Hydrological drivers of organic matter quality, mineralization and export in a tropical dam-impacted floodplain system

Roland Zurbrügg

Acknowledgements:

Stephan Suter, Bernhard Wehrli, David B. Senn
Institute of Biogeochemistry and Pollutant Dynamics, ETH Zürich
Eawag, Swiss Federal Institute of Aquatic Science and Technology

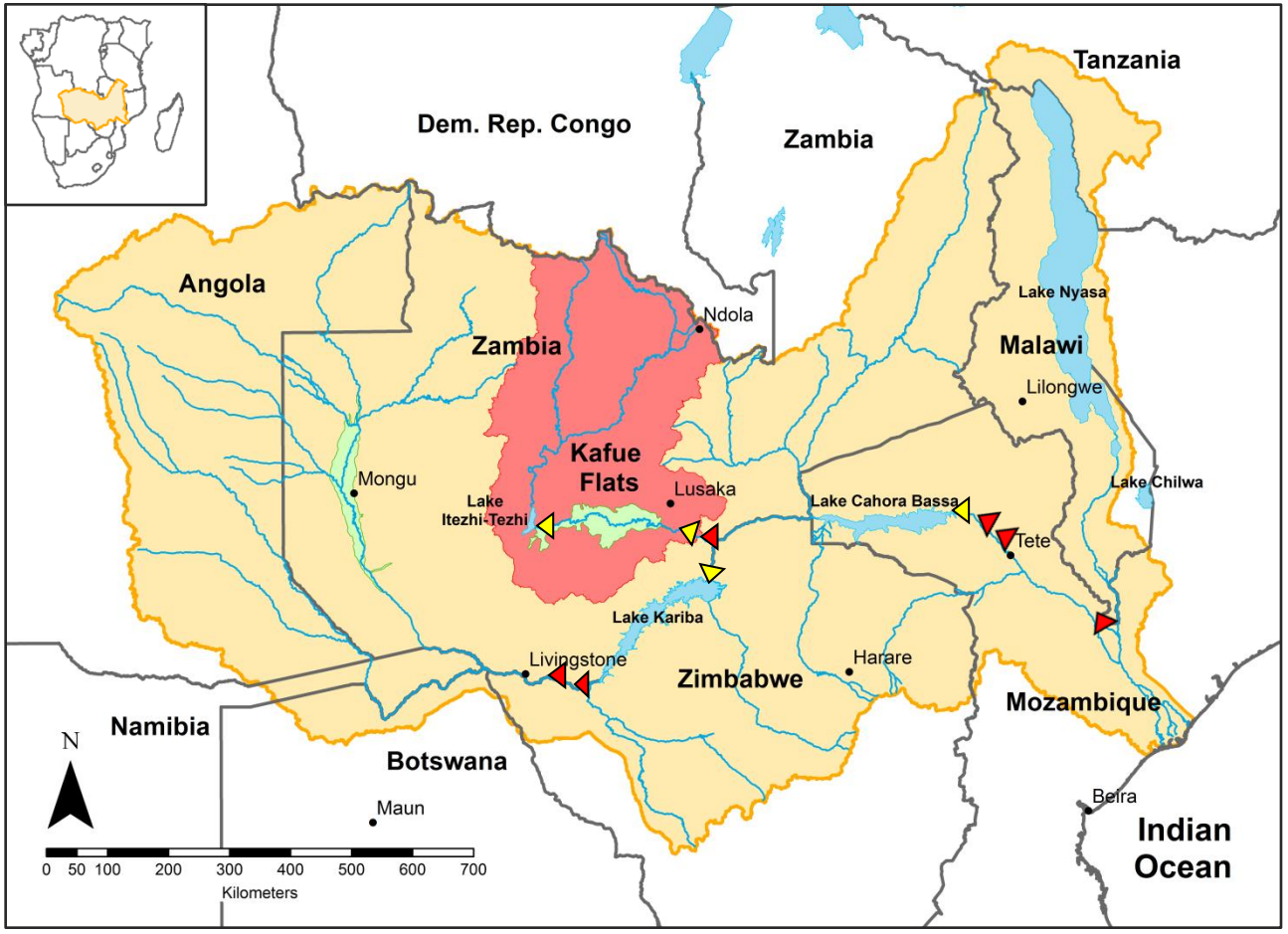
Moritz F. Lehmann
Institute of Environmental Geosciences, University of Basel, Switzerland

Jason Wamulume, Griffin Shanungu
University of Zambia, Zambia Wildlife Authority

Eawag: Das Wasserforschungs-Institut des ETH-Bereichs


J. Janssen, kafueflats.org

The Zambezi River Basin

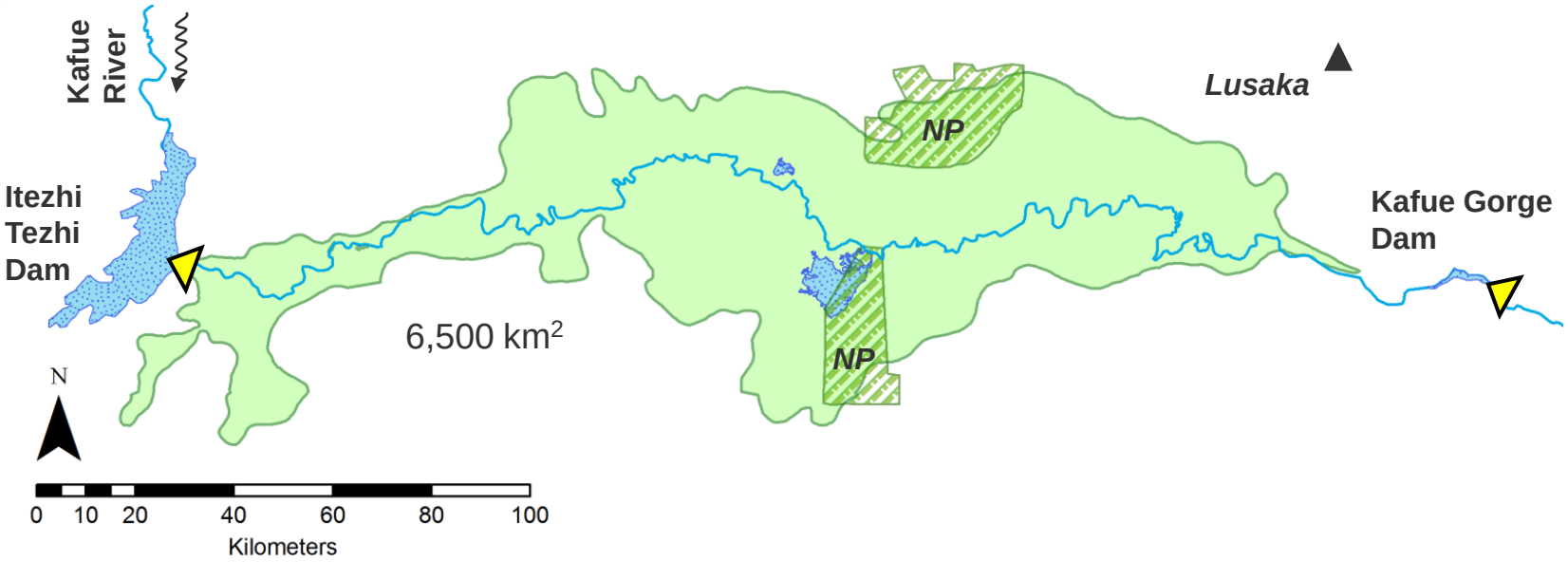


- 8 riparian countries
- Rainfall 950 mm
  evaporation >90%
- 4 existing dams (◁)
  6 planned dams (◁)

Kafue River Basin:

- 152,000 km^2
- 2 large dams built in 1970s

The Kafue Flats



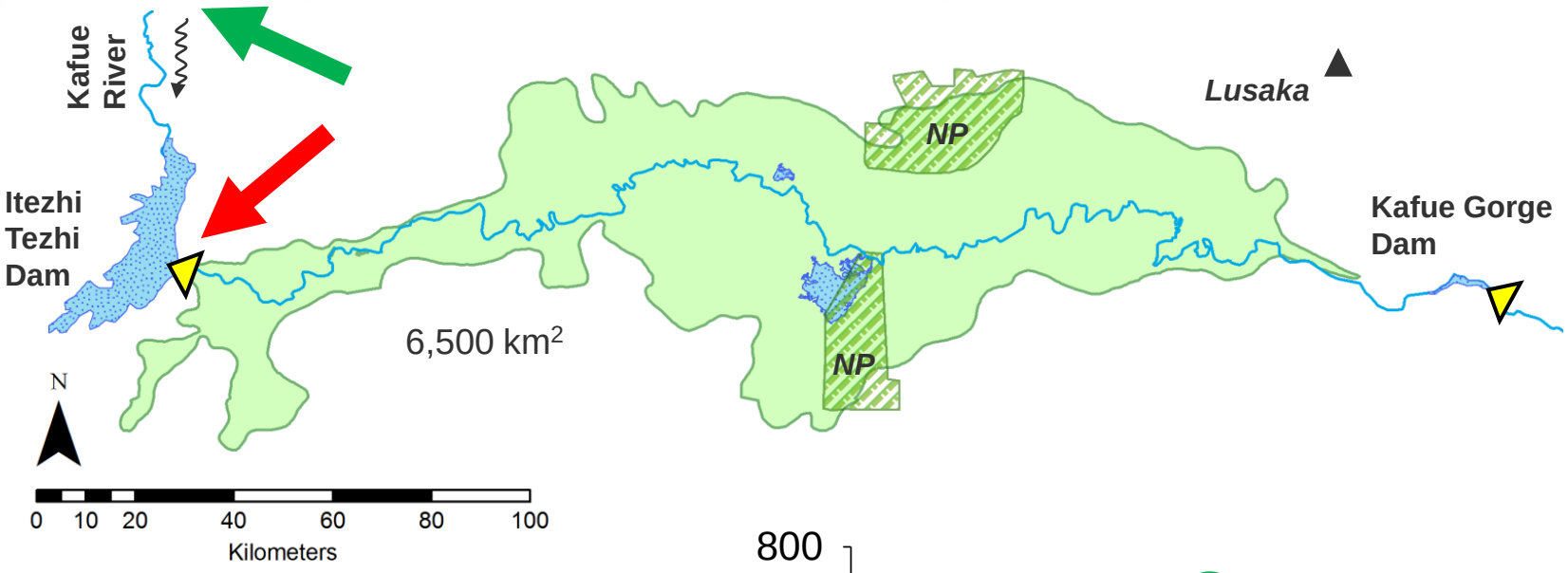
Upstream Itezhi-Tezhi dam (closed 1978)

B. McMorrow

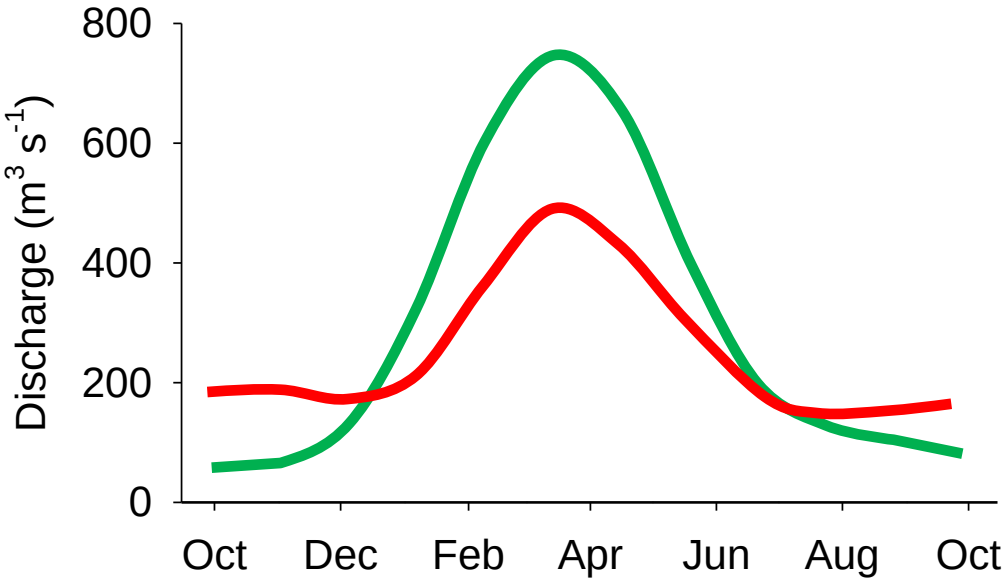
Kafue River in the Kafue Flats

G. Shanungu

The Kafue Flats



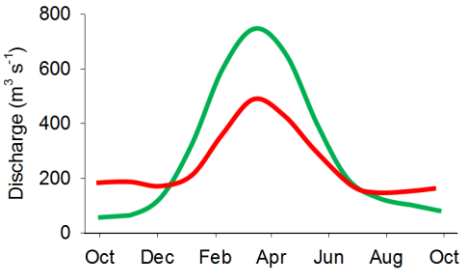
- Seasonal flooding
- Dams changed flooding patterns
- Affected plant and wildlife ecology
- No biogeochemical evidence

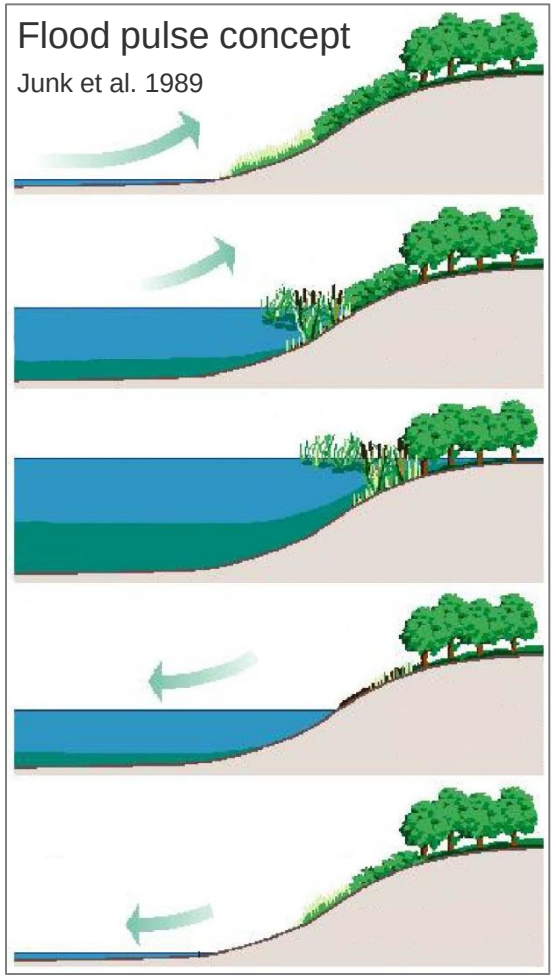


(from Mumba & Thompson 2005)

Importance of tropical floodplain ecosystems

- Floodplains = high-value ecosystems
  habitat, water supply, flood mitigation, food production
- Important reactors for C and nutrient turnover
- Hydrological exchange: crucial process
  - Biogeochemistry
  - Ecological functioning
- Dam impact on exchange?





Bayley, 1995 / epa.gov

Research objectives

1. **Hydrological drivers**

   Quantify the hydrological exchange between Kafue River and floodplain. Related to dam operation?

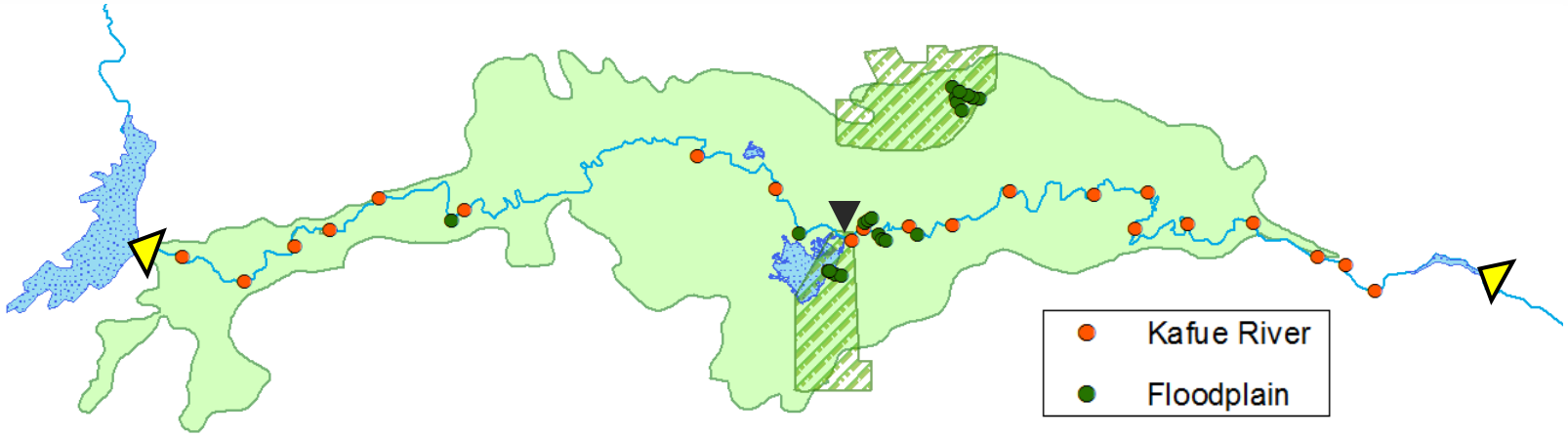
2. **Mineralization**

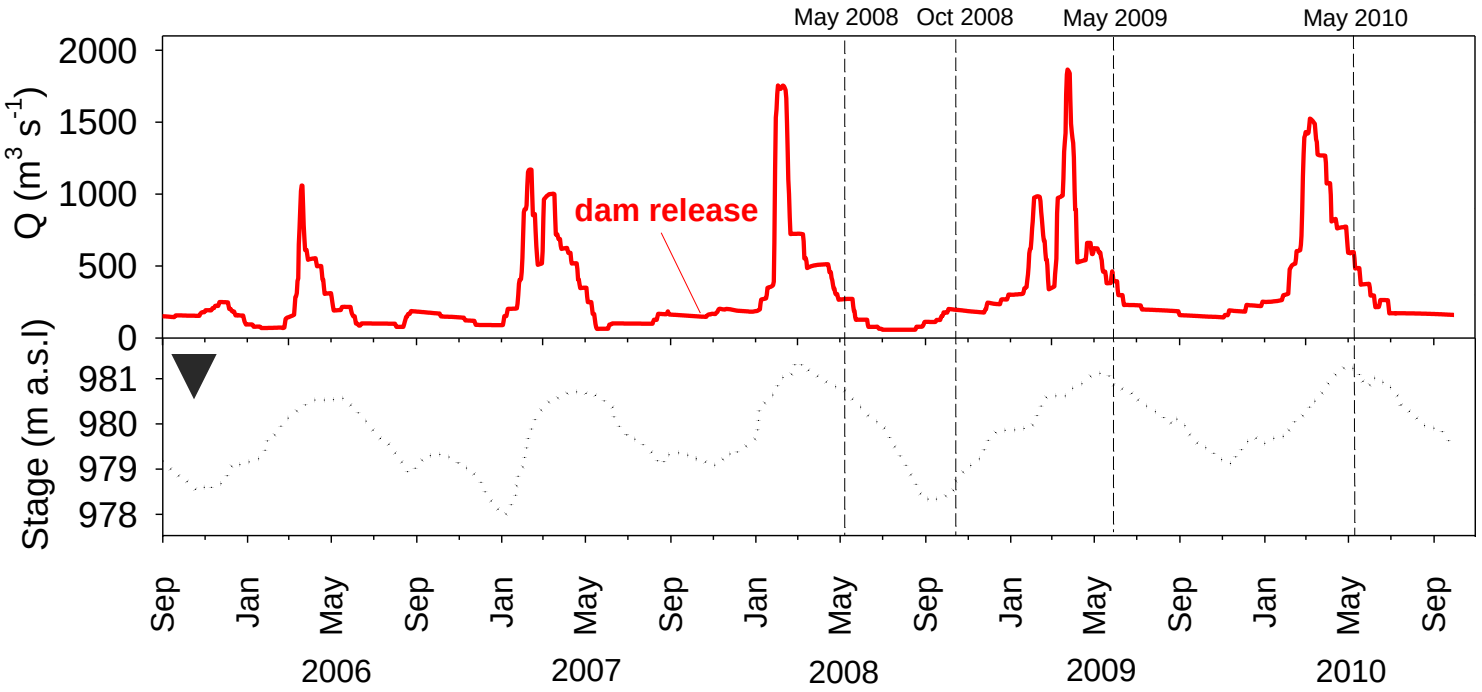
   Effects of river-floodplain exchange on the dissolved oxygen regime

3. **Organic matter quality and export**

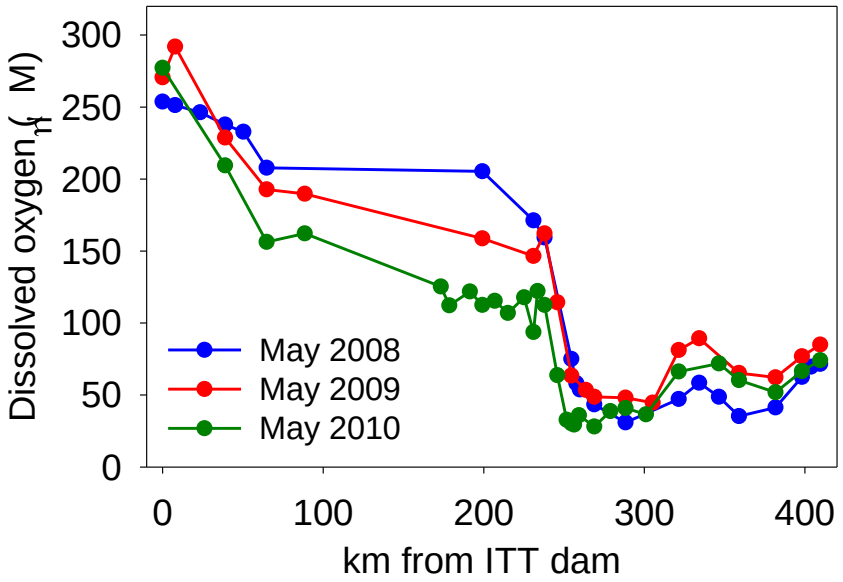
   Effects of lateral exchange and dam operation on fluxes and quality of organic C and N

Sampling strategy

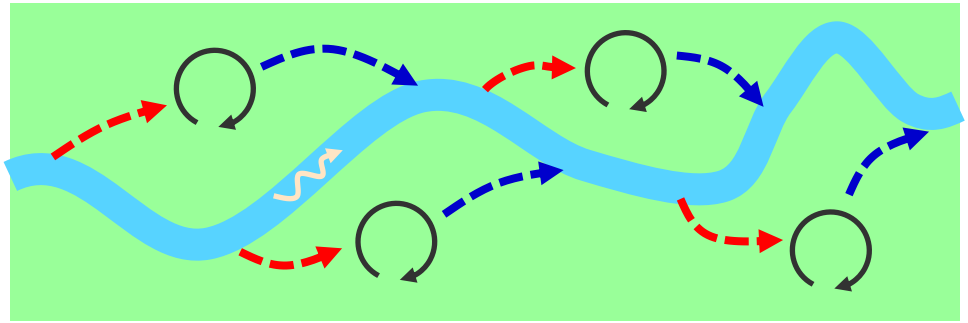




Dissolved oxygen (DO)



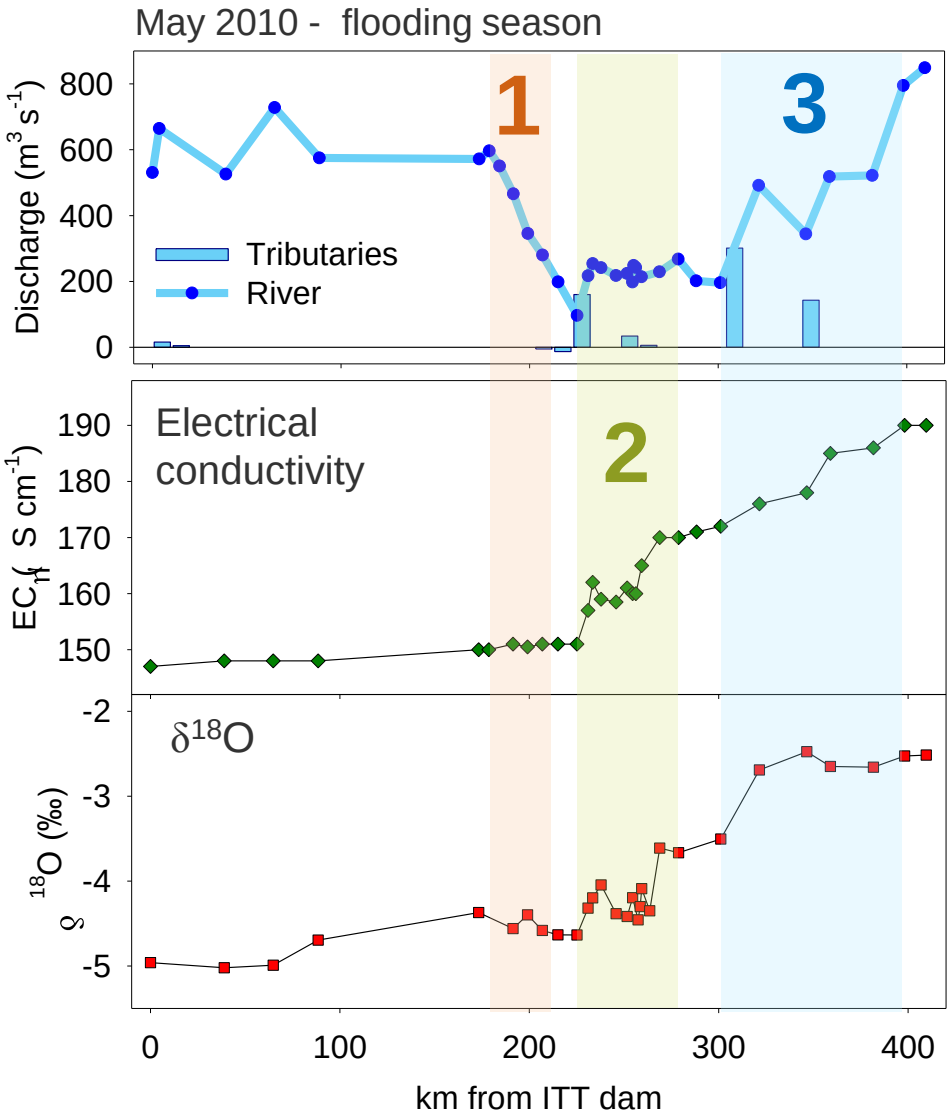
- Steep DO decline over 40 km
- Low DO levels for 150 km
- Floodplain DO <15 µM



Hypotheses:

- Inflow of low-DO water
- Injection of labile OM to river
- Exchange with the floodplain

Discharge (Q) and natural tracers



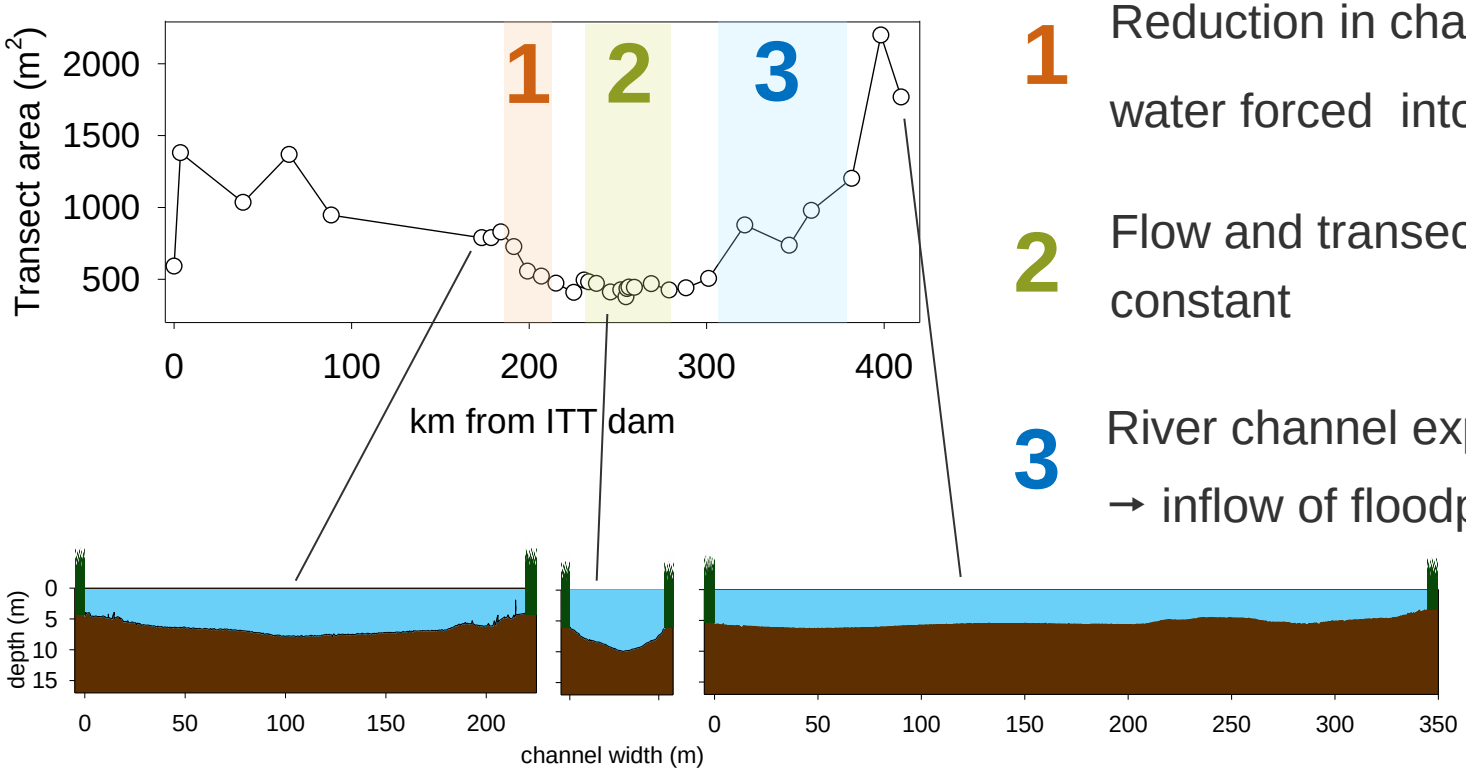
1 steep Q decline

- ~80 % loss to floodplain
- no outflows detected

2 increase in tracers at constant Q (DO decline)

3 gain in Q after 300 km and tracer increase (evaporation)

Channel morphology



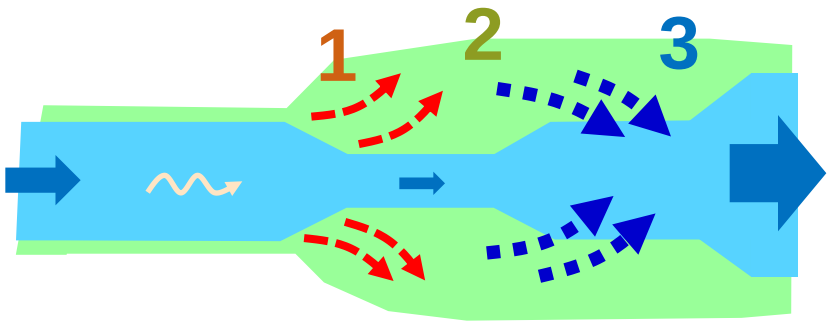
1 Reduction in channel cross section

water forced into the floodplain

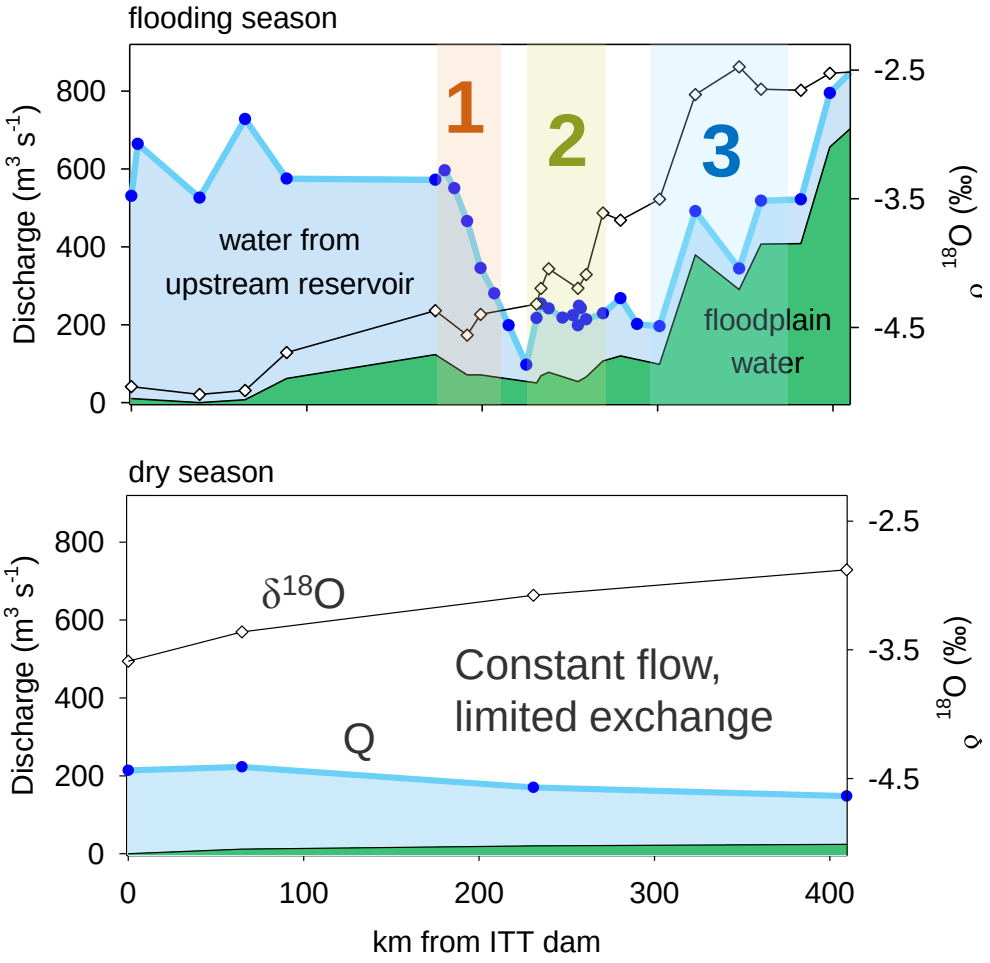
2 Flow and transect area constant

3 River channel expansion

→ inflow of floodplain water



Tracer mixing model: $\delta^{18}O$



1 No exchange

2 Intense exchange at constant flow

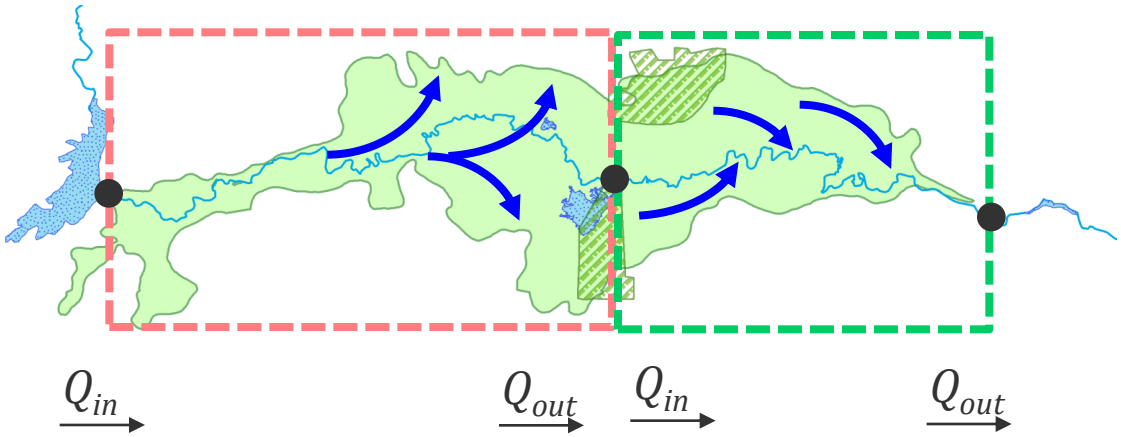
3 >80 % of discharge from floodplain

Mass balance calculations:

Lateral exchange → DO decline

- Seasonal variations?
- Role of upstream dam?

River-floodplain exchange over longer time scales



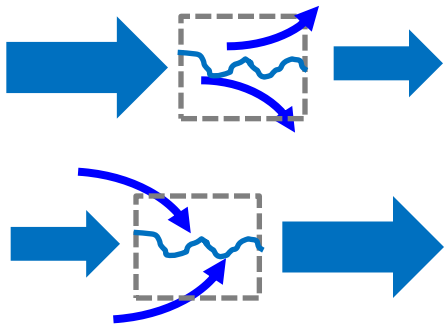
- Comparison with data since the 1960s
- FE = measure of river-floodplain exchange

Fractional exchange ratio FE:

$$if\ Q_{out}\text{-}Q_{in} \geq 0 \quad \mathrm{FE} = \frac{Q_{out}-Q_{in}}{Q_{out}}$$

$$if\ Q_{out}\text{-}Q_{in} < 0 \quad \mathrm{FE} = \frac{Q_{out}-Q_{in}}{Q_{in}}$$

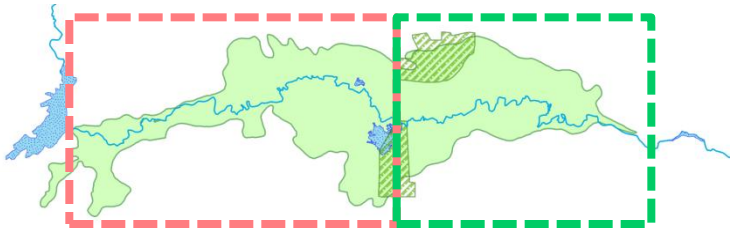
Fractional exchange ratio FE:

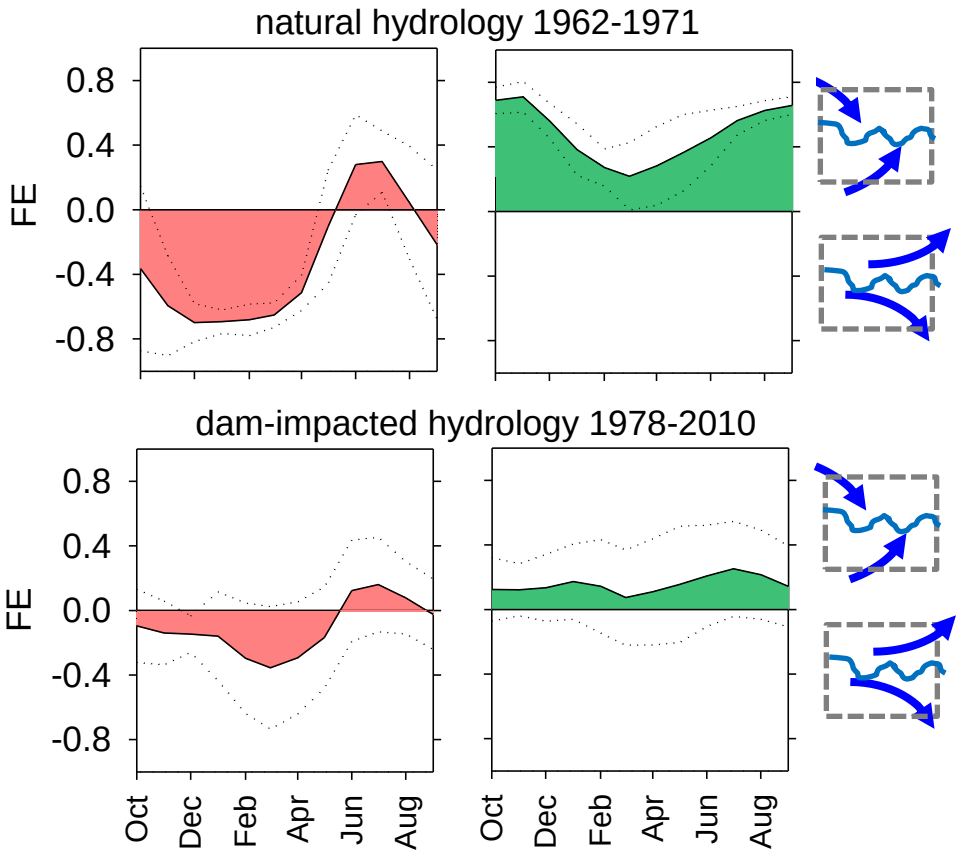


FE < 0

FE > 0

River-floodplain exchange over longer time scales



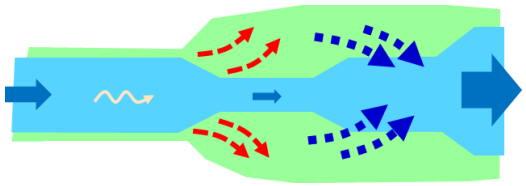


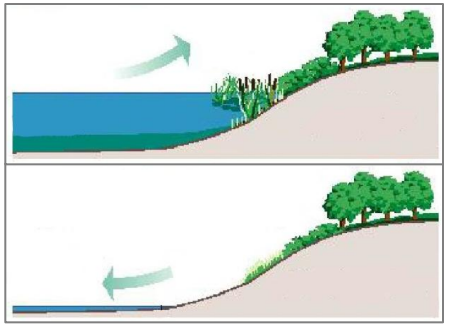
- Upstream: outflows from Oct-May
- Downstream: consistent inflows
- Similar seasonality
- Reduction in FE amplitude

Dams have reduced river-floodplain exchange by 50%

Conclusions

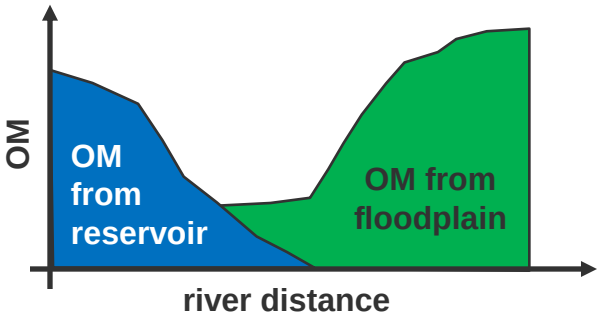
- River-floodplain exchange: dominant hydrological driver
  - Flooding season: >80% of water passes through floodplain
  - Driven by channel morphology
  - Beyond current concepts
  - Impacts on DO regime of the river
  - 50% reduction by dam operation



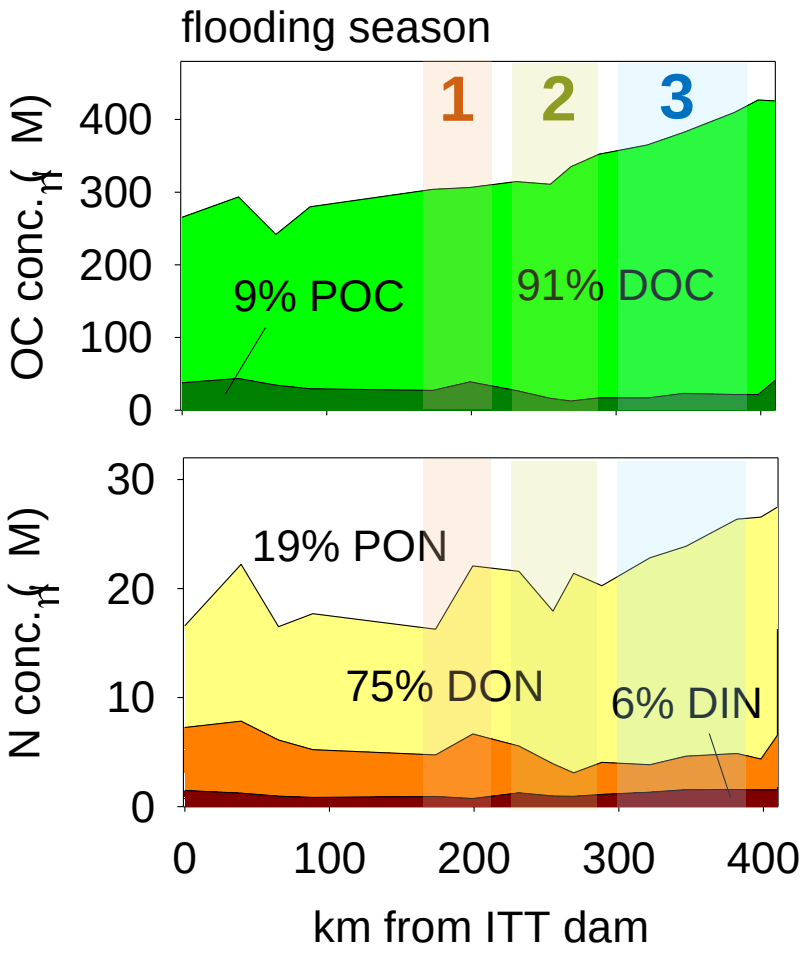


Effects on source and fate of organic C and N in the Kafue River?

Hypothesis: Large change in organic matter quality



Carbon and nitrogen speciation



- Along sections of high exchange:

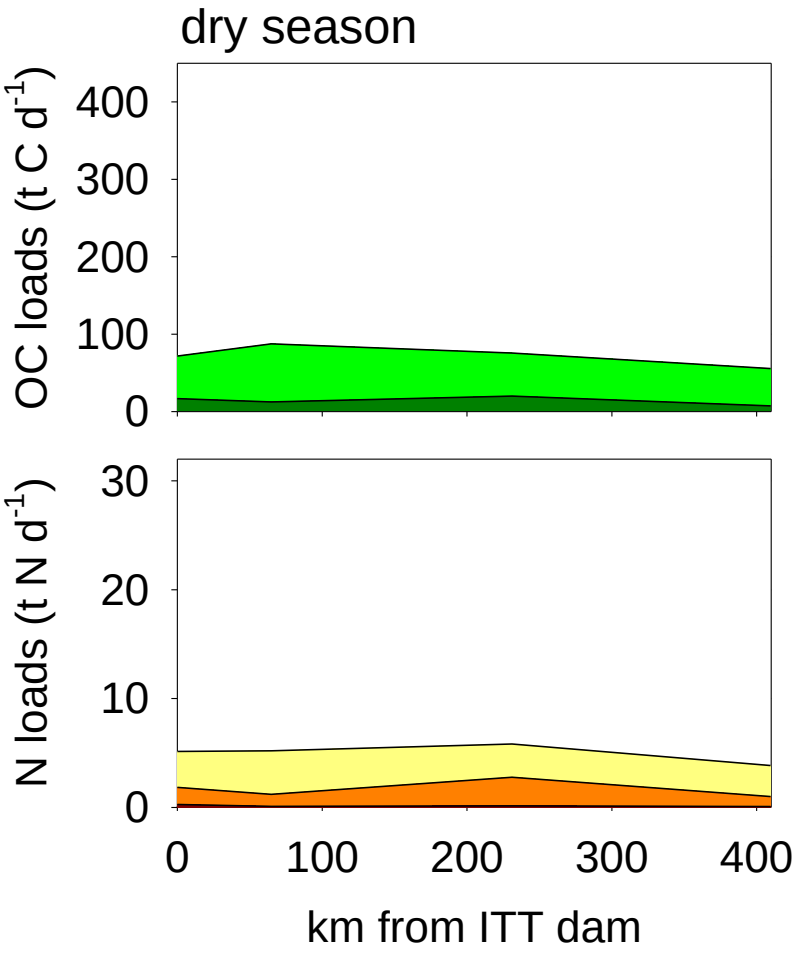
  DOC increase, POC decrease

- High contribution of DON

- Low (<2 µM) DIN concentrations

Loads, source and quality of OM?

Export of OC and ON



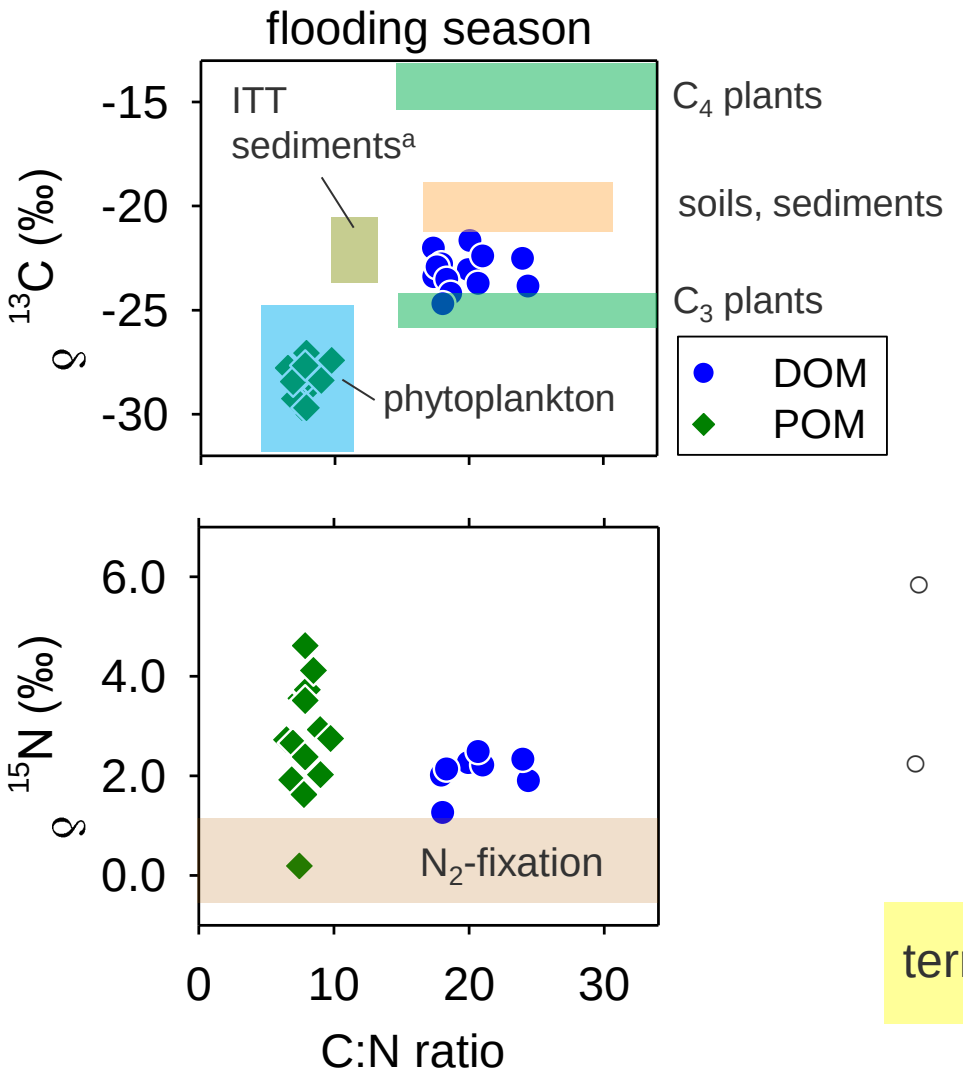
OC and N loads: C × Q [t d^{-1}]

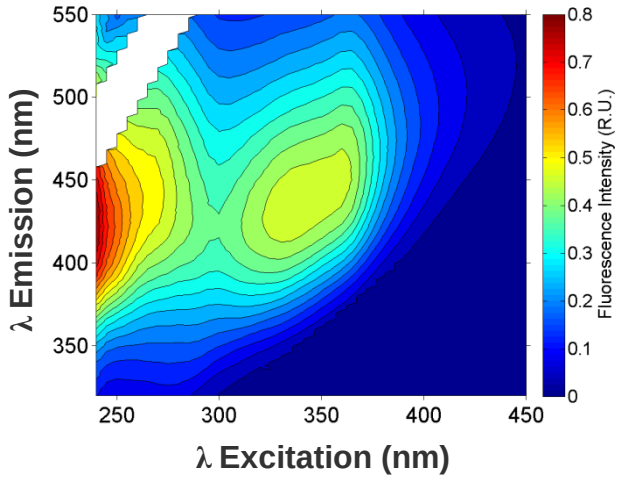
- 4-fold increase in OC, mostly DOC
- 5-fold increase in N, mostly DON
- Deficit: 1,300 t N per year

Large OC and ON exports,

>70% mobilized from floodplain

Sources of DOM and POM





- Spectroscopy: terrestrial origin
  humic/fulvic acids
- Constant δ^{15}N-DON, high N_2-fixation?

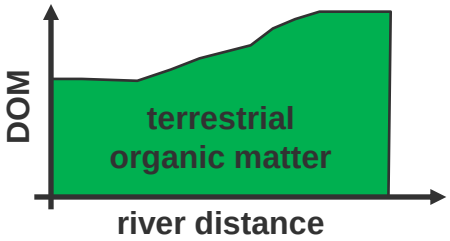
terrestrial DOM, phytoplankton POM

[a]Kunz et al. 2011

Conclusions

- Mobilization and export of floodplain DOM
- Little variation in DOM composition
  - Stable, refractory (from upstream wetlands?)
  - No change during reservoir transit

DOM: mobilized from floodplain



- Terrestrial POM trapped by dam
  (Kunz et al. 2011)
- Discharge of phytoplankton POM

POM: PP from reservoir and floodplain

→ high dam impact