Nonlinear dynamics in treatment wetlands: Identifying systematic drivers of volatile outlet concentrations

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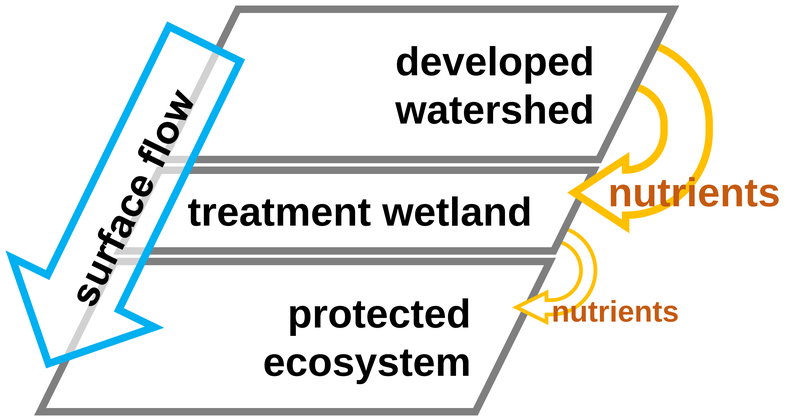
Treatment wetlands intercept **nutrients** in **surface runoff** to protect downstream ecosystems. Effective nutrient removal requires management of hydraulic loads and nutrient loads.[a]



Faced with volatile treatment dynamics, **managers lack a reliable means of distinguishing between systematic variation and random scatter in nutrient concentrations in outflows (CONCout)**. This question dictates whether and how managers intervene to improve treatment performance.

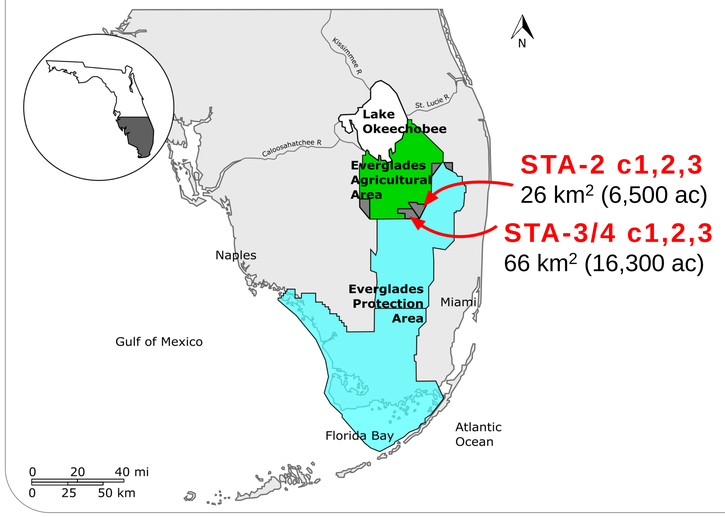
OBJECTIVE: Identify systematic drivers of **CONCout** to support management intervention decisions.

QUESTIONS

1. Are **CONCout** dynamics predominantly **random** (linear-stochastic) or **systematic** (nonlinear-deterministic)?
2. If systematic, is **CONCout** driven by **FLOWin**, **FLOWout** or **CONCin**?

STUDY AREAS: Everglades Stormwater Treatment Areas 3/4 and 2.

The STAs remove **phosphorus** from **agricultural stormwater** in south Florida, USA—an important part of the **Everglades restoration** effort.[b]

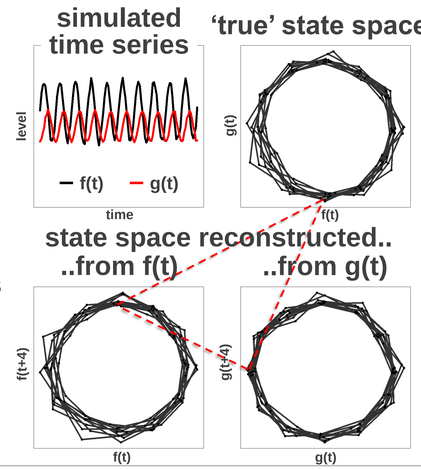


METHODS

1. Reconstruct and characterize system dynamics using **nonlinear time series** diagnostics.[c]
2. Infer **causal relationships** among **FLOWin**, **FLOWout**, **CONCin** and **CONCout** at each STA using **convergent cross-mapping**.[d]

Key concepts:

- **Reconstruction of system dynamics from a single time series.**[e]
- **Correspondence between reconstructions implies causality.**[d]

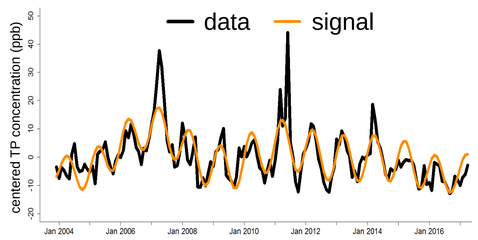


RESULTS & CONCLUSIONS

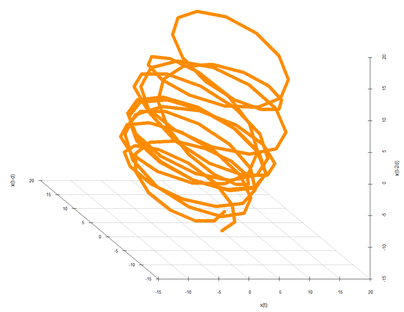
STA-3/4: Phosphorus **CONCout** volatility is highly systematic and strongly driven by **FLOWin** and **FLOWout**, with evidence of management feedbacks. The wetland effectively removes the **CONCin** signal.
Conclusion: Enhanced management of **hydraulic loads** (e.g. **upstream storage**) may improve treatment performance.

STA-2: Phosphorus **CONCout** volatility is predominantly stochastic, and the wetland effectively removes **FLOWin**, **FLOWout** and **CONCin** signals.
Conclusion: Neither hydraulic loads nor P loads *systematically* drive **CONCout** volatility.

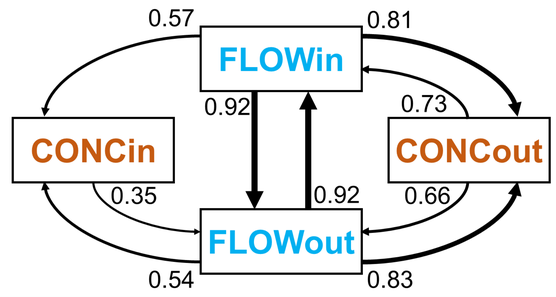
STA-3/4 CONCout signal explains 62% of variance



STA-3/4 state space reconstructed from **CONCout**



STA-3/4 causal network



Refs: [a]**Kadlec & Wallace** (2009) *Treatment Wetlands*. [b]**Chimney et al** (2001) *Water Sci & Tech* 44. [c]**Huffaker et al** (2017) *Nonlinear time series analysis with R*. [d]**Sugihara et al** (2012) *Science* 338. [e]**Takens** (1980) *Detecting strange attractors in turbulence*.