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Impact of Reservoir Operations and Climate Variability on Regulated Flow Regimes

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Introduction

CLIMATE CHANGE & WATER MANAGEMENT: a topic of great interest!
Some Papers …

Milly, P. C. D., Betancourt, J., Falkenmark, M., Hirsch, R. M., Kundzewicz, Z. W., Lettenmaier, D. P., & Stouffer, R. J. (2008). **Stationarity is dead: Whither water management?** ***Science***, 319, 573–574.

Barnett, T. P., Pierce, D. W., Hidalgo, H. G., Bonfils, C., Santer, B. D., Das, T., et al. (2008). **Human-induced changes in the hydrology of the western United States.** ***Science***, 319, 1080–1083.

van Vliet, M. T. H., Jarsley, J. R., Ludwig, F., Vogele, S., Lettenmaier, D. P., & Kabat, P. (2012). **Vulnerability of US and European electricity supply to climate change.** ***Nature Climate Change***, 2, 676–681.

Poff, N. L., Brown, C. M., Grantham, T. E., Matthews, J. H., Palmer, M. A., Spence, C. M., et al. (2015). **Sustainable water management under future uncertainties with eco-engineering decision scaling. Nature Climate Change**, 6, 25–34.

FLOOD

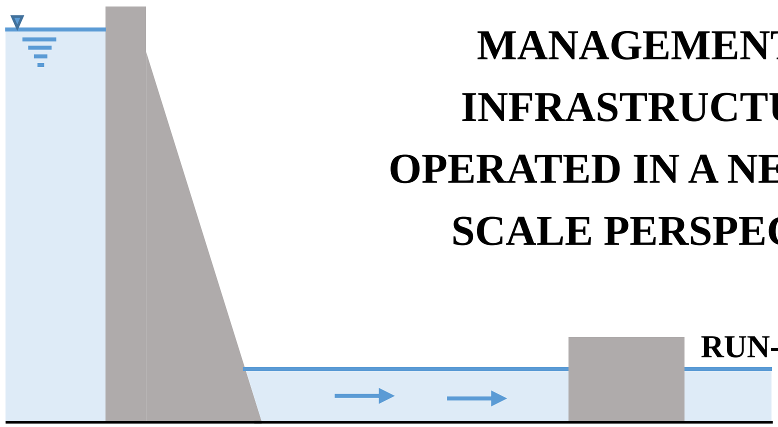
DROUGHT

The number of dams is expected to increase to mitigate the responsiveness of flow regimes to climate change

Research Questions & Scopes

- **Are there distinctive patterns of river regime alterations associated to specific reservoir functions and features?**
- **Are reservoirs able to mitigate long-term fluctuations of flow regimes?**
- **How is this related to reservoir features and management strategies ?**

SCOPE

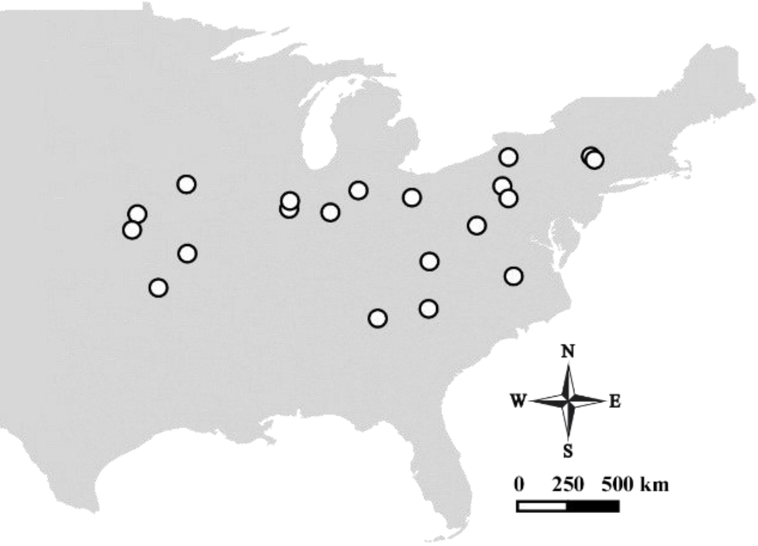


MANAGEMENT OF INFRASTRUCTURES OPERATED IN A NETWORK SCALE PERSPECTIVE

SCOPE

UNDERSTANDING OF THE ECOLOGICAL AND GEOMORPHOLOGICAL EVOLUTION OF DAMMED RIVERS

Study Sites



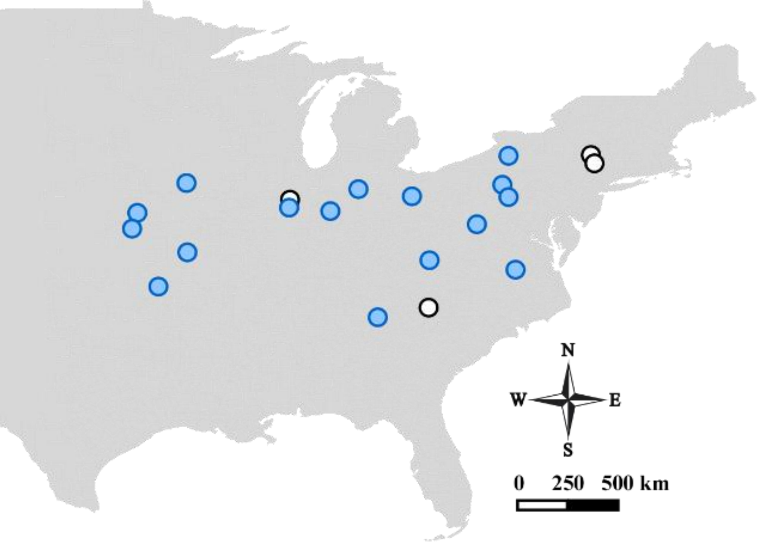
HUMAN WATER USES

20 isolated dams spanning different water uses …

FLOOD CONTROL

WATER SUPPLY

ENERGY PRODUCTION



REGULATION CAPACITY [R_C]

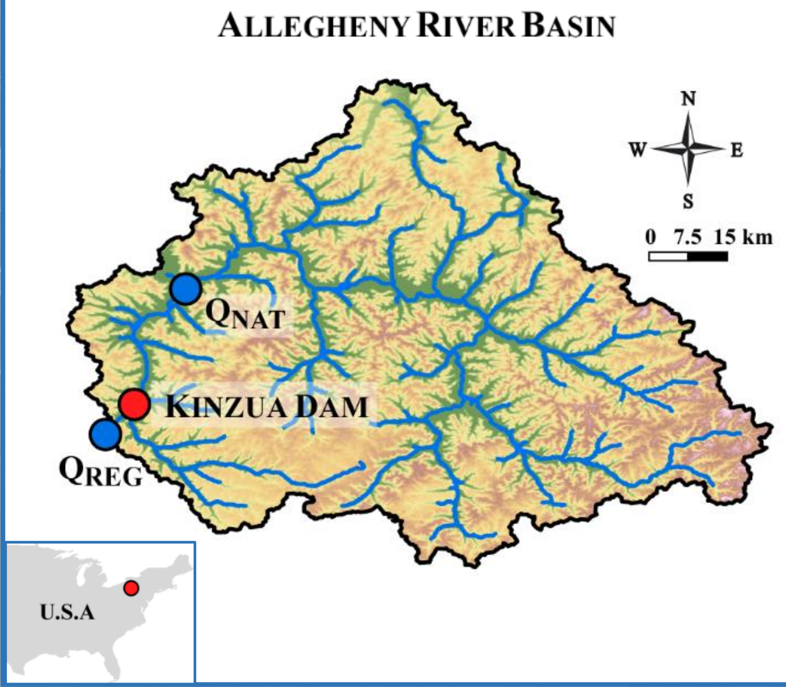
… as well as different values of regulation capacity [R_C]

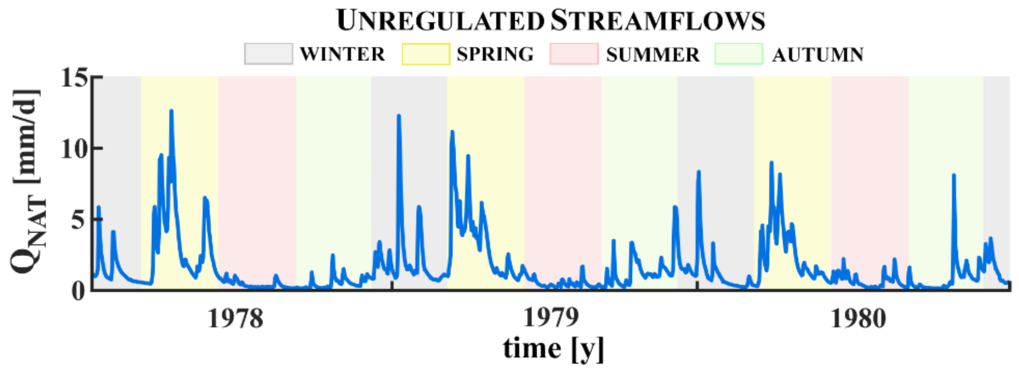
$$R_C\ [d] = \frac{storage\ allocated\ to\ flood\ control\ [m^3]}{mean\ annual\ inflow\ [m^3/d]}$$

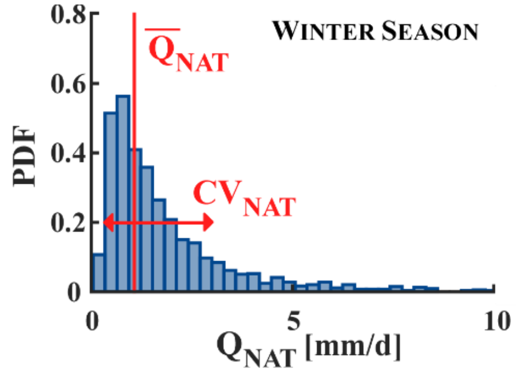
INCLUDING FLOOD CONTROL

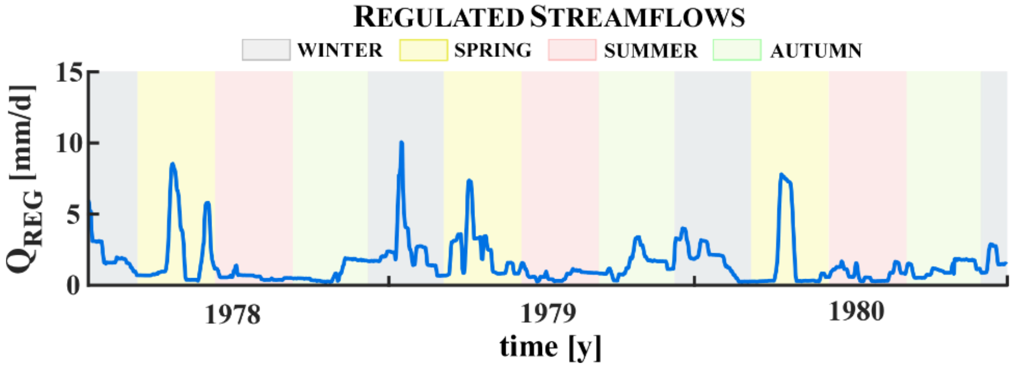
Theoretical Framework

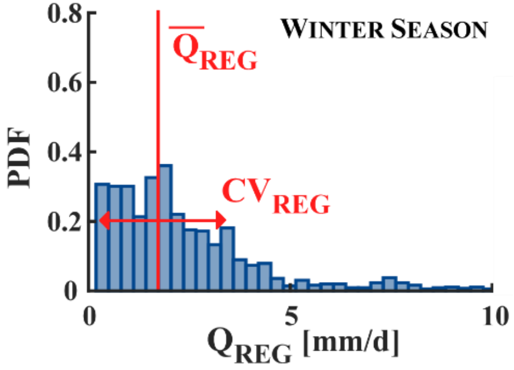
FLOW REGIME ALTERATIONS BY DAMS











UNREGULATED FLOWS

SEASONAL VALUES OF

$\overline{Q}_{NAT}$ & CV_{NAT}

→

DAM

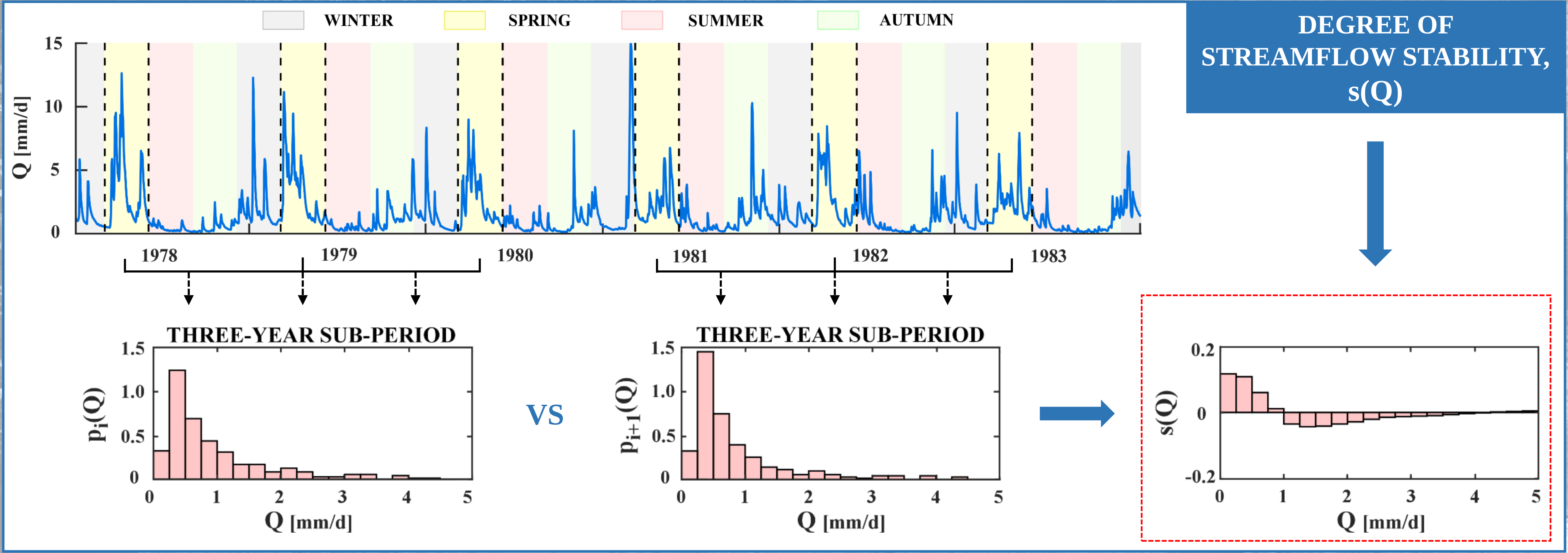
→

REGULATED FLOW

SEASONAL VALUES OF

$\overline{Q}_{REG}$ & CV_{REG}

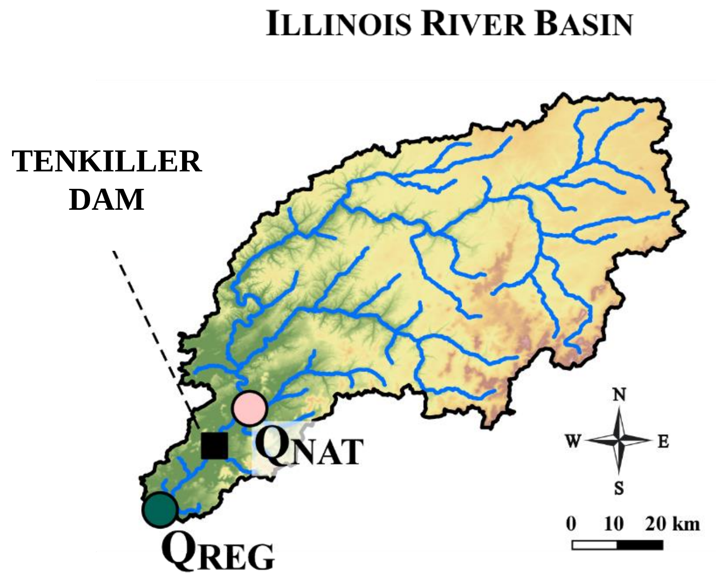
Theoretical Framework

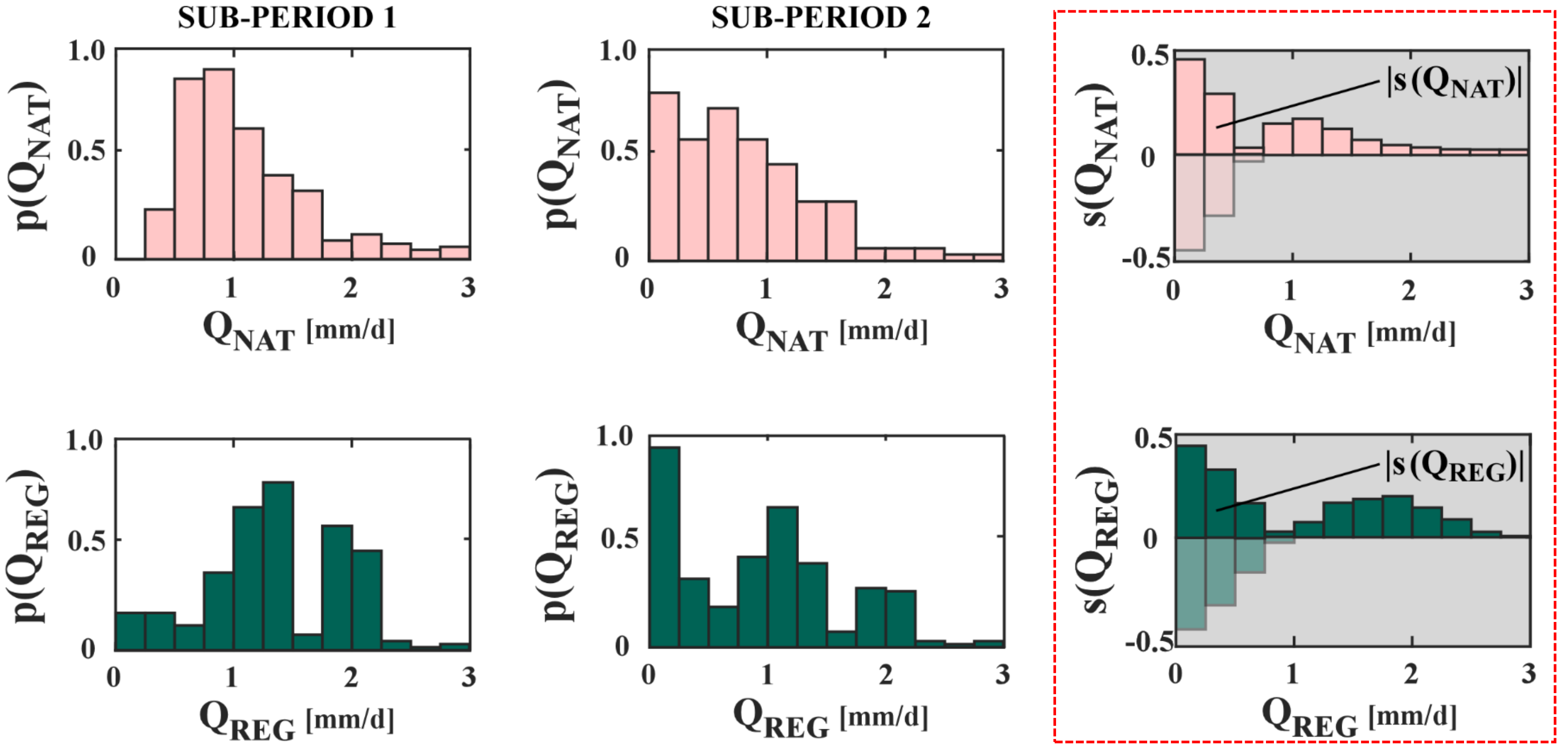


DEGREE OF STREAMFLOW STABILITY [s(Q)] :
ability of flows to buffer their responsiveness to hydroclimatic fluctuations

$$s(Q) = \Delta p(Q) = p_{i+1}(Q) - p_i(Q)$$

Theoretical Framework





NATURAL vs REGULATED REGIMES

➢ **INDICATOR 1/2**

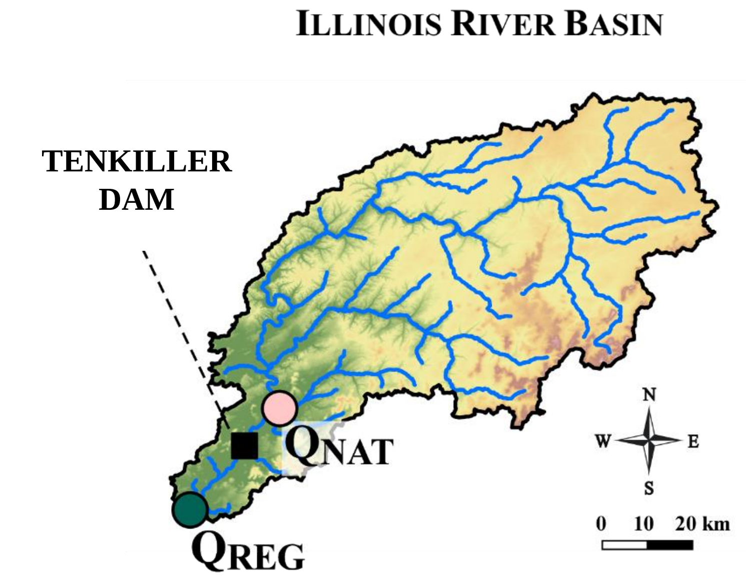
STABILITY RATIO [SR] :

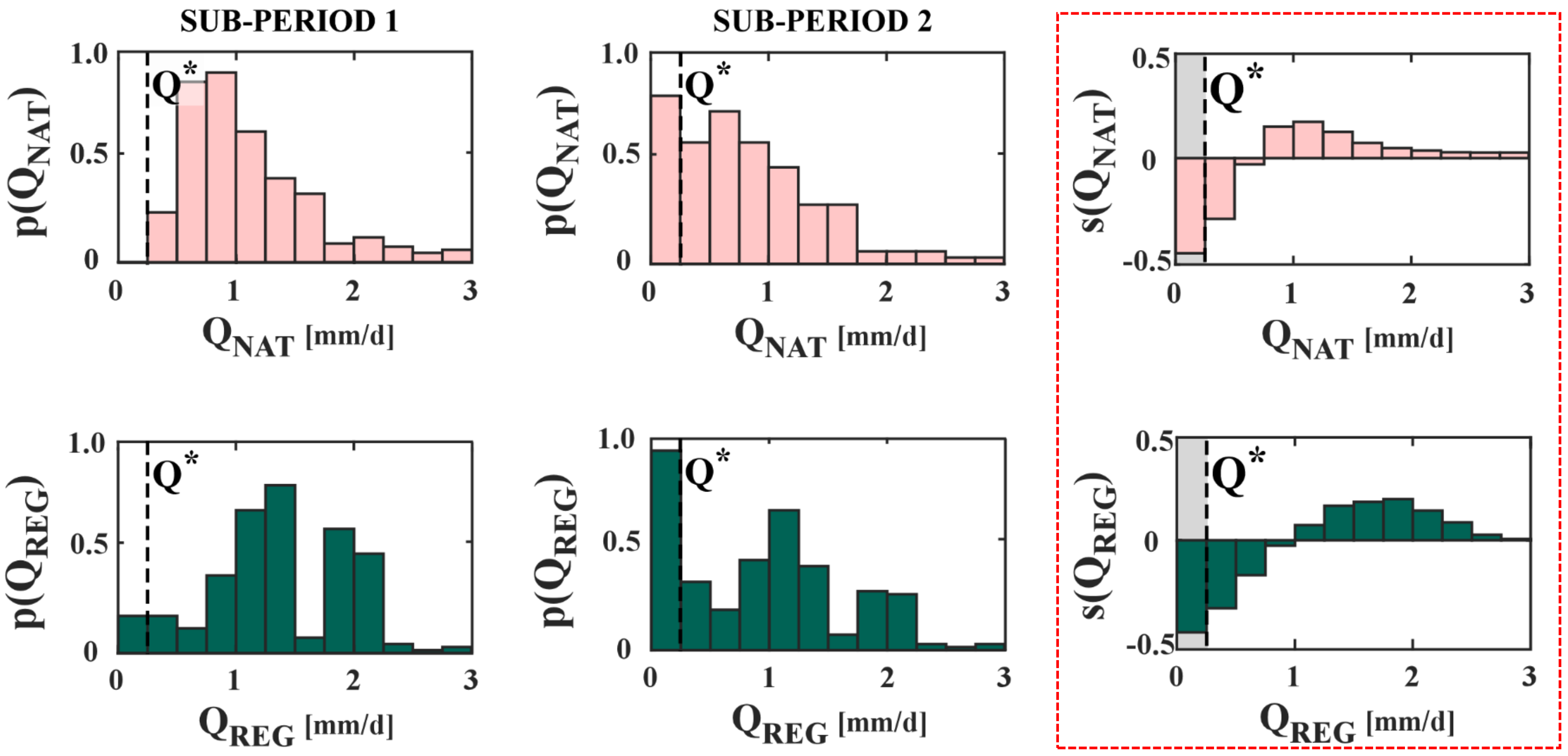
$$SR = \frac{S_*(Q_{REG})|_0^\infty}{S_*(Q_{NAT})|_0^\infty} = \frac{\int_0^\infty |s(Q_{REG})|\, dQ}{\int_0^\infty |s(Q_{NAT})|\, dQ}$$

< 1 : regulation SMOOTHS inter-annual fluctuations

> 1 : regulation ENHANCES inter-annual fluctuations

Theoretical Framework





NATURAL vs REGULATED REGIMES

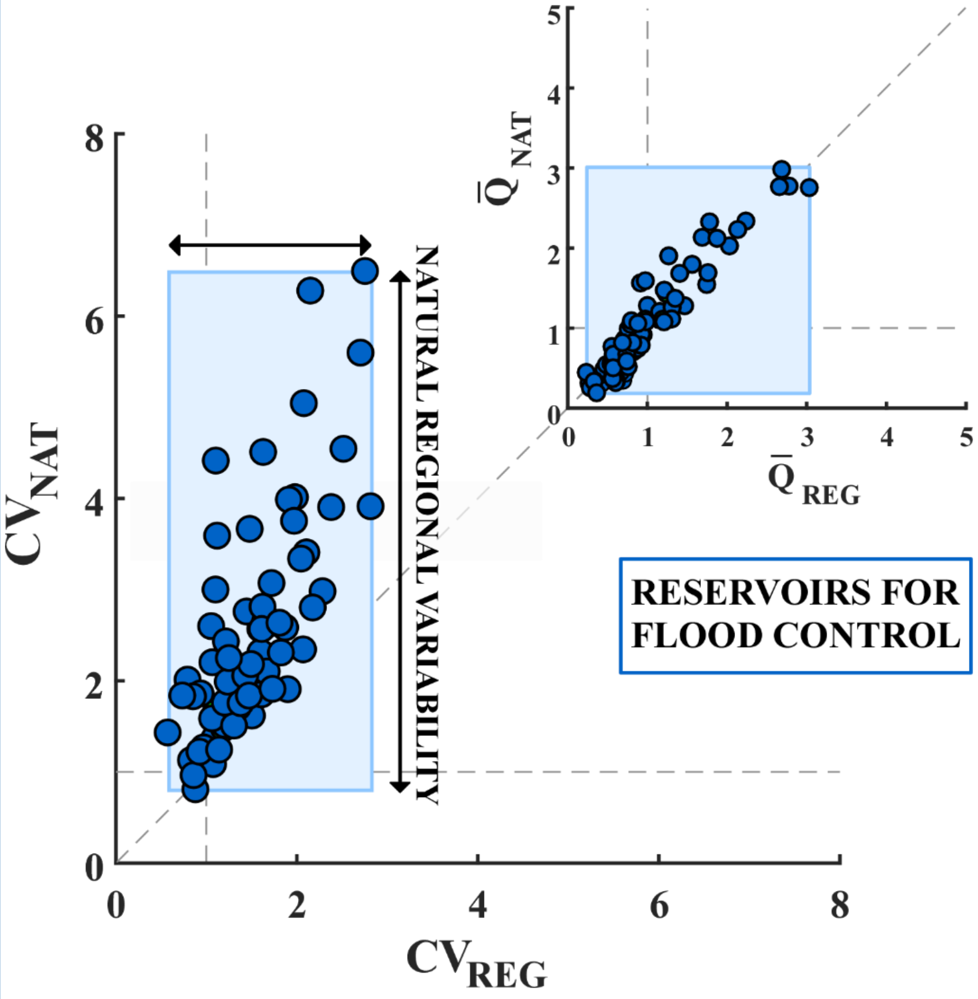
➢ **INDICATOR 2/2**

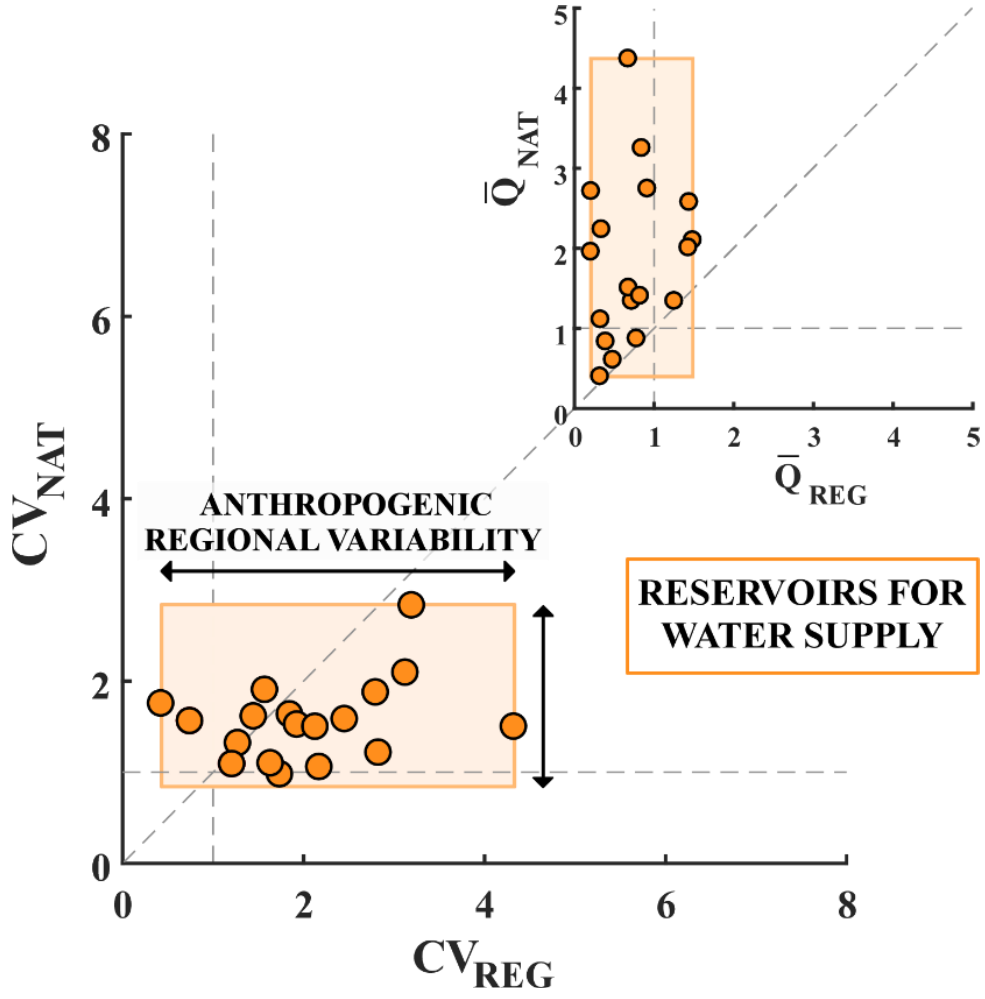
LOW-FLOW STABILITY [LS] :

stability of flows smaller than the threshold Q^*

$$LS = S(Q)|_0^{Q^*} = \int_0^{Q^*} s(Q)\, dQ \qquad \text{with} \quad Q^* = 0.25\, mm/d$$

Results – Flow Regime Alterations





FLOOD CONTROL

$$\overline{Q}_{NAT} \approx \overline{Q}_{REG}$$
$$CV_{NAT} > CV_{REG}$$

HOMOGENIZATION OF FLOWS

WATER SUPPLY

$$\overline{Q}_{NAT} > \overline{Q}_{REG}$$
$$CV_{NAT} < CV_{REG}$$

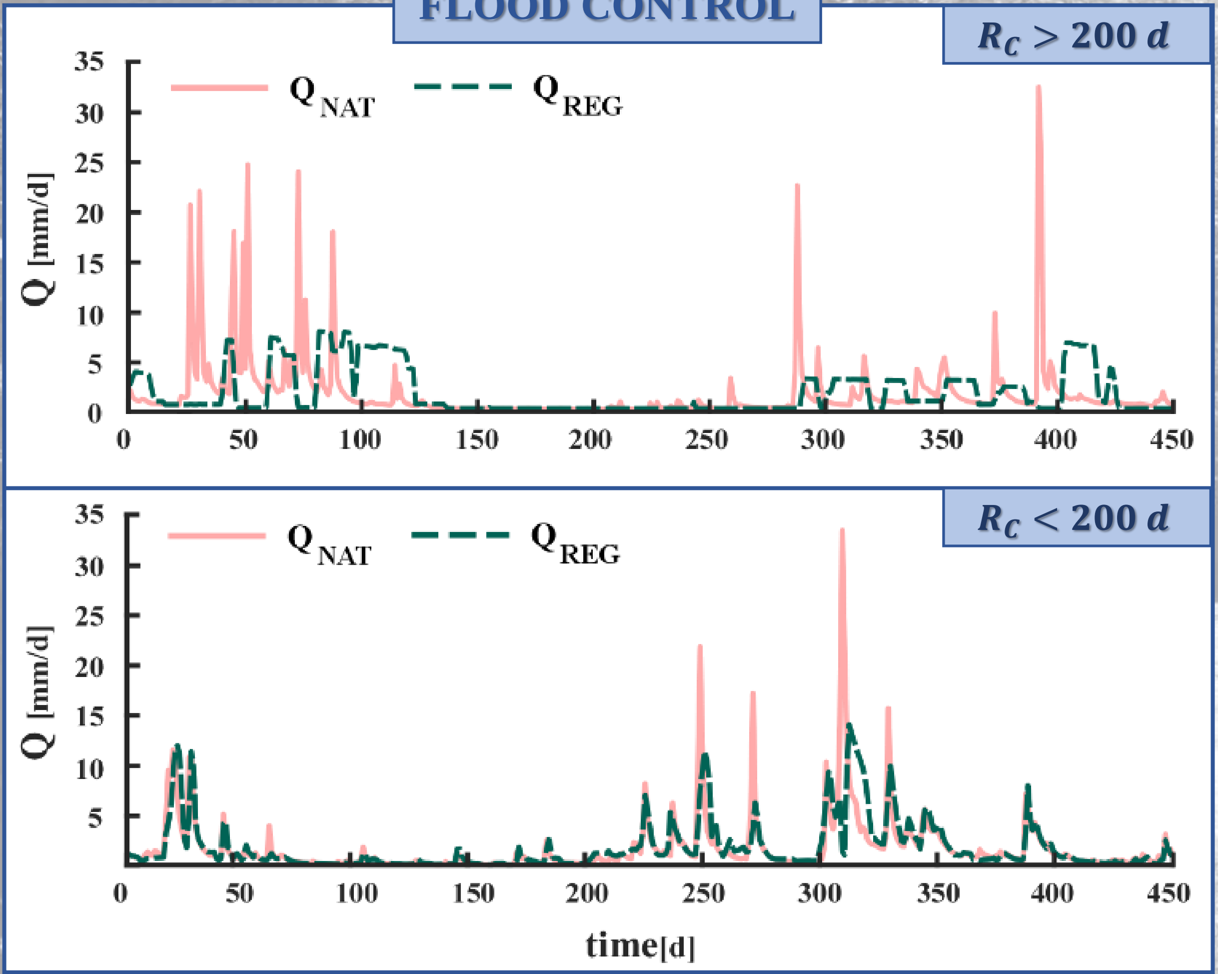
DIVERSIFICATION OF FLOWS

[Ferrazzi and Botter, 2019]

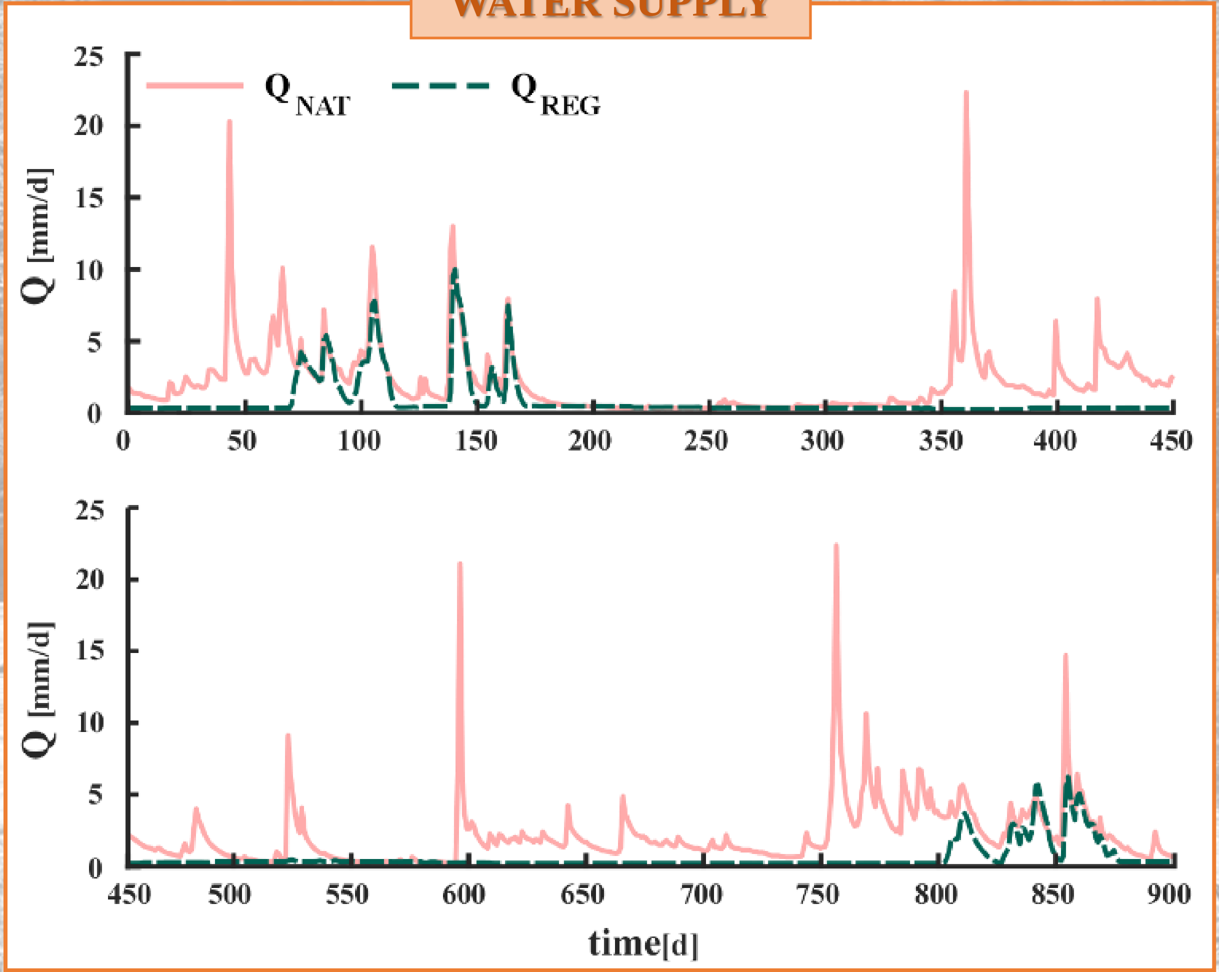
FLOOD CONTROL AND WATER SUPPLY PRODUCE DISTINCTIVE IMPACTS ON FLOW REGIMES

Results – Flow Regime Alterations

FLOOD CONTROL

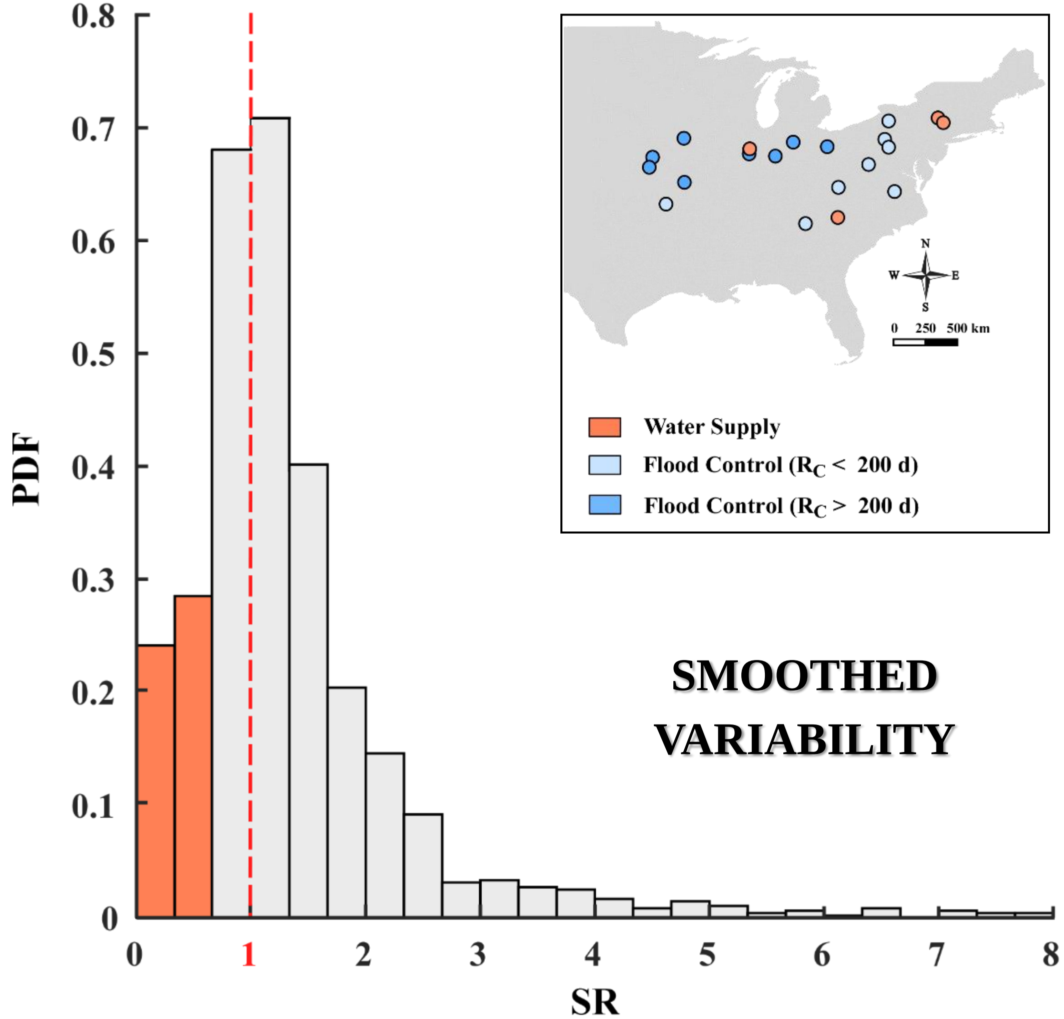


WATER SUPPLY

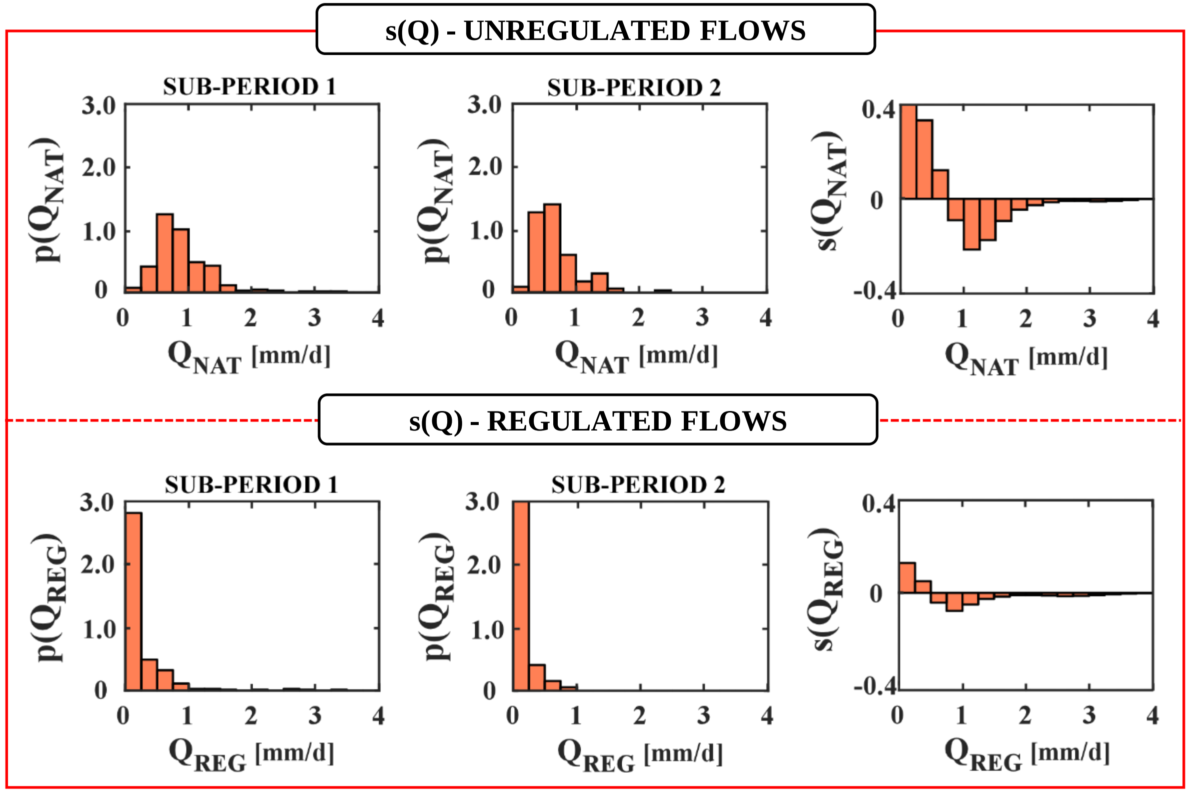


FLOOD CONTROL WATER SUPPLY PRODUCE DISTINCTIVE IMPACTS ON FLOW REGIMES

Results – Streamflow Ratio



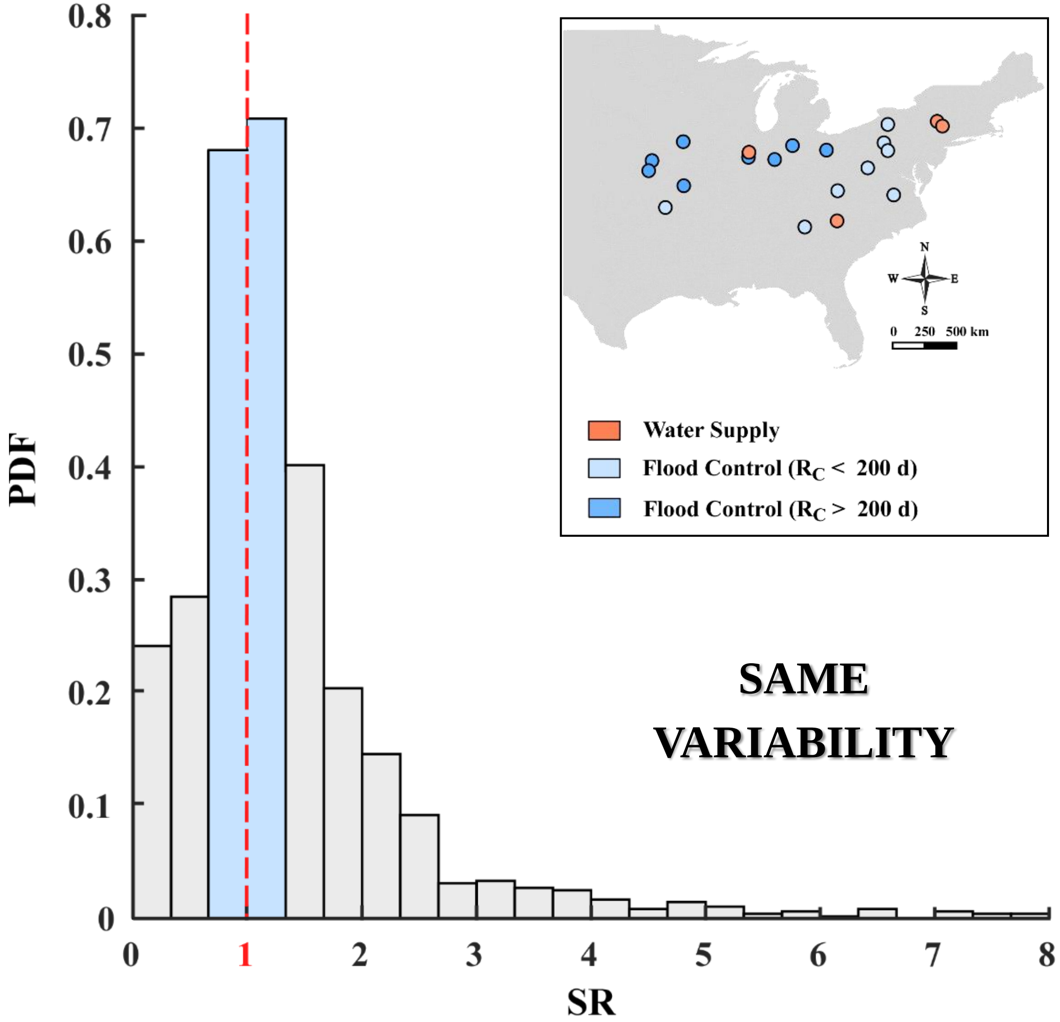
WATER SUPPLY DAMS



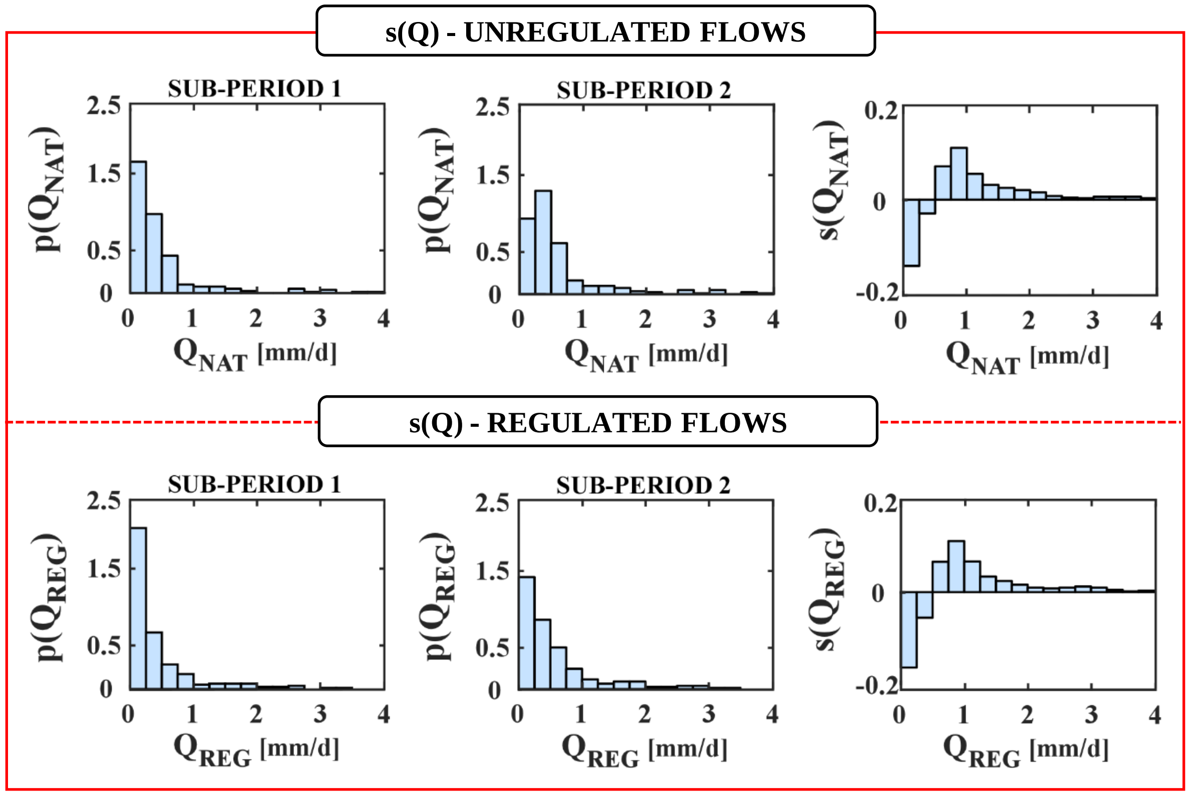
[Ferrazzi et al., 2019]

WATER SUPPLY SMOOTHS FLUCTUATIONS BY NARROWING THE SPECTRUM OF FLOWS

Results – Streamflow Ratio



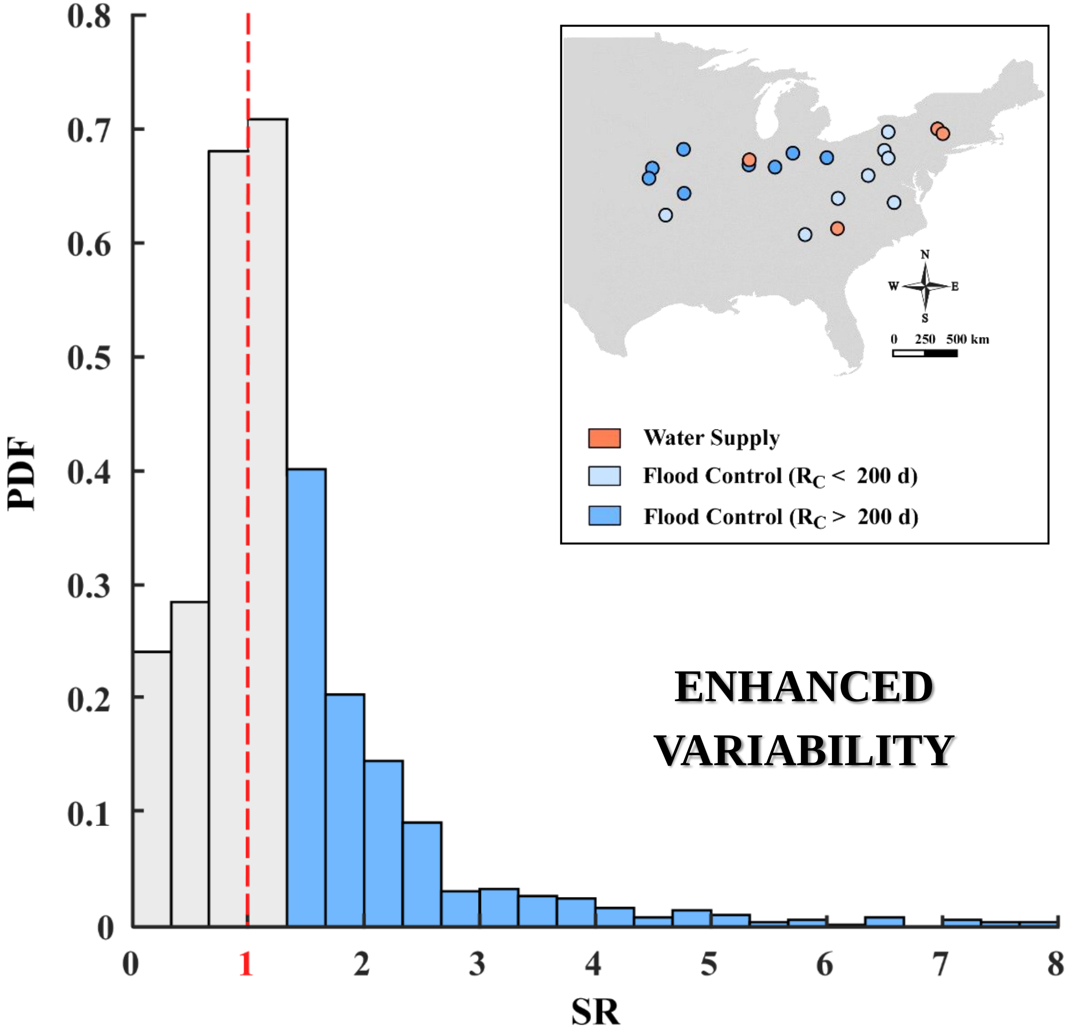
FLOOD CONTROL DAMS [R_C < 200 d]



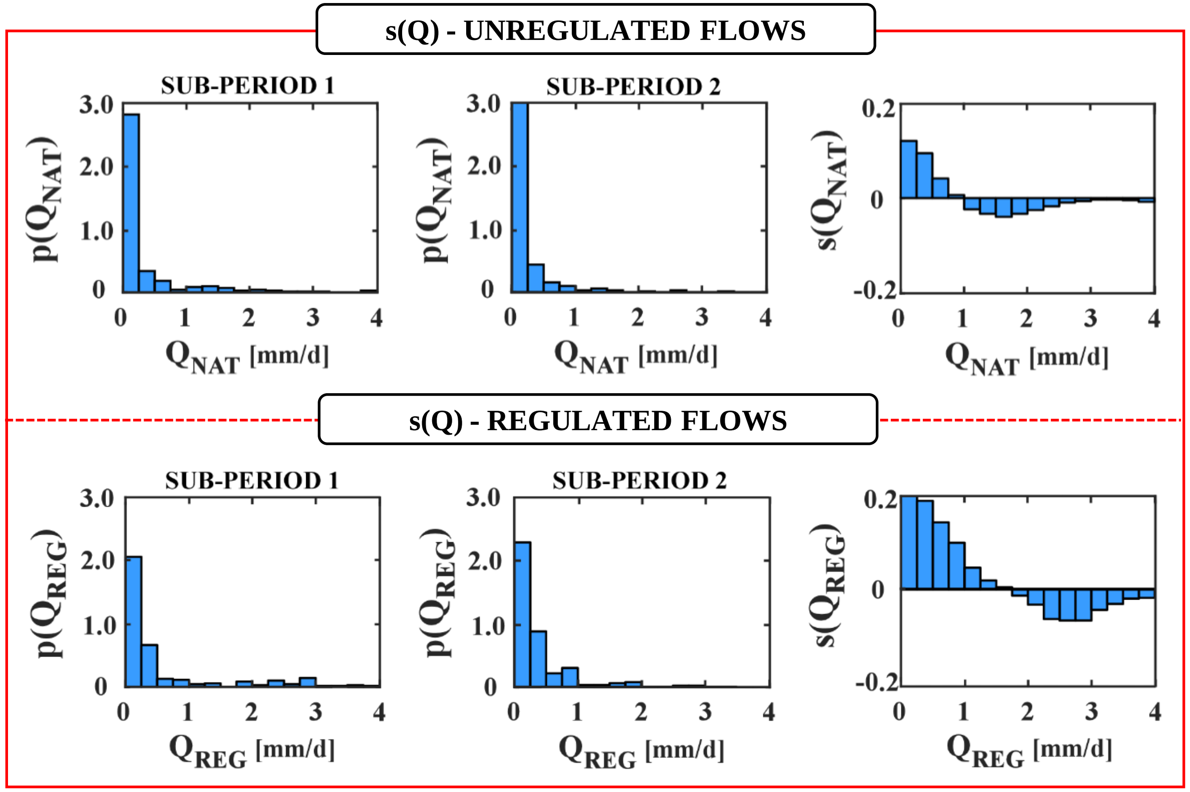
[Ferrazzi et al., 2019]

LOW REGULATION CAPACITY DAMS LEAVE UNALTERED STREAMFLOW FLUCTUATIONS

Results – Streamflow Ratio



FLOOD CONTROL DAMS [R_C > 200 d]

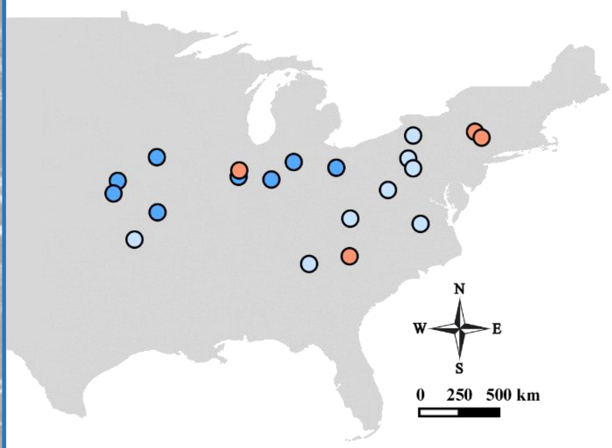


[Ferrazzi et al., 2019]

HIGH REGULATION CAPACITY DAMS ENHANCE FLUCTUATIONS BY UNEVEN OPERATIONS

Results – Low-Flow Stability

WATER SUPPLY



Water Supply

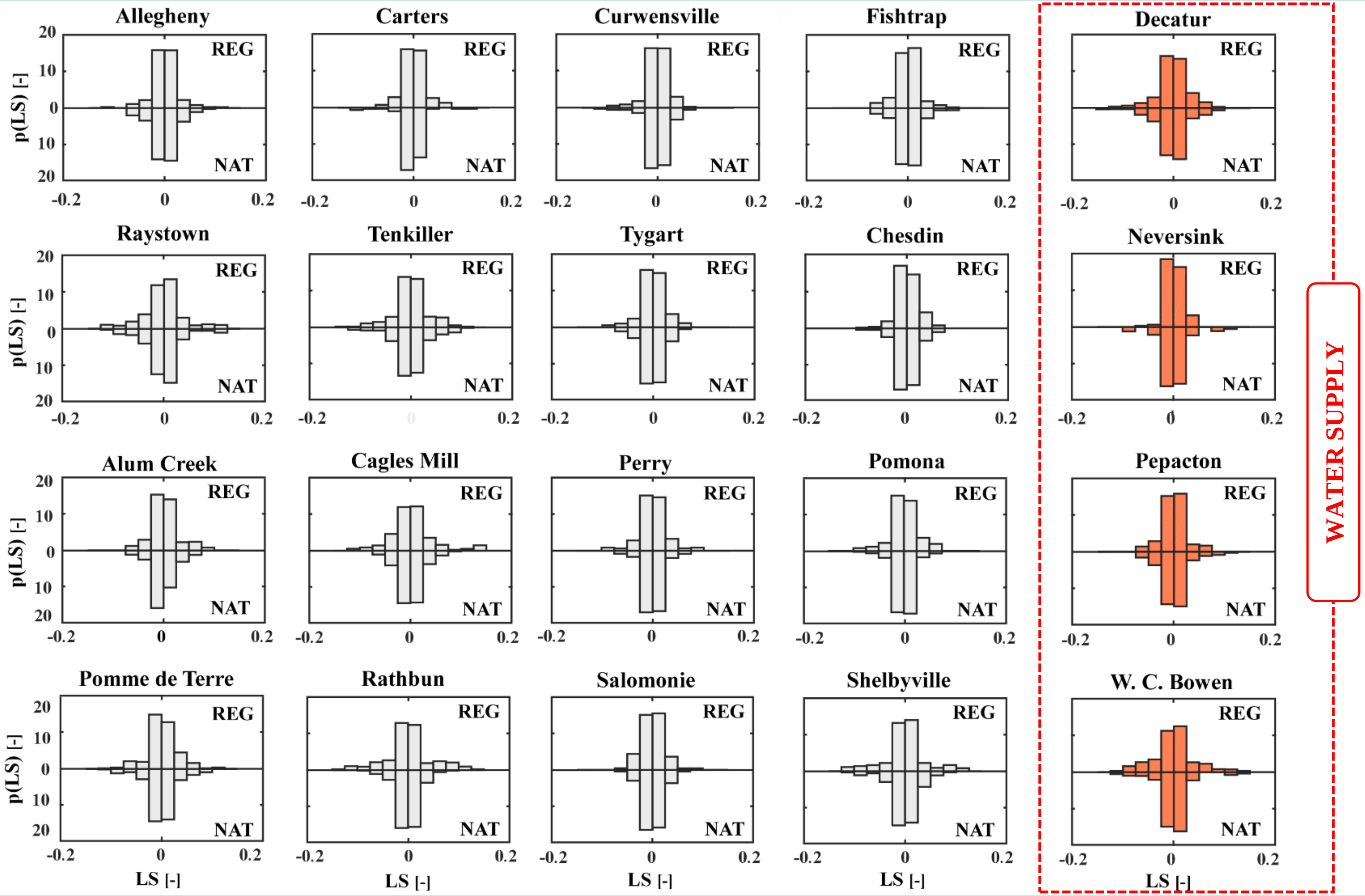
Flood Control ($R_C <$ 200 d)

Flood Control ($R_C >$ 200 d)

UPPER PDFs – REGULATED FLOWS

LOWER PDFs – UNREGULATED FLOWS

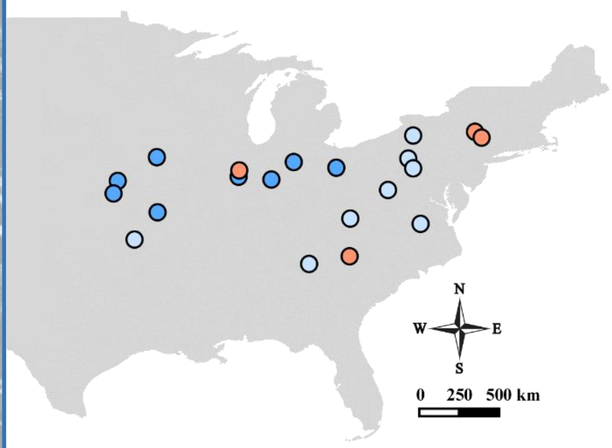
[Ferrazzi et al., 2019]



DAMS LEAVE UNALTERED LOW-FLOW FLUCTUATIONS

Results – Low-Flow Stability

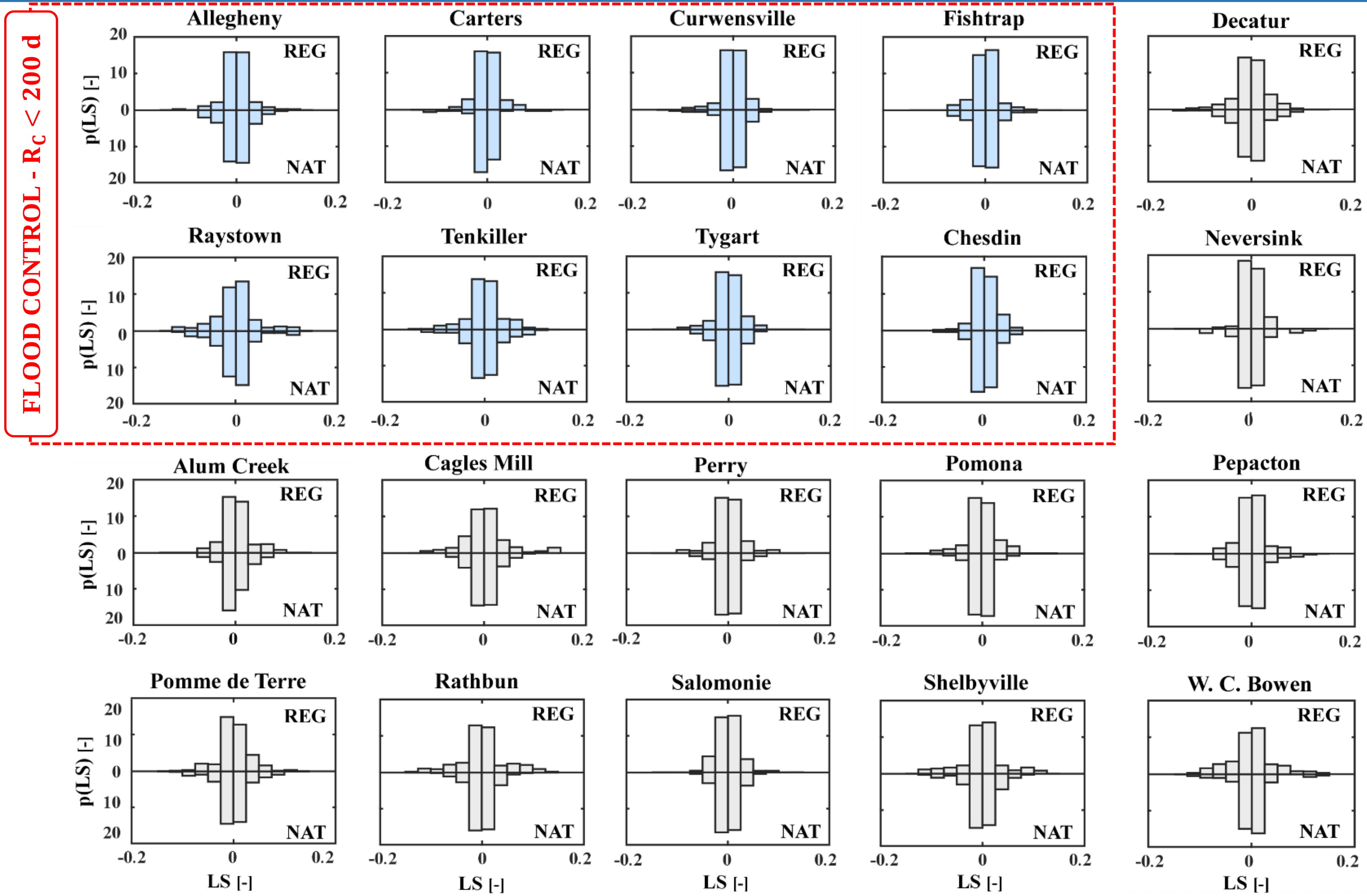
FLOOD CONTROL [R_C < 200 d]



Water Supply

Flood Control (R_C < 200 d)

Flood Control (R_C > 200 d)



UPPER PDFs – REGULATED FLOWS

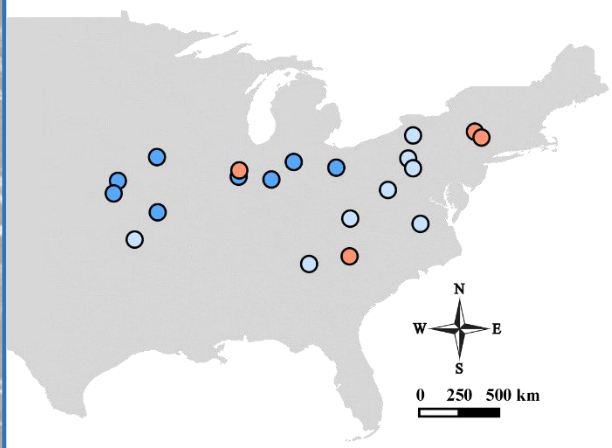
LOWER PDFs – UNREGULATED FLOWS

[Ferrazzi et al., 2019]

DAMS LEAVE UNALTERED LOW-FLOW FLUCTUATIONS

Results – Low-Flow Stability

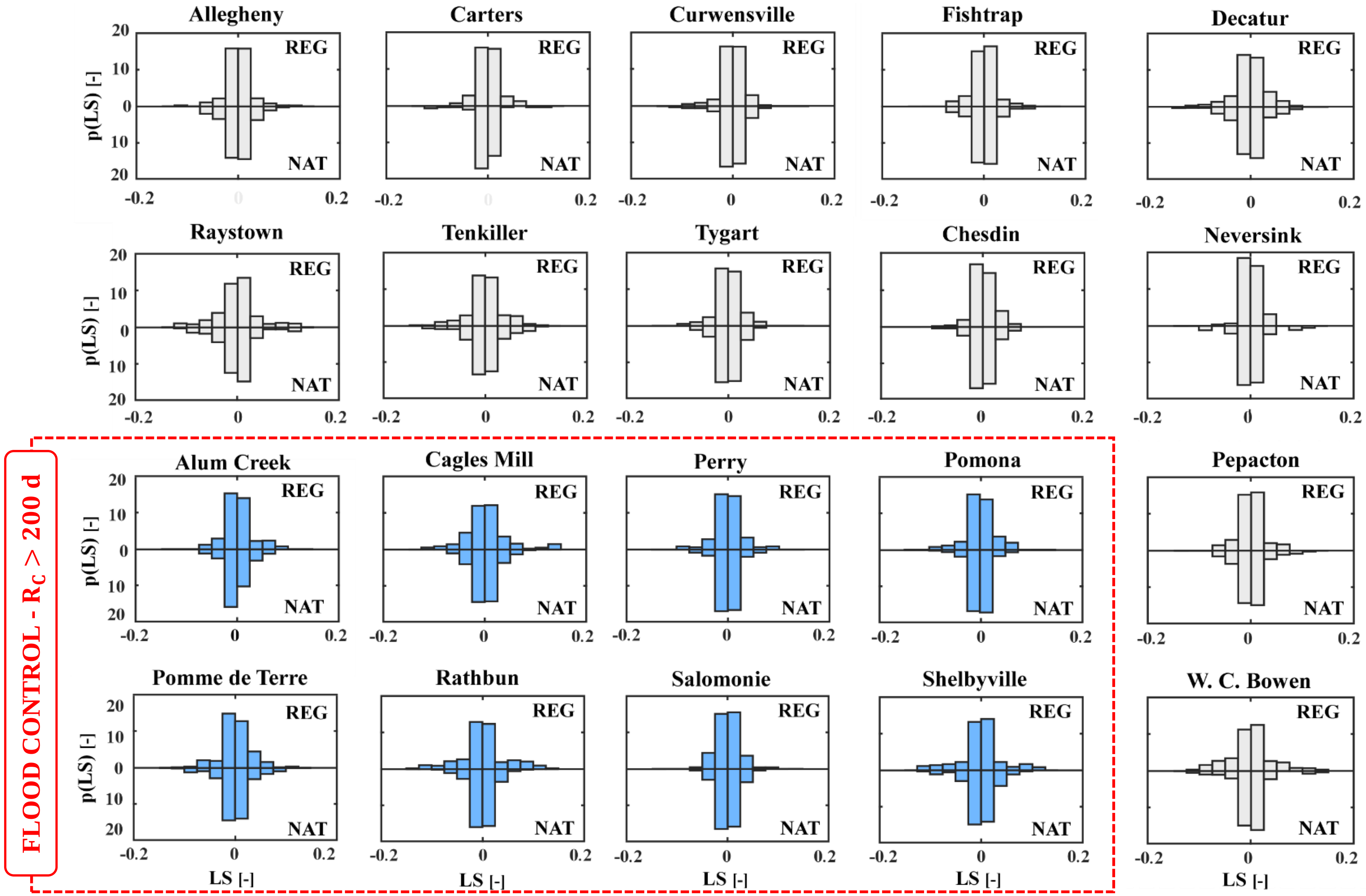
FLOOD CONTROL [$R_C > 200$ d]



Water Supply

Flood Control ($R_C <$ 200 d)

Flood Control ($R_C >$ 200 d)



UPPER PDFs – REGULATED FLOWS

LOWER PDFs – UNREGULATED FLOWS

[Ferrazzi et al., 2019]

DAMS LEAVE UNALTERED LOW-FLOW FLUCTUATIONS

Conclusion

1. Reservoir functions and regulation capacity control the patterns of dam releases under unsteady hydroclimatic conditions.

2. The control of reservoir functions and regulation capacity does not extend to low flows.

3. Dams are unlikely to reduce the sensitivity of flows to climate variability supporting the security of downstream water uses.

Thanks for your attention!