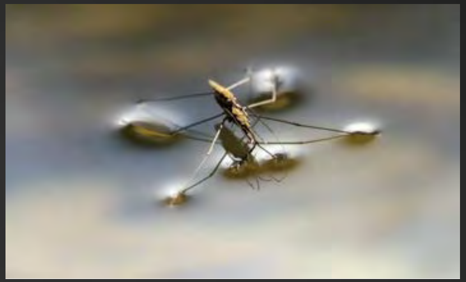
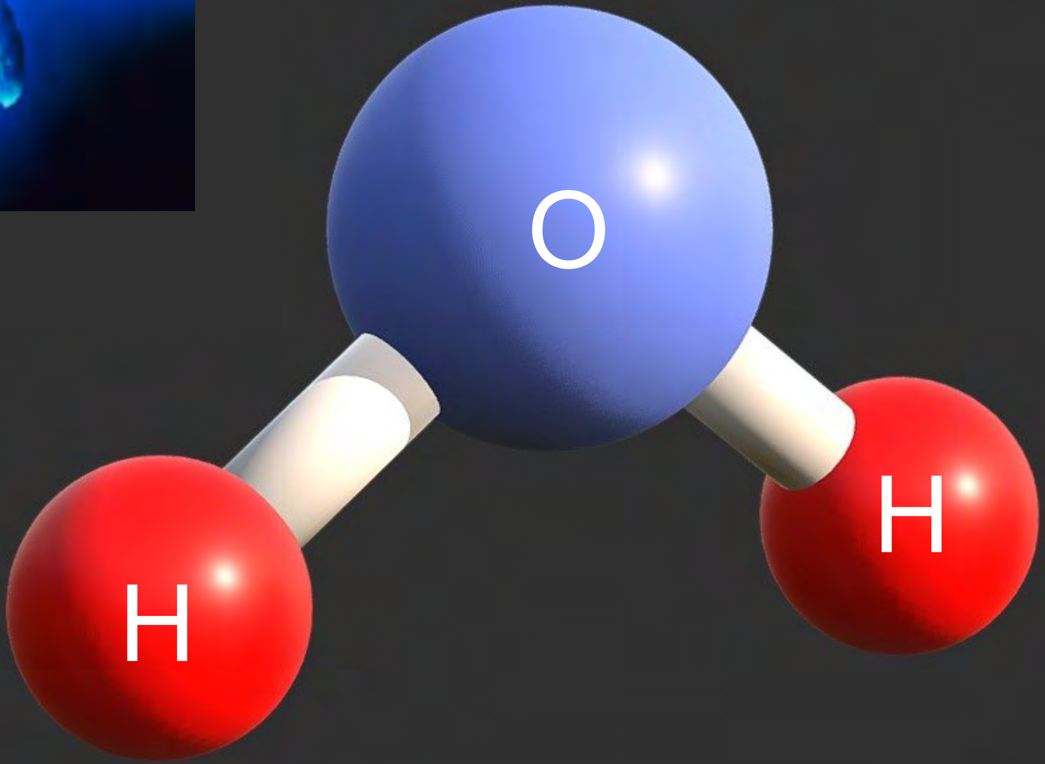
“Wer dies Wasser und seine Geheimnisse verstünde, so schien ihm, der würde auch viel anderes verstehen, viele Geheimnisse, alle Geheimnisse.”

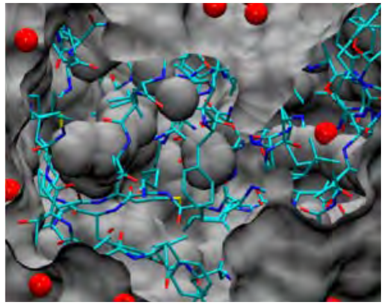
It seemed to him that those understanding this water and its secrets also understood much more, many secrets, all secrets.

The only chemical formula in the vernacular – The weirdest liquid on the planet





A precondition for human existence and all life as we know it



CHEMICAL REVIEWS

Review

pubs.acs.org/CR

Water Determines the Structure and Dynamics of Proteins

Marie-Claire Bellissent-Funel,[†] Ali Hassanali,[‡] Martina Havenith,[§] Richard Henchman,[∥] Peter Pohl,[⊥] Fabio Sterpone,[#] David van der Spoel,[∇] Yao Xu,[§] and Angel E Garcia[*,¶]

2016

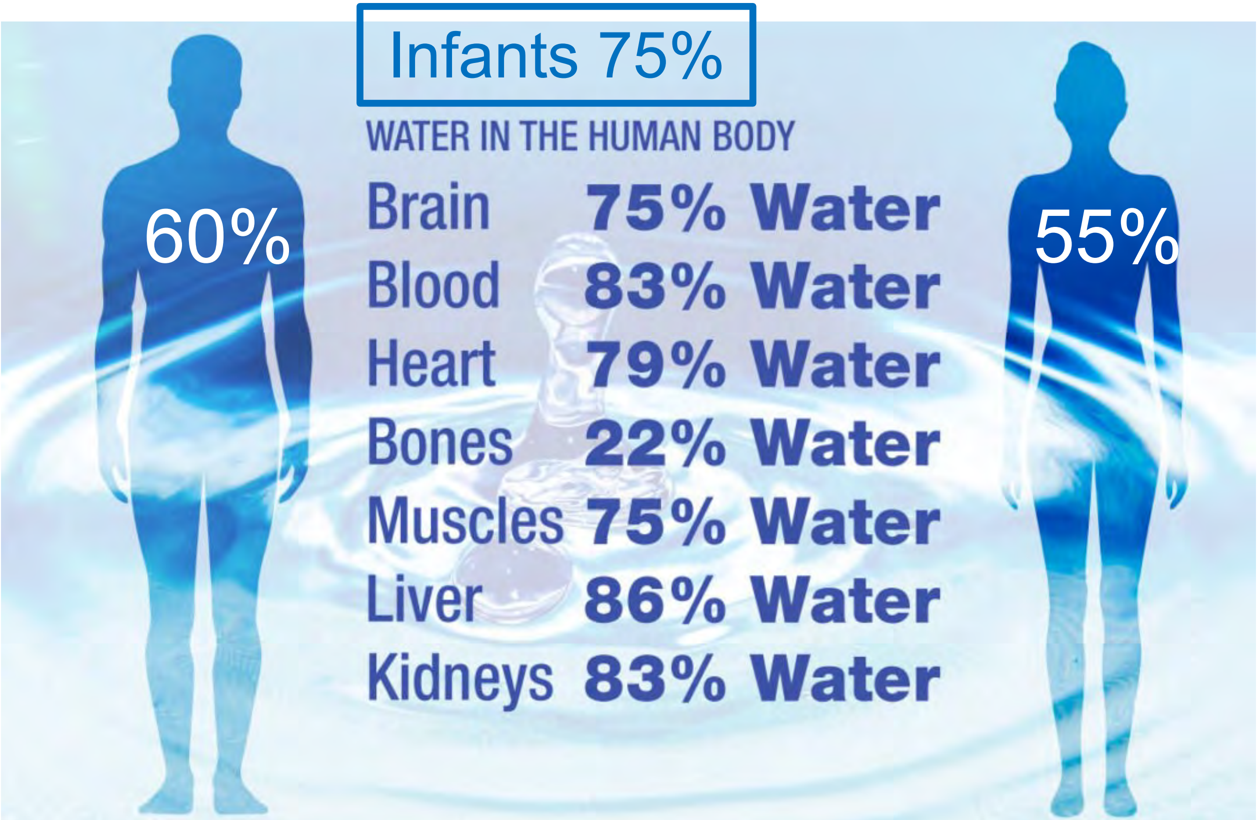
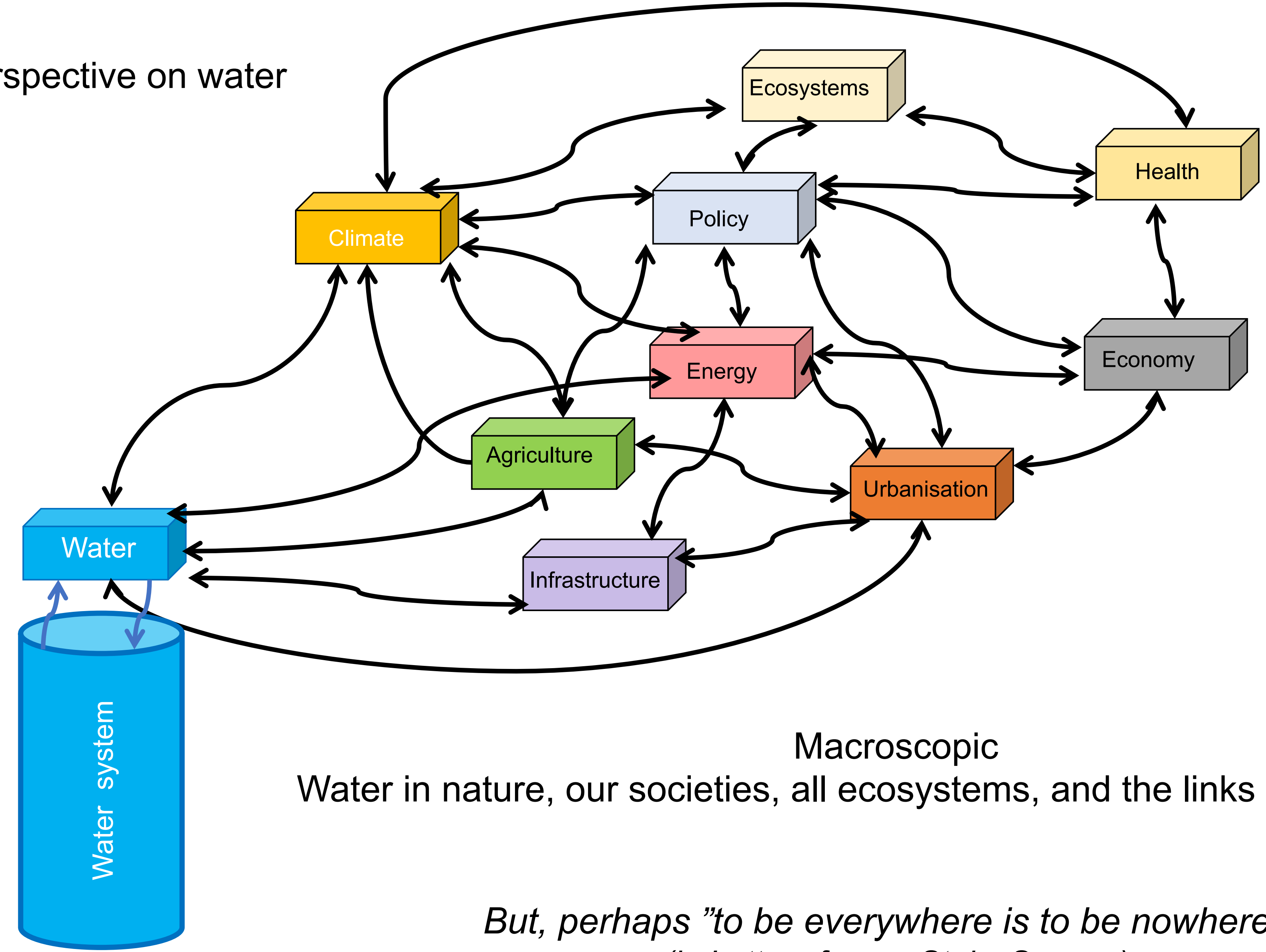


Illustration by Hugo Lin. ThoughtCo

https://www.usgs.gov/special-topics/water-science-school/science/water-you-water-and-human-body

My research perspective on water

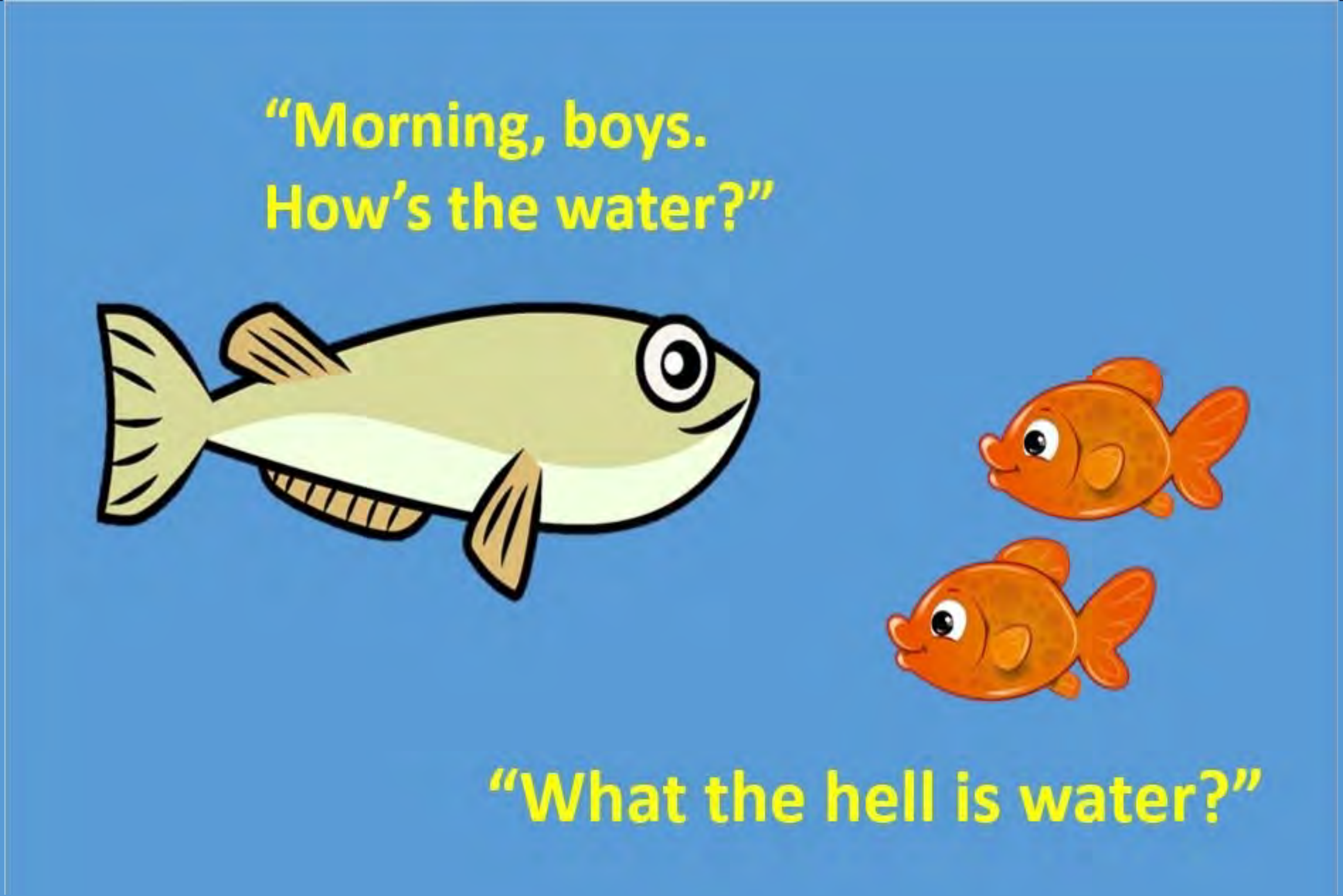


Macroscopic

Water in nature, our societies, all ecosystems, and the links between them

But, perhaps ”to be everywhere is to be nowhere” …

(in Letters from a Stoic, Seneca)



"the most obvious, important realities are often the ones that are hardest to see and talk about"

In "This is Water" by David Foster Wallace, 2005


Turfmagazine.com


HaV Rapport 2022:2 – Gävle Sweden 2021

Too little, too much, too dirty water: **where, when, why?**

How polluted is your local river and which regions are worst hit?


The Guardian Wed 27 Mar 2024

Gia Destouni
STIAS seminar , 9 Apr 2024

Outline

My research through the risk narratives of too much, not enough, and polluted water

- Some basics to start with

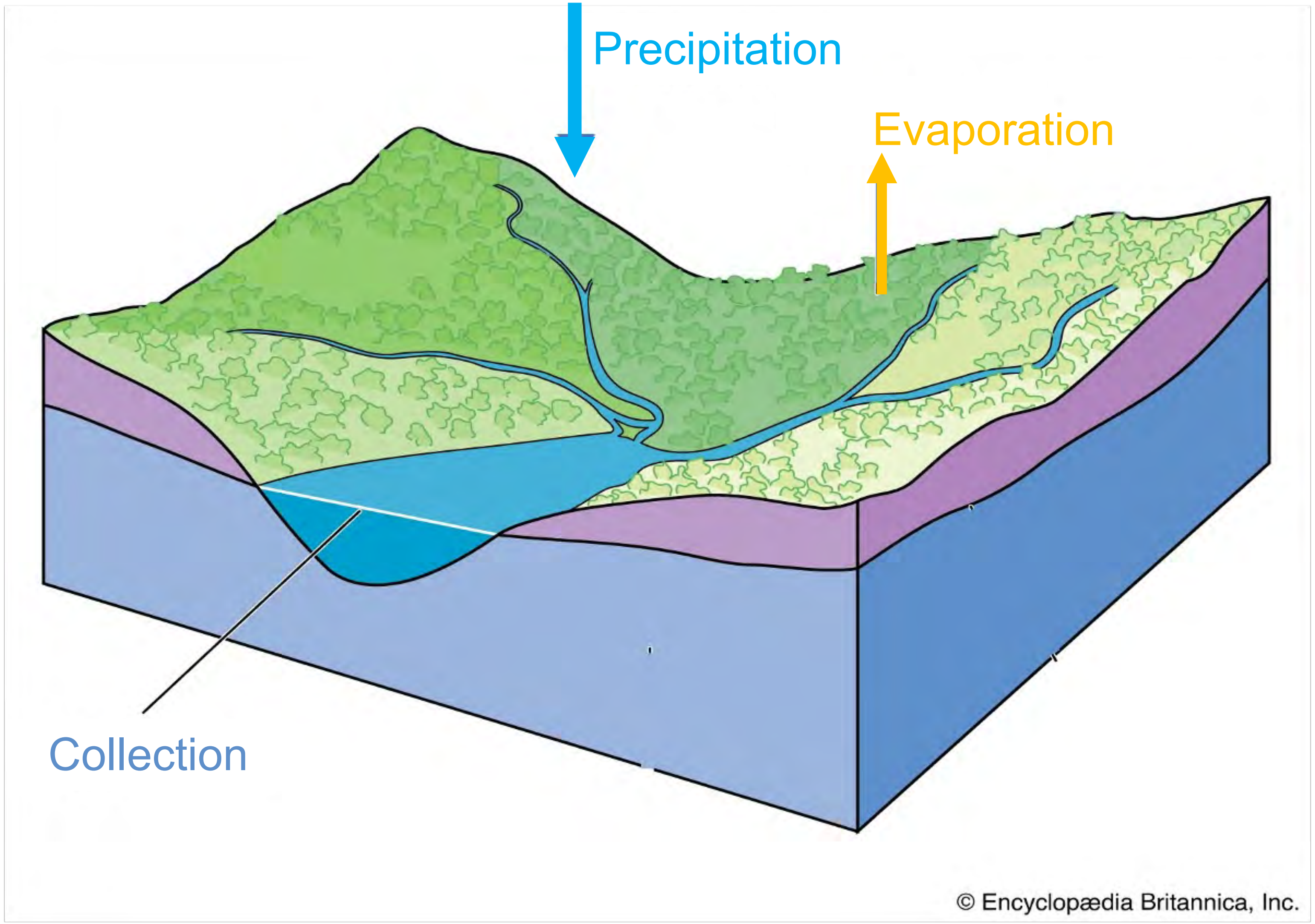
  - *From mundane to complex*
  - *From just water to what's in the water*

- What we don't know

  - *"Out of sight, out of mind" subsurface water vs visible water*
  - *World vs Africa – fooled by data & model bias*
  - *Lost in translation - Earth System links & interactions*

- SATORI Research Lab for coupled natural-human systems

  - *The blue thread of water - in global change & sustainability research*
  - *Towards consilience - topics, questions, methods*



“The water cycle consists of three key phenomena

— evaporation, precipitation, and collection —

and all of them are equally boring”

The Grim Grotto, Lemony Snicket 2004

Hydrological catchment – basic spatial unit for water in nature

Watershed, River basins Drainage basin

Collection

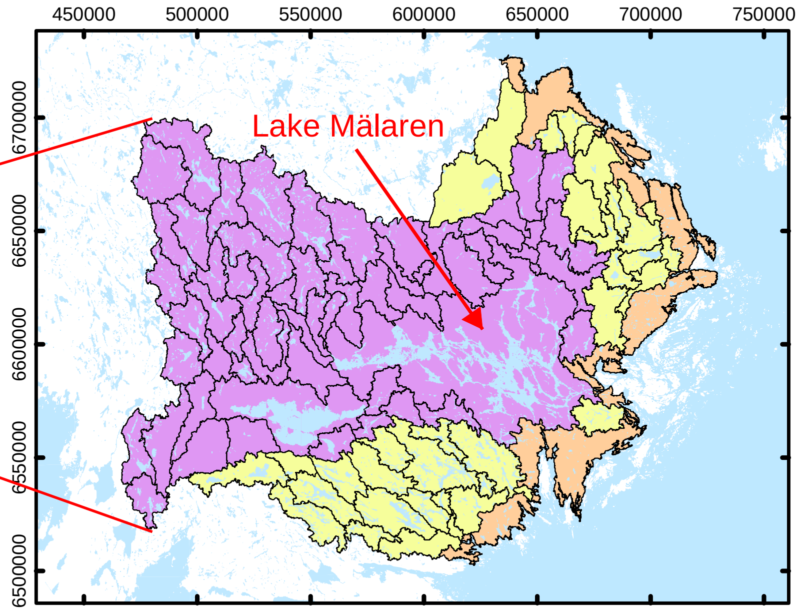
Outlet

(Incremental sub-)catchment of a landscape point / coastline

Small /Ephimeral stream / lake / wetland / Point within landscape

Diffuse groundwater/stream discharge along coastline – coastal catchment

Whole stream network / river / lake



Quin et al., *Ambio*, 2015

Any measurement point in landscape / coastline

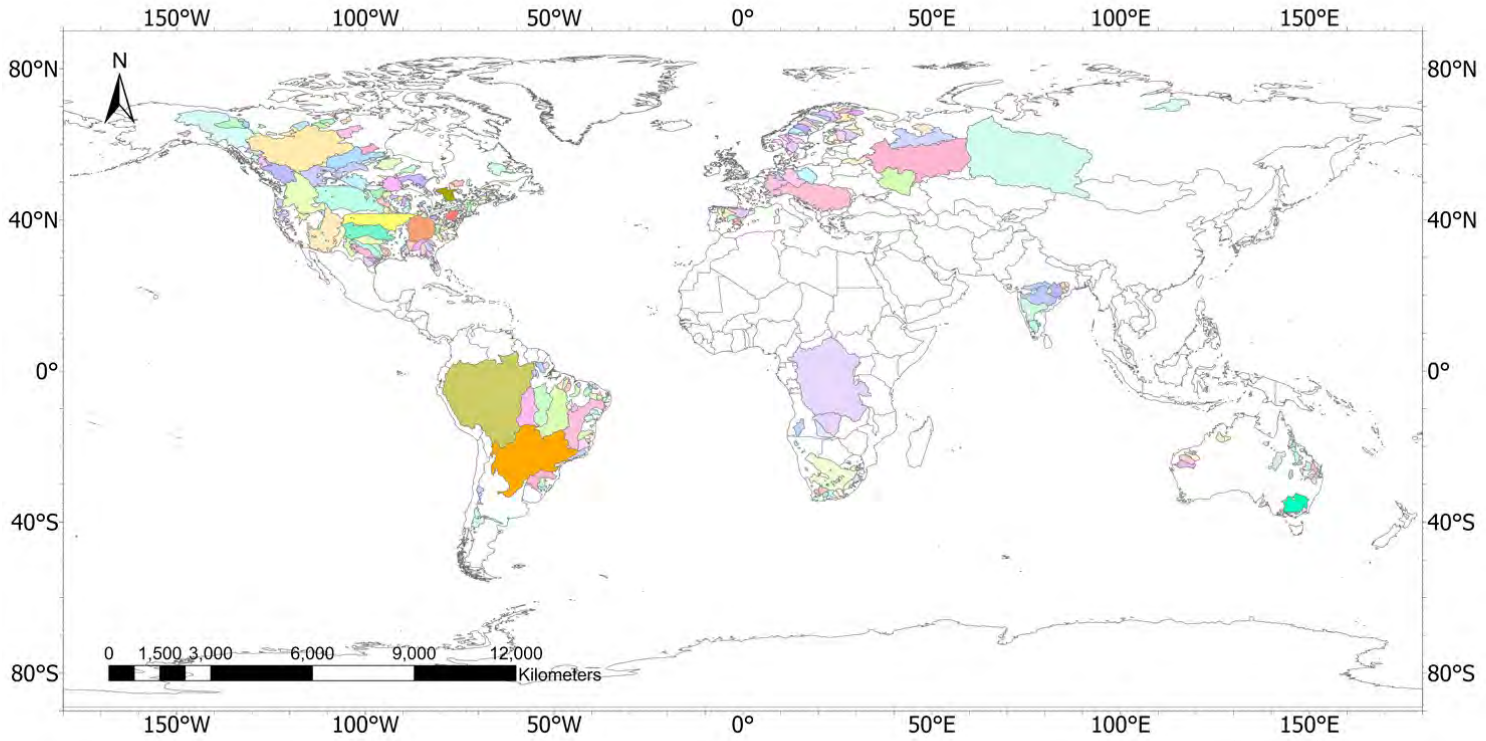
Hydrological catchment – basic spatial unit for water in nature

Watershed, River basins Drainage basin

At **any scale** – e.g., 1561 catchments with relevant open data time series 1980-2010 -
around the world, and up to continental or global scale

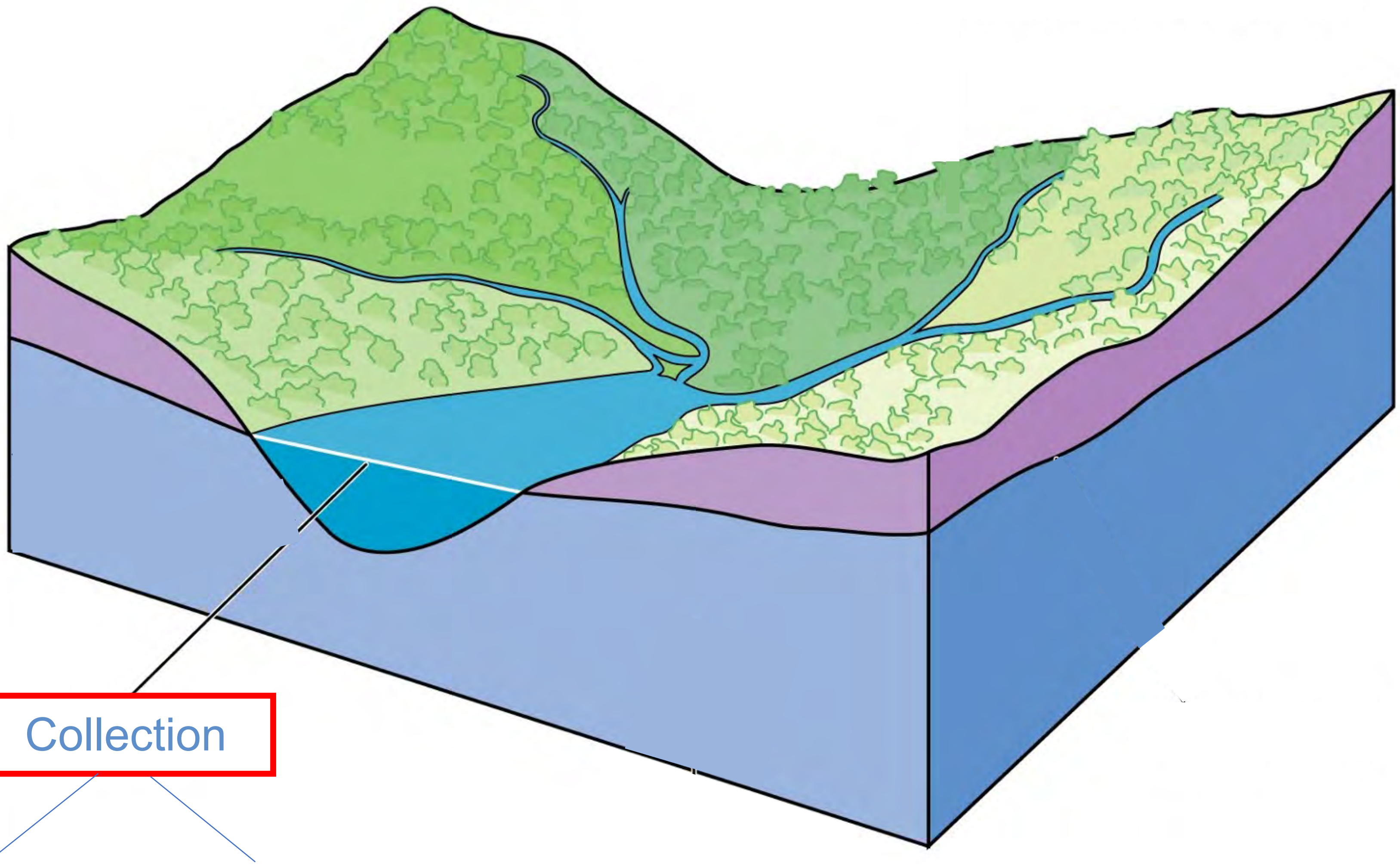
Collection

Outlet



Zarei, Destouni. Global HydroClimatic Database [Data set]. Zenodo (2024)

Any measurement point in landscape / coastline

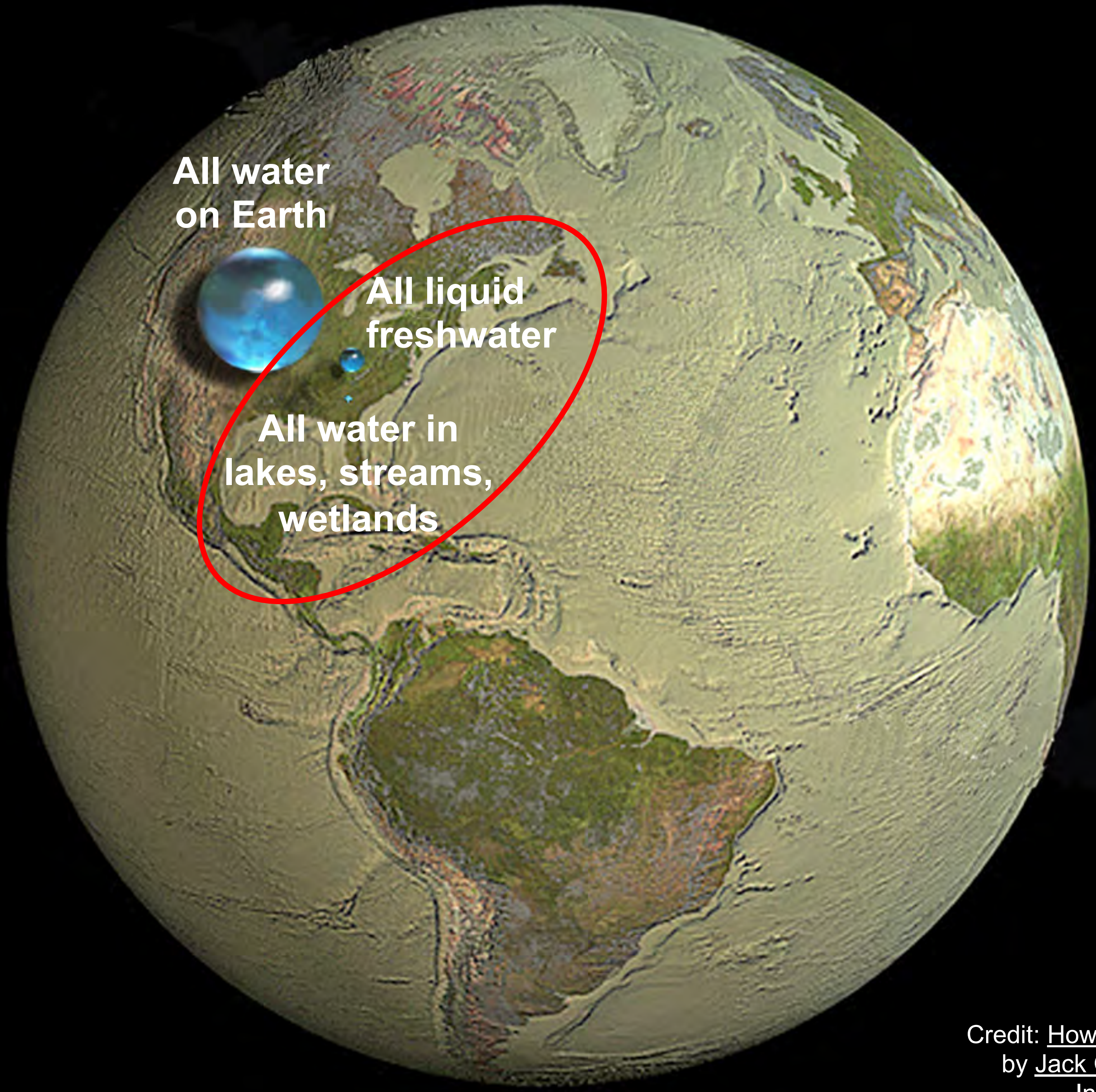


Collection

Storages

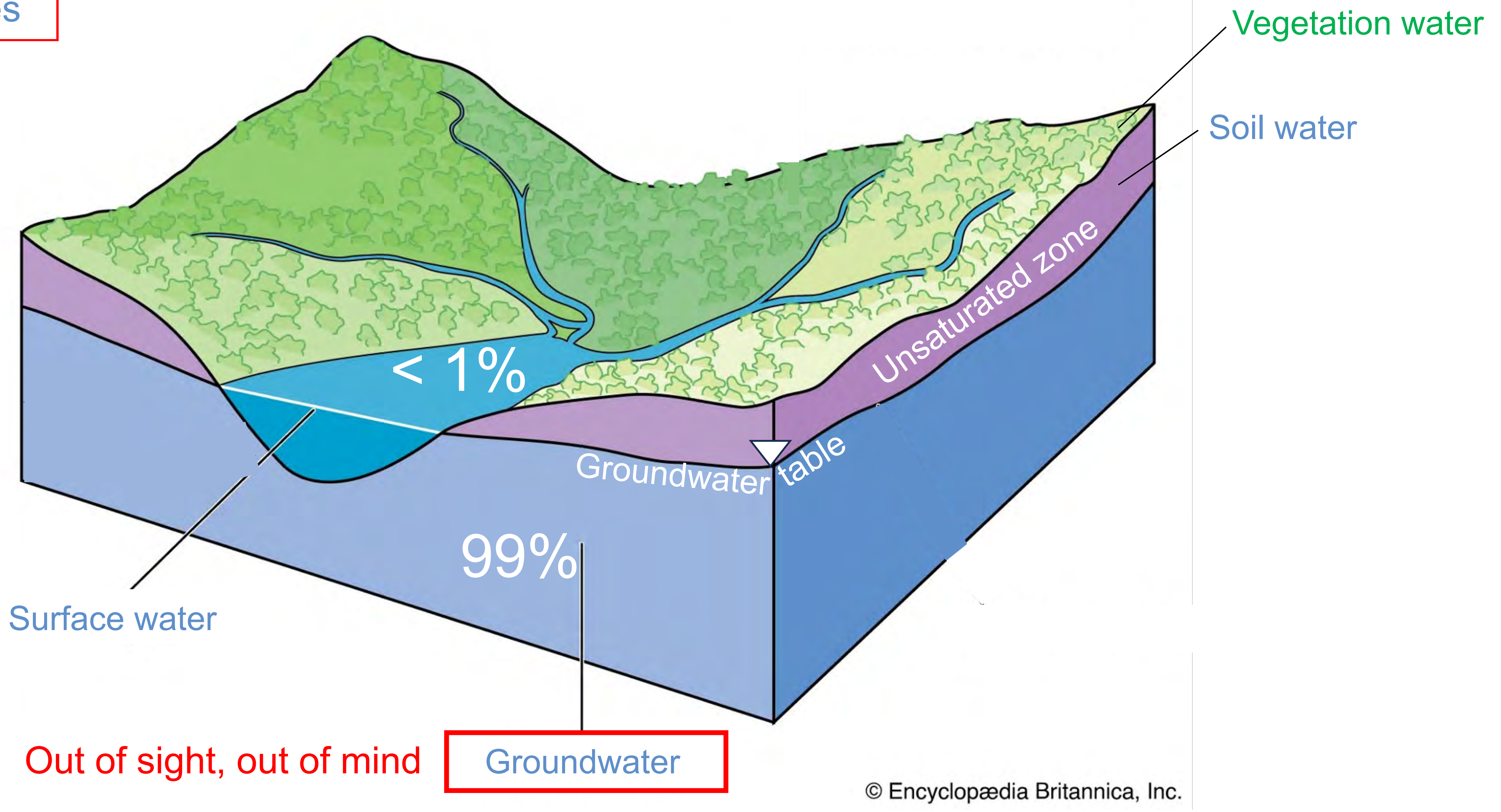
Fluxes

Collection
→Storages



Credit: Howard Perlman, USGS; globe illustration by Jack Cook, Woods Hole Oceanographic Institution (©); Adam Nieman.

Collection
→Storages

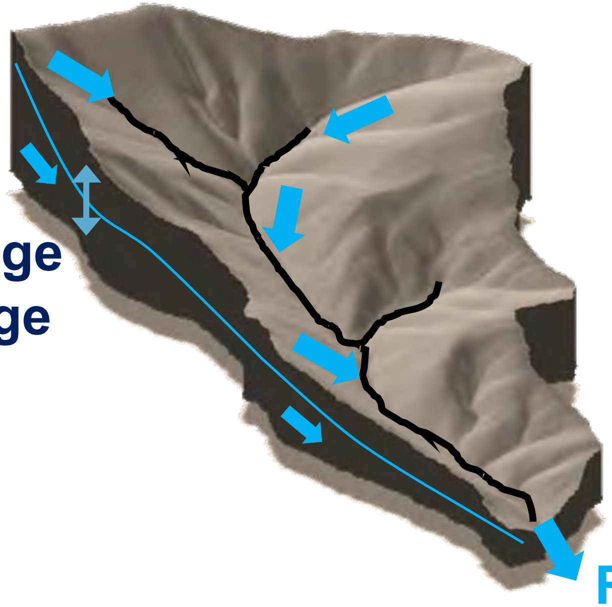


Out of sight, out of mind

Collection
→Fluxes

Runoff (R): output from catchment system

Storage change (DS):
output from storage (storage decrease) to other water fluxes
or
input to storage (storage increase) from other water fluxes



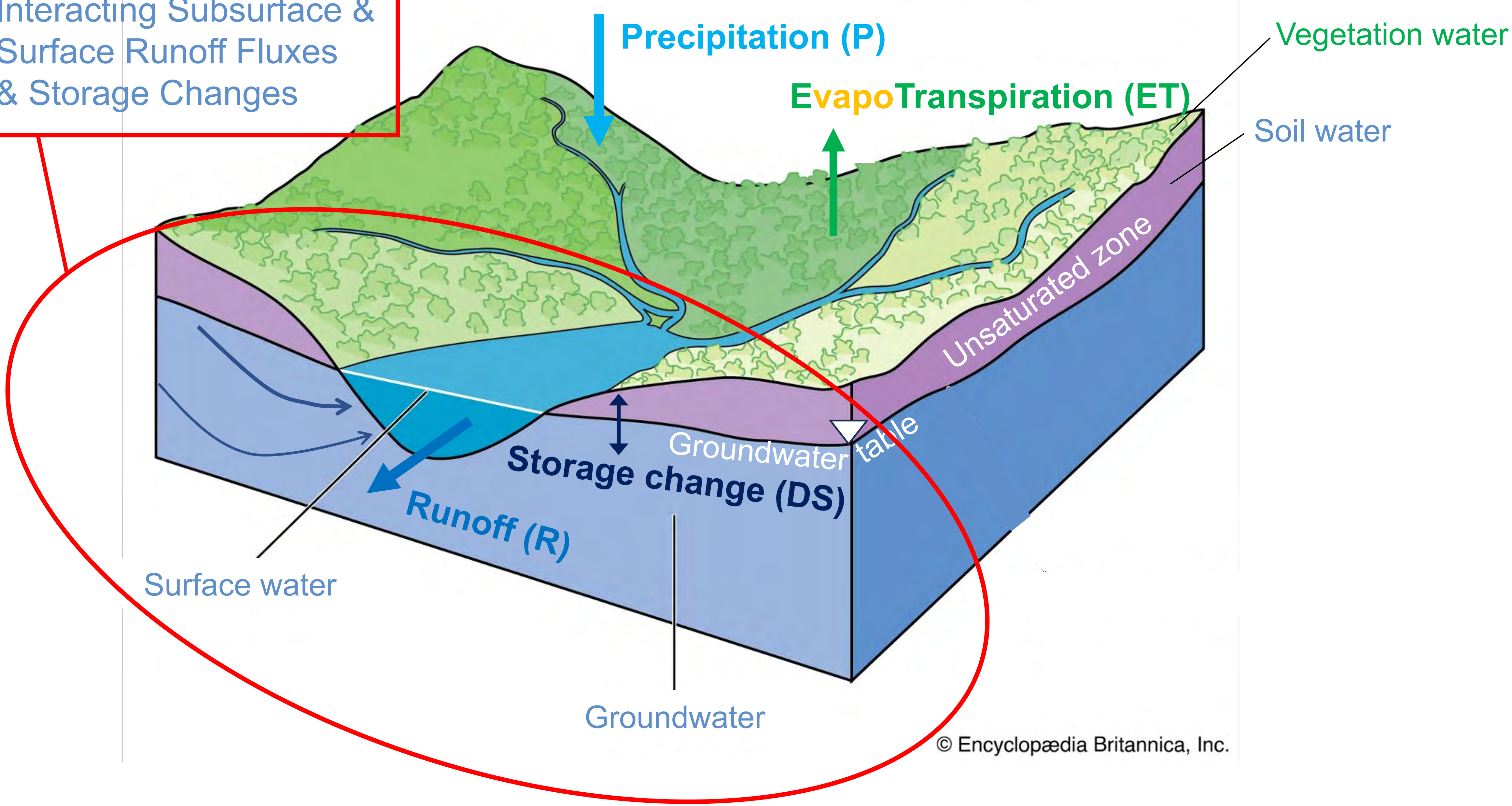
Storage change (DS)

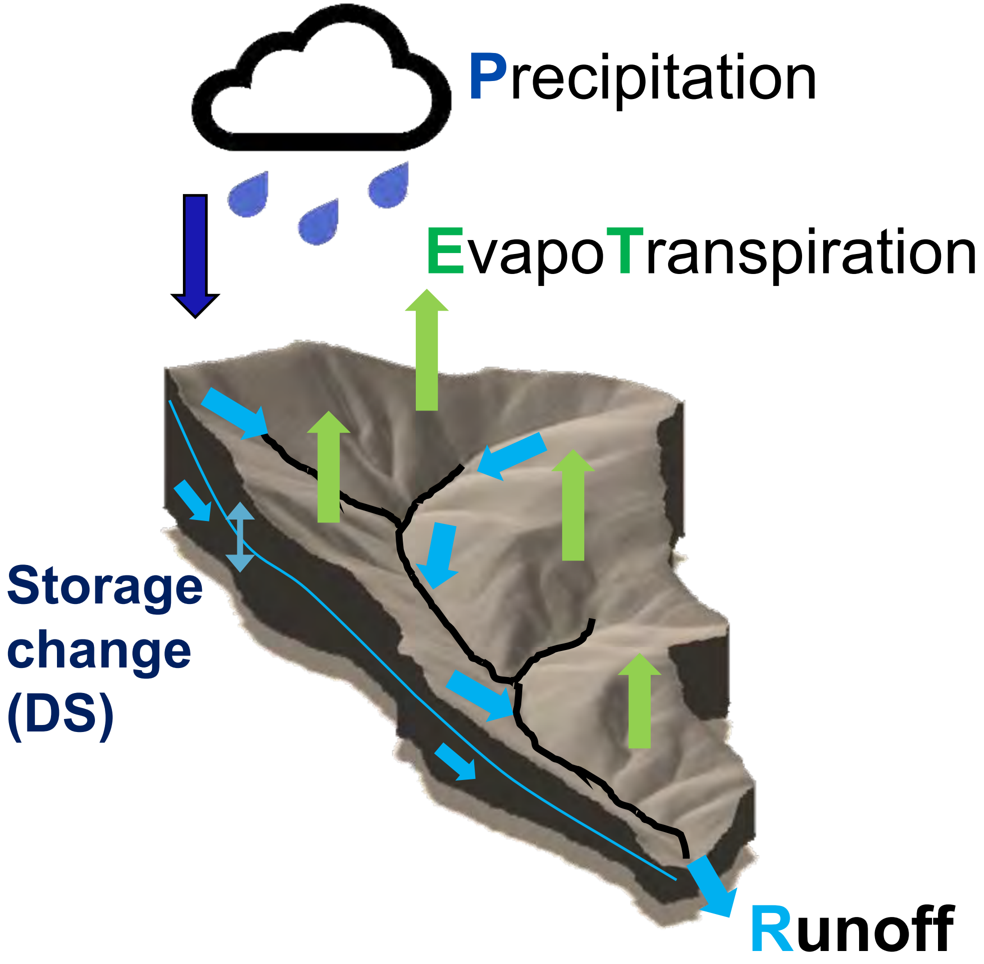
Runoff (R)

Collection → Fluxes

- Interacting Subsurface & Surface Runoff Fluxes
- & Storage Changes

The other main water fluxes on land





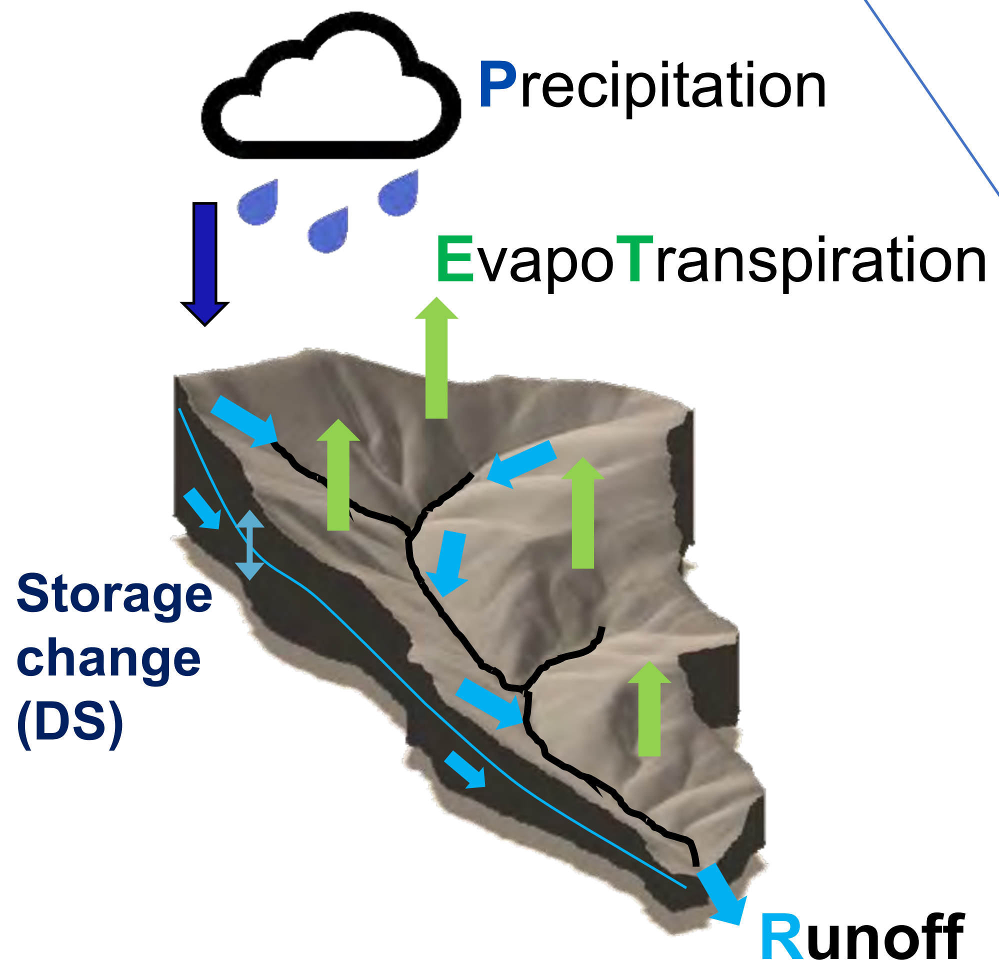
Fundamental investigation key for variations & change trends:

Catchment-wise water balance

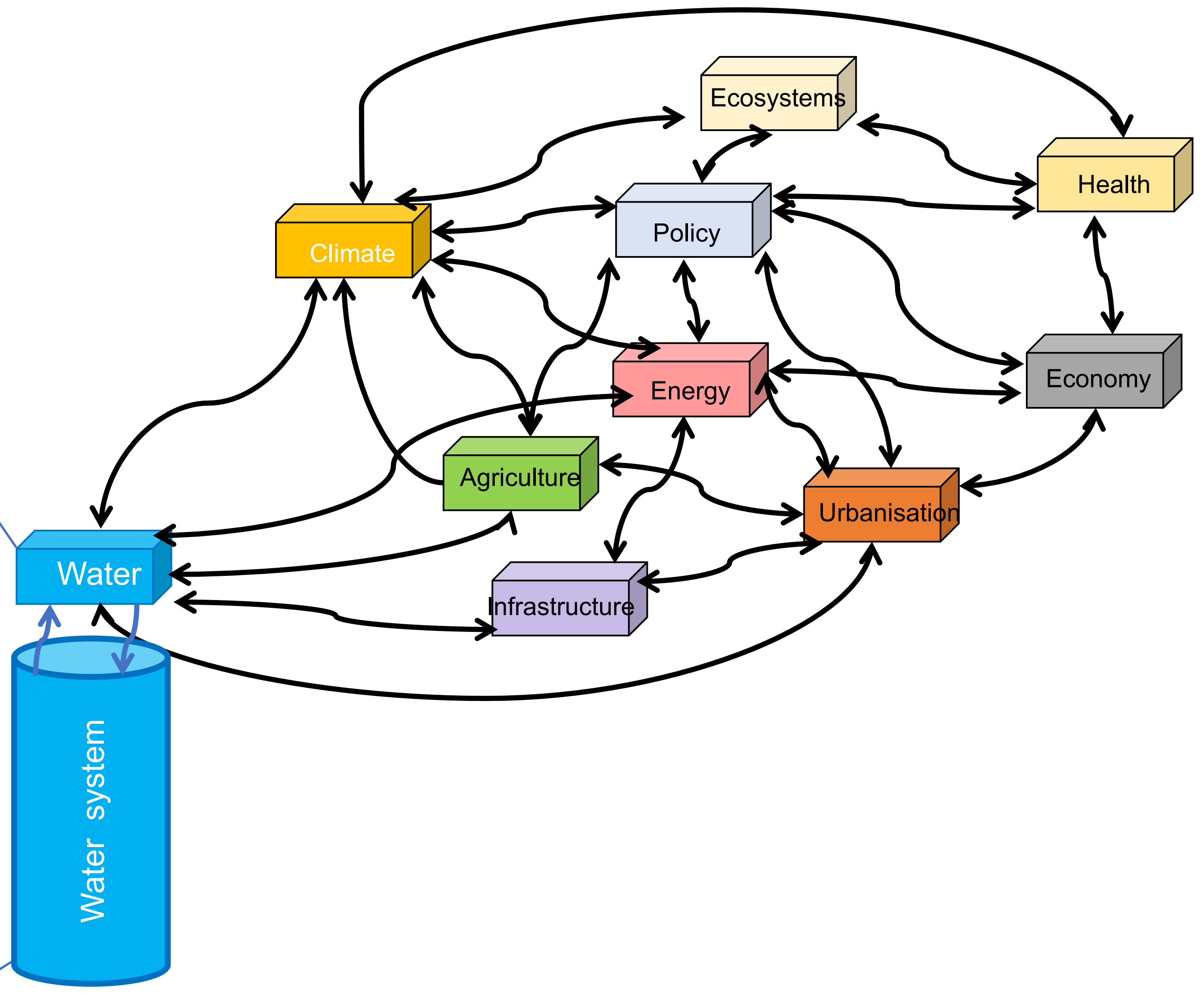
relating-constraining the water fluxes & storage changes

P- ET - R = DS

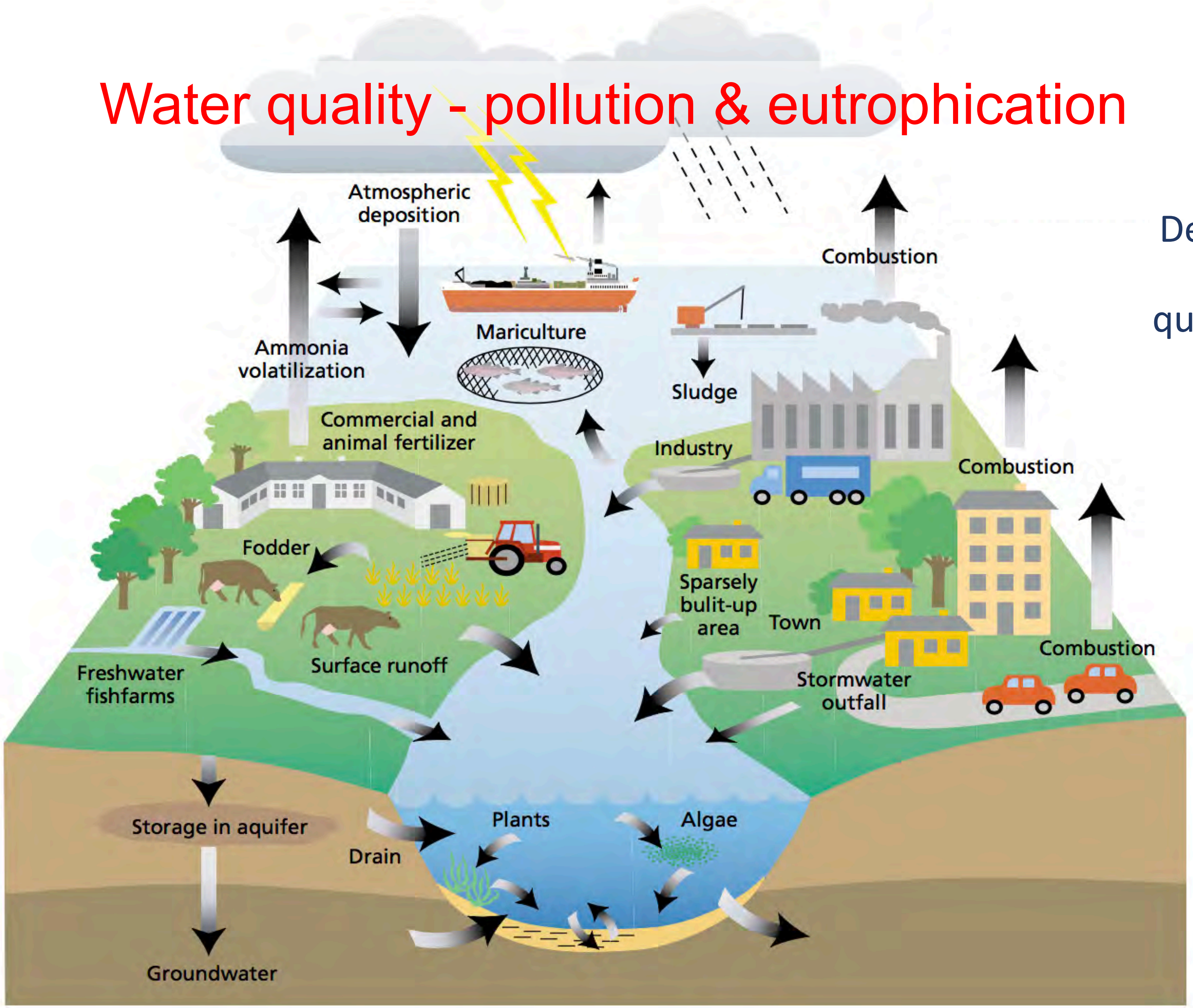
Water quantity –
too little, too much water?



P- ET - R = DS

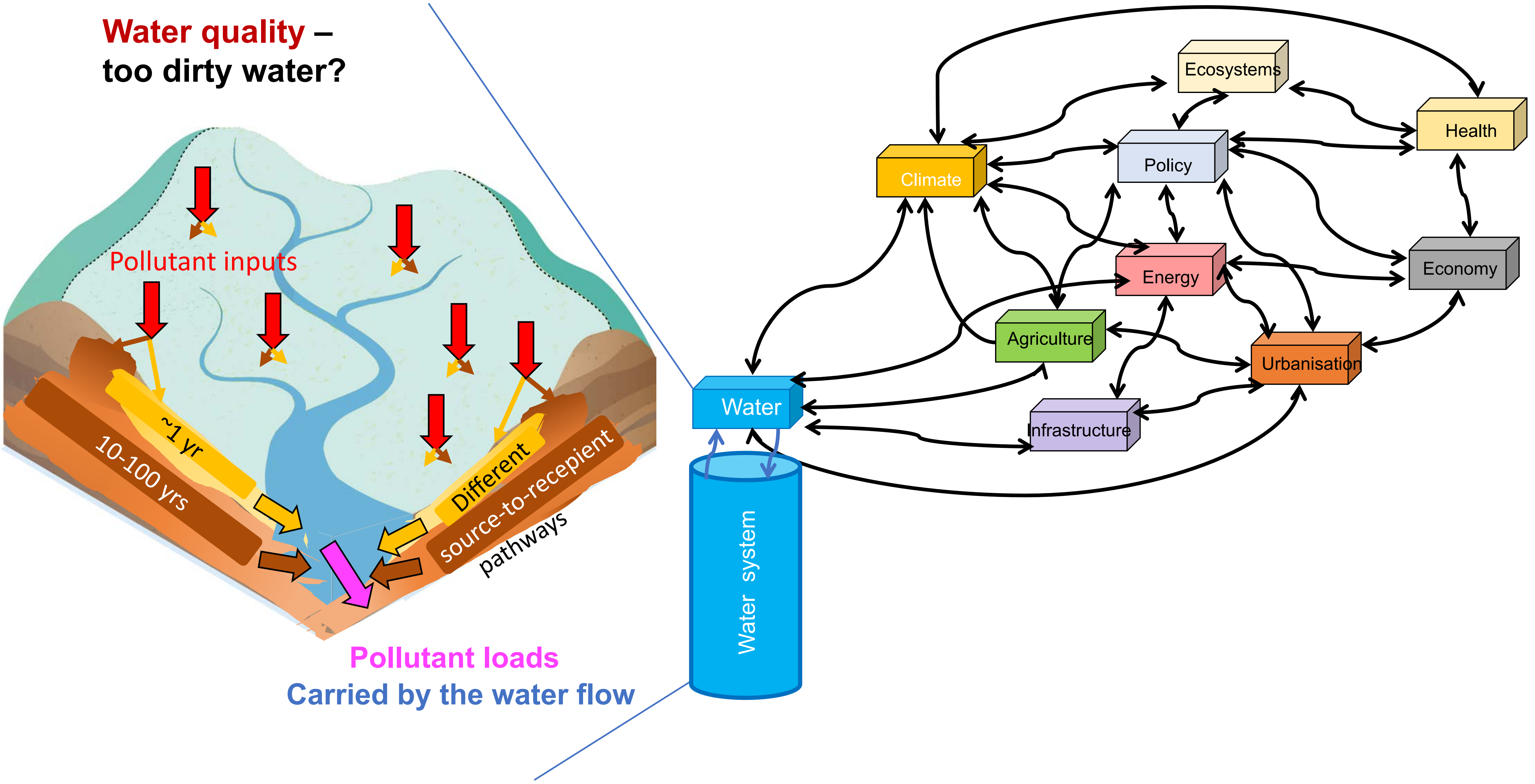


Water quality - pollution & eutrophication



Deterioration of inland and coastal water quality - major problem around the world

Source of figure: Ærtebjerg et al. (2003)



Water quality –
too dirty water?
Pollutant inputs
~1 yr
10-100 yrs
Different
source-to-recepient
pathways
Pollutant loads
Carried by the water flow
Water system
Water
Climate
Ecosystems
Health
Policy
Energy
Economy
Agriculture
Urbanisation
Infrastructure

What we don't know

Earth's Future 2024

REVIEW ARTICLE

10.1029/2023EF003792

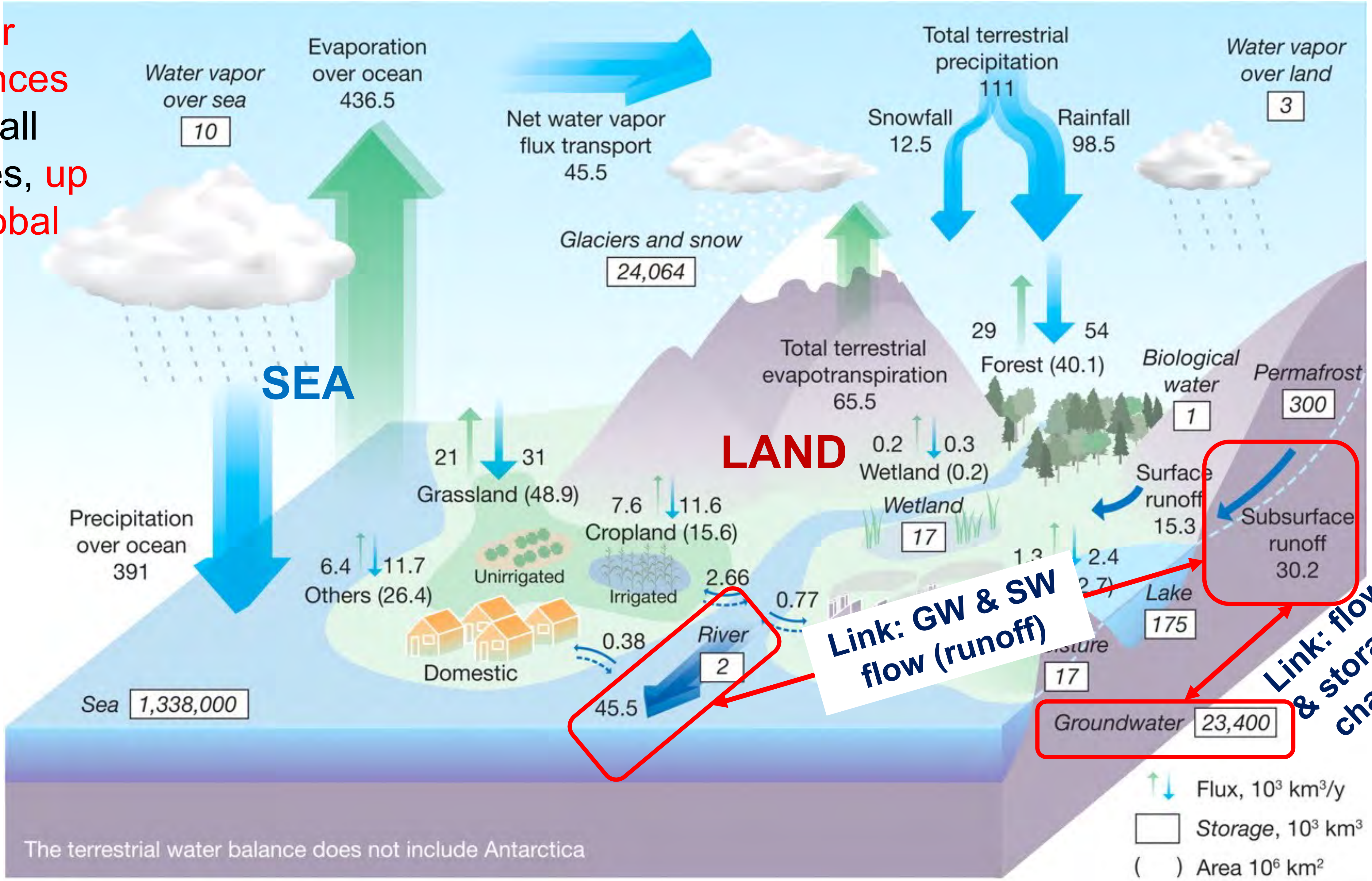
Research Gaps and Priorities for Terrestrial Water and Earth System Connections From Catchment to Global Scale

Mohanna Zarei[1] and Georgia Destouni[1,2]

Key Points:

- Coupling of the ground-surface water system is a key gap in terrestrial water research, particularly at large scales
- Research on terrestrial water interactions with other geospheres and key challenges of Earth System change is rare but impactful
- Major geographic gaps in research on the large-scale coupled terrestrial water system emerge for South America and Africa

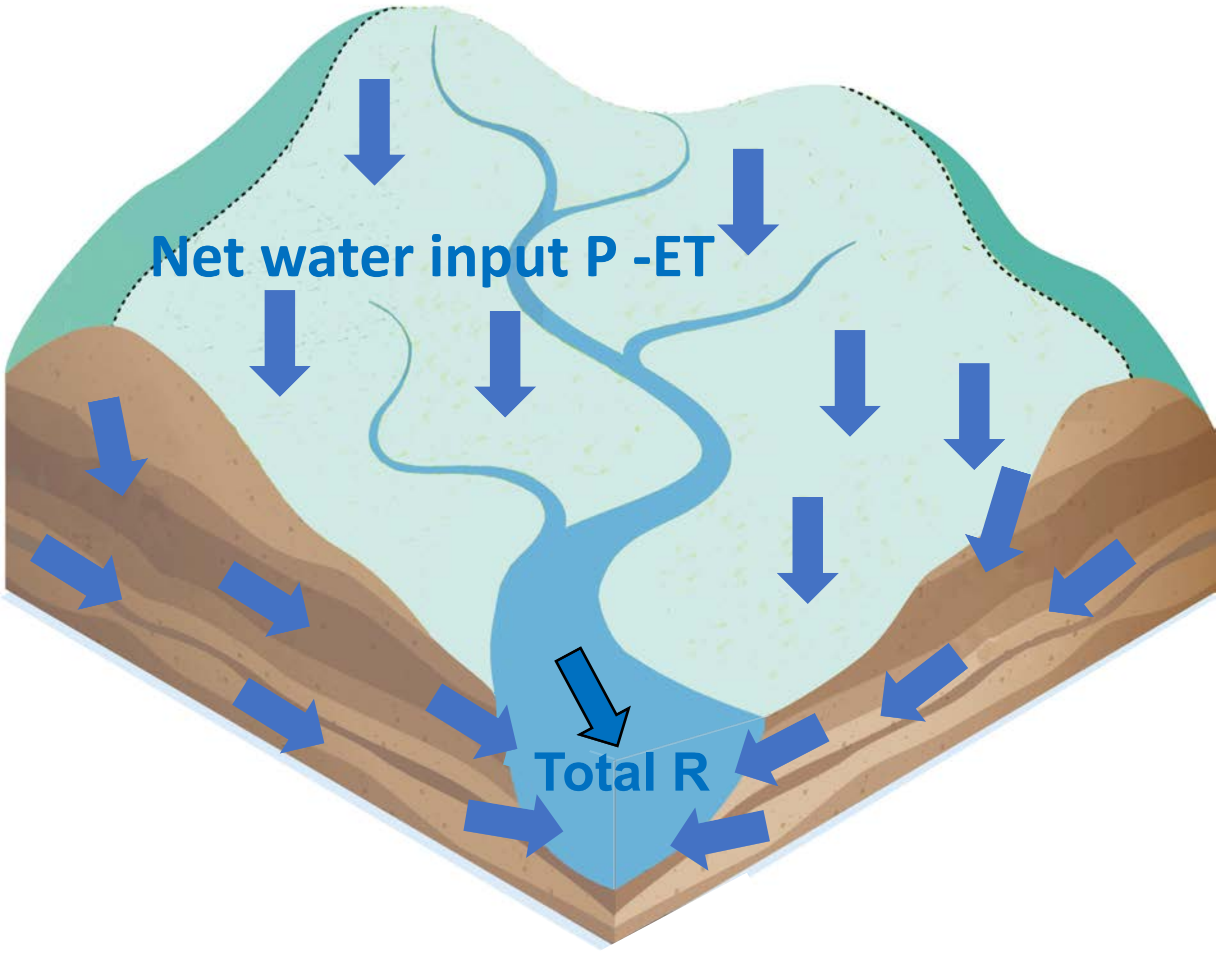
Water balances over all scales, up to global



Oki and Kanae (2006) *Science*

Water quantity – flow, storage change –
too little, too much water?

- **Groundwater flow contributions to total runoff**
  - 98% (Shiklomanov & Sokolov, 1985)
  - 66% (Oki & Kanae, 2006)
  - not reported (Abbott et al., 2019)



- **Storage changes** seldom estimated

Important, e.g., for:

regulation / dampening of droughts, floods

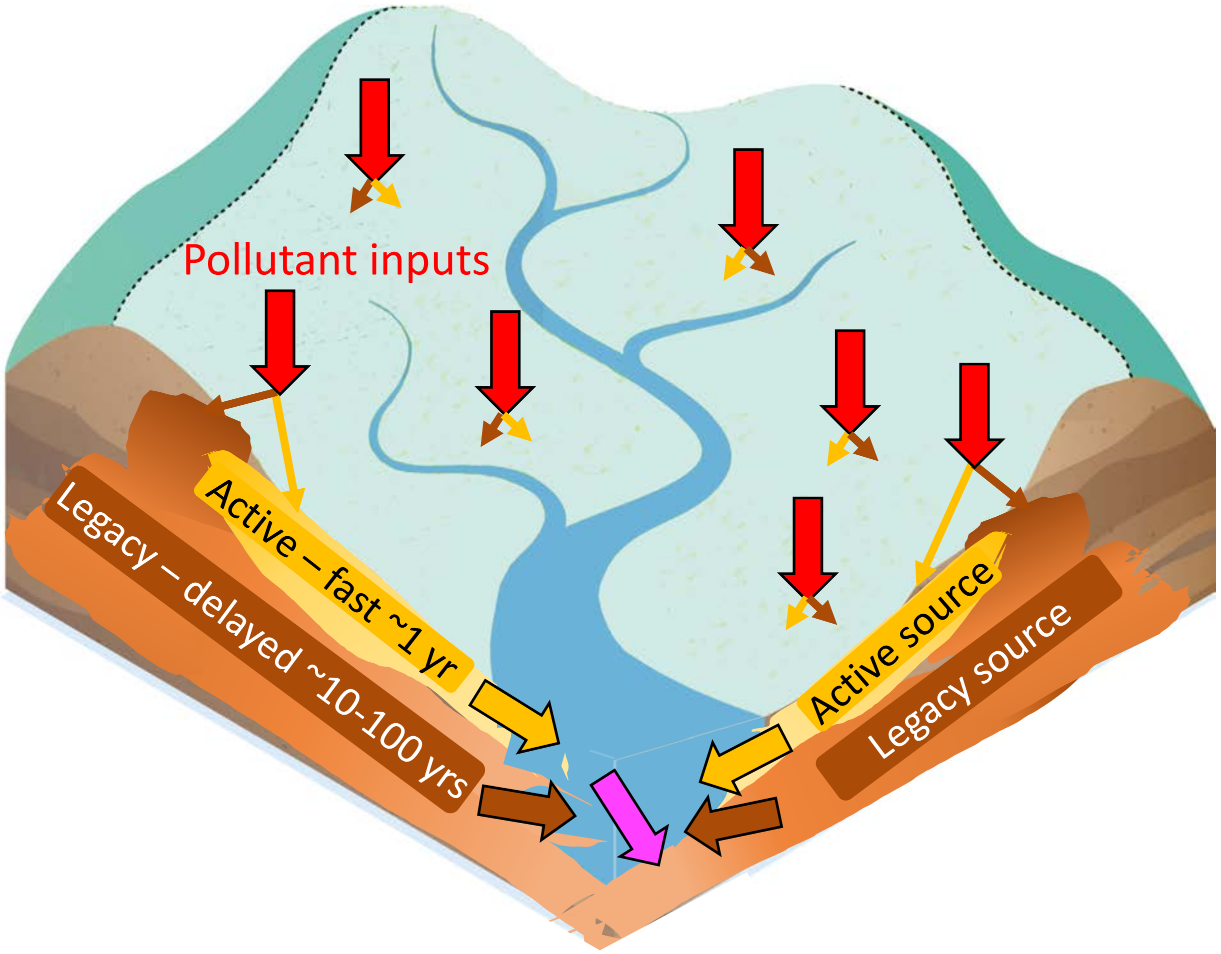
Water quality – too dirty water?

Hugely important

- where the water comes from
- how & where it flows
- for how long time

For:

- source-pathway attribution for different hydro-chemicals
- mitigation options, lag times to effects
- water quality evolution



Pollutant loads

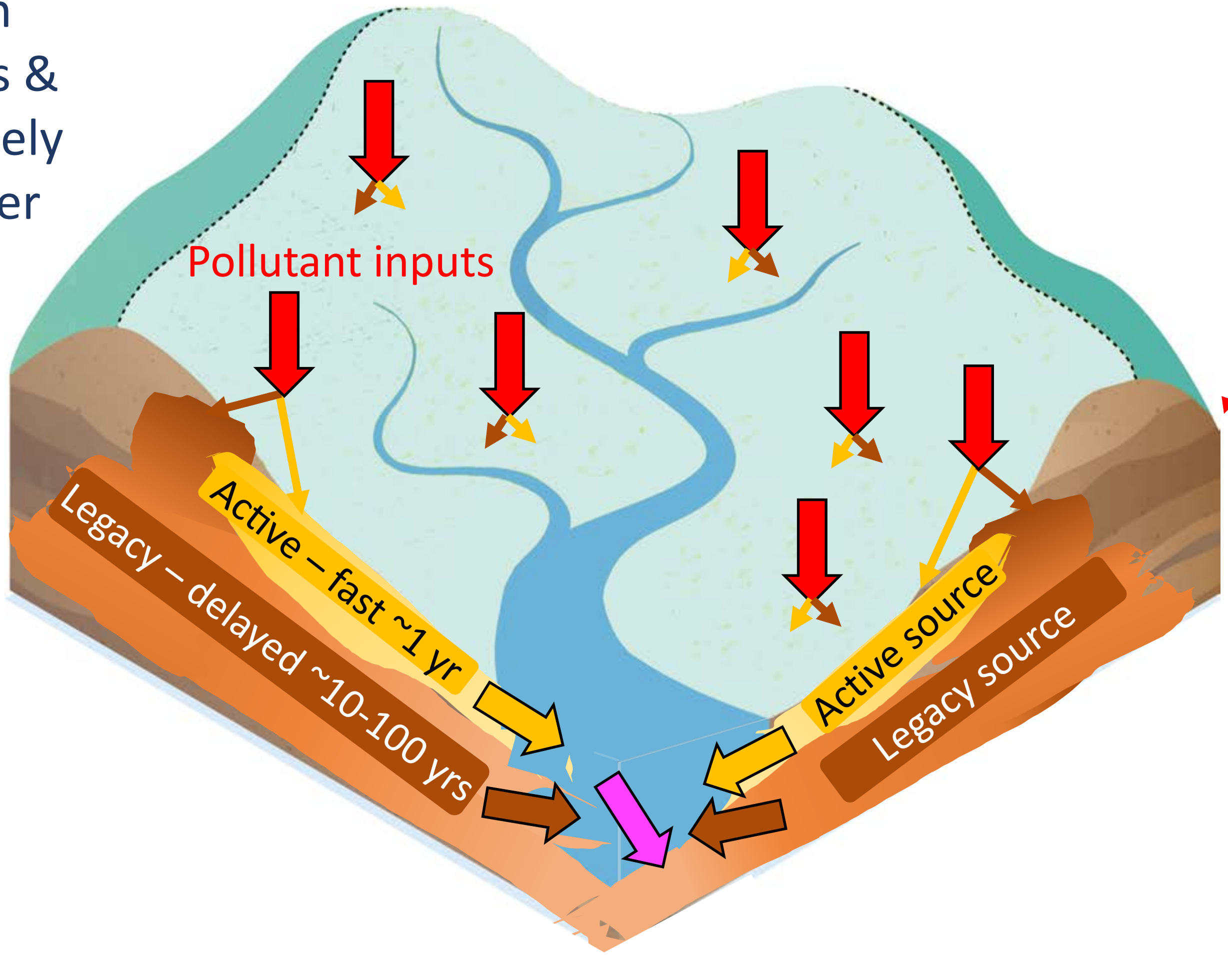
Carried by the water flow

- In many countries, known point sources of nutrients & pollutants have been largely mitigated, improving water quality

- Major mitigation efforts have continued to target known active pollutant sources

But

- Small or no water quality improvements in recent decades, e.g., in nutrient load reduction of nutrient loads to the Baltic Sea

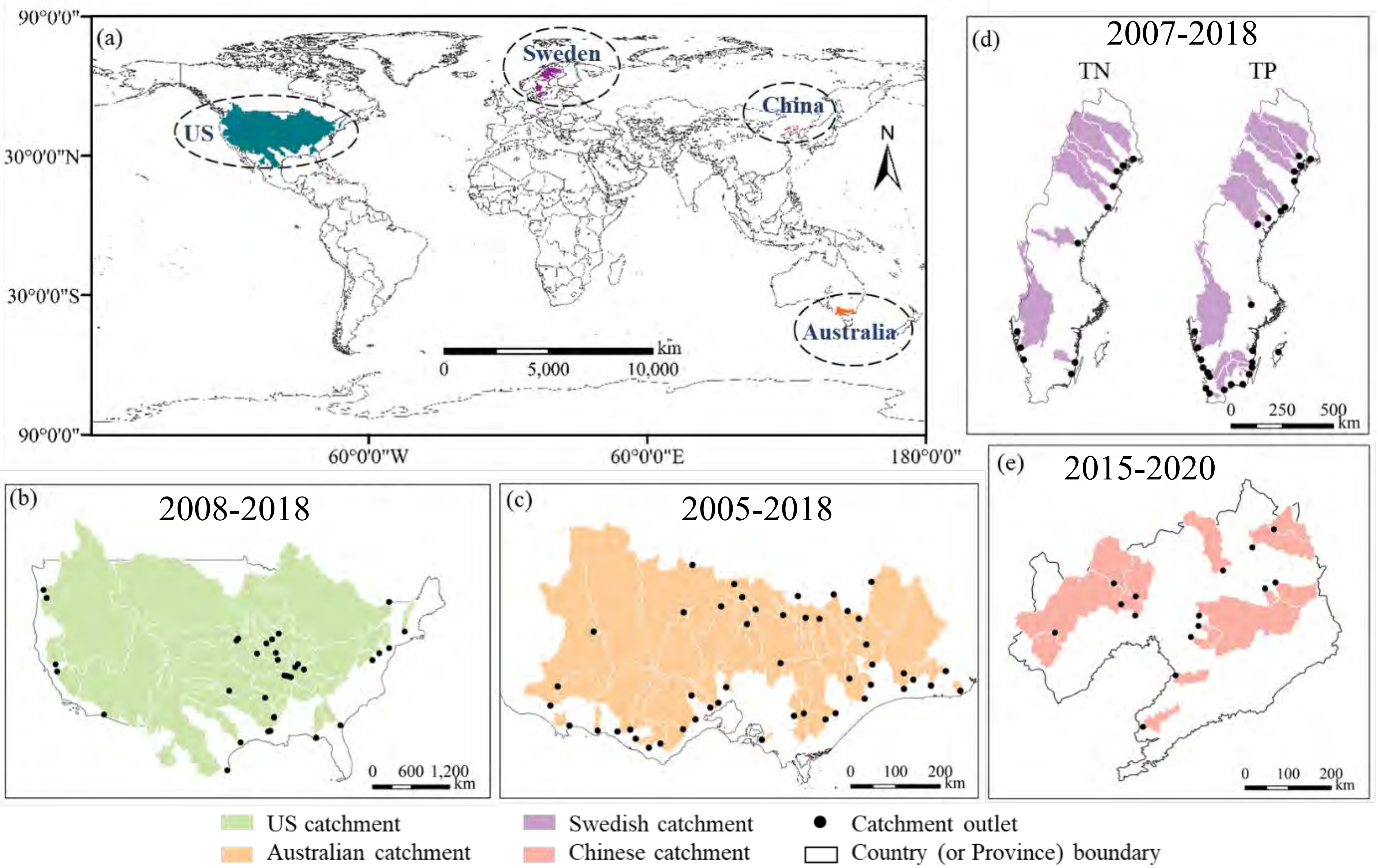


Accumulated legacies increasingly proposed as possible main reason

Remaining in the subsurface (soil, slow-moving groundwater and sediments) from earlier pollutant inputs at the surface

¨Basu et al., Managing Nitrogen Legacies to Accelerate Water Quality Improvement, *Nature Geoscience*, 2022
Destouni, Jarsjö, Zones of untreatable water pollution call for better appreciation of mitigation limits and opportunities *WIREs Water*, 2018

Testing approaches for active-legacy source distinction around the world



Han et al., Legacy sources determine current water quality: nitrogen and phosphorus in streams of Australia, China, Sweden and USA , 2023 (in review)

What don't we know?

Earth's Future 2024

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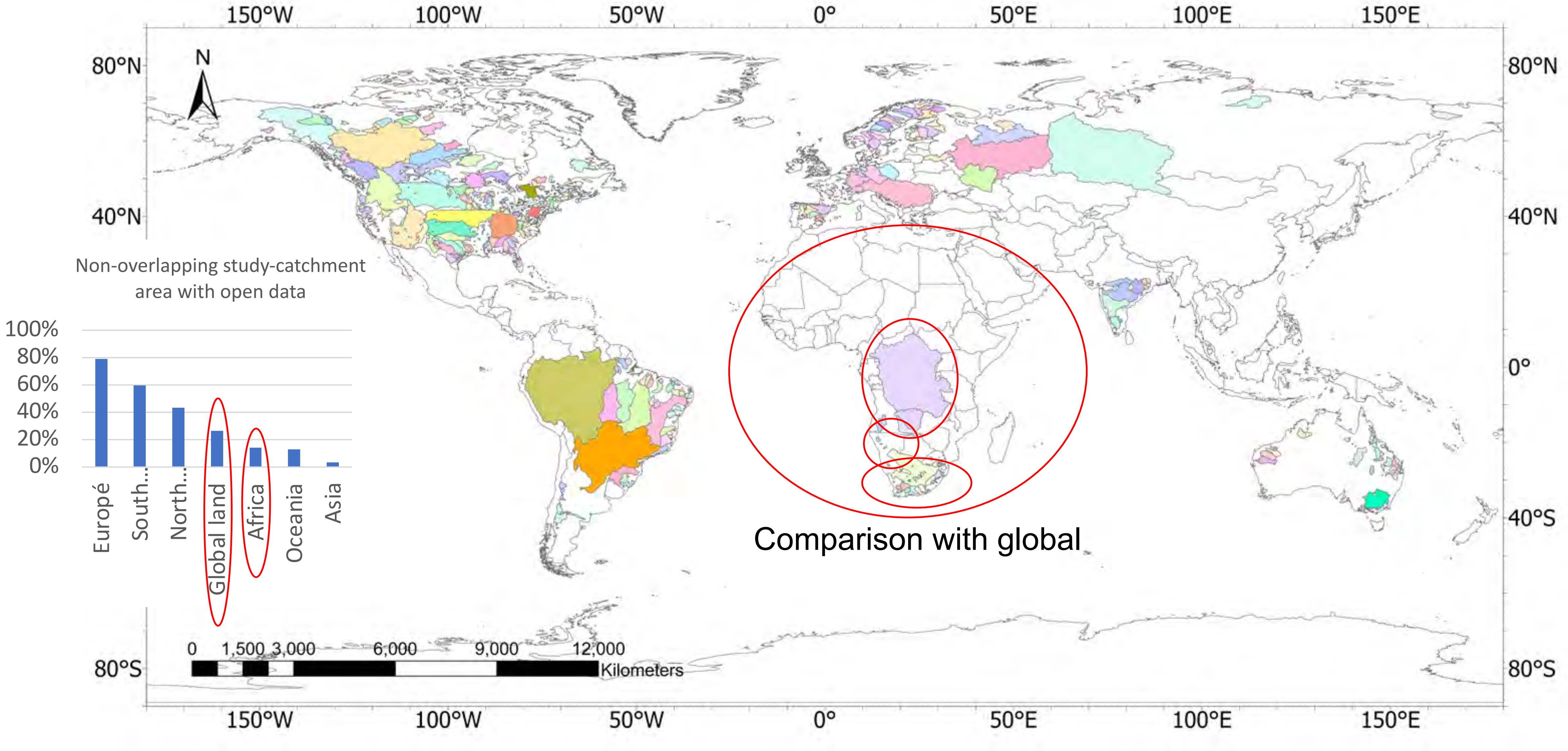
Few studies

But how about data for these regions?

1561 catchments around the world with open data time series for R over 1980-2010



Zarei, Destouni. Global HydroClimatic Database [Data set]. Zenodo (2024)

What can we learn from the openly available data time series?
E.g., about less/more available water, trends to wetter/drier land conditions?

Comparative datasets

Dataset: / Variable	"Obs"	"Mixed"	"GLDAS"	"ERA5"
	Ground observations	**Ground and satellite observations**	**Reanalysis with Land Surface Modeling**	**Reanalysis with Earth System Modeling**
Precipitation	GPCC-V7[a]	GPCC-V7[a]	GLDAS NOAH025 M2.0[f]	ERA5[g]
Evapotranspiration	Water Balance[b]	GLEAM v3.3a[e]	GLDAS NOAH025 M2.0[f]	ERA5[g]
Runoff	GSIM[c]	GSIM[c]	GLDAS NOAH025 M2.0[f]	ERA5[g]
Soil moisture	-	GLEAM v3.3a[e]	GLDAS NOAH025 M2.0[f]	ERA5[g]
Temperature	GHCN-CAMS[d]	GHCN-CAMS[d]	GLDAS NOAH025 M2.0[f]	ERA5[g]

Zarei, Destouni. Global HydroClimatic Database [Data set]. Zenodo (2024)

Global

	Variable Median values	Obs	Mixed	GLDAS	ERA5
Consistent warming	**T trend** (°C/year)	0.03	0.03	0.024	0.025
Divergent P wetting/drying	**P trend** (mm/year^2)	0.4	0.4	0.098	-0.72
Consistent R drying	**R trend** (mm/year^2)	-0.29	-0.29	-0.44	-0.75
Consistent ET wetting	**ET trend** (mm/year^2)	0.78	0.98	1 .0	0.57

Warming

Wetting

Drying

Concurrently for water on land both wetting/flux acceleration & drying/flux deceleration

Not simple binary either / or

Precipitation wetting/drying trend does not alone determine the wetting/drying trends of runoff and evapotranspiration in the landscape

Zarei, Destouni. Global HydroClimatic Database [Data set]. Zenodo (2024)

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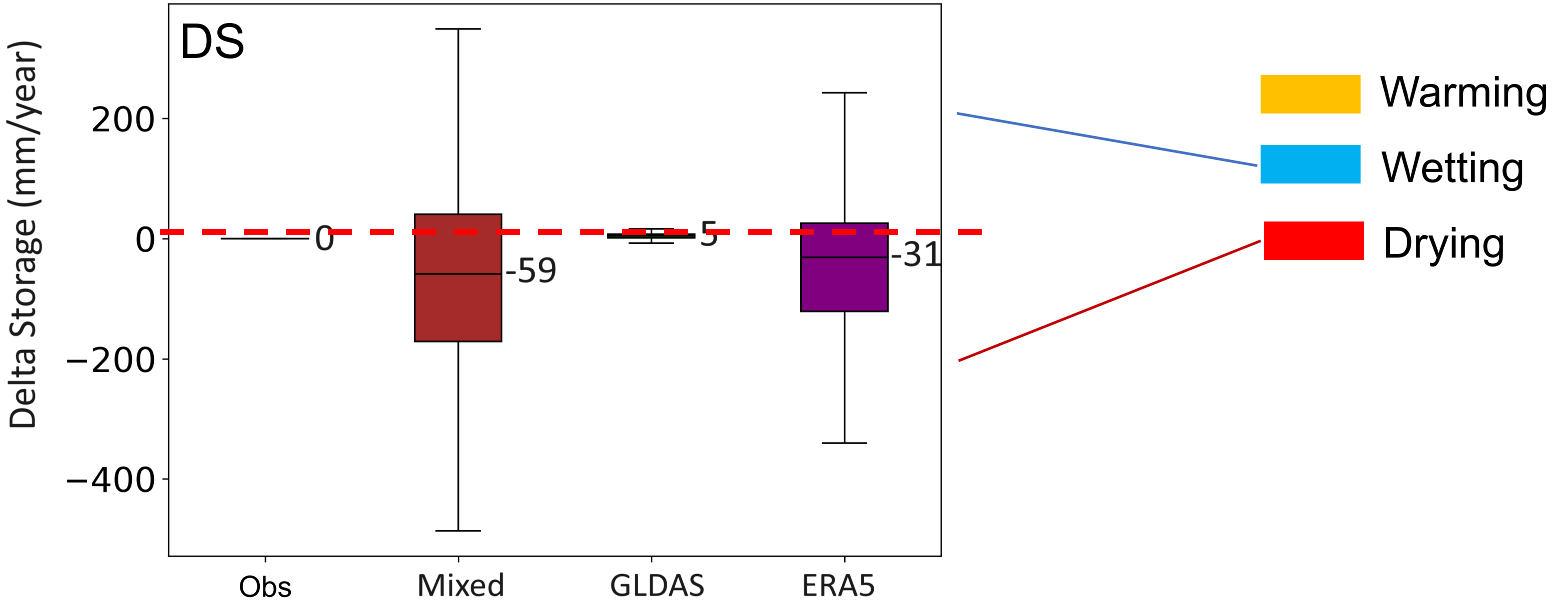
Water balance closure →

Highly divergent annual average storage change DS ~zero or heavily drying



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Congo River Basin

	Variable	Obs	Mixed	GLDAS	ERA5
Consistent warming ~similar	**T trend** (°C/year)	0.03	0.03	0.02	0.02
Divergent P drying/wetting	**P trend** (mm/year²)	-2.9	-2.9	0.63	-13.9
Divergent R wetting/drying	**R trend** (mm/year²)	1.5	1.5	0.28	-12.3
	ET trend (mm/year²)	-4.4	0.66	0.29	-0.46

Zarei, Destouni. Global HydroClimatic Database [Data set]. Zenodo (2024)

Africa

Divergent wetting/drying

Variable	Obs	Mixed	GLDAS	ERA5
T trend (°C/year)	0.012	0.012	0.02	0.015
P trend (mm/year²)	0.23	0.23	-0.37	0.47
R trend (mm/year²)	0.27	0.27	0.14	0.013
ET trend (mm/year²)	-0.44	1.14	-0.55	-1.23

South Africa

Divergent drying/wetting

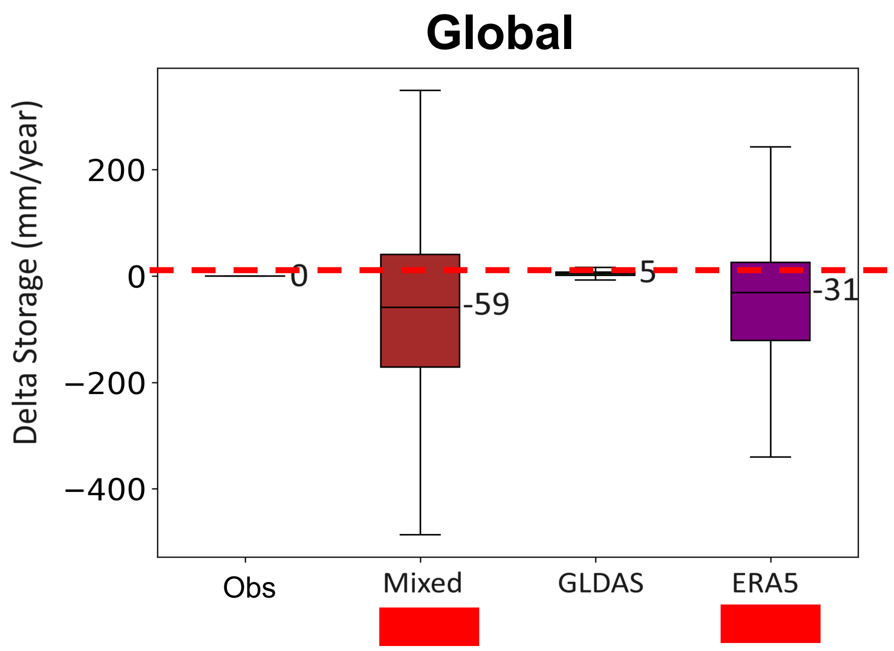
Variable	Obs	Mixed	GLDAS	ERA5
T trend (°C/year)	0.011	0.011	0.02	0.015
P trend (mm/year²)	-0.09	-0.09	-0.5	0.22
R trend (mm/year²)	0.3	0.3	0.14	-0.02
ET trend (mm/year²)	-0.6	1.06	-0.6	-1.3

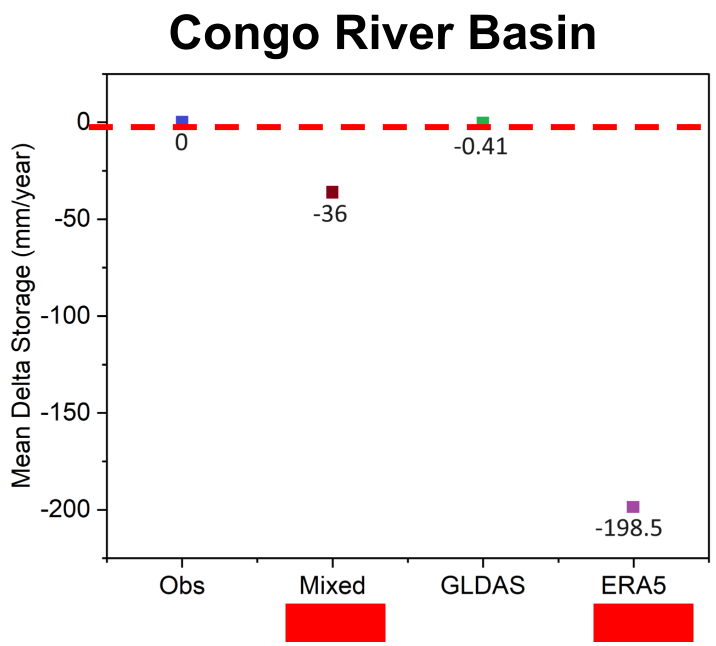
Namibia

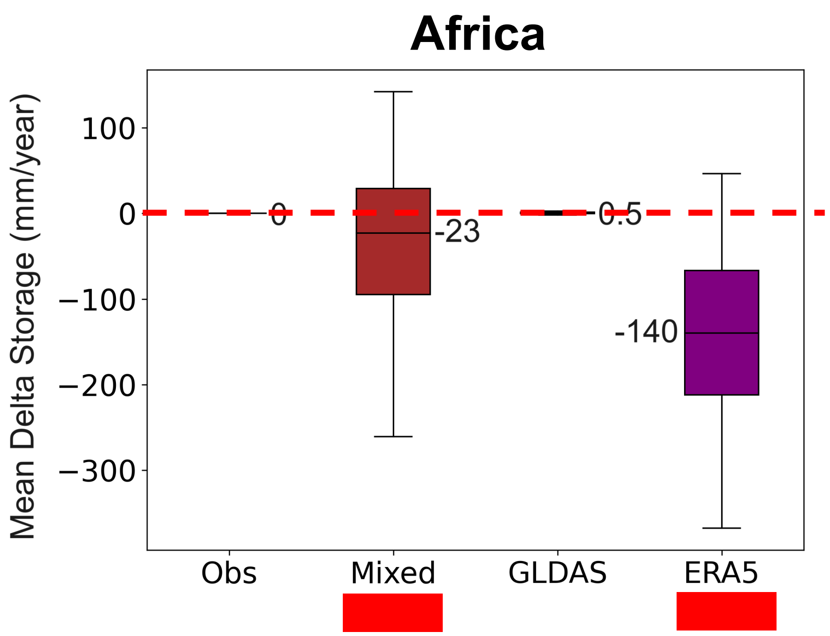
Largely wetting

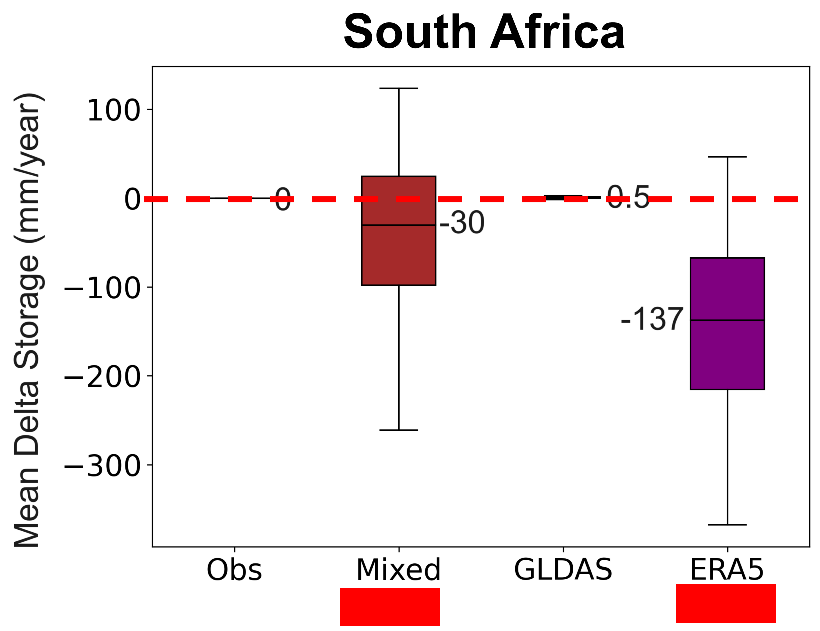
Variable	Obs	Mixed	GLDAS	ERA5
T trend (°C/year)	0.04	0.04	0.008	0.017
P trend (mm/year²)	7.2	7.2	3.9	8.6
R trend (mm/year²)	0.040	0.040	0.035	1.3
ET trend (mm/year²)	6.2	7.0	2.5	-1.1

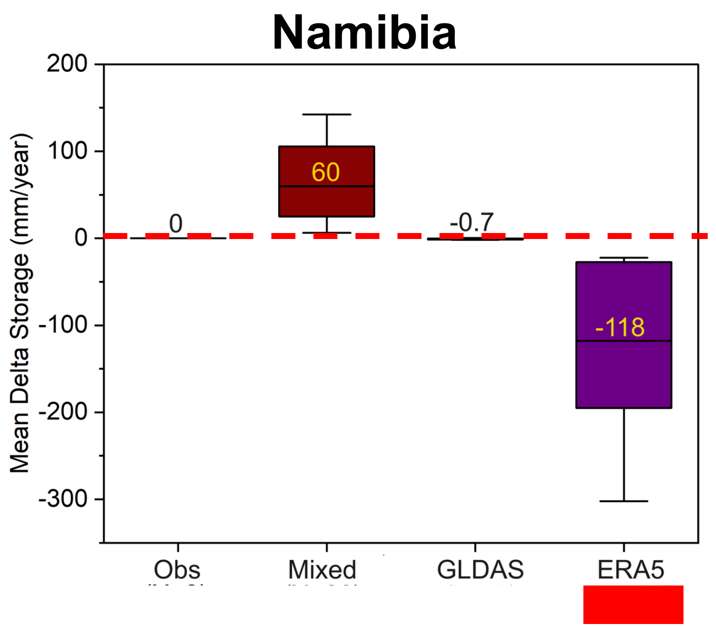
Water balance closure → Average DS











Highly divergent annual average storage change DS

Warning: ERA5 largely "odd one out" for terrestrial water fluxes → heavy drying storage change bias for water on land

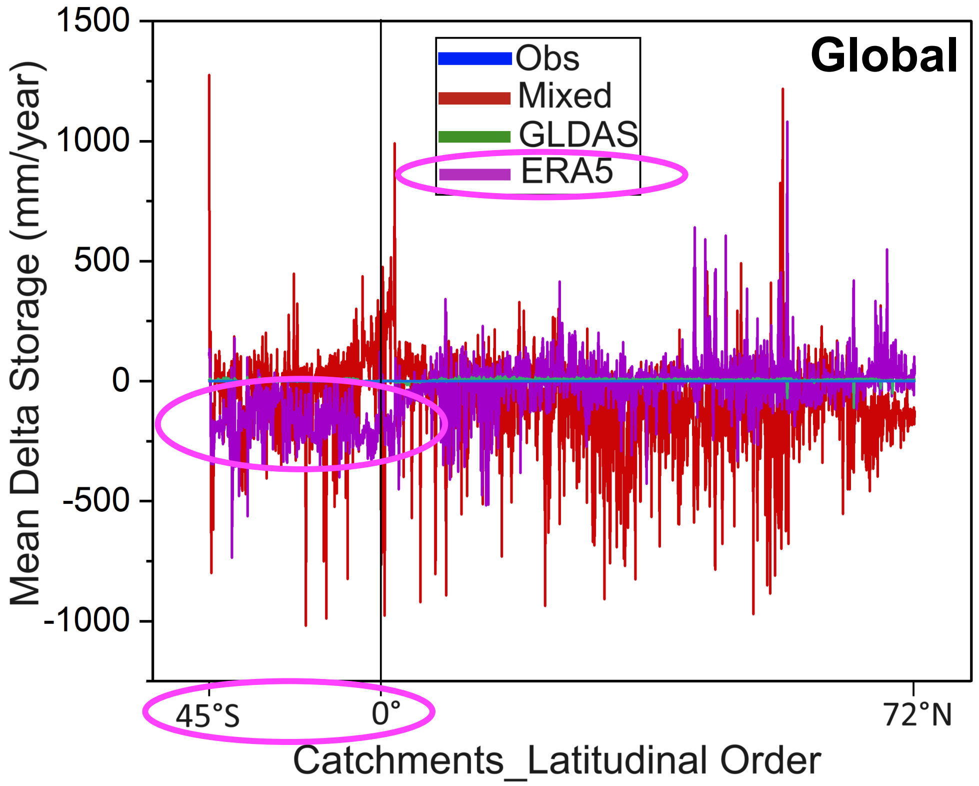
Particularly for Africa / Southern Hemisphere

Annual average storage change DS (mm/year)

Over the global land area

&

Its evolution with time over Africa



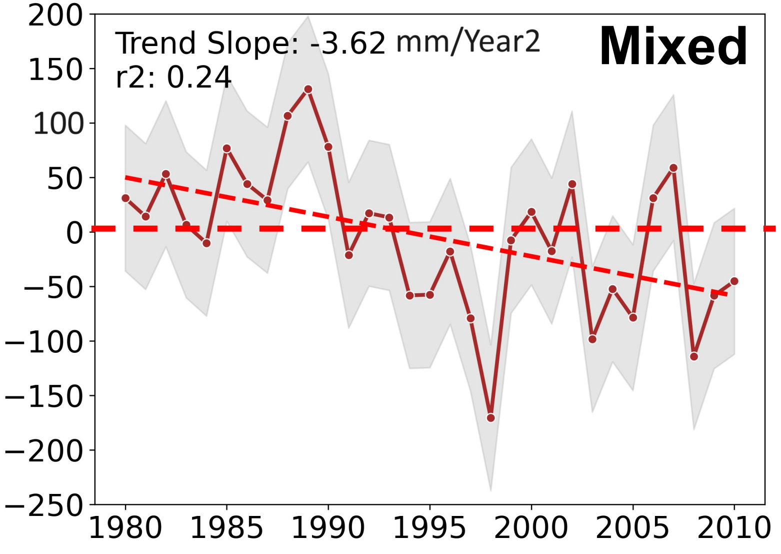
The

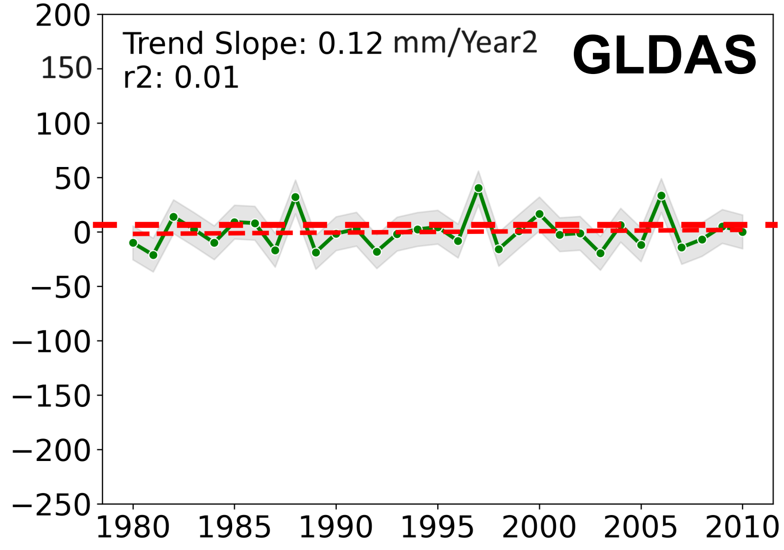
ERA5 Southern Hemisphere / Africa bias

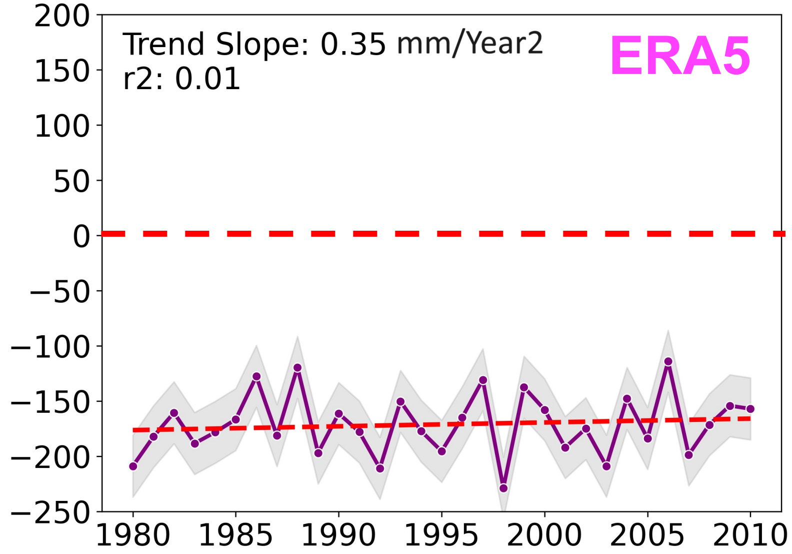
of unrealistic & unexplained systematic, continuous average storage drying

for water on land

Africa







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Global Change
Sustainability
Anthroposphere
Atmosphere
Coastal-Marine Hydrospchere
Cryosphere

SATORI Research Lab

Hosted by University Alliance Stockholm Trio

Initiative Stockholm Trio for Sustainable Action

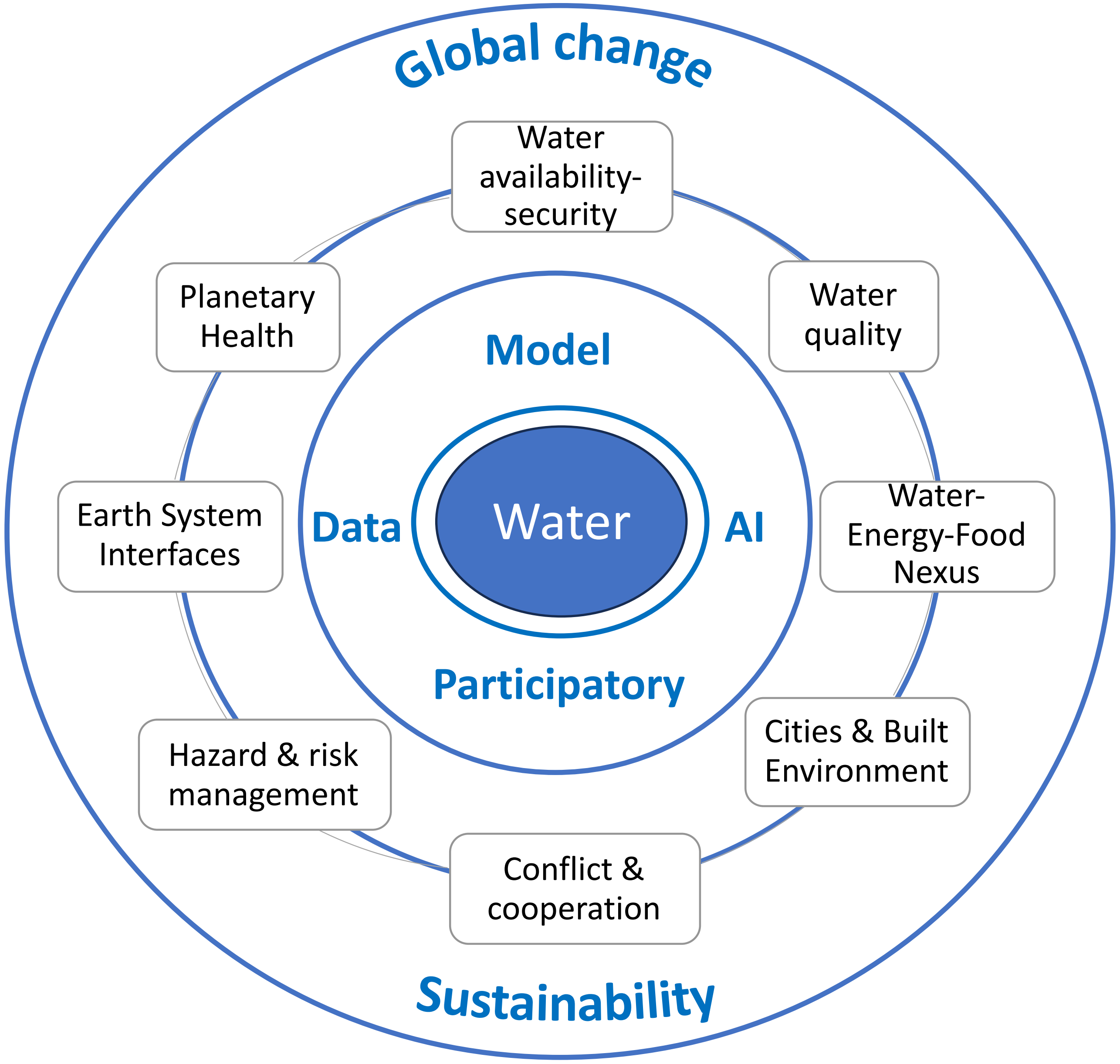
SATORI Research Lab

for coupled natural-human systems

The **SATORI (**Geo**S**p**A**tial da**T**a-m**O**del-a**R**tificial **I**ntelligence) **Research Lab** for coupled natural-human systems

SATORI Research Lab

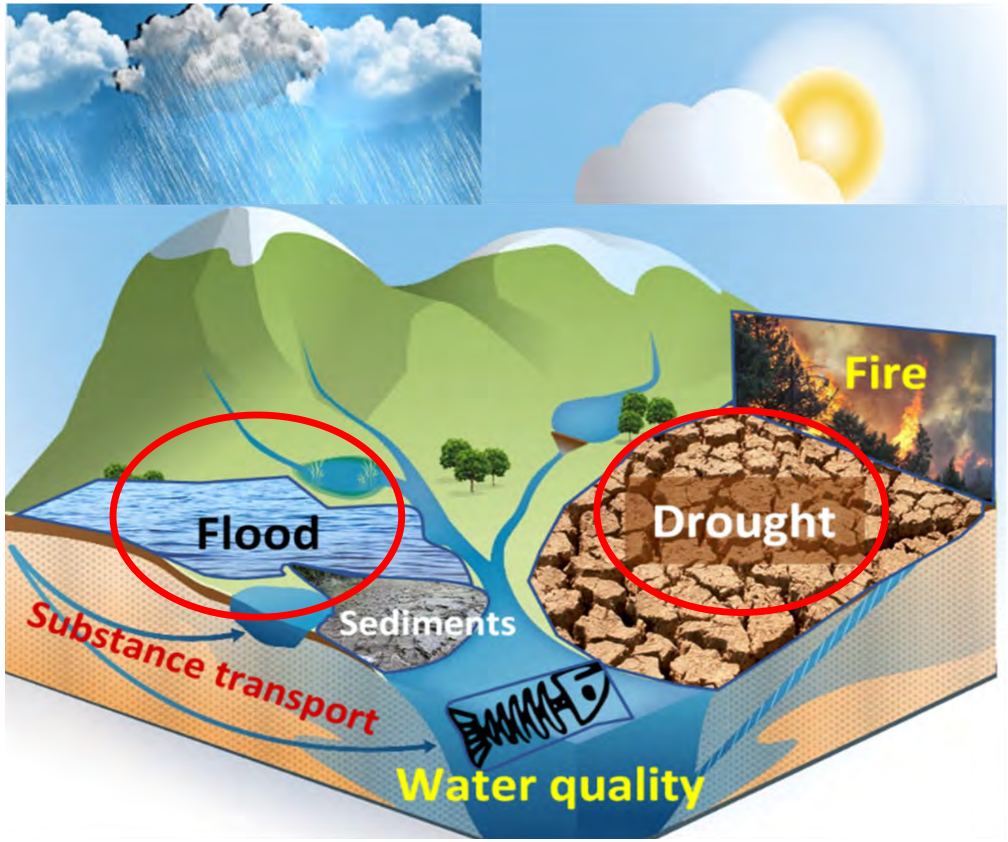
- Water as a blue thread
- For research on different global change and sustainability topics
- Interdisciplinary – seeking water consistency, consilience across topics
- Data-driven – physically-based & interpretable AI/ML modeling
- Participatory methods for solutions to water as resource or risk



Projects

Coupled freshwater system variations, trends and their drivers around the world	The Swedish Research Council VR	Gia Destouni	2023-2026

Hydrological trends in flows & extreme events

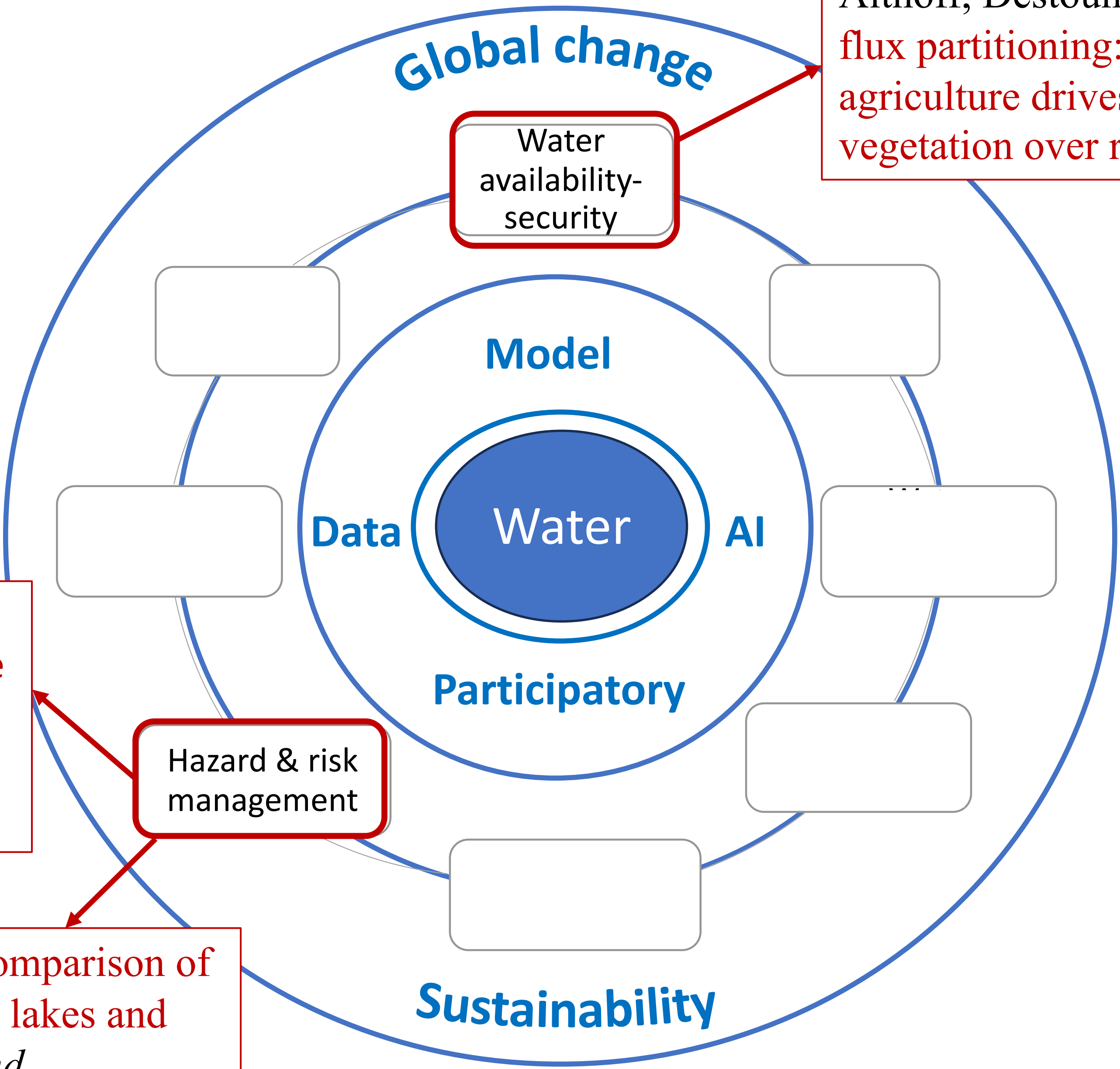


Too little, too much water
… where, when, why?

Hydro-climatic hazard, risk, and crisis management	The Swedish Research Council VR	Zahra Kalantari, Gia Destouni, et al.	2023-2026

SATORI Research Lab

Althoff, Destouni, Global patterns in water flux partitioning: Irrigated and rainfed agriculture drives asymmetrical flux to vegetation over runoff, *One Earth*, 2023



Orth, Destouni, Drought reduces blue-water fluxes more strongly than green-water fluxes in Europe, *Nature Communications*, 2018

Quin, Destouni. Large-scale comparison of flow-variability dampening by lakes and wetlands in the landscape. *Land Degradation & Development*, 2018

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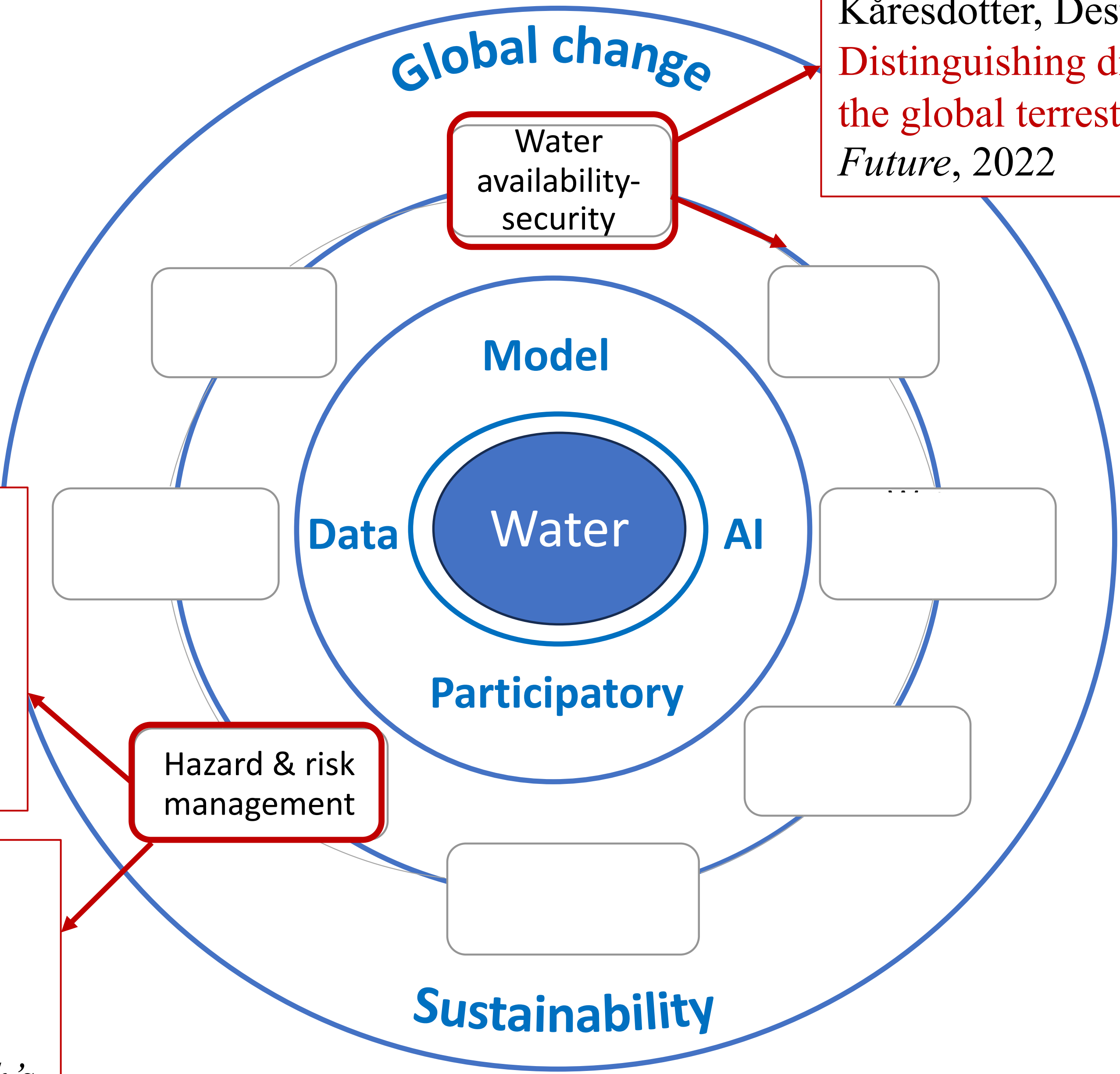
Kåresdotter, Destouni, Ghajarnia, et al., Distinguishing direct human-driven effects on the global terrestrial water cycle. *Earth's Future*, 2022



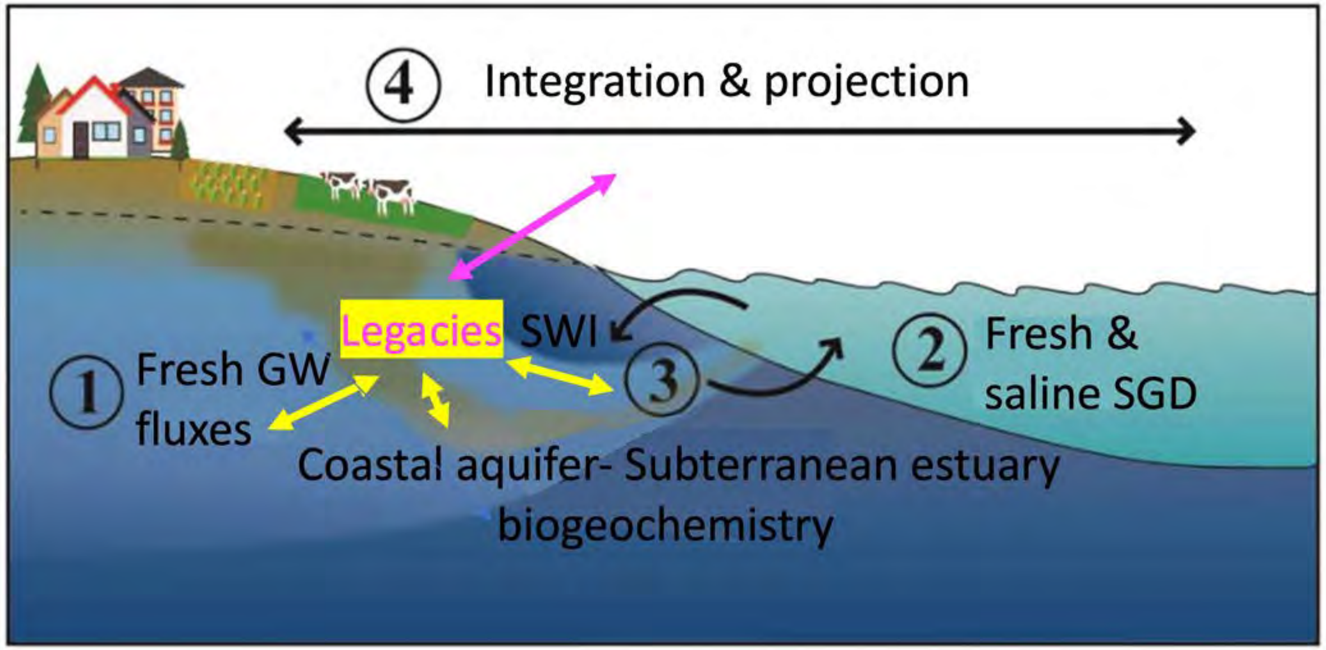
Kan, Ferreira, Destouni, et al., Predicting agricultural drought indicators: ML approaches across wide-ranging climate and land use conditions, *Ecological Indicators*, 2023

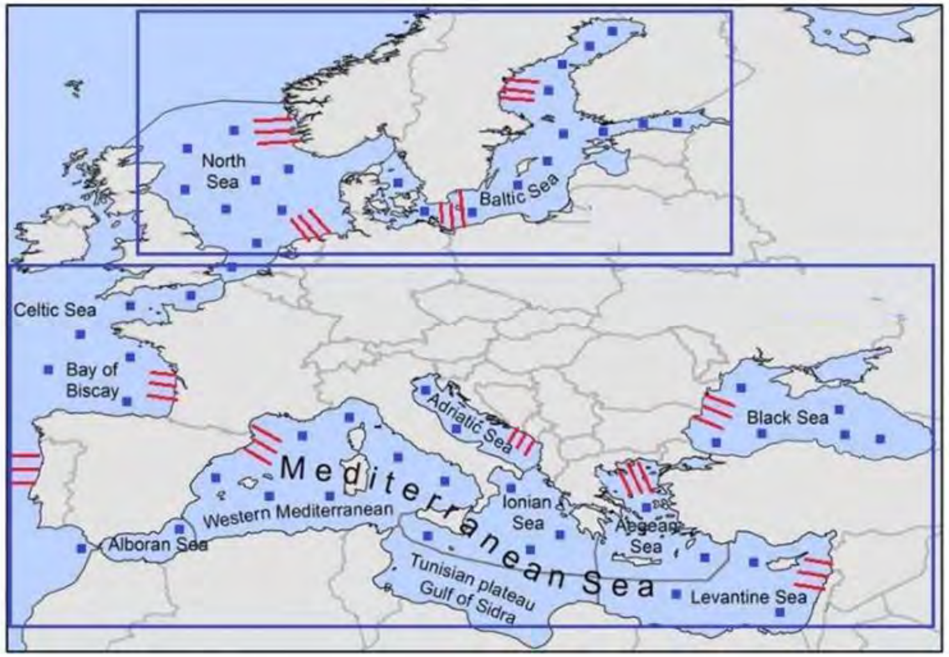
Panahi, Khosravi, Rezaie, Ferreira, Destouni, Kalantari, National-Scale Spatial Flood Modeling with an Optimized Deep Learning Approach, *Earth's Future*, 2023

Project

Unravelling the legacy of historical, emerging and future groundwater pollution to the coastal ocean	Knut & Alice Wallenberg Foundation	Stefano Bonaglia, Gia Destouni, Zahra Kalantari, Isaac Santos	2023-2028

Water pollution propagation across aquatic interfaces





Too dirty water … **where, when, why?**

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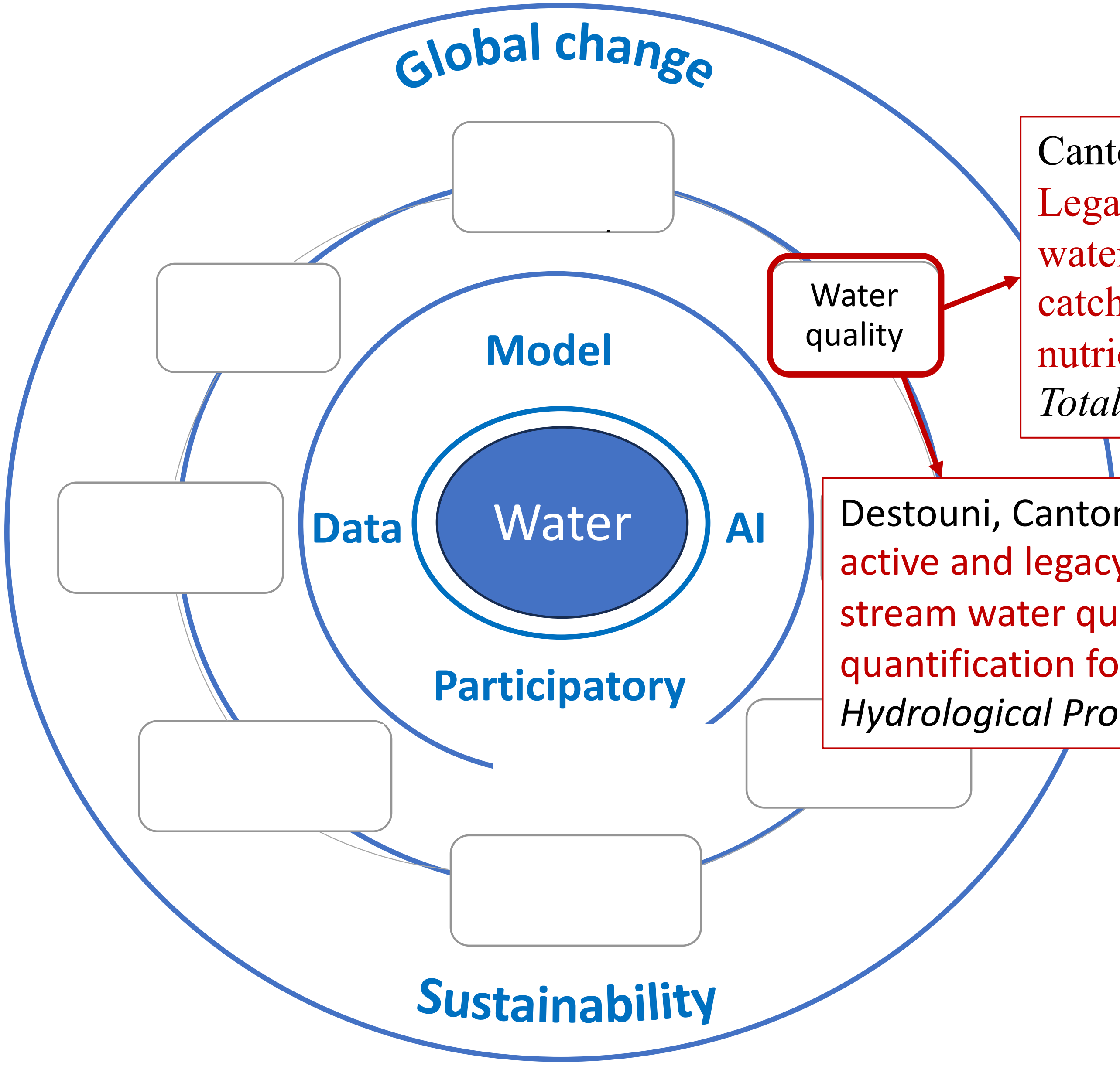
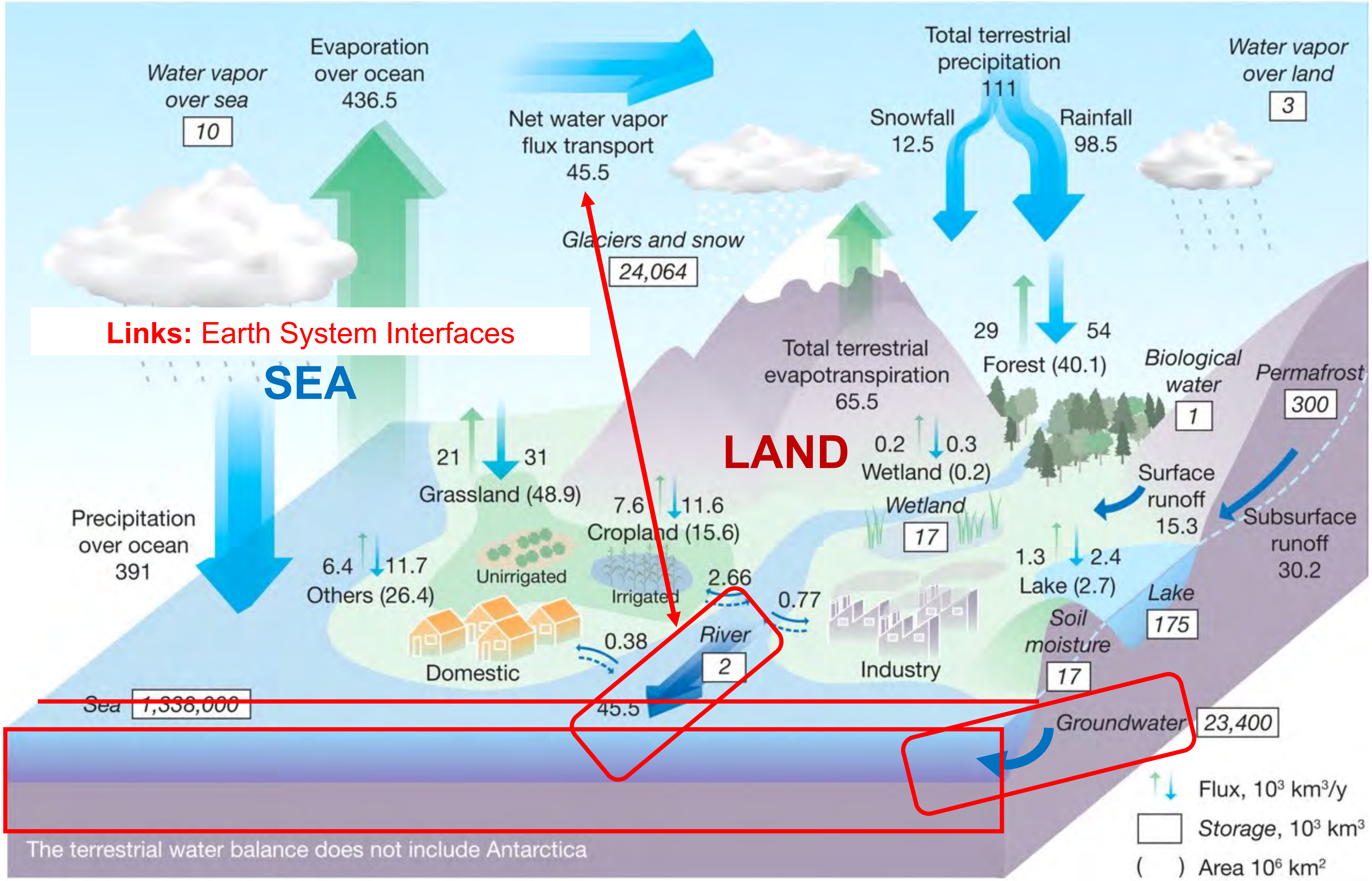


Cantoni, Kalantari, Destouni, Legacy contributions to diffuse water pollution: Data-driven multi-catchment quantification for nutrients and carbon, *Science of the Total Environment*, 2023

Destouni, Cantoni, Kalantari, Distinguishing active and legacy source contributions to stream water quality: Comparative quantification for chloride and metals, *Hydrological Processes*, 2021

Links: Earth System Interfaces



Oki and Kanae (2006) *Science*

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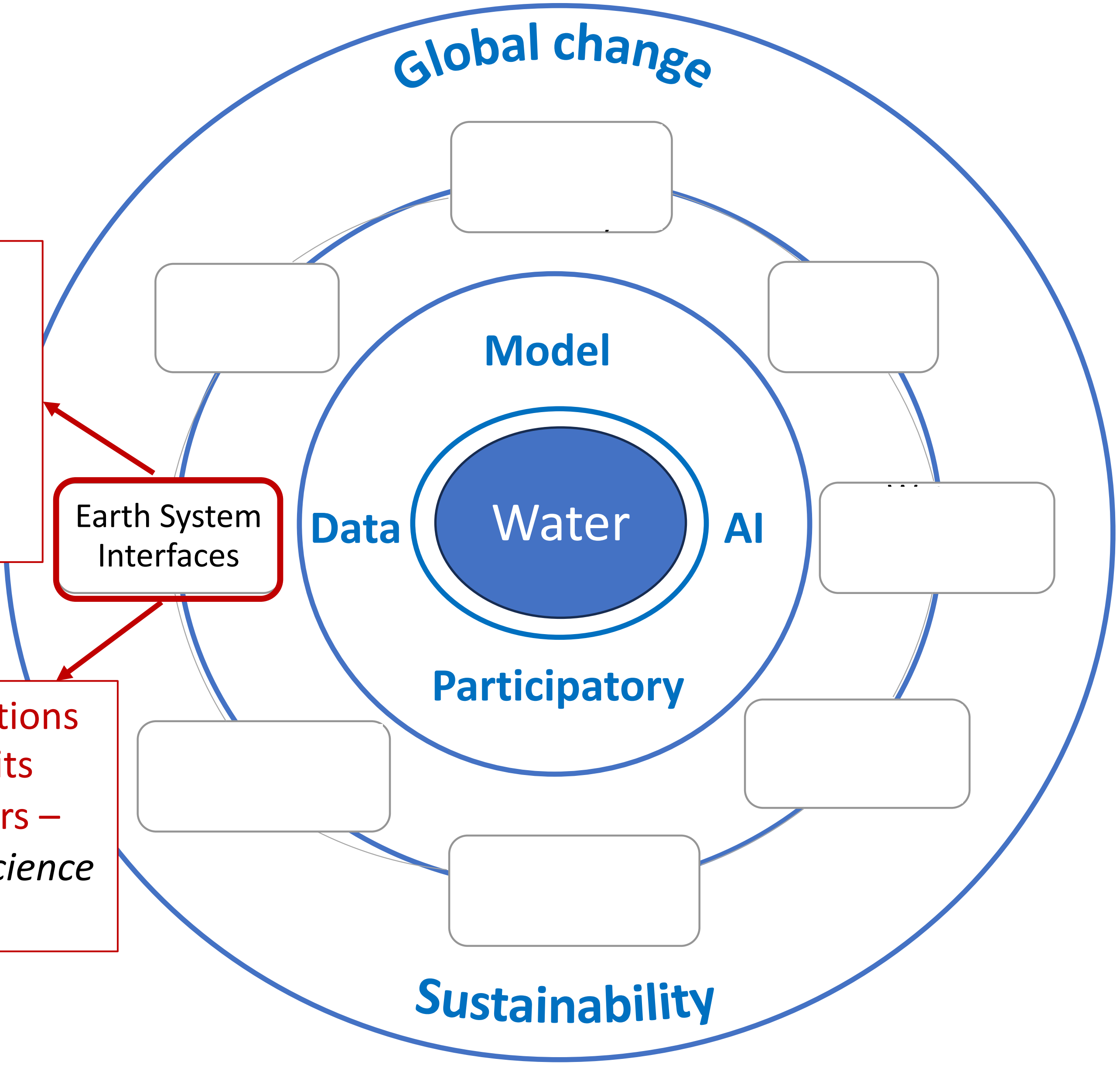
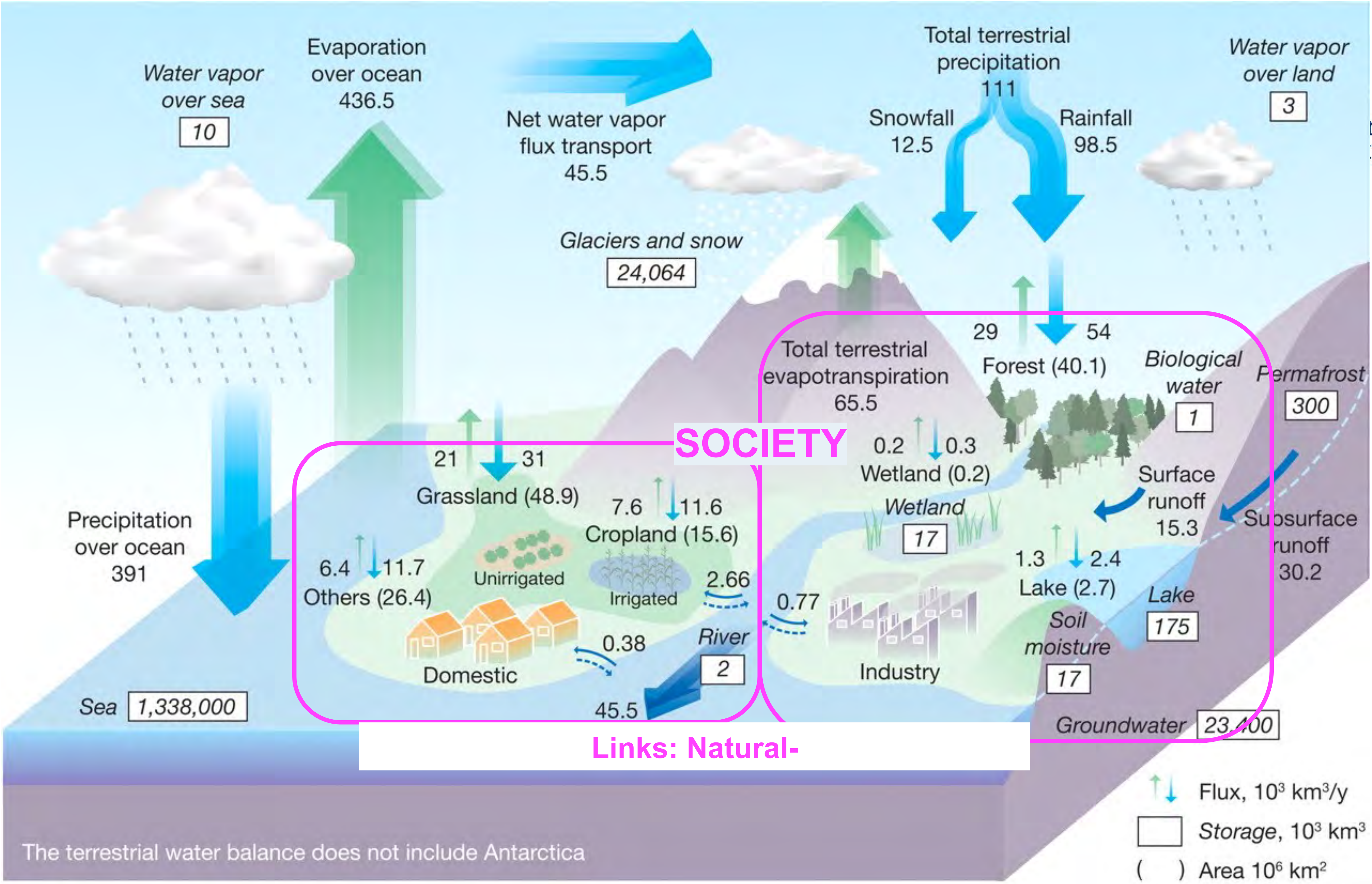
Zhang, Yi, Destouni, et al., Water limitation regulates positive feedback of increased ecosystem respiration, *Nature Ecology & Evolution*, 2024 (*in review*)



Vigouroux, ët al., Trend correlations for coastal eutrophication and its main local and whole-sea drivers – Application to the Baltic Sea, *Science of the Total Environment*, 2021



Oki and Kanae (2006) *Science*

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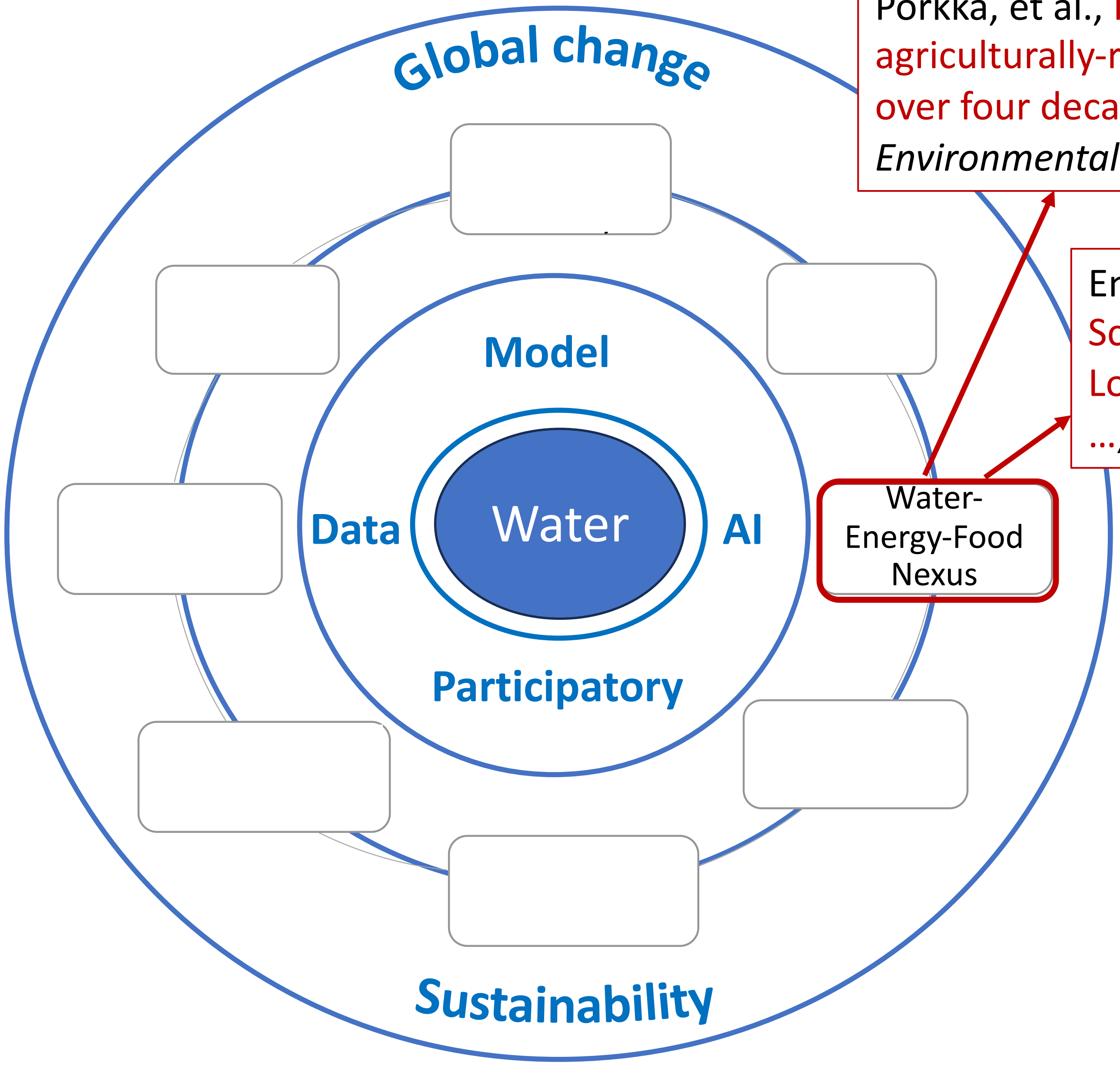

Porkka, et al., Is wetter better? Exploring agriculturally-relevant rainfall characteristics over four decades in the Sahel, *Environmental Research Letters*, 2021

Engström, Destouni, et al., Cross-Scale Water and Land Impacts of Local Climate and Energy Policy …, *Sustainability*, 2019

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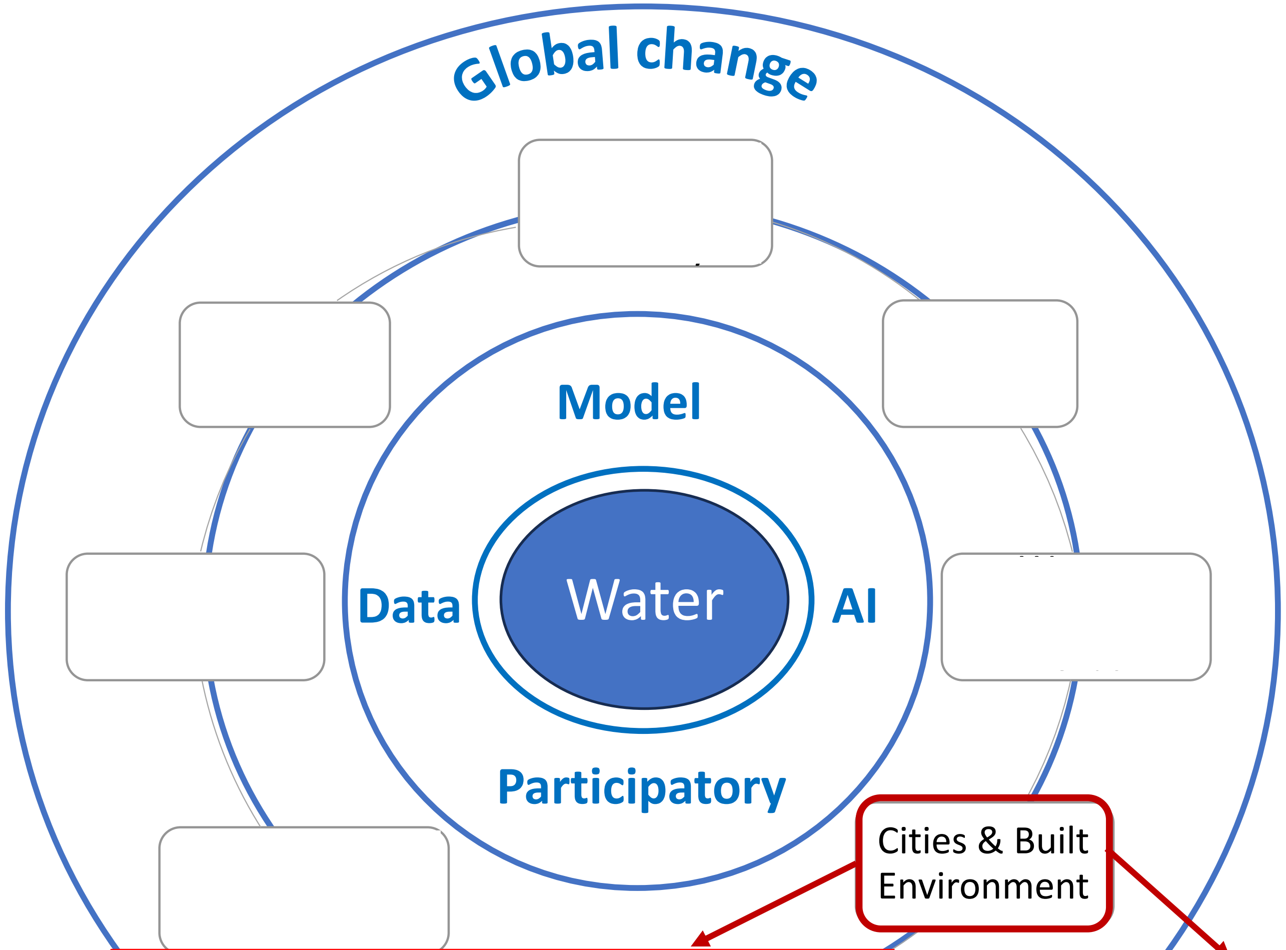


Kong, et al., Urban flood risk management needs nature-based solutions: a coupled social-ecological system perspective, *npj Urban Sustainability*, 2024 (in press).

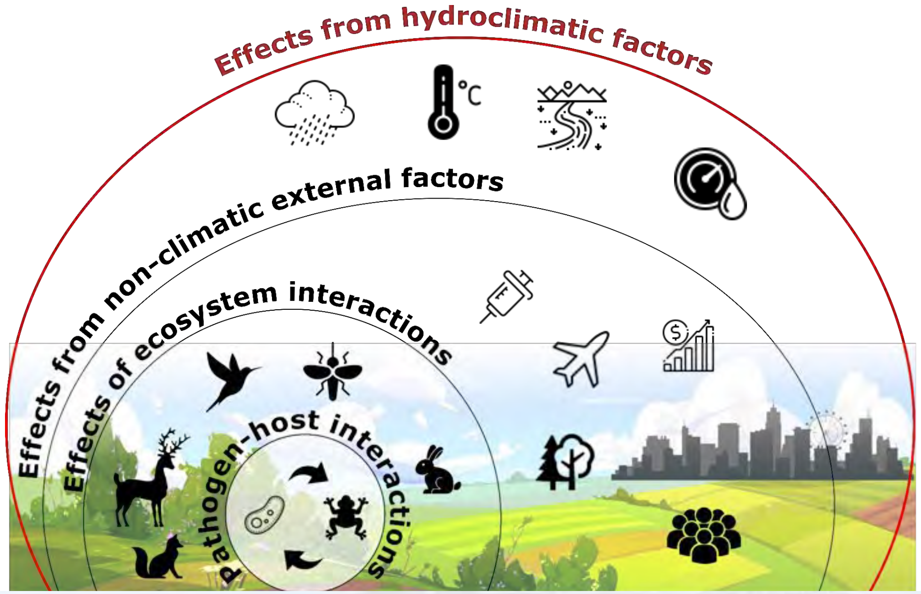
Kalantari, et al., Nature-based solutions for flood-drought risk mitigation in vulnerable urbanizing parts of East-Africa, *Current Opinion in Environmental Science & Health*, 2018

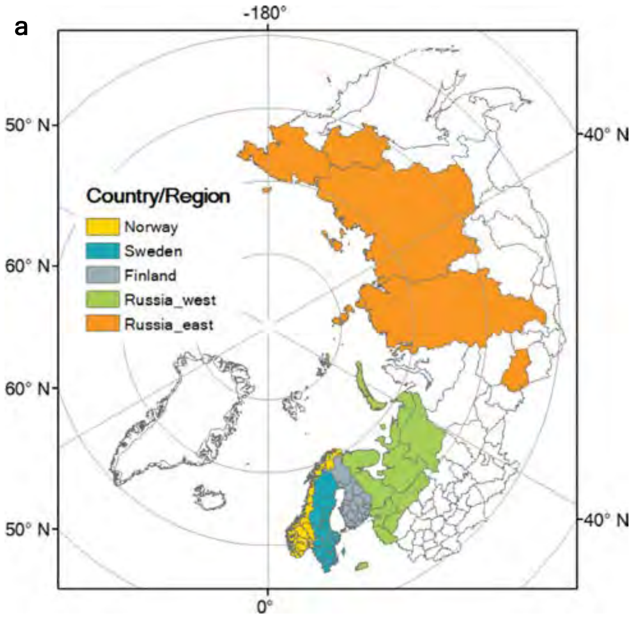
Climate change effects on the epidemiology of infectious diseases and the impacts on Northern societies

Nordic Excellence Project, NordForsk

Hydro-climatic sensitivity of infectious diseases

Change trends in infectious disease occurrence under hydro-climatic change





Ma, PhD thesis, 2023

CLINF

Interdisciplinary research team

- Biologists
- Ecologists
- Economists
- Hydrologists
- Veterinarians
- Climatologists
- Social philosophers
- Human health experts
- Sociologists and anthropologists
- Mathematicians and bioinformaticians
- Experts on gender and traditional knowledge

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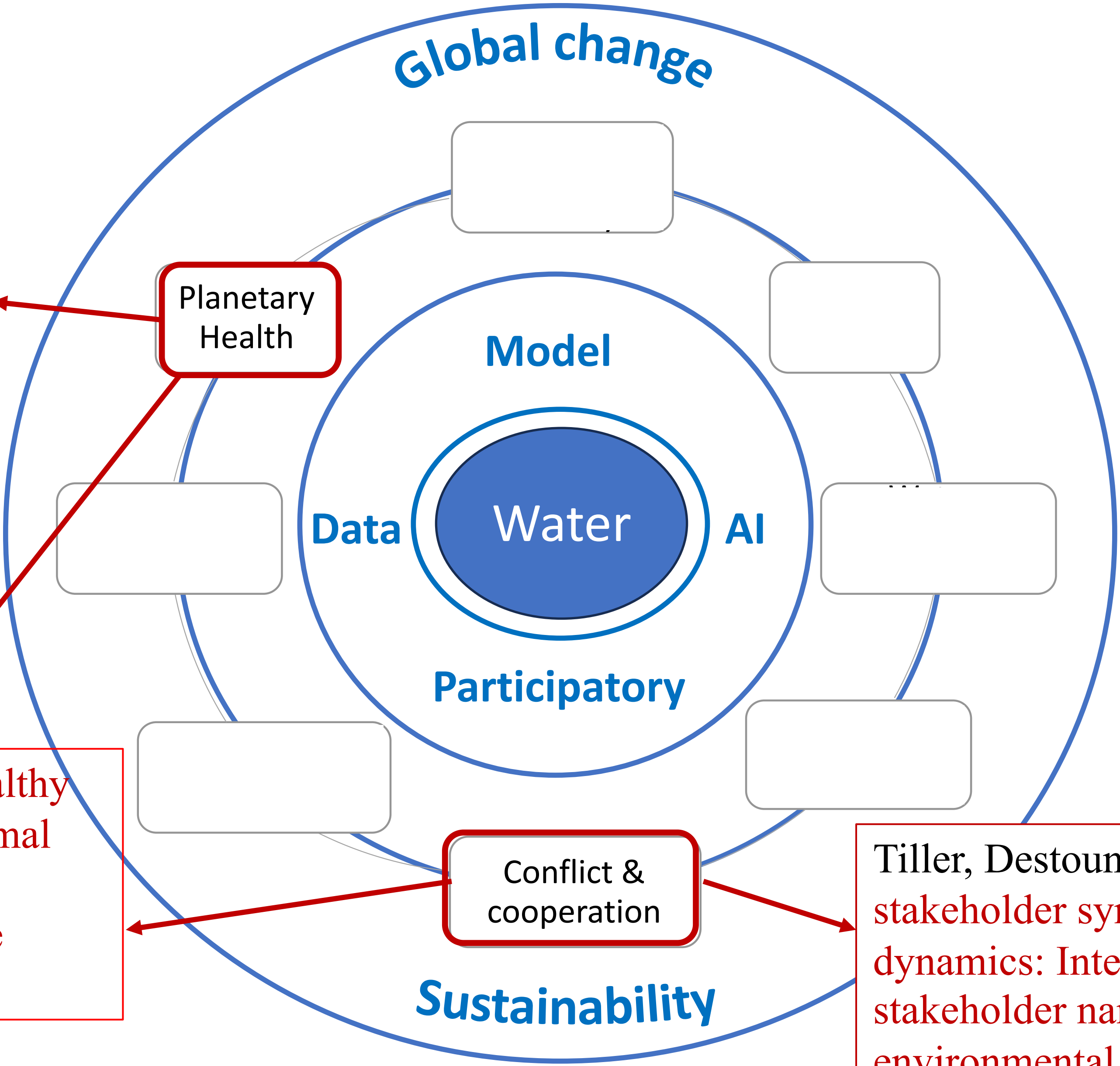

Ma, Destouni, et al., Linking climate and infectious disease trends in the Northern/Arctic Region, *Scientific Reports*, 2021

Evengård, Destouni, et al., Healthy ecosystems for human and animal health: Science diplomacy for responsible development in the Arctic, *Polar Record*, 2021

Tiller, Destouni, et al., Understanding stakeholder synergies through system dynamics: Integrating multi-sectoral stakeholder narratives into quantitative environmental models. *J. Frontiers in Sustainability*, 2021

Based on my work and networking while at STIAS, look forward to further collaboration on:

Critical Zones Africa South & East Network (CzASE)

led by **Professor Lesley Green** of Environmental Humanities South (EHS) at the University of Cape Town - funded by the Science for Africa Foundation

Research over the coming four years on how lived experience in Africa's Anthropocene can support decision-makers to improve habitability in peri-urban areas

- **Critical Zone rapid appraisal:** assessing metabolism of water, nutrients and contaminants
- **Small-scale farming:** soil and seed care to address emerging climate-based gender struggles
- **African environmentalism:** landscape knowledge as ecological philosophy
- **Contaminant legacies and environmental justice:** cleaning up the Critical Zone
- **Ecological economics for governance of the commons in the Critical Zone**
- **Reducing precarity by amplifying habitability:** toward Critical Zone-based environmental governance policy

African partners and cases in: South Africa, Ethiopia, Mozambique, Tanzania, Malawi, Zimbabwe + University of Leeds, UK