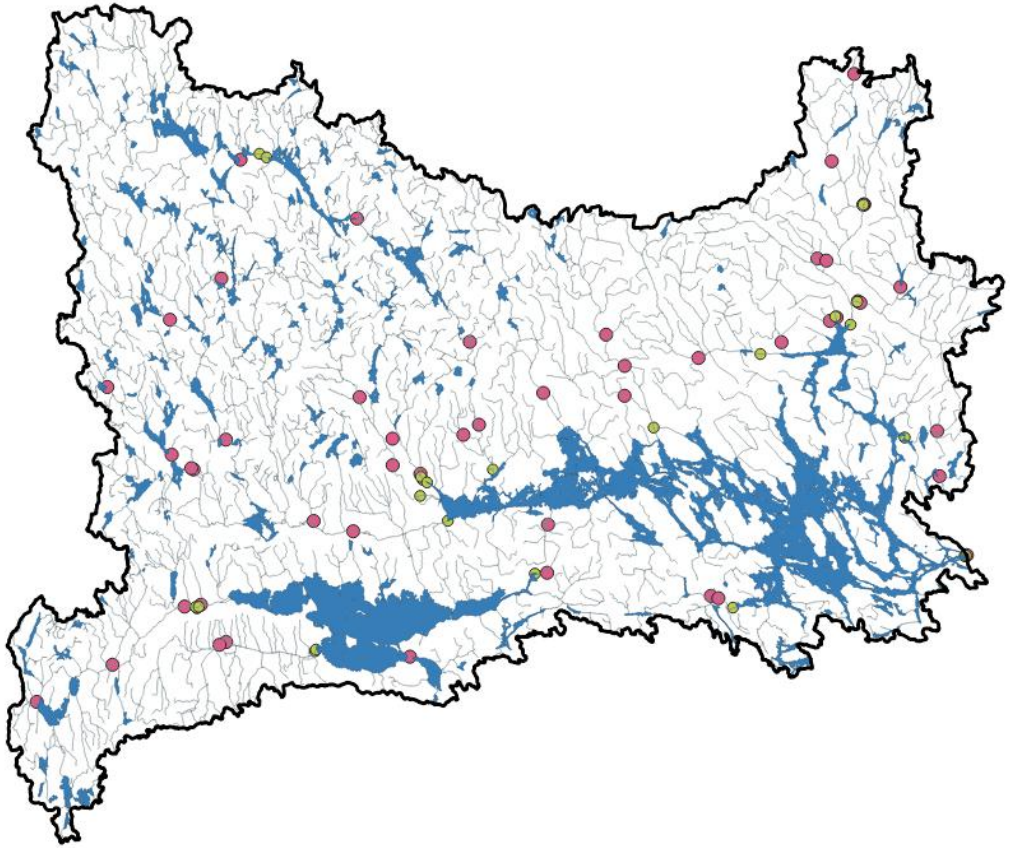
Parishes/hundreds

- Agricultural census in 1886, 1907, 1932, 1951, 1975, 1985, 1995 and 2010
- Population census 1880, 1890, 1900 and 1910



Data sources regarding **output (discharge of N, P)**

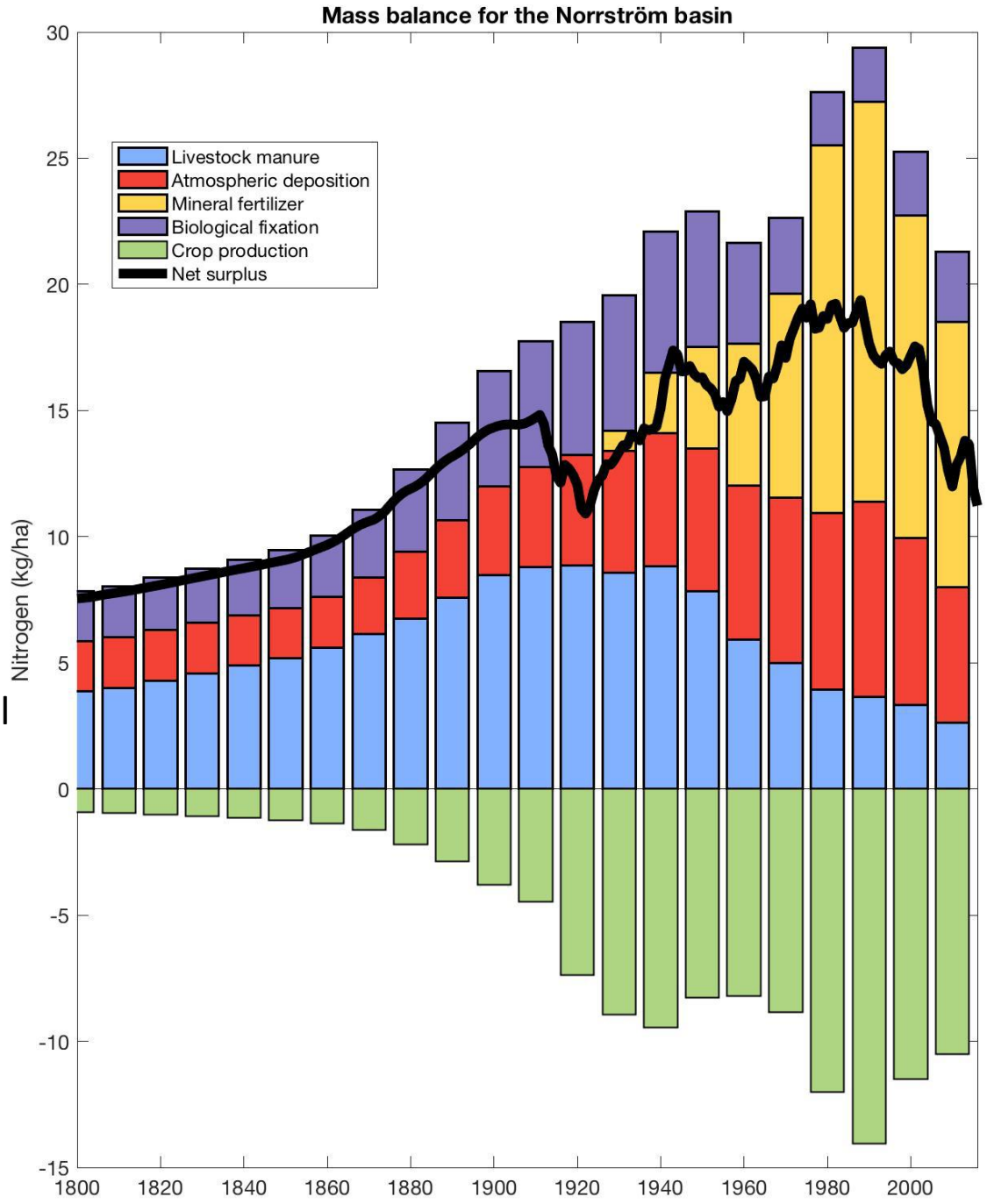
- Hydrological measurements compiled by the Swedish Meteorological and Hydrological Institute (SMHI) – in pink ->
- Water quality measurements compiled by the Swedish Agricultural University (SLU) – in green ->
- At the outlet: daily flow measurements since 1900, chemistry monthly since 1965
- In subcatchments, combined series of flow and chemistry start around 1980



Synthesis results:

Annual N input to the Norrström basin (1800-2016)

(to be used as input for ELEMeNT simulation of N accumulation in soil and groundwater)

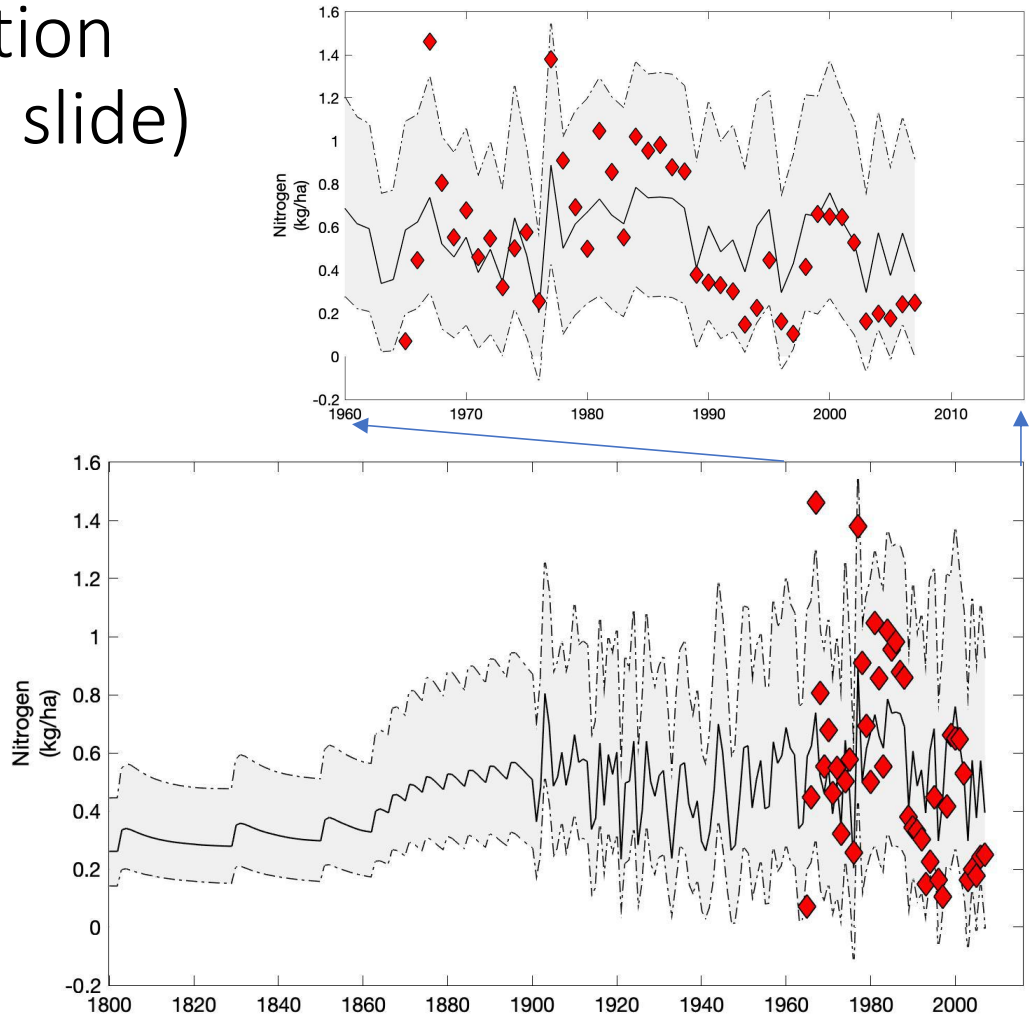


ELEMeNT-N model calibration (N input according to prev. slide)

Calibration of model output (black curve) to observed N conc at catchment outlet

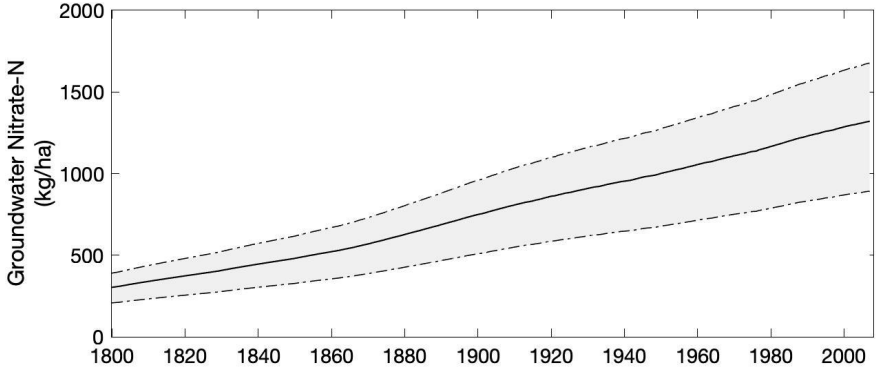
Semi-automatic calibration using a genetic algorithm for 3 parameters :

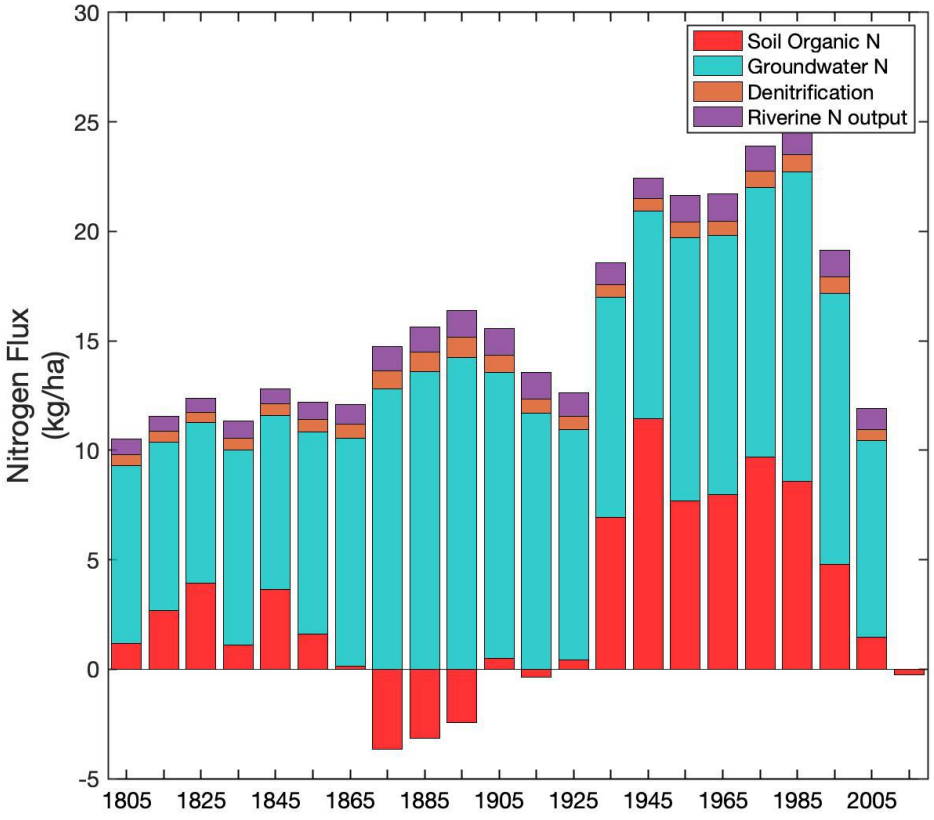
- mean travel time
- denitrification rate in groundwater
- denitrification rate for human waste



ELEMeNT-N model results

- Groundwater is the main sink for the N-surplus.
- Soil organic N seems to display three regimes:
  - 1800-1860: modest sink for N
  - 1860-1930: source of N or small sink
  - 1930-present: large sink of N





4. The use of wetlands in mitigating impacts of global change

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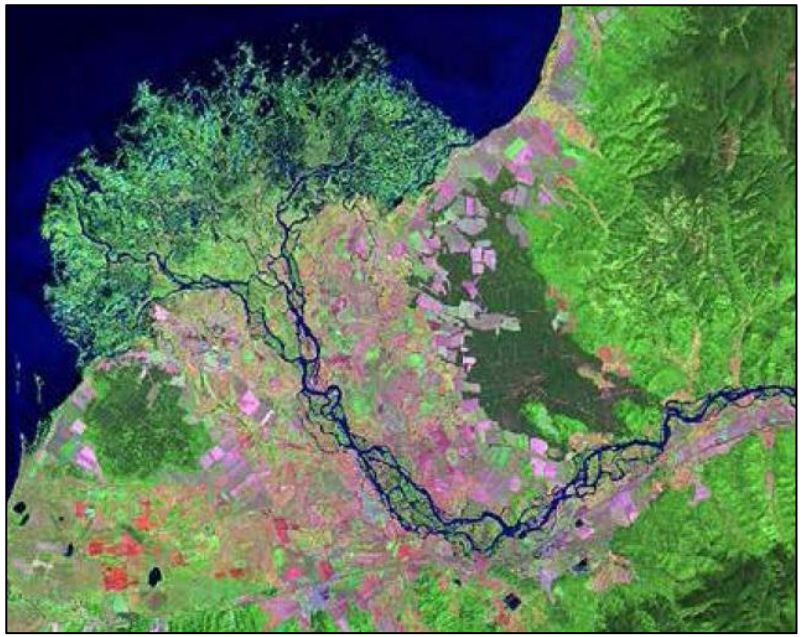
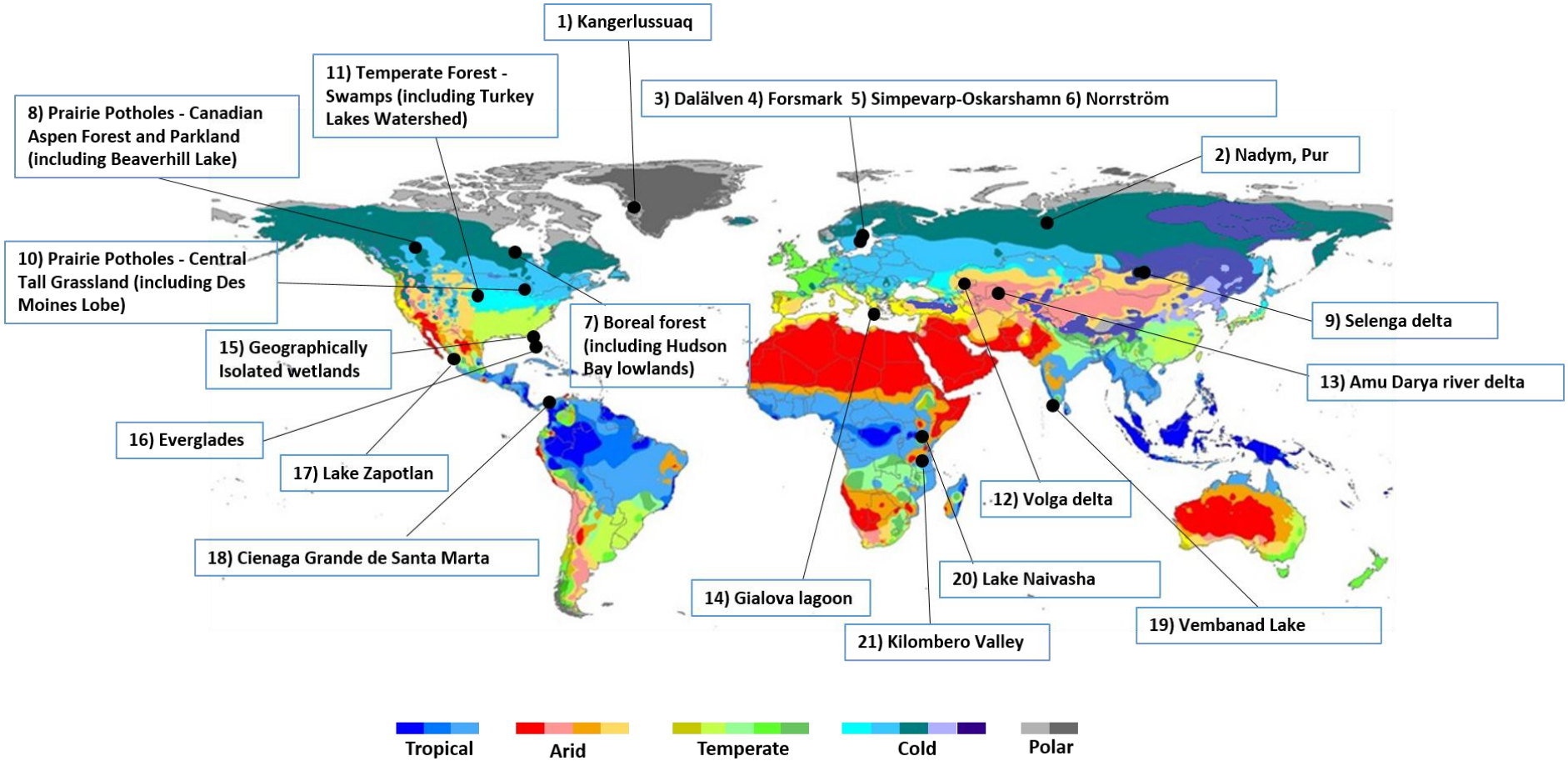
Stockholm University



Global Wetland Ecohydrology Network (GWEN)

(coordinated from Stockholm University)

Studying 21 wetland sites across the globe



www.gwennetwork.se

www.gwennetwork.se/

GWEN

Global Wetland Ecohydrology Network – An Agora for Scientists and Study Sites

HOME PHASE 1 PHASE 2 PUBLICATIONS

Welcome to the Global Wetland Ecohydrology Network – GWEN!

GWEN consists of a network of wetland researchers and study sites from around the world, who are all interested in sharing, investigating and applying research to improve knowledge on the large-scale function of and changes to wetland ecosystems.

Example pictures from different wetlands that we study

See more about who we are and what we do under the menu tabs: *Home, Phase 1-2 and Publications*

Opportunities of using wetlands as nature-based solutions

- Wetlands have the **potential to address a variety of environmental, social and economic challenges** for societies in sustainable ways.

- **Multi-beneficial** ecosystem **services** (climate-change regulation and adaptation, pollution mitigation, coastal protection)

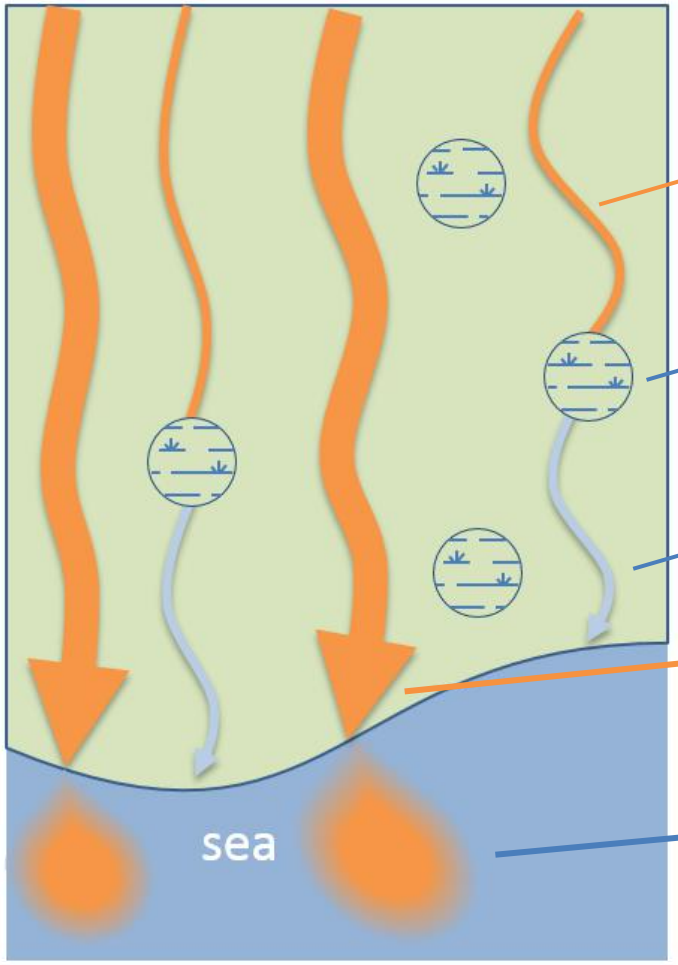
- Globally, wetland services are **highly valued** at more **than 20% of the total global service value** from all biomes (Costanza et al., 2014)

Challenges to wetland management today?

- **Large scale changes: climate, water-use, land-use that drive** water fluxes and balances
- **Major challenge**: understanding, evaluating, mitigating impacts of regional-global drivers on wetland functions and associated ecosystem services
- **Management decisions** - individual wetland sites, detailed observations and local conditions
- Increases the **need of strategies** for implementing large-scale nature-based solutions

"***The scale must be enlarged*** *from the individual wetland project to include the* ***broader landscape****. Only this broader view can* ***provide the context within which decision-makers can evaluate*** *the potential cumulative effects of individual mitigation decisions on broad-scale patterns of wetland diversity".* (Bedford and Preston 1988)

Example difference in contaminant removal between an individual wetland and a wetlandscape



Contaminated water

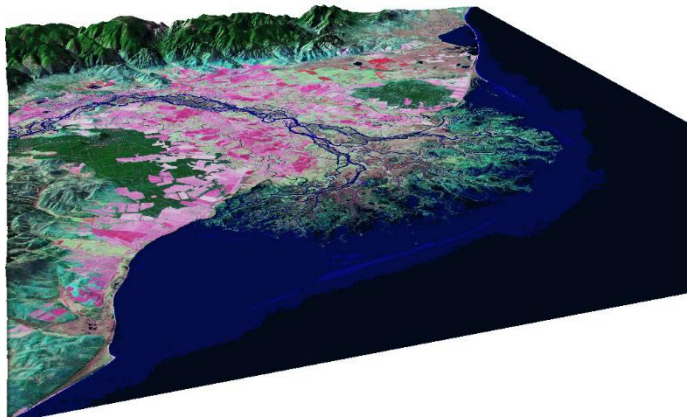
Efficient contaminant removal *in individual wetland*

Clean water

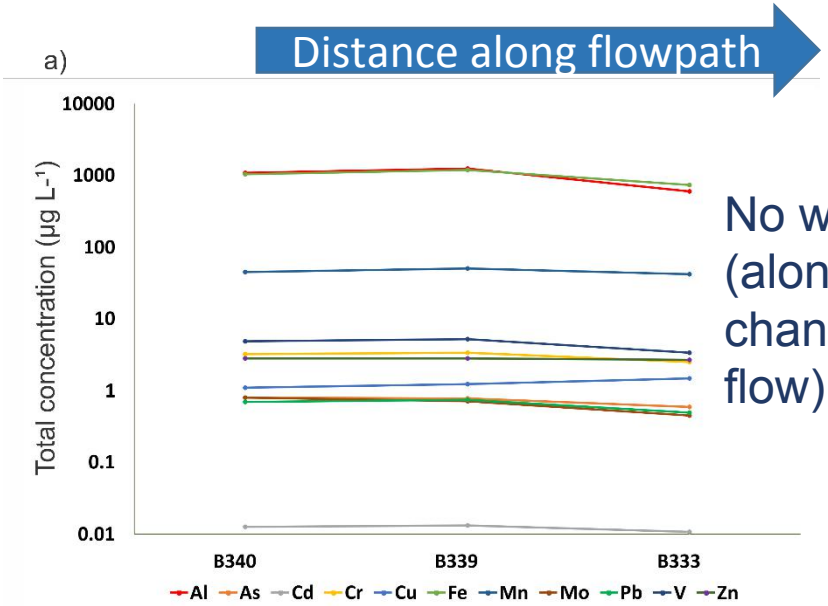
Contaminated water bypassing wetlands

Poor contaminant removal *by wetlandscape*

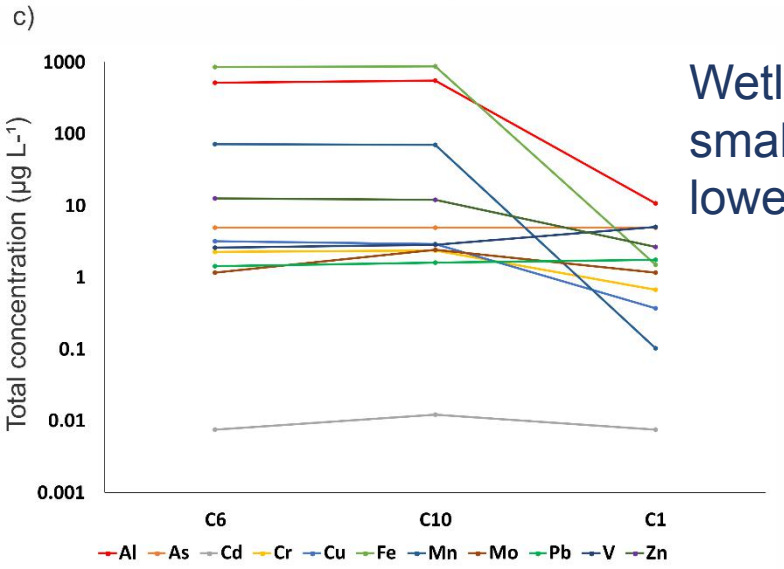
We observed /measured this phenomenon in the Selenga River delta at Lake Baikal, Russia



Impacts on recipient processes?

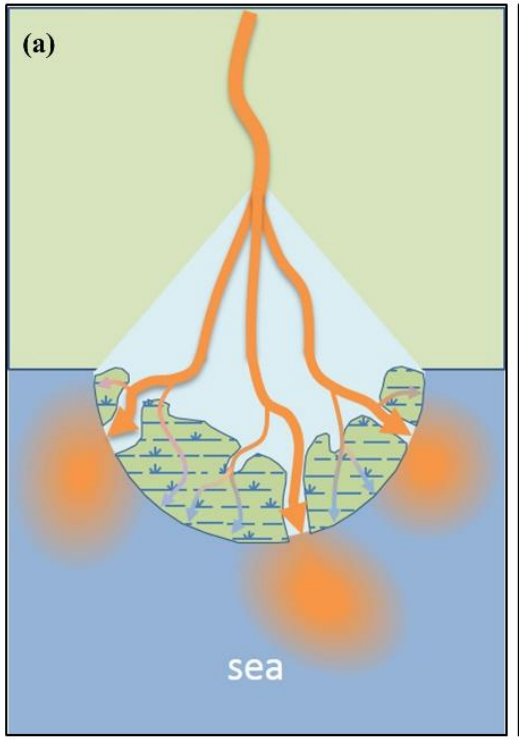


No wetlands (along large channel / higher flow)

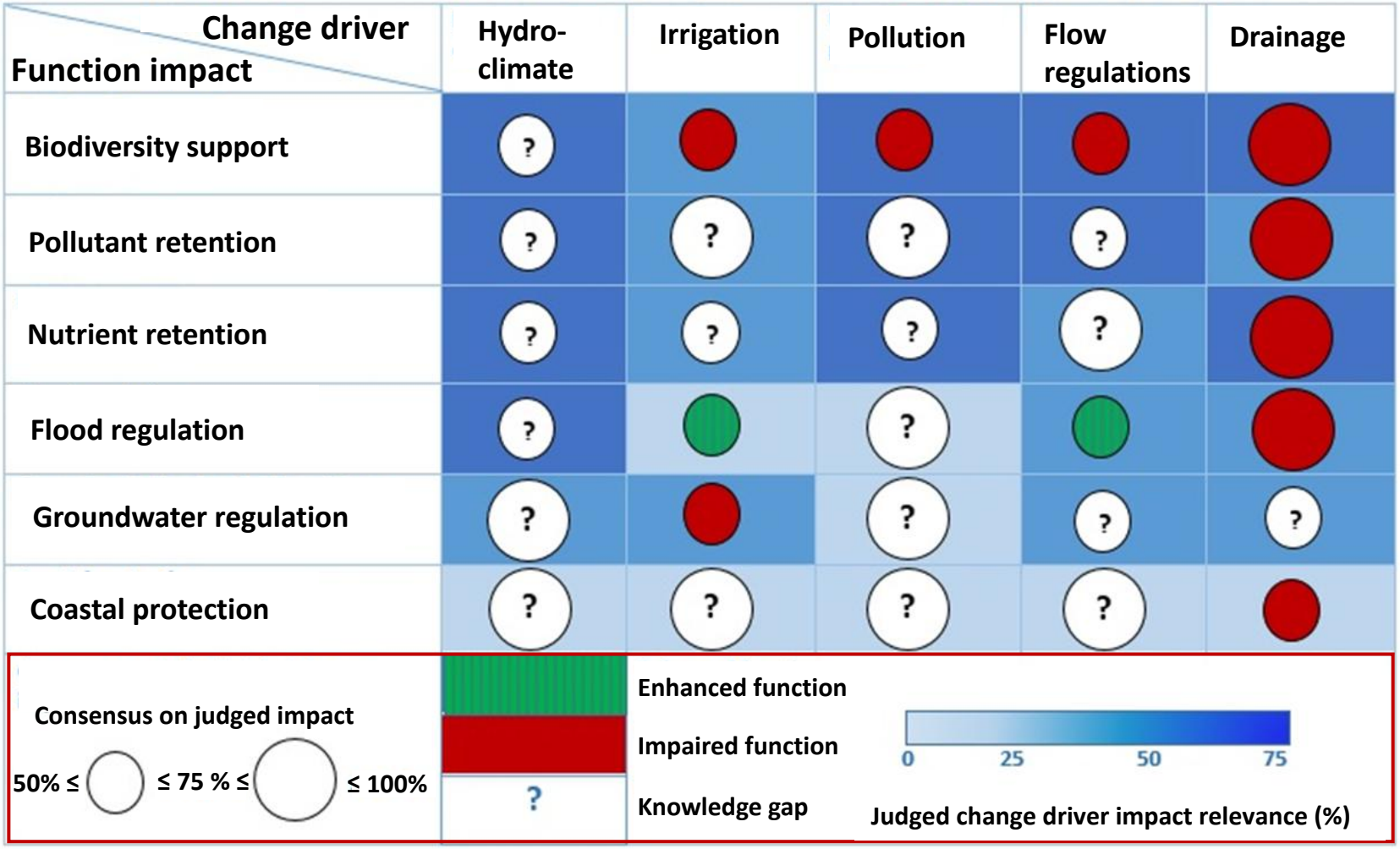


Wetlands (along small channels / lower flow)

Retention within the Selenga delta



What do we know?
The opinion of 20 GWEN researchers
Literature surey of 21,000 publications



From: Thorslund, et al. (2017) *Ecological Engineering,* 108, 489–497

Main research questions

- *If and how do research address and understand **large-scale wetlandscape dynamics** under regional-global change?*

- *To which extent may **large-scale wetlandscape** functions, services and impacts **differ between regions, and from those of individual wetlands**?*

- *Can they even be **predictable** from the behavior of individual wetlands?*

Case study Norrström drainage basin, Sweden

GIS-based analysis + field measurements:

-15 wetland catchments (“wetlandscapes”)

-1699 wetlands

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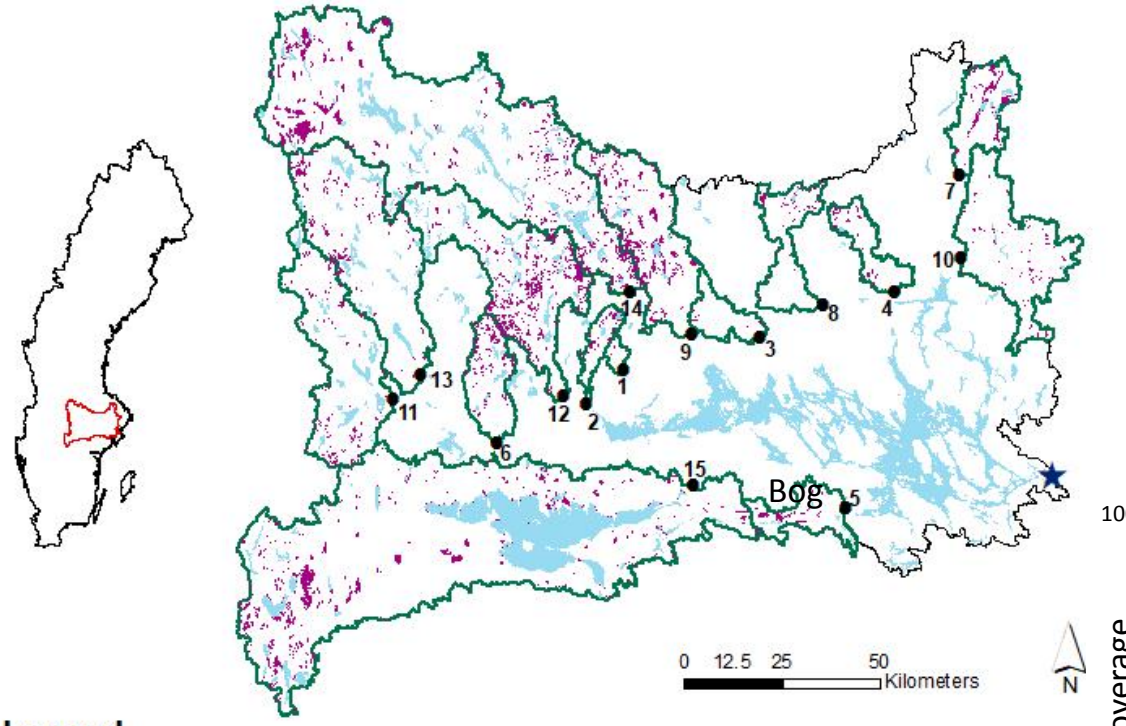


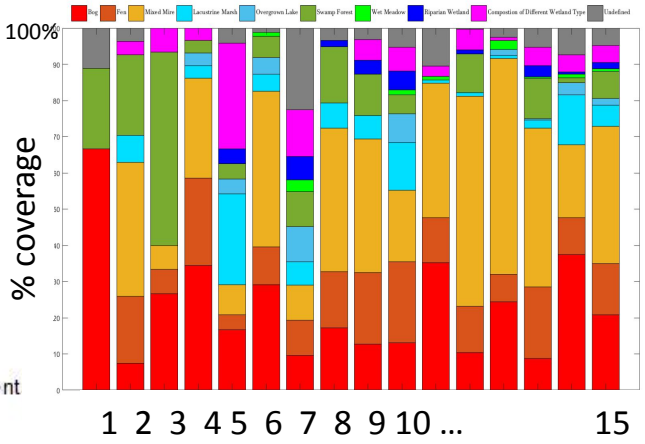
Legend

★ STOCKHOLM	5 ●	ÅKERS KRUTBRUK	11 ●	HAMMARBY	Wetlands
Discharge stations	6 ●	FELLINGSBRO	12 ●	DÖMSTA	Lakes
1 ● BERG	7 ●	VATTHOLMA	13 ●	DALKARLSHYTTAN	Wetlandscapes (catchment
2 ● ODENSVIBRON	8 ●	HÄRNEVI	14 ●	RAMNÄS	
3 ● GRÄNVAD	9 ●	ÅKESTA KVARN	15 ●	ÖVRE HYNDEVAD	
4 ● RANSTA	10 ●	SÄVJA			

Wetland type:

- Bog
- Fen
- Mixed mire
- Lacustrine march
- Swamp forest

etc…



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Field measurements:

* Water levels (continuous – pressure transducers installed end of March-beginning of April 2019)

* Streamflow (today + this summer)

* Insect traps (this summer)

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Concluding remarks

Stockholm University

1. **The Lake Baikal basin study showed that:**
   - The climate model results regarding runoff trend were inconsistent with observations
   - Seasonal changes in runoff indicate basin-wide permafrost thaw

2. **The Aral Sea studies showed that:**
   - N concentrations decreased in river water near the Aral Sea
   - Main reason: increased N filtering effect of the groundwater system
   - BUT: groundwater becomes more contaminated (e.g. with N)

Concluding remarks

Stockholm University

3. The Baltic Sea studies showed that:

- The eutrophication problem remains despite hard restrictions on agriculture
- Main reason: increased N storage in the groundwater system
- Even if we remove all of today's N input, the groundwater-fed streams may continue to feed the Baltic sea with N for many decades to come
- Current research focus: How long is this time lag more exactly? What is the possible additional impact of climate change?

Concluding remarks

Stockholm University

4. The wetland studies showed that:

- Wetlands/ wetlandscapes perform important services (e.g. cleaning water)

But

- There are large knowledge gaps regarding how climate change will impact wetlandscapes (nutrient retention, biodiversity, etc)
- The functions of individual wetlands can be very different from the functions of wetlandscapes
- Functions can also be very different in different wetlandscapes.

E.g.:

- in the studied Norrström drainage basin (Sweden), only wetlandscapes above a certain size (~250 km2) showed the ecohydrological characteristics required for large-scale nutrient/ contaminant retention and biodiversity support

Outlook – future plans

Intensified wetland monitoring (including constructed wetlands)

Target: measurements in >100 wetlands

Long term mass balances (with the ELEMeNT model) to determine legacy stores in multiple catchments across the world

New project on mining impacts in the Arctic

New collaboration on the Three gorges reservoir area

water

an Open Access Journal by MDPI

Call for papers

IMPACT FACTOR 2.069

Pollutant/Nutrient Transport and Fate under Changing Hydroclimatic Conditions

Guest Editors:

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Deadline for manuscript submissions:
30 November 2019

Message from the Guest Editors

Dear Colleagues,

This Special Issue welomes contributions on key challenges in a wide spectrum of complex problems related pollutant/nutrient transport under hydroclimatic change at different scales. Important aspects include, but are not limited to (changes in):

- *Water and/or sediment discharge patterns*, impacting e.g., mobilization, concentration, and mass flows (suspended, dissolved and total) of pollutants and nutrients.
- *Soil moisture, infiltration rates, and leaching conditions,* impacting pollutant/nutrient transport through, and retention in, the unsaturated zone.

Key publications

Bring, A., Asokan, S.M., Jaramillo, F., Jarsjö, J., Levi, L., Pietroń, J., Prieto, C., Rogberg, P. and Destouni, G., 2015. Implications of freshwater flux data from the CMIP5 multi-model output across a set of Northern Hemisphere drainage basins. *Earth's Future*, 3, doi:10.1002/2014EF000296.

Chalov, S.R, Thorslund, J., Kasimov, N., Aybullatov, D. Ilyicheva, E., Karthe, D., Kositsky, A., Lychagin, M, Nittrouer, J., Pavlov, M., Pietroń, J., Shinkareva, G., Tarasov, M. Garmaev, E., Akhtman, Y. and Jarsjö, J., 2017. The Selenga River delta: a geochemical barrier protecting Lake Baikal waters. *Regional Environmental Change*, 17, 2039–2053.

Destouni, G. and Jarsjö, J., 2018. Zones of untreatable water pollution call for better appreciation of mitigation limits and opportunities. *Wiley Interdisciplinary Reviews: Water*, e1312.

Jarsjö, J., Törnqvist, R. and Su, Y., 2017. Climate-driven change of nitrogen retention – attenuation near irrigated fields: Multi-model projections for Central Asia. *Environmental Earth Sciences*, 76, 117.

Törnqvist, R., Jarsjö, J., Thorslund, J., Rao, P.S.C., Basu, N.B. and Destouni, G., 2015. Mechanisms of basin-scale nitrogen load reductions under intensified irrigated agriculture. *PLoS ONE*, 10(3), e0120015, doi:10.1371/journal.pone.0120015.

Thorslund, J., Jarsjö, J., Jaramillo, F., et al., 2017. Wetlands as large-scale nature-based solutions: status and challenges for research, engineering and management. *Ecological Engineering*, 108, 489–497.

Thank you !