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The systematic underestimation of nutrient load variability in coupled streamflow-water quality models: Effects on lake cyanobacteria blooms

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INTRODUCTION

- Many watershed and lake managers seek simulated streamflow and river water quality time series under different conditions
- Simulated time series tend to have lower variances than observed time series due to the omission of calibration residuals
- Few “best practices” for coupling of streamflow and water quality simulation models, including treatment of calibration residuals
- How much does coupling method affect estimates of extreme total phosphorus (TP) loads and lake cyanobacteria blooms?

MISSISQUOI BAY, LAKE CHAMPLAIN

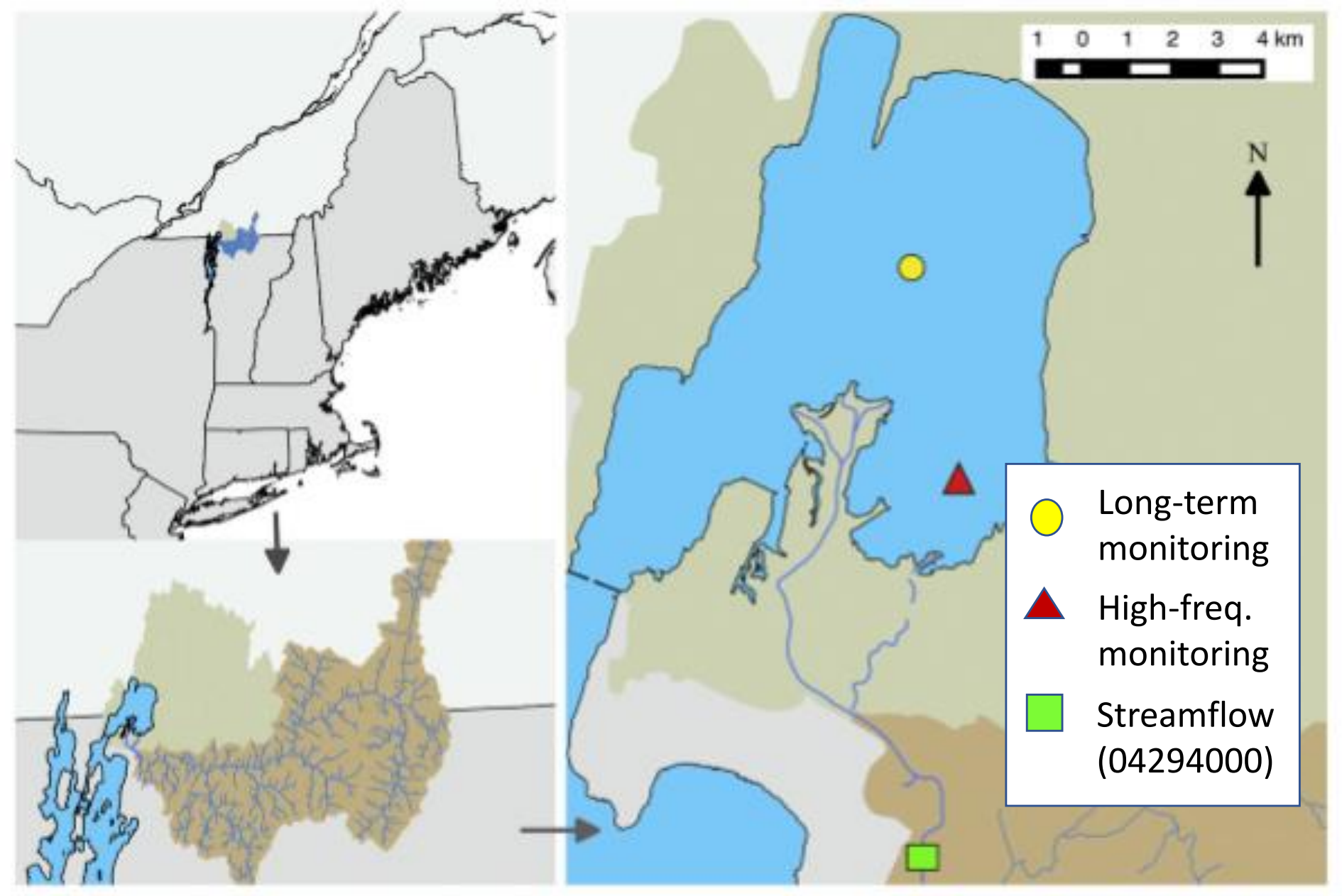
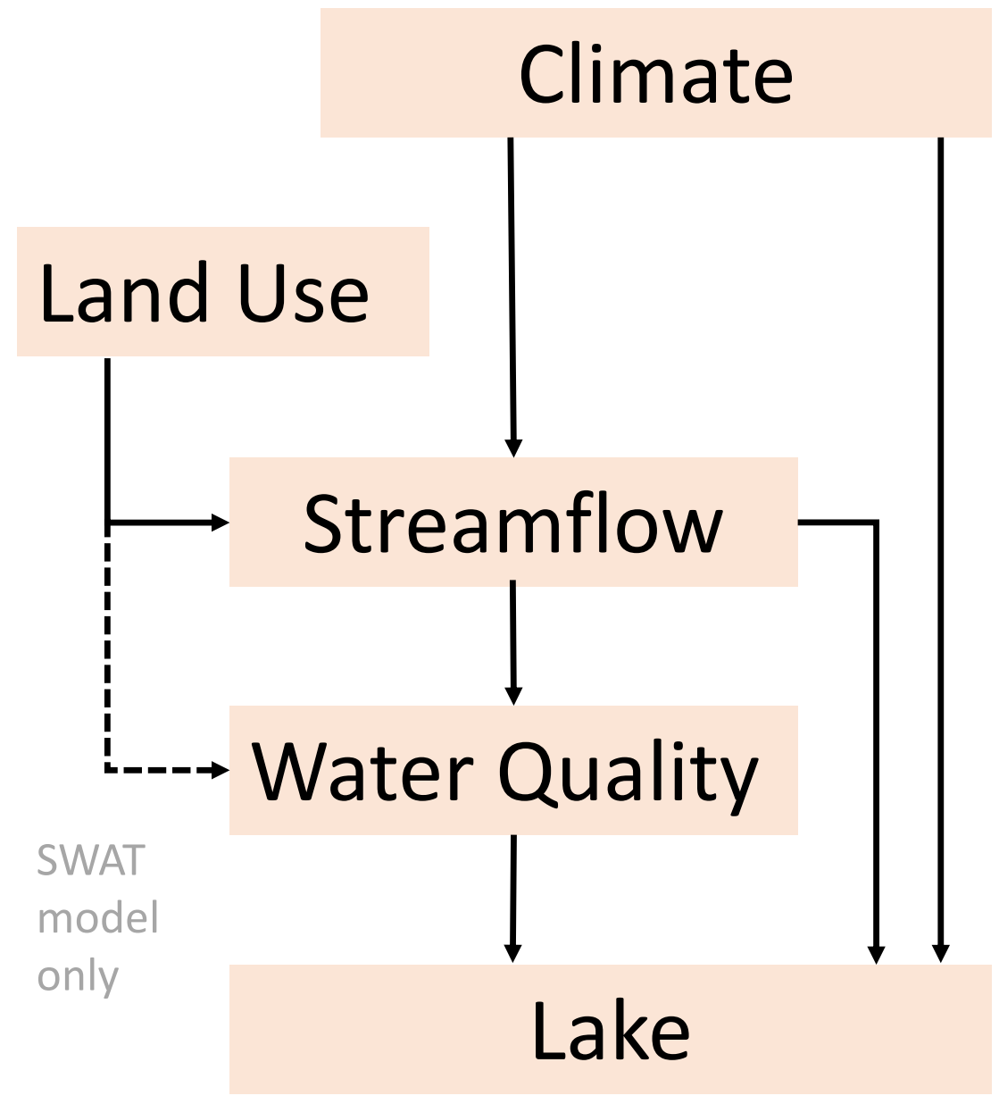


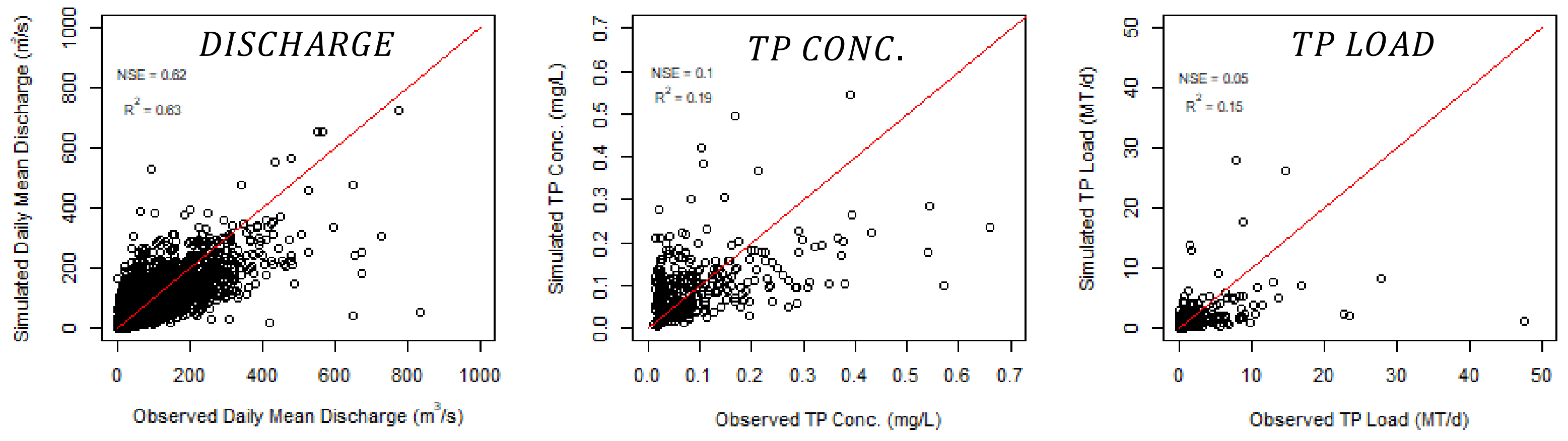
Figure adapted from Isles *et al.* (2015). Missisquoi Bay and the Missisquoi River watershed in Vermont, USA and Quebec, Canada.



Integrated Assessment Model used in cyanobacteria bloom simulations.

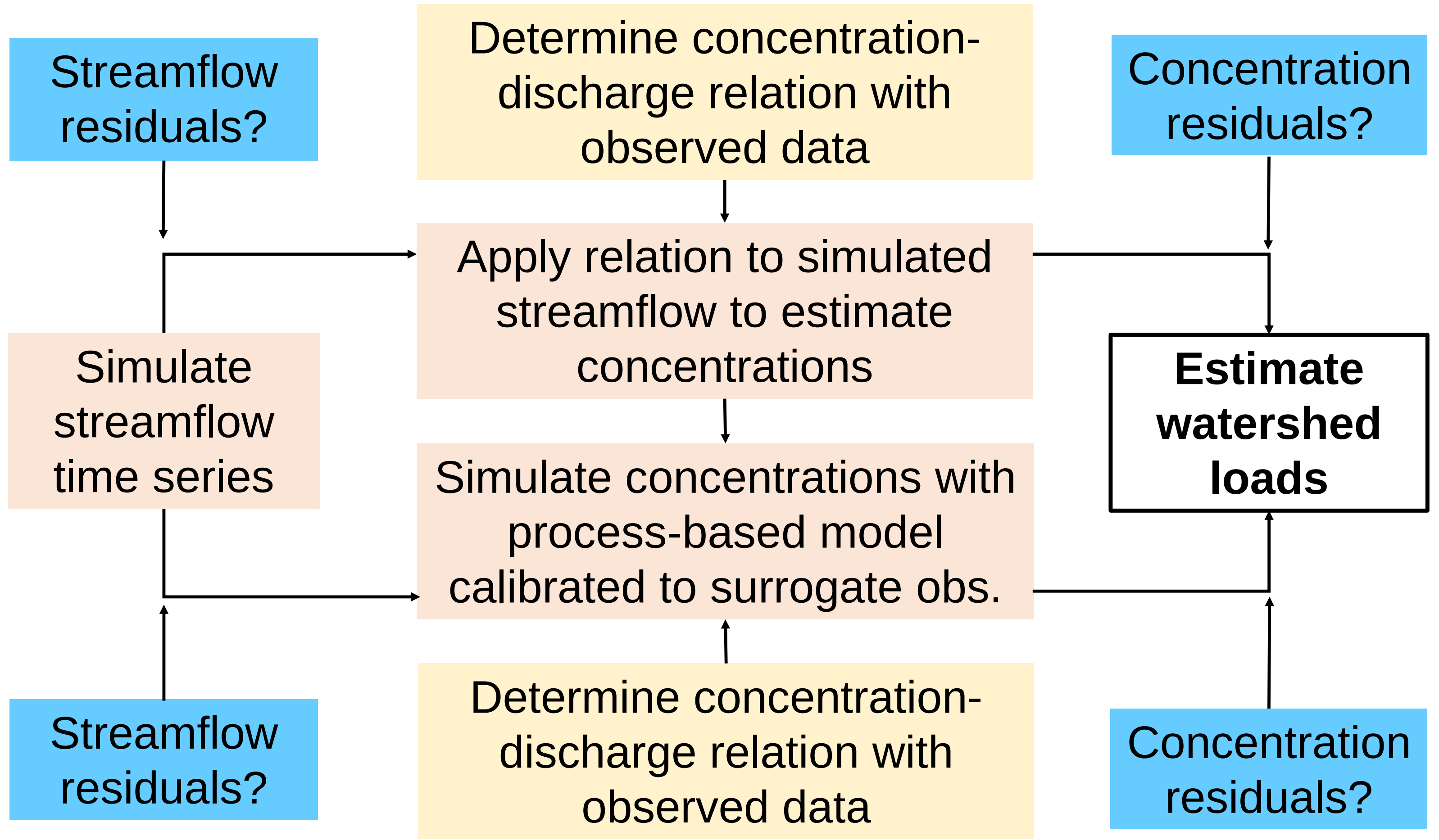
- Both external (watershed) and internal phosphorus loads have caused cyanobacteria blooms in bay since 1960’s
- Form under high water temperatures and low wind speeds
- Hazardous for recreation, drinking water, aquatic ecosystems
- Revised TMDL (2016) requires 64.3% load reduction by 2035

Lake Champlain TMDL Case Study (SWAT model, 1991-2010)



$\sigma^2_{sim} = 0.71\,\sigma^2_{obs}$ $\sigma^2_{sim} = 0.54\,\sigma^2_{obs}$ $\sigma^2_{sim} = 0.43\,\sigma^2_{obs}$

MODEL COUPLING APPROACHES



ESTIMATING RIVER PHOSPHORUS LOADS

Estimating daily total phosphorus loads at Swanton, VT (1991-2010)

Choose an existing streamflow time series → Choose streamflow residual adjustment → Choose streamflow-concentration model → Choose concentration residual adjustment

Choose an existing streamflow time series	Choose streamflow residual adjustment	Choose streamflow-concentration model	Choose concentration residual adjustment
• Observed (Q_obs) • Simulated (SWAT) • Simulated (RHESSys)	• None • Mean percent residuals by obs. discharge decile (DecileAdj) • Linear regression with obs. discharge • Bourgin (2015) bootstrapping • Discharge + seasonal	• Observed TP + Linear interpolation • Bayesian segmented regression • Process-based model (SWAT) • Quadratic regression (QuadReg) • WRTDS • DLM for hysteresis	• None • Proportional Linear • Proportional rectangular

Shown in results

Not shown in results or upcoming runs

Variance attenuation in coupled models: A regression example

Adapted from Farmer and Vogel (2016)

STEP 1: Fit separate regression equations to observed data

$$Q_t = a_Q + b_Q * P_t + \varepsilon_{Q,t}$$

$$\hat{Q}_t = a_Q + b_Q * P_t$$

$$C_t = a_C + b_C * Q_t + \varepsilon_{C,t}$$

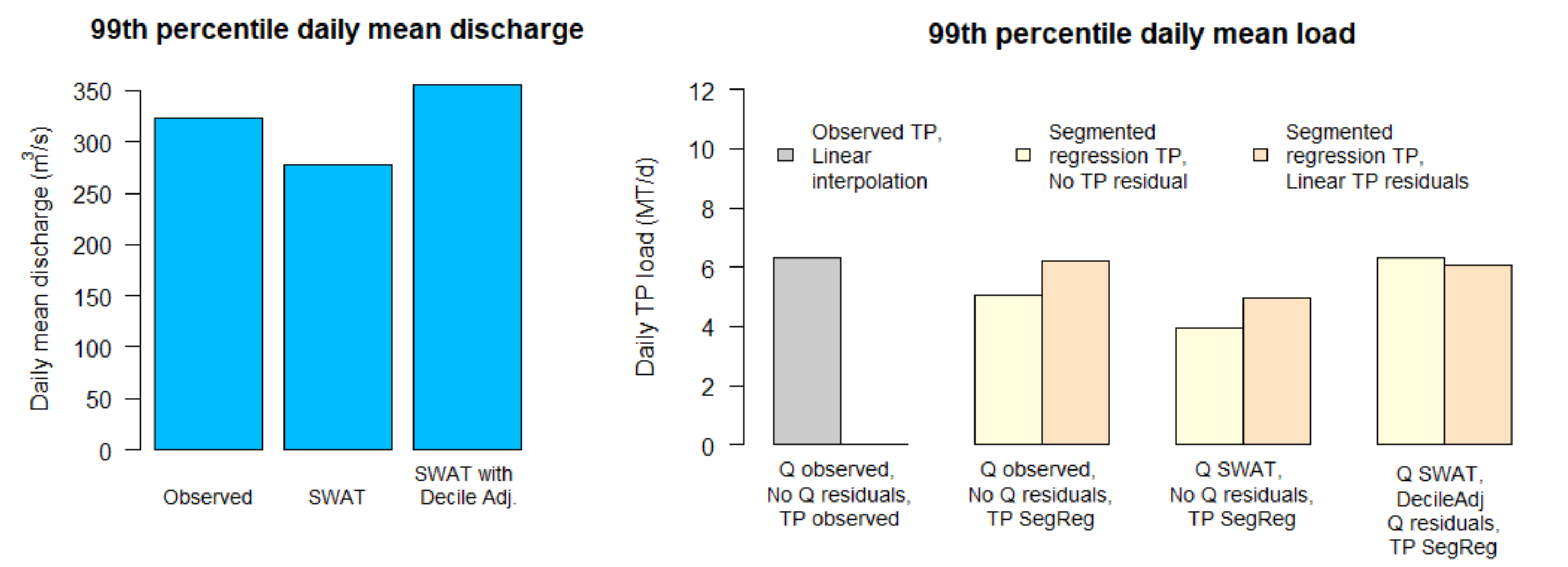
$$\hat{C}_t = a_C + b_C * Q_t$$

STEP 2: Estimate concentrations as a function of *simulated* streamflow

$$\hat{C}_t = a_C + b_C * \hat{Q}_t$$

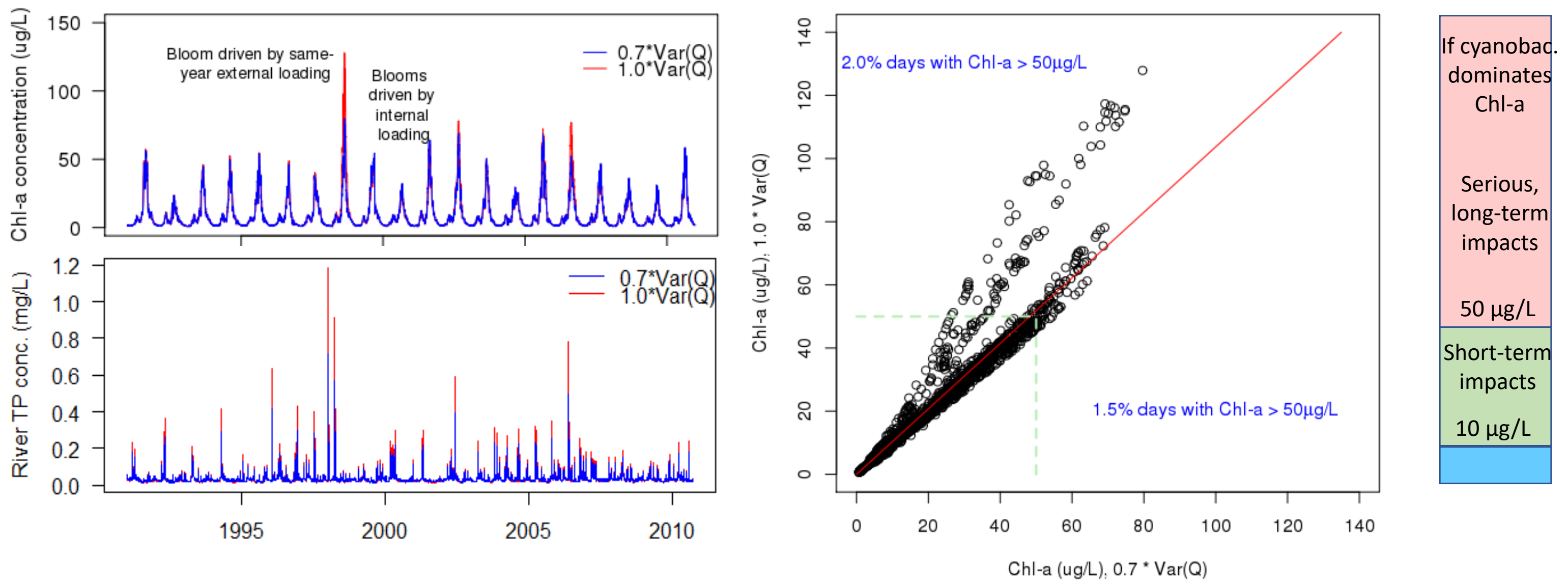
- $Var[Q_t]$ is underestimated
- Coefficients fit for C_t cannot be adjusted for lower $Var[Q_t]$
- $Var[\varepsilon_{C,t}]$ also not part of $Var[\hat{C}_t]$

RESULTS: RIVER PHOSPHORUS LOADS



- Incorporating residuals tends to raise extreme flows and TP loads
- DecileAdj flows too high, but TP residuals reduce its load impact
- Interpolated observed TP concentrations have a high-flow bias
- Cross-validation experiments to compare methods underway

LAKE BLOOM SENSITIVITY TO FLOW VAR.



- Daily mean discharge (Q) variance modeled with LN2 dist. Compared blooms with 0.7*Var(Q) and 1.0 *Var(Q)
- Left: some blooms are more sensitive to external loading (e.g. 1998), others to internal legacy loadings (e.g. 1999, 2001)
- Right: Days > 50 µg/L is 33% more frequent under 1.0 * Var(Q)

KEY TAKEAWAYS & NEXT STEPS

- Accounting for calibration residuals worsens severe blooms resulting from recent external (watershed) loading events
- Yet, bloom sensitivity to calibration residual treatment depends on external vs. internal loading contributions
- Tradeoffs between higher-fidelity modeling (e.g. hysteresis, snow vs. rain) and residual adjustments merit further research
- Must compare results using daily mean and 15-min discharges