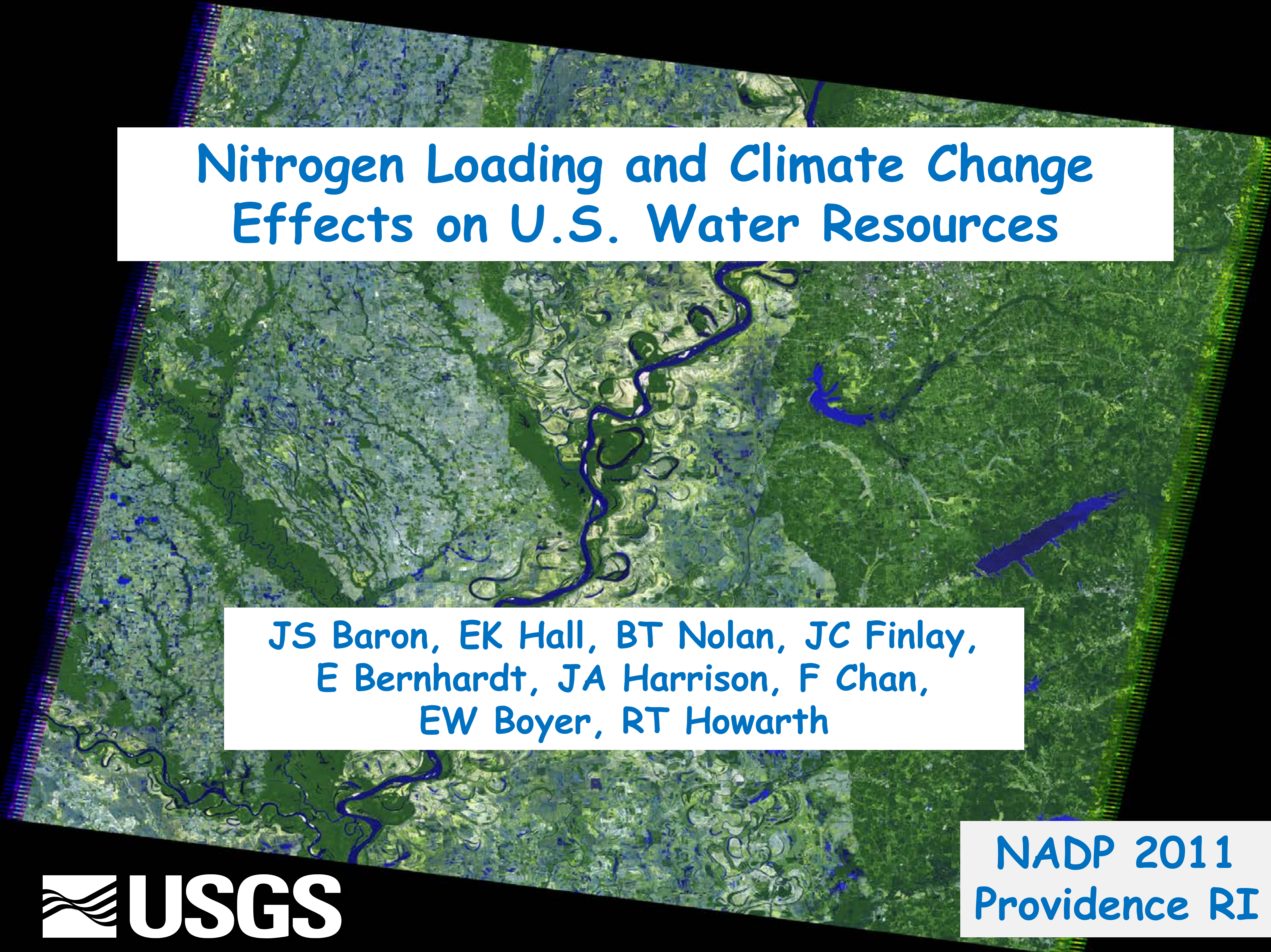
Nitrogen Loading and Climate Change Effects on U.S. Water Resources



JS Baron, EK Hall, BT Nolan, JC Finlay, E Bernhardt, JA Harrison, F Chan, EW Boyer, RT Howarth

USGS

NADP 2011
Providence RI

U.S. Water Resources

Lakes, Reservoirs, Streams, Rivers, Wetlands, Estuaries

Climate-N Interactions

1. Nearly all US waters are degraded by excess Nr
2. Nr is transported to coastal waters if not processed along the way → burial or denitrification

AQUATIC SYSTEMS ARE HOTSPOTS FOR DENITRIFICATION

3. Massive hydrologic manipulation of US waters both increases and decreases the rate of delivery to coasts
4. Climate change will also both increase and decrease rate of delivery through changes in the hydrologic cycle

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Where Does the N Come From?

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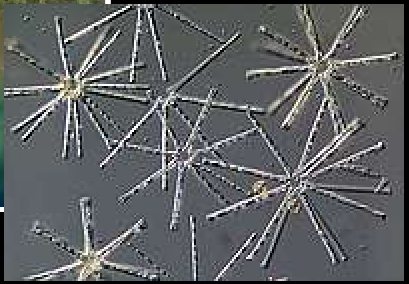
Climate-N Interactions

Nearly all US waters are degraded by excess Nr

Well-known adverse effects

- Eutrophication
- Acidification (incl. marine)
- GHG production
- Damage to human health
- Hypoxia and anoxia
- Biodiversity loss
- Economic costs



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Many US Waters Have Excessive Nitrogen

- Median [Total N] in Ag regions 6X greater than background (0.5 mg/L)
- 64% of shallow groundwaters in ag/urban have elevated N
- >20% shallow groundwater wells exceed human health standards for N
- Northeast, Midwest, and all mountains affected by atmospheric deposition





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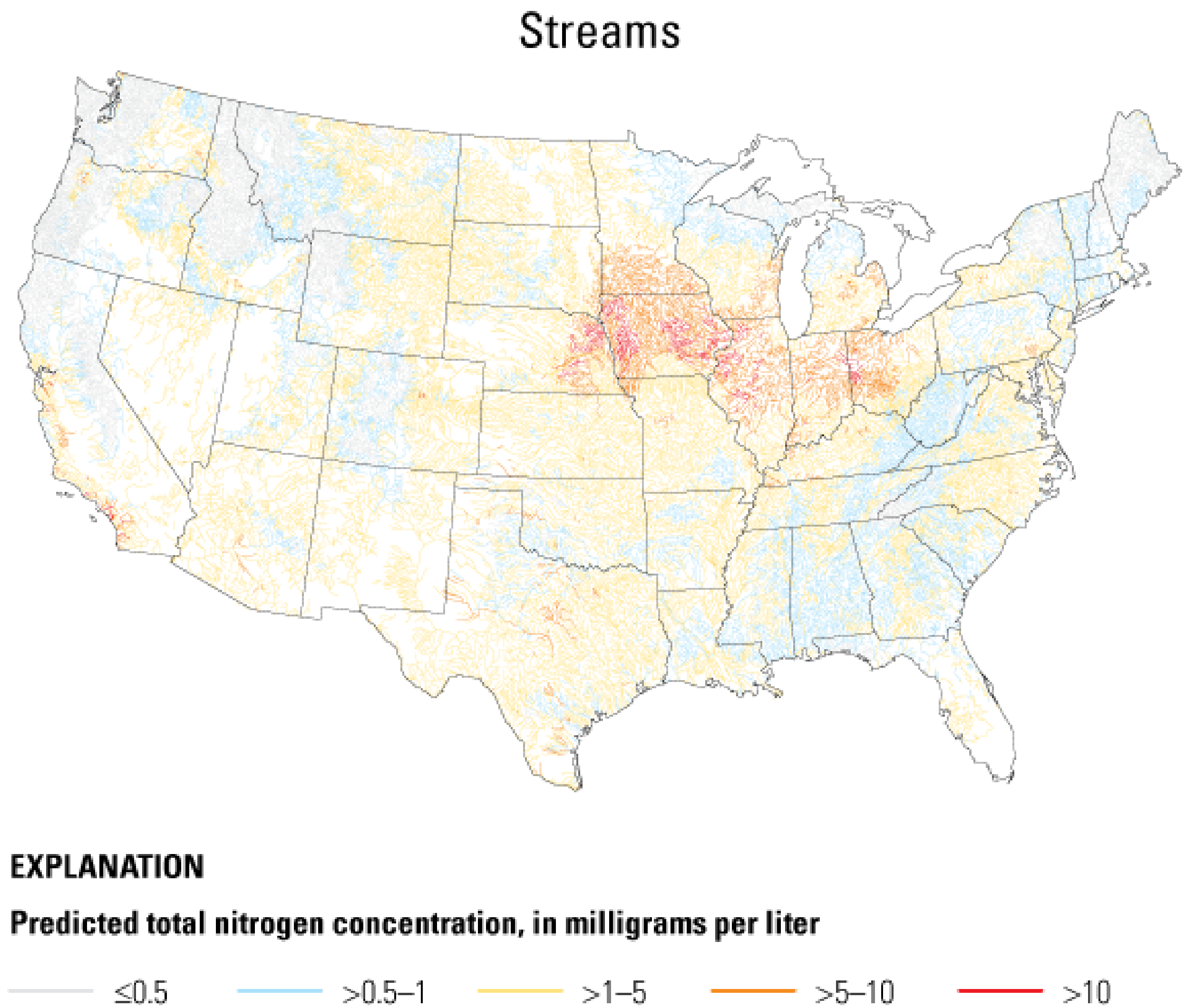
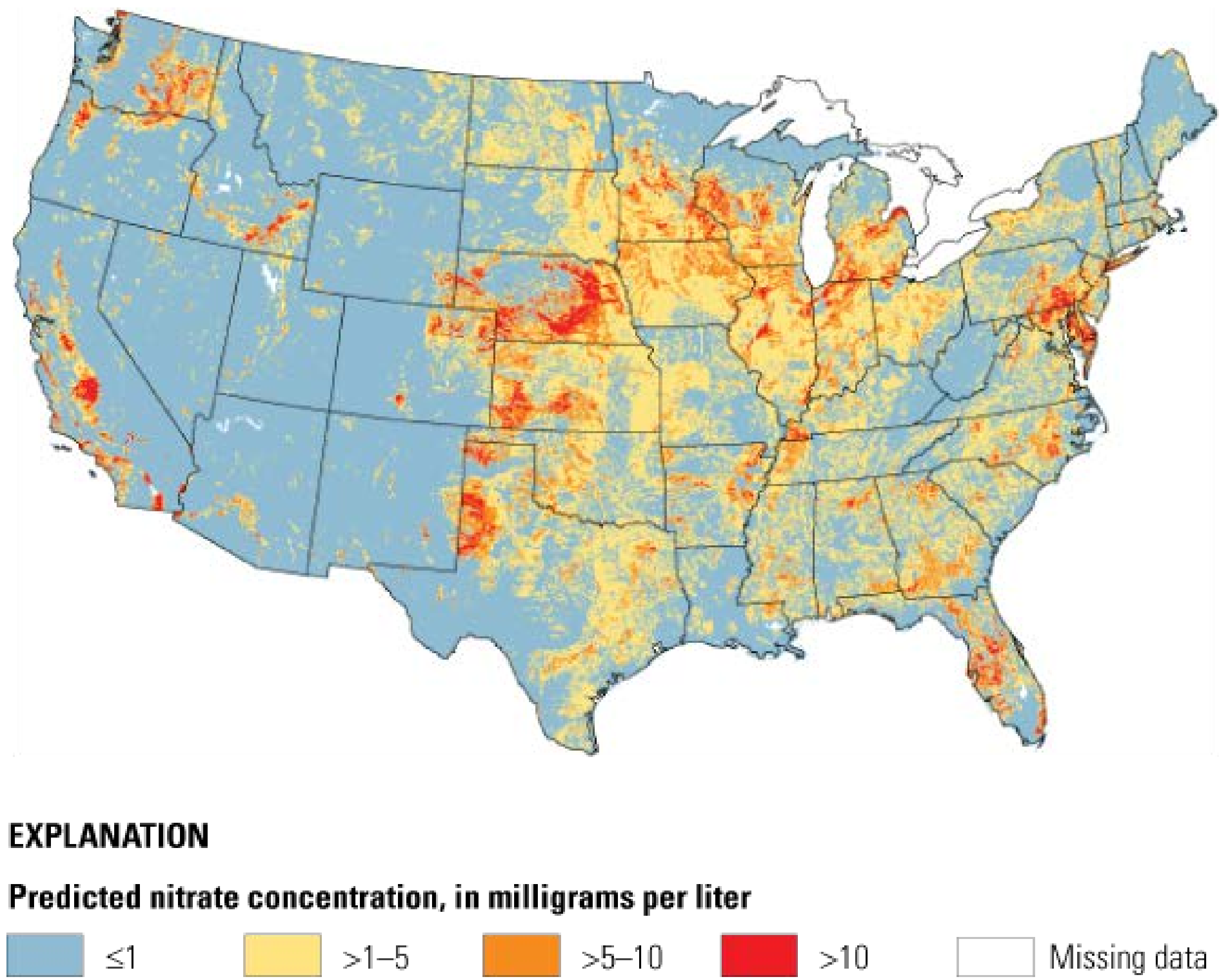
US Streams Have High N Concentrations



USGS
science for a changing world

Dubrovsky et al. 2010

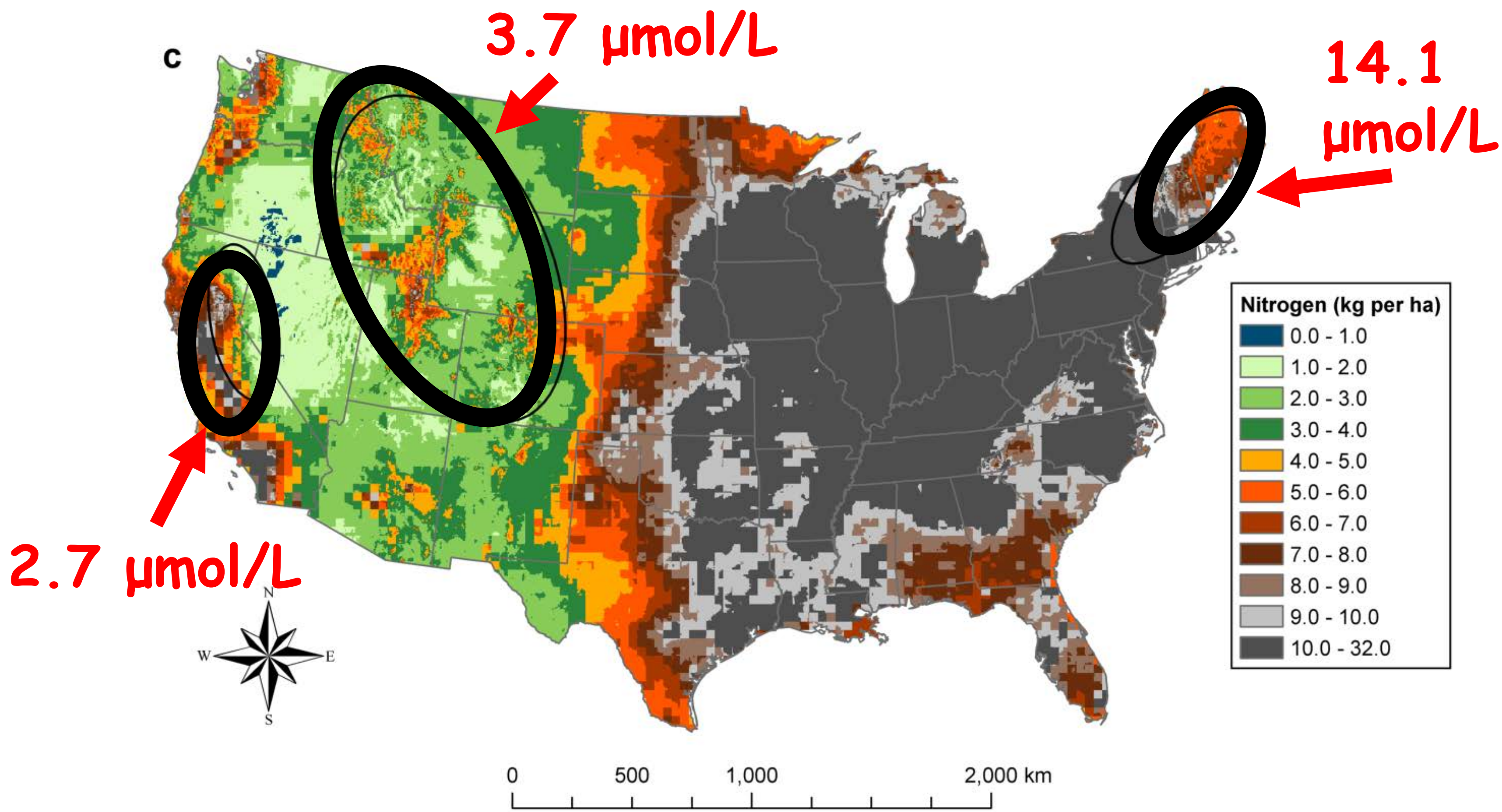
High N Concentrations in US Groundwaters



USGS
science for a changing world

Dubrovsky et al. 2010

Most Mountain Lakes Have Nitrate in Excess of the Critical Load



NADP+PRISM + CMAQ Dry N 2002

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Colorado State University Knowledge to Go Places

Nitrogen Pollution in Coastal Waters
Shifting Redox in Coastal Waters

Eutrophic
Hypoxic

World Resource Institute 2011

Climate-N Interactions

- Nearly all US waters degraded by excess Nr

USGS

Climate-N Interactions

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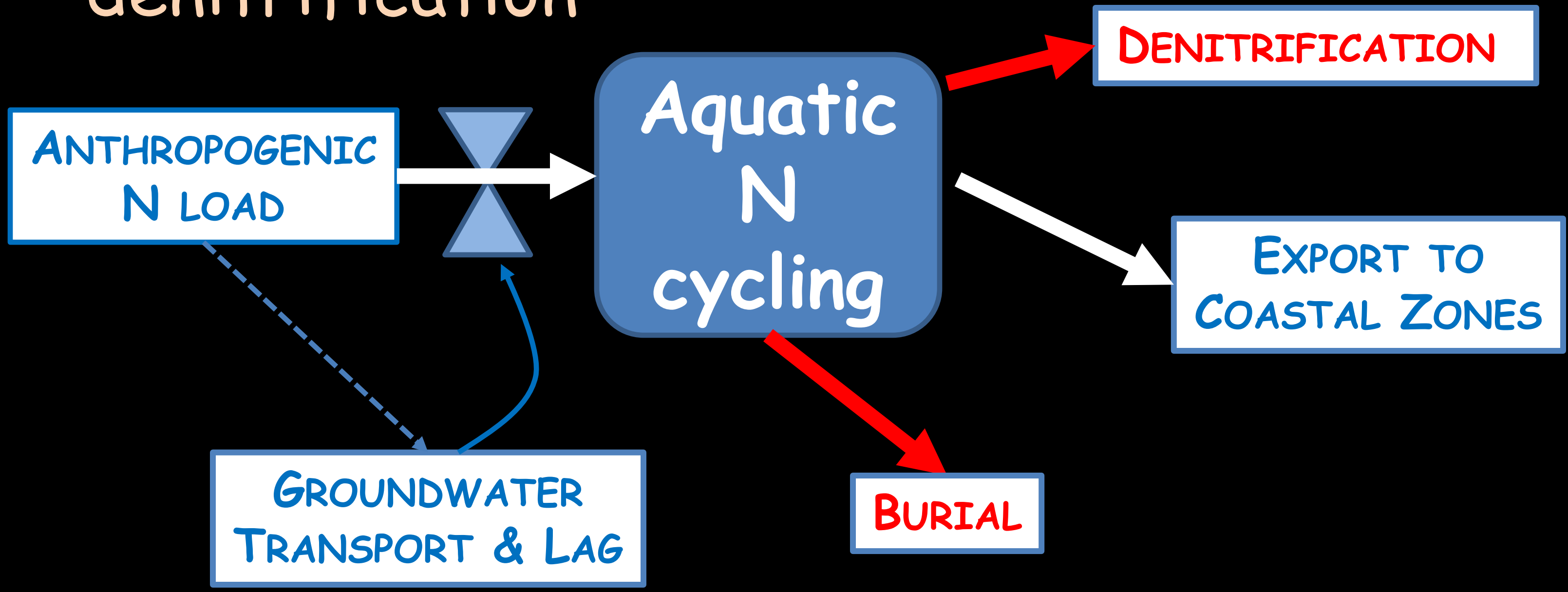

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Climate-N Interactions

Denitrification is Microbial

Need sufficient residence time,
landscape connectivity,
low O_2, organic C, nutrients
to maintain optimal microbial sites





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Climate-N Interactions

Denitrification is Microbial

Need sufficient residence time, landscape connectivity, low O_2, organic C, nutrients to maintain optimal microbial sites





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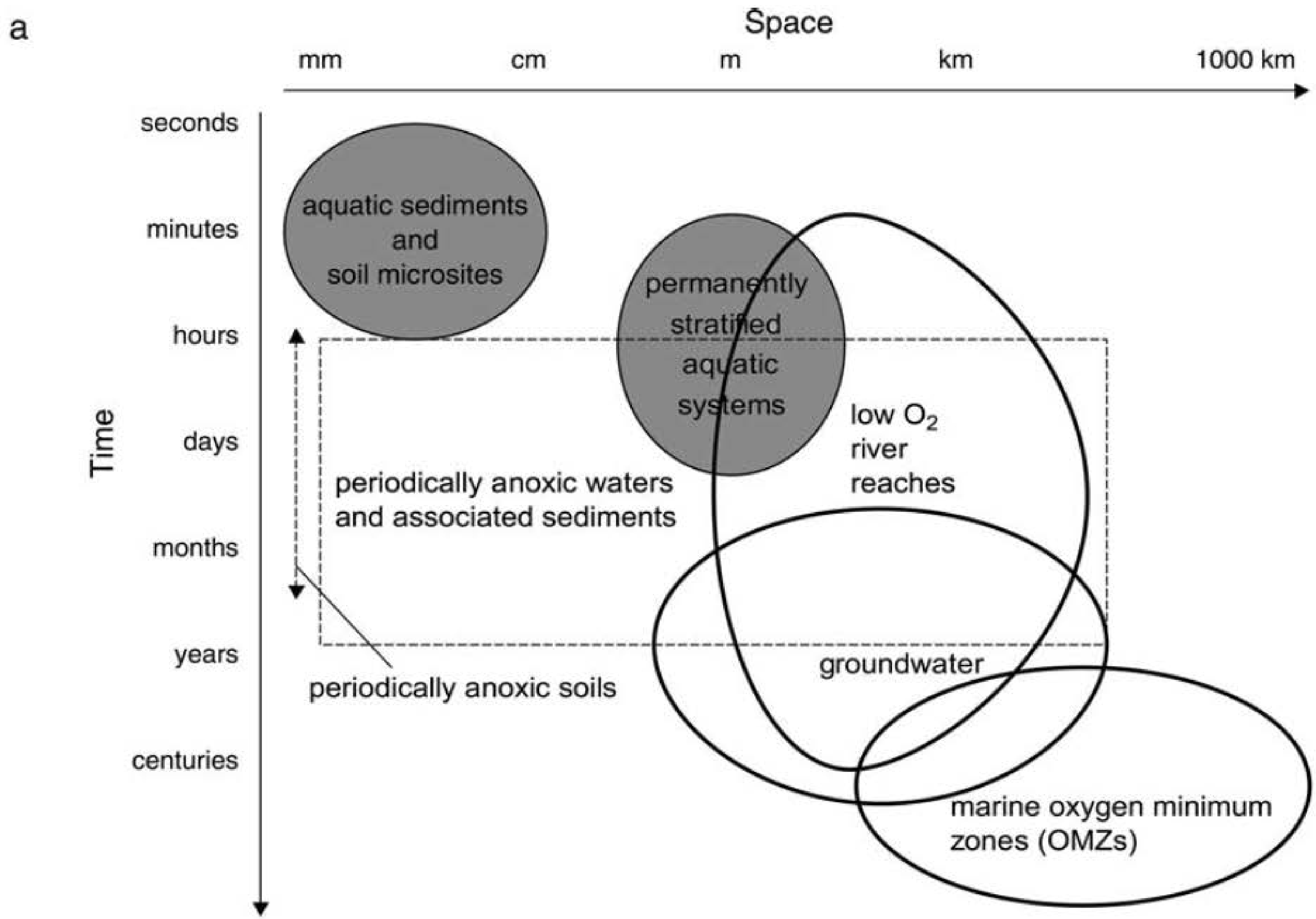

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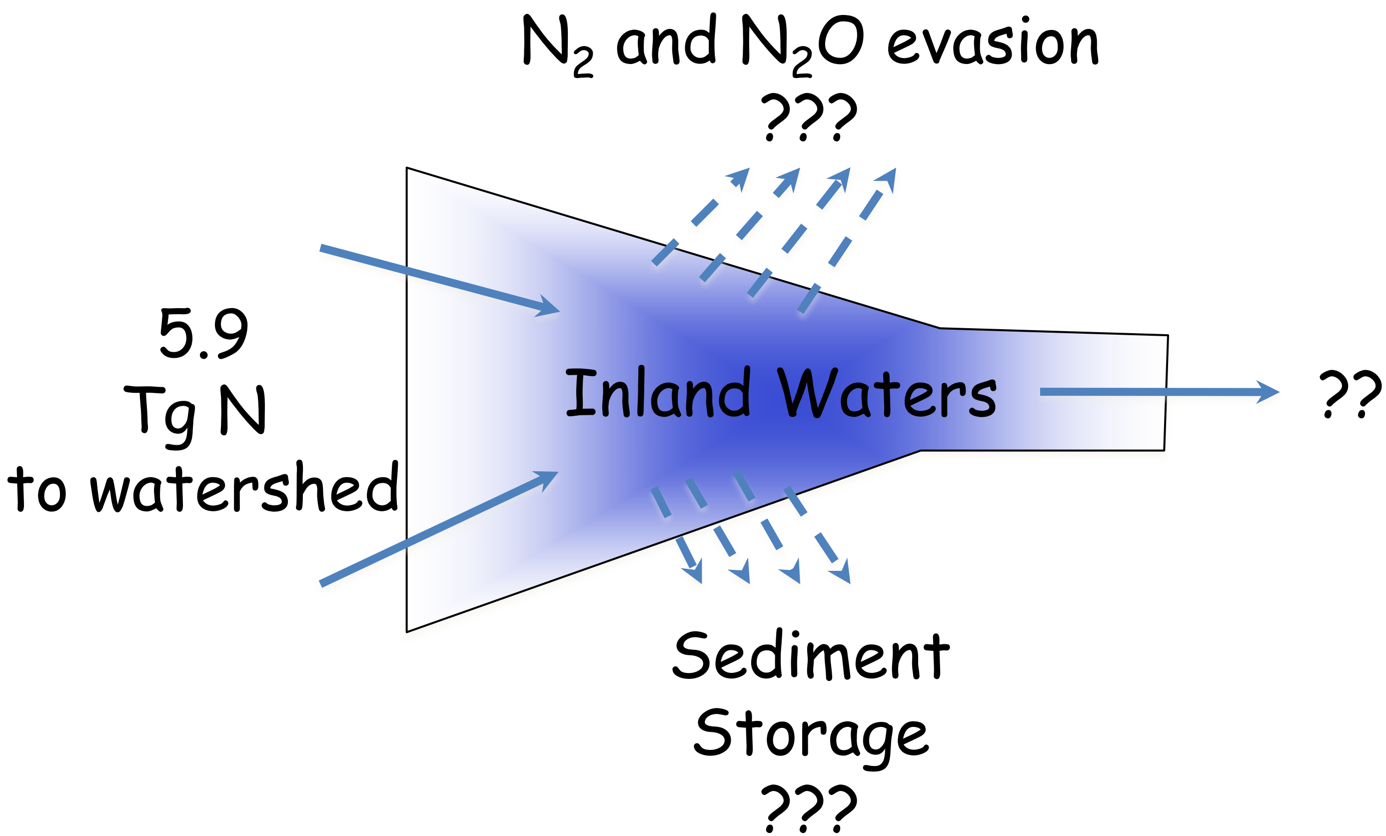
Seitzinger et al. 2006

Pre-1900 U.S. River N Flux



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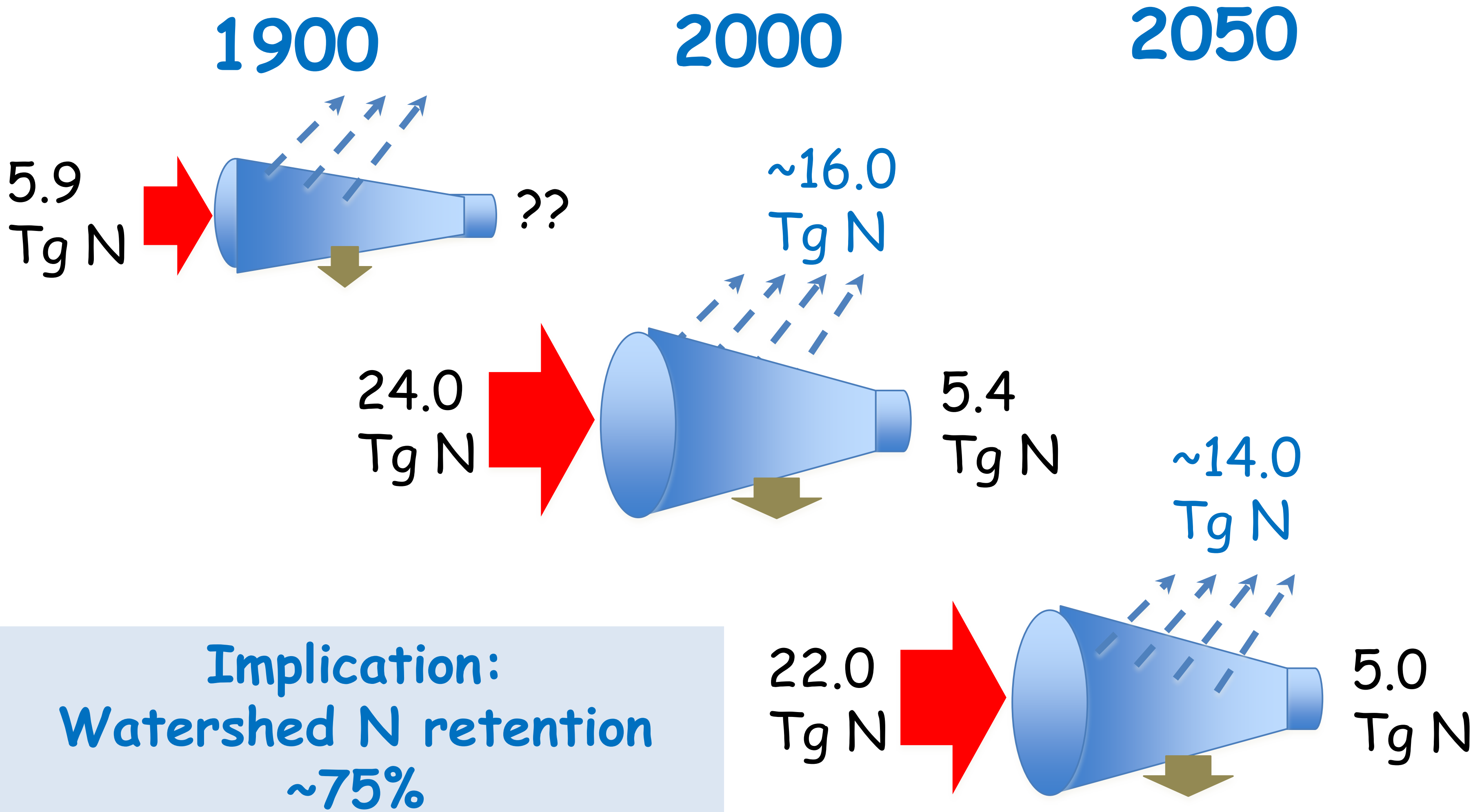
J. Harrison, w/ thanks to E. Bernhardt, J. Cole, S. Seitzinger, J. Galloway



Implication:
Watershed N retention
~75%

Global NEWS estimates (Harrison)
w/thanks to E. Bernhardt, J. Galloway,
E. Boyer, S. Seitzinger, J. Cole

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For watersheds with inputs >1070 kg N km^{-2} yr^{-1}, ~25% of NANI is exported from landscapes to coastal oceans

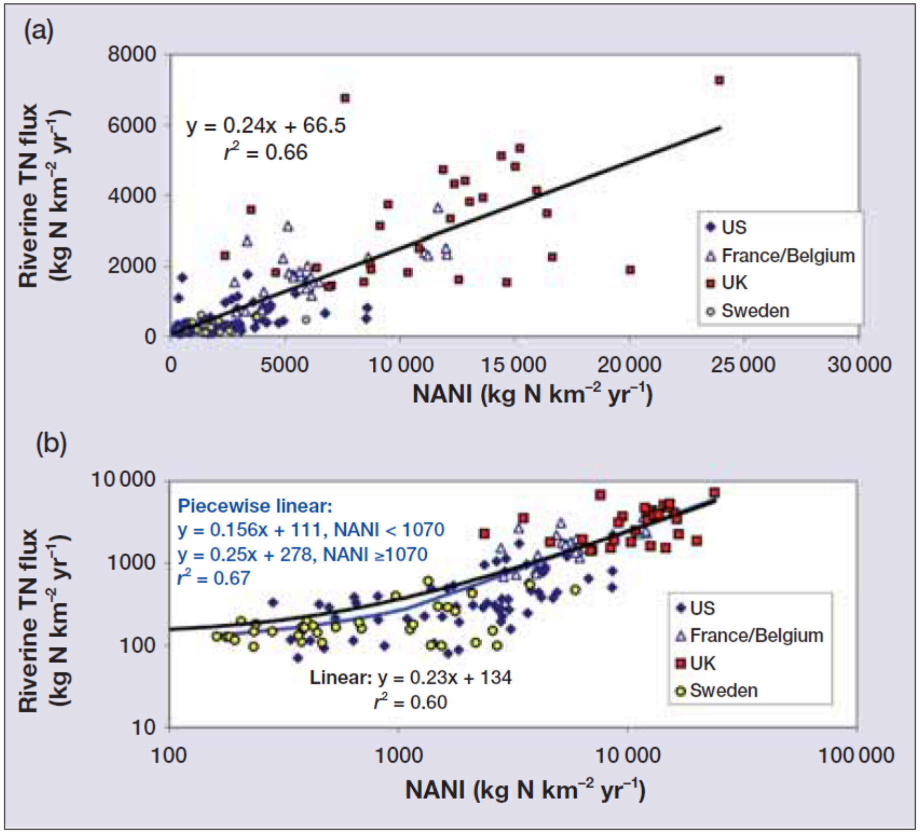

Figure 2. The flux of N from the landscape in rivers is significantly and highly correlated with NANI on both (a) linear ($P = 2 \times 10^{-37}$) and (b) log–log ($P = 3 \times 10^{-32}$) scales across the 154 watersheds. In the log–log plot, we explored a possible threshold break

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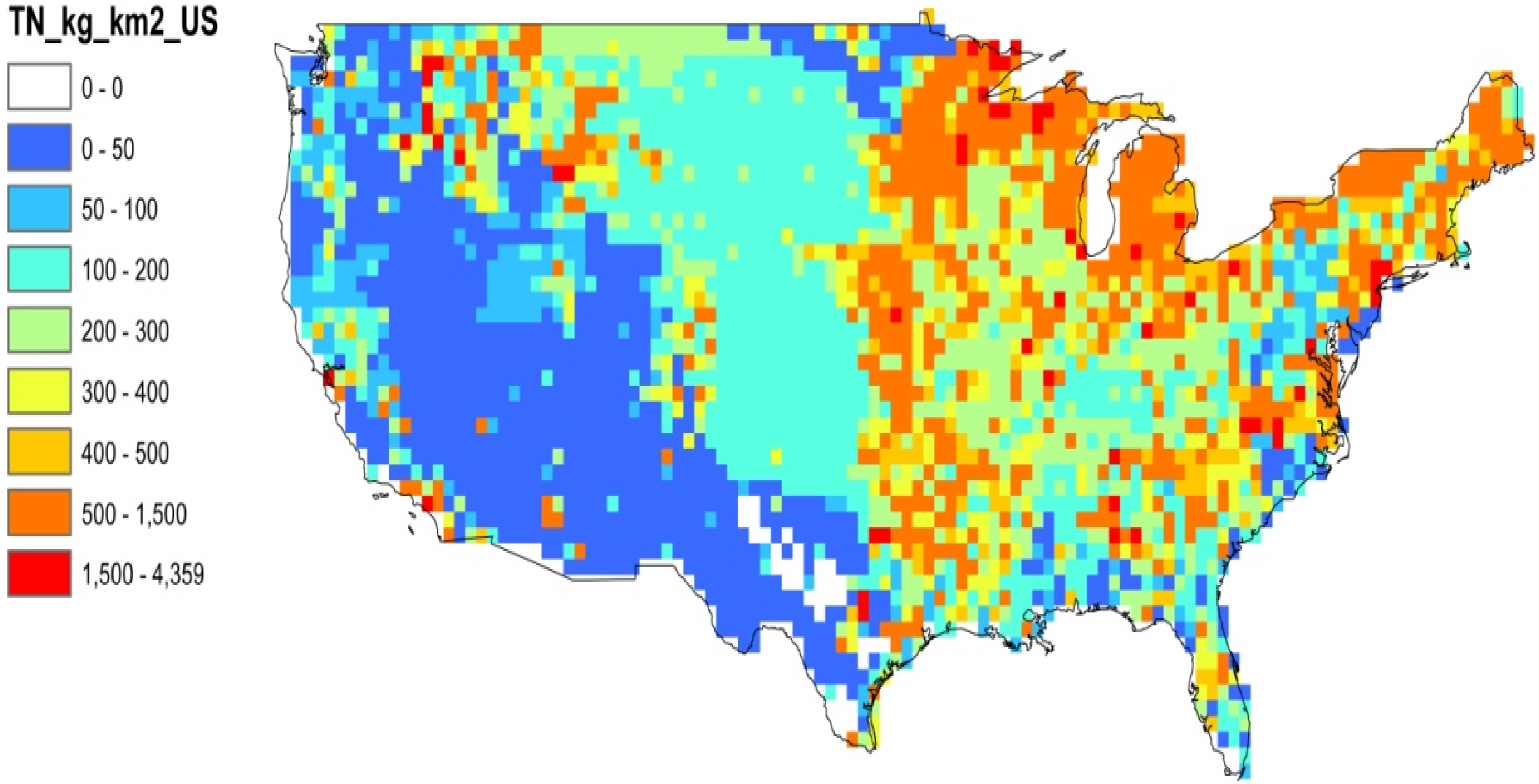
(Howarth et al. 2011)

TN retention in lentic systems in the conterminous US (kg N km^{-2} yr^{-1}) (Total of about 5.5 Tg)



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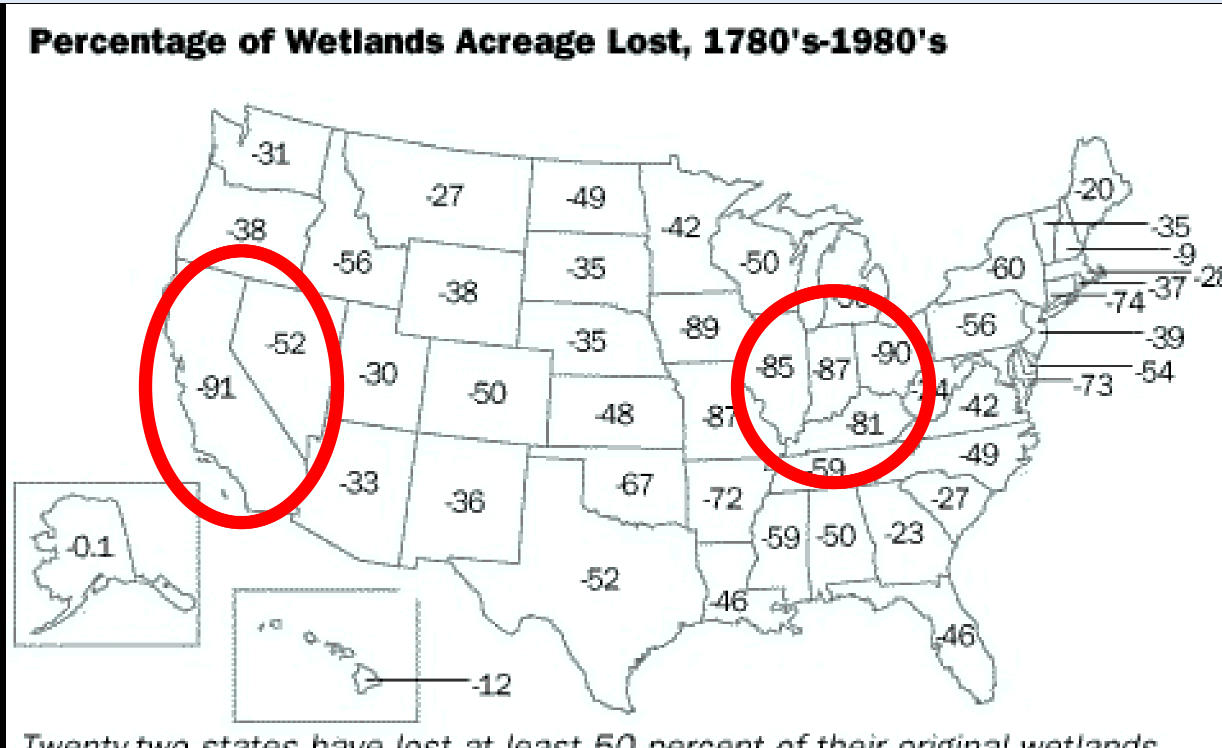
NiRReLa estimates
w/ thanks to J. Harrison

US wetlands denitrify ~5.8 Tg yr^{-1}, roughly 20% of the total anthropogenic reactive N load



> 50% Wetlands Drained

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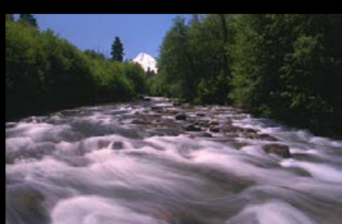
Map: Mitsch and Gosselink 1993
Denitrification,: Jordan et al. 2011

N_2O emissions from aquatic ecosystems are globally important

- Total global anthropogenic N_2O ~17 Tg
- Agricultural soils most important source
- Rivers: 0.68 Tg; <1% of total N denitrified (Beaulieu et al. 2011)
- Rivers and estuaries 0.3-2.1 Tg (Kroeze et al. 2011)
- Lakes : 0.04-2.0 Tg from deposition alone (thus conservative; McCrackin and Elser et al. 2011)
- N_2O emissions increase with N load

N Load Affects Other GHG Production

- Wetlands and lakes are strong sources of CH_4 emissions
- CH_4 and CO_2 increase with both N load and temperature (Liu and Greaver 2009)





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Climate-N Interactions

- Nearly all US waters degraded by excess Nr
- Nr is transported to coastal waters if not processed along the way → burial or denitrification

3. Massive hydrologic manipulation of US waters both increases and decreases the rate of delivery to coasts





US Water Resources are Highly Managed

- 75,000 dams > 2 m
- 1000s of small reservoirs
- Tile drains and urban storm drains
- Levees and channelization
- Wetland conversion





USGS

Climate-N Interactions

- Nearly all US waters degraded by excess Nr
- Nr is transported to coastal waters if not processed along the way → burial or denitrification
- The massive hydrologic manipulation of US waters both increases and decreases the rate of delivery to the coasts
- Climate change will both increase and decrease rate of delivery through changes in the hydrologic cycle and increases in temperature

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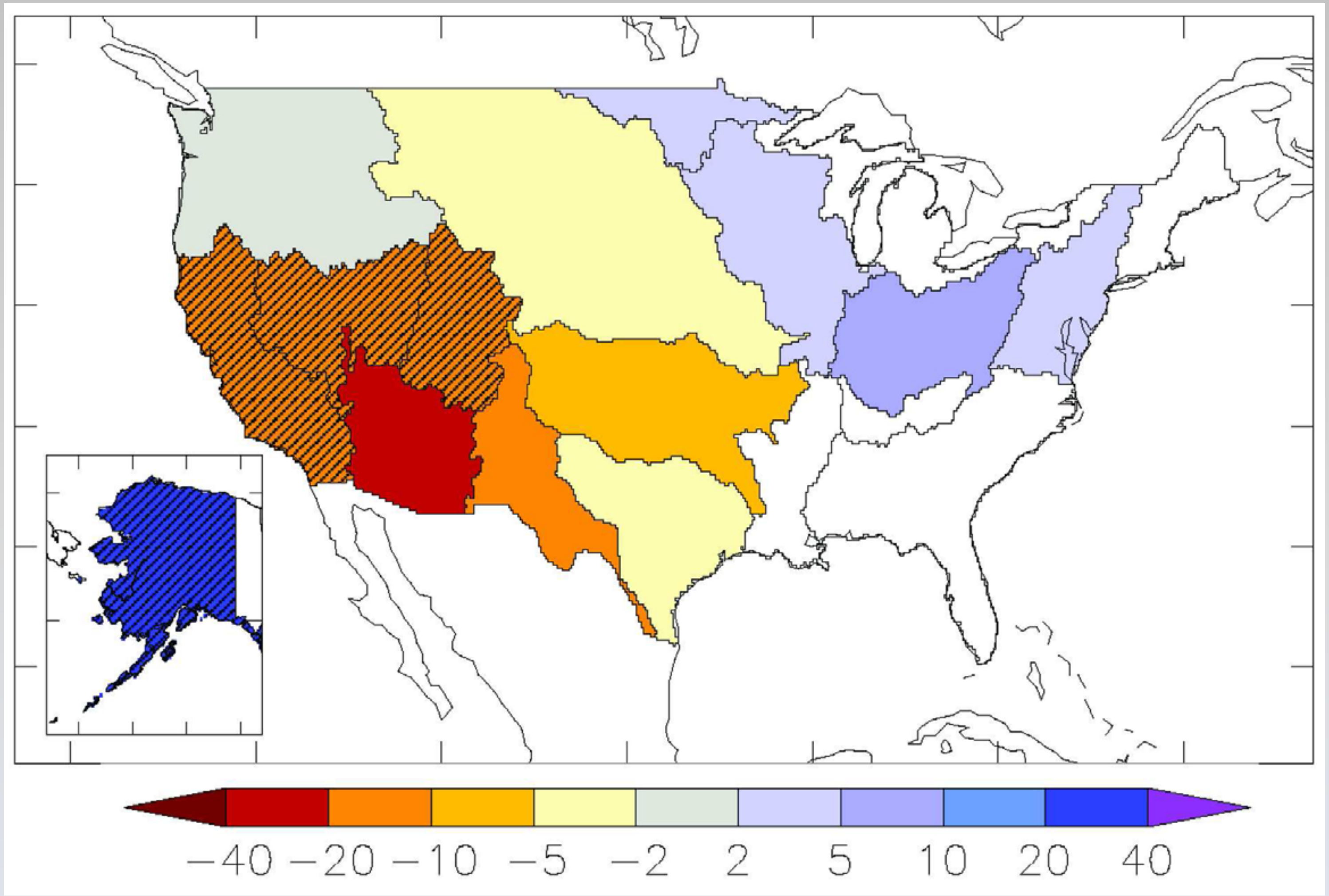
Projected Changes in Annual Runoff, 2041-2060



Percentage change relative to 1900-1970 baseline. Any color indicates >66% of models agree on sign of change; diagonal hatching indicates >90% agreement.

Milly et al. 2005

Climate-N Interactions

	Water Response to ...	Denitrification Response
		↓
		↓
		↓↑
		↓↑
	...mperature	↑

Storms/Floods Can Overwhelm Urban Infrastructure





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Climate-N Interactions
Summary

- N export to coasts is proportional to the input
- N export is approx. 25% of inputs

- Freshwaters are hotspots for N denitrification
  - Total N inputs to US ~24 Tg in 2000
    - Lakes/reservoirs retain 5.5 Tg
    - Wetlands 5.8 Tg
    - Rivers similar to lakes





USGS

Climate-N Interactions
Summary

- For denitrification to be effective, it requires NO_3 and microbes to be coupled in time and space
  - Hydrologic manipulation and climate change alter residence time and landscape connectivity; restoration is not yet a mature science
- To reverse and prevent the damage from Nr the real solution is to reduce the inputs





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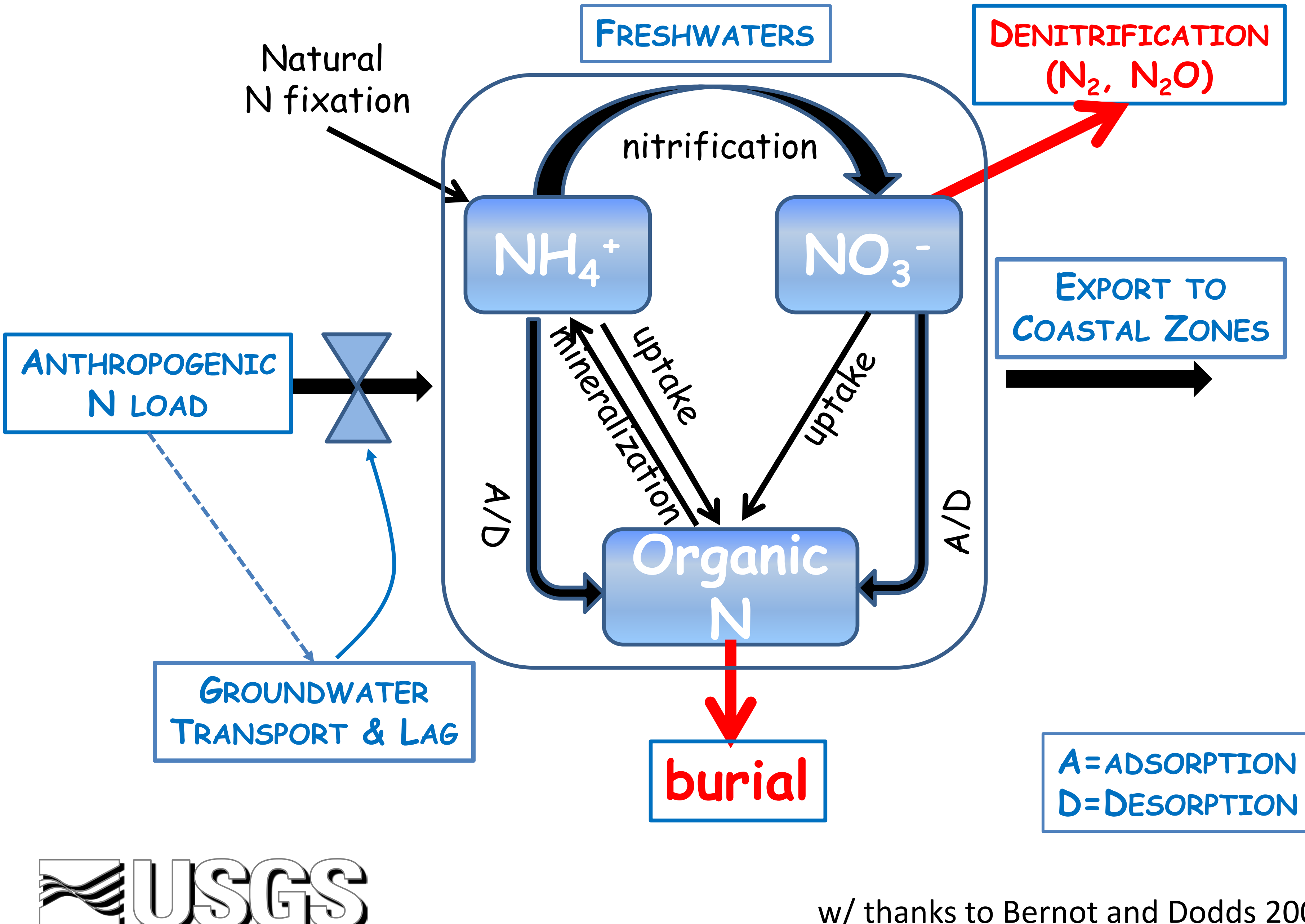
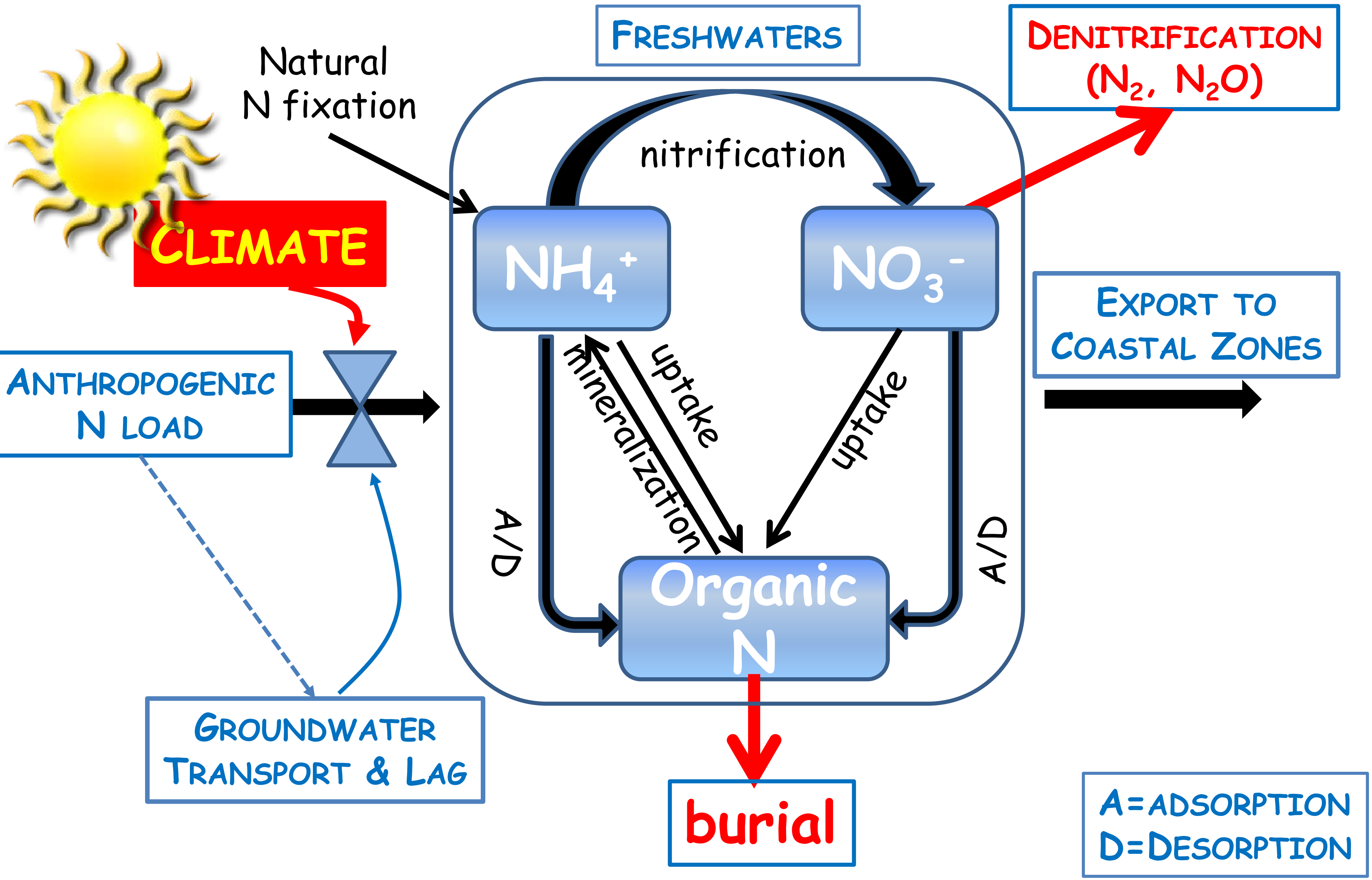


w/ thanks to Bernot and Dodds 2005


Natural
N fixation
CLIMATE
FRESHWATERS
DENITRIFICATION
(N2, N2O)
nitrification
NH4+
NO3-
uptake
mineralization
uptake
A/D
A/D
Organic N
EXPORT TO
COASTAL ZONES
ANTHROPOGENIC
N LOAD
GROUNDWATER
TRANSPORT & LAG
burial
A=ADSORPTION
D=DESORPTION

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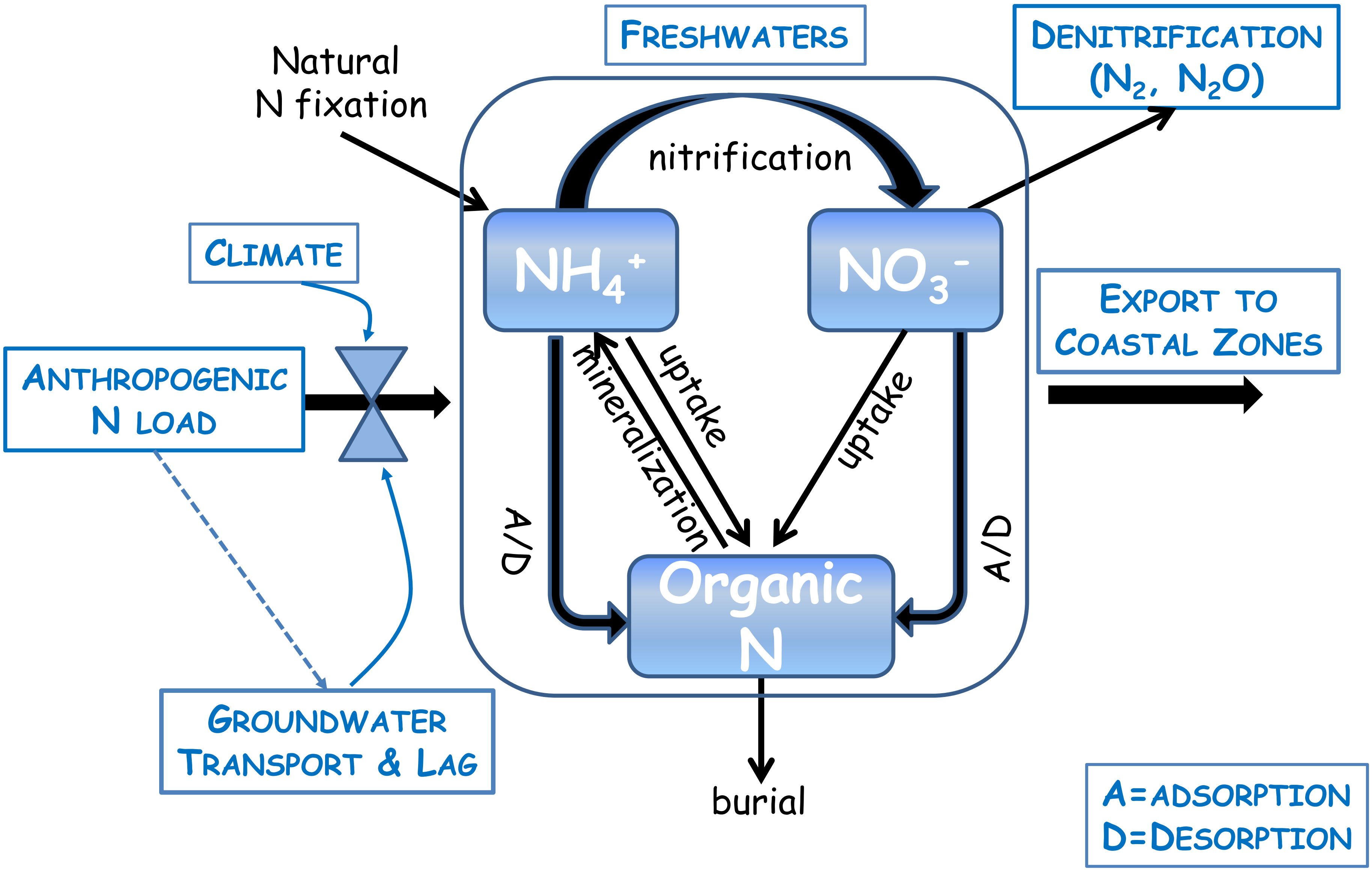
The remainder of Nr not accounted for in riverine exports is stored or emitted to the atmosphere as N_2 or N_2O

- Nitrate loading stimulates denitrification; N_2O is only ~1% of total denitrification in streams and rivers (Beaulieu et al. 2011)
- Same is true for lakes; total estimated US denitrification is 20,000 kg N km-2 yr-1
- The load is more important than climatic differences

Howarth et al. 2011)


Freshwaters
Denitrification
(N2, N2O)
Natural
N fixation
nitrification
Climate
NH4+
NO3-
Export to
Coastal Zones
Anthropogenic
N load
uptake
mineralization
uptake
A/D
A/D
Organic
N
burial
Groundwater
Transport & Lag
A=adsorption
D=Desorption