Effect of Water Quality Model Uncertainty on the Non-Tidal Passaic River Basin Phosphorus TMDL and Trading Program

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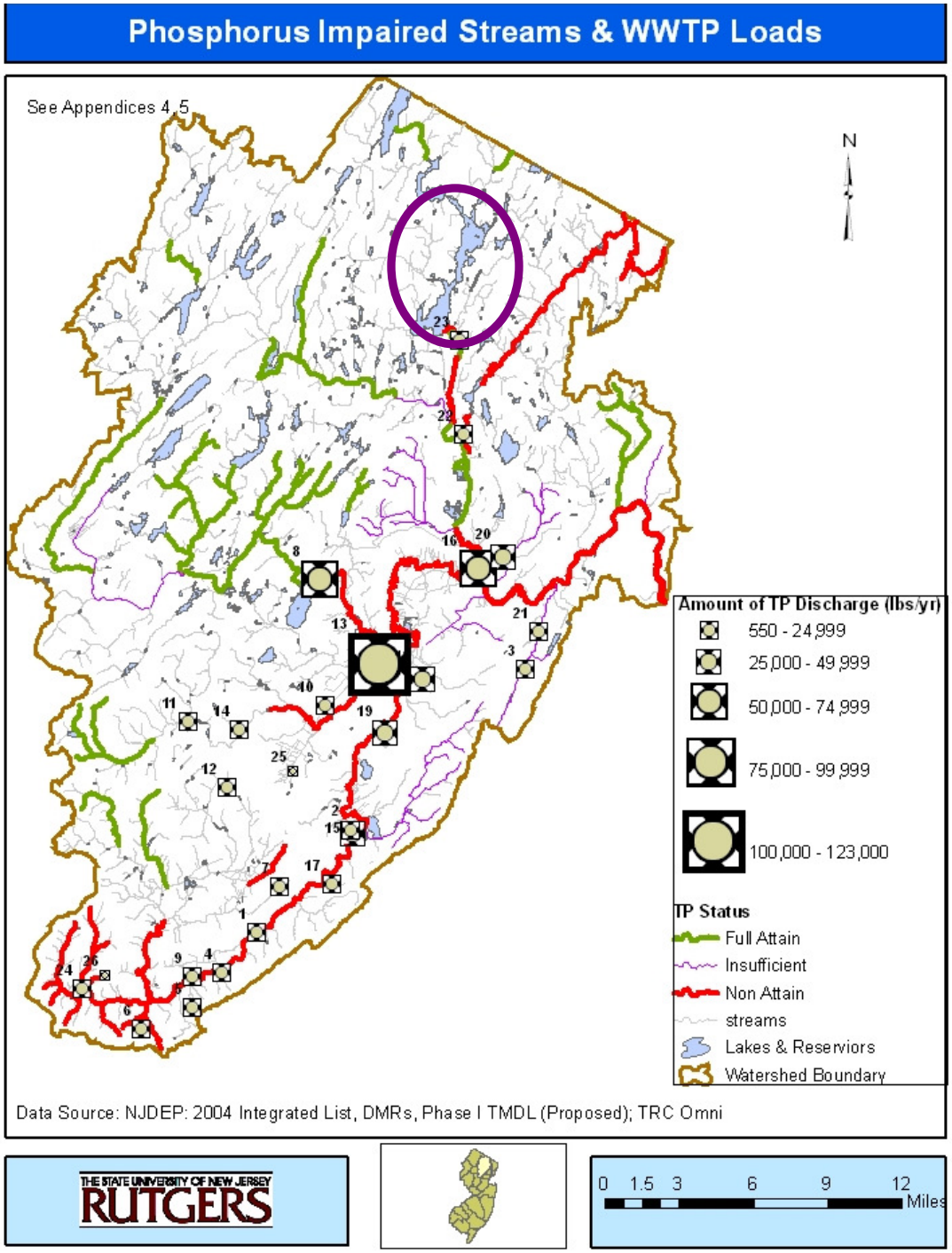
Disclaimer

- EPA and NJDEP have not officially endorsed this presentation, and the views expressed herein may not reflect the views of the EPA and NJDEP.

Overview

- Background on Passaic TMDL and trading program
- Need for uncertainty analysis (UA)
- Methodology and results of UA
- Conclusions



- 25 WWTPs with capacity > 0.1 MGD
- Contribute > 60% phosphorus load to Wanaque Reservoir and Dundee Lake
  - Affects NJ's largest drinking water reservoir
- Phosphorus loading is point source dominated


Confluence of Passaic and Pompton Rivers
8/24/06

Passaic TMDL

- Passaic TMDL approved July 2008
  - ***TMDL allocations based on extensive water quality modeling***
  - WWTP allocation: 0.4 mg/l long-term average (LTA) total phosphorus effluent
    - WWTPs currently discharging 0.2 to 3.3 mg/l LTA
    - Cost estimate of compliance ranges from 60 to 300 million dollars to upgrade each WWTP
- Rutgers University received EPA grant to develop a water quality trading program that implements Passaic TMDL

Water Quality Trading (WQT)

Background

- Sources in a watershed can face very different costs to control the same pollutant.
- A trading program allots a certain number of pollution credits to each source in the watershed.
- The sources can either discharge under their limit and sell their credits, or discharge over their limit and purchase credits.
- Goal:
  - Improve water quality at a lower cost than command and control approach.
  - Incentive for nonpoint source pollution reduction

Water Quality Trading: Criticisms

Policy

- Lets polluters off the hook
- Legal uncertainty

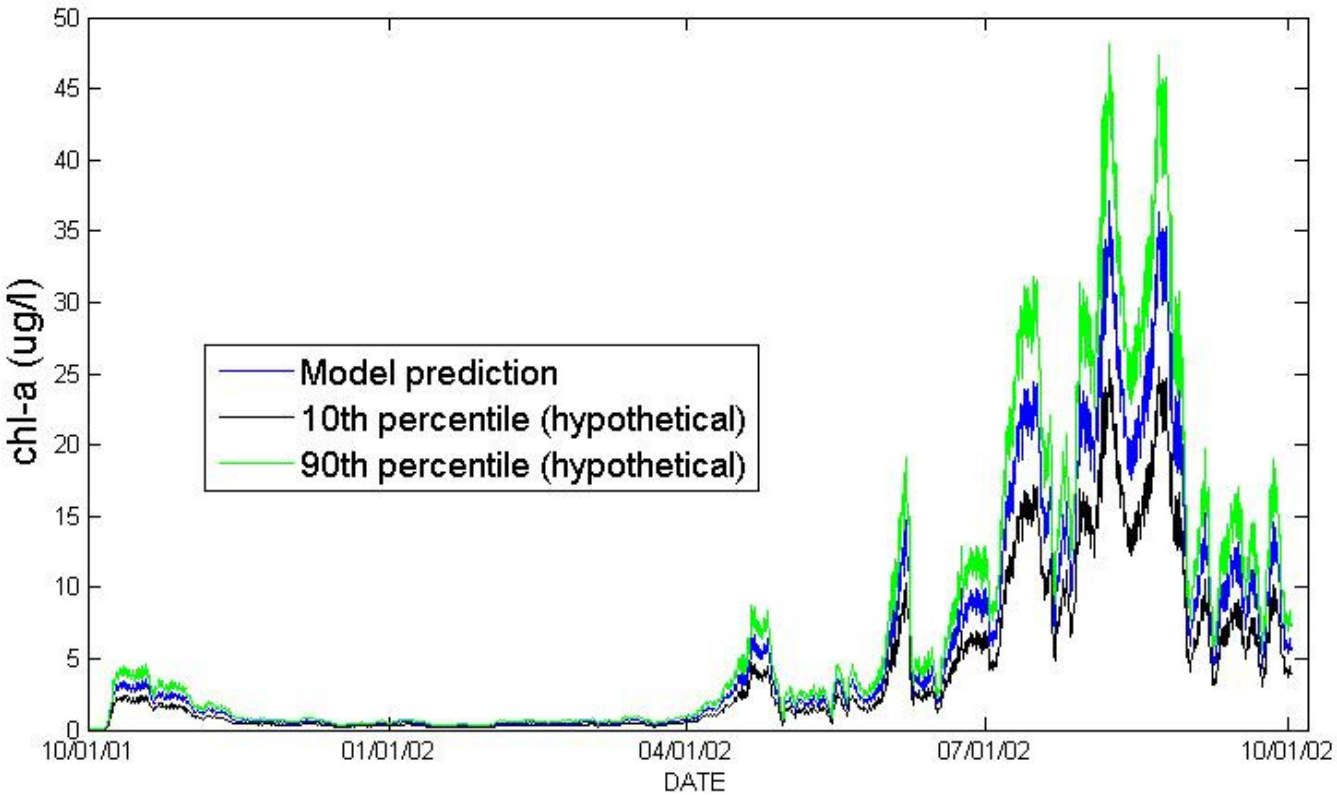
Science

- Risk of hot spots
- Reliability of water quality models

Uncertainty analysis

Model uncertainty

- Models are abstractions of reality
- Model predictions contain uncertainty



Uncertainty analysis (UA)

- "Avoids the mistaken impression that assessments are precise and well understood" – Reckhow, 1994
- Aids decision makers and public in evaluating options
- Especially appropriate when water quality criteria is in percentile terms
- National Research Council (2001) recommended UA should be part of TMDL process

  … ***and water quality trading ?***

Research objectives

- Test three hypotheses
  1. TMDL will result in attainment of dissolved oxygen and chl-*a* standards at Dundee Lake, with < 10% *exceedance probability*
  2. TMDL will result in targeted reduction of phosphorus loads diverted to Wanaque Reservoir, with < 10% *exceedance probability*
  3. Trading will not significantly increase uncertainty of attaining water quality targets at potential hot spots, relative to C&C approach

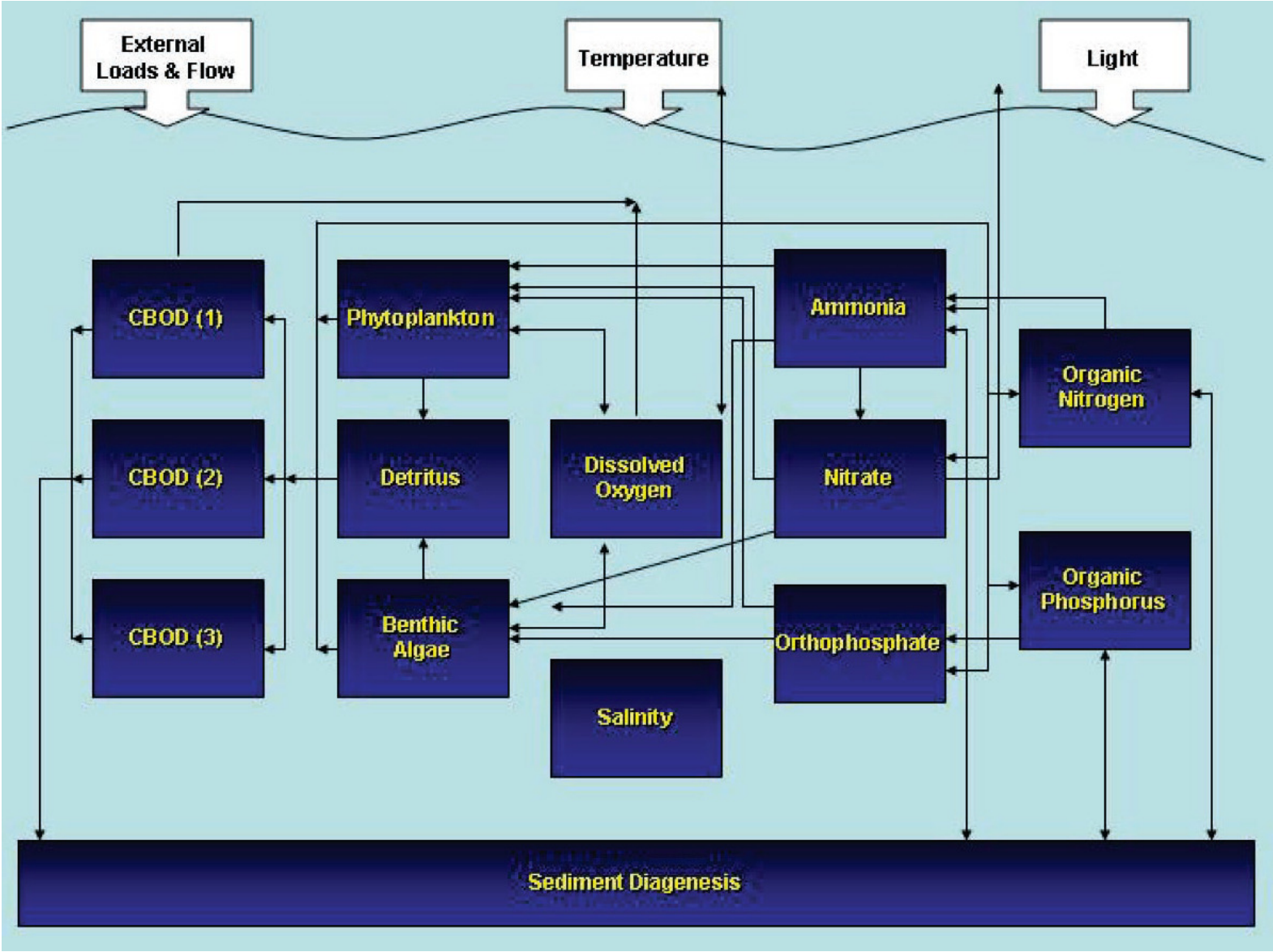
Key issues in UA

- Scope of UA
  - Several sources of model uncertainty
- Method efficiency
- *Credibility* of UAs for complex models
  - How credible is the **estimate** of uncertainty for alternate scenarios?
  - Not adequately addressed in literature for *complex* model UA
    - methods exist for simple models, but not feasible for complex models

Methodology: scope definition

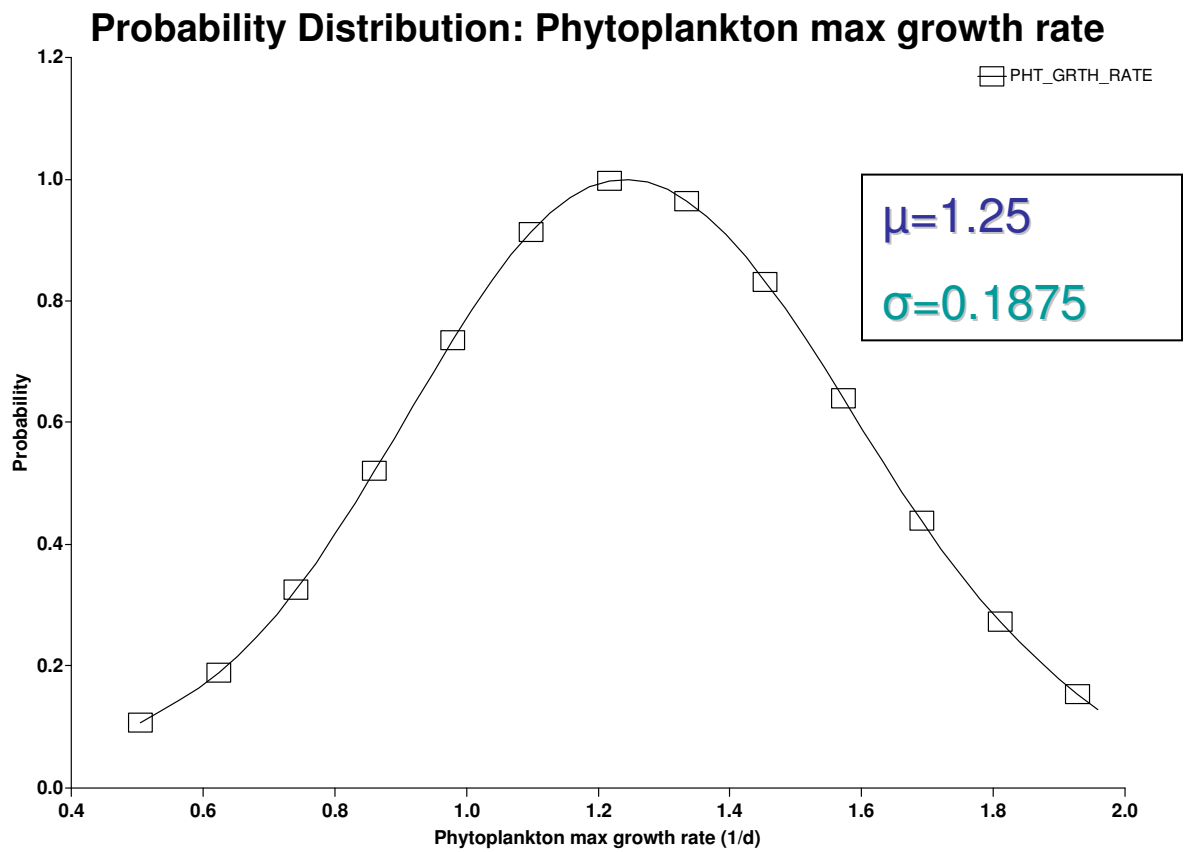
- Different types of model uncertainty
  - Natural randomness
  - Measurement uncertainty
  - **Input parameter uncertainty**
  - Uncertainty in model structure
- Sources of Passaic TMDL model uncertainty
  - Hydrodynamic Model
  - Nonpoint source load model
  - **Water quality Model**
    - **Kinetic parameters and boundary conditions**

WASP model


External Loads & Flow
Temperature
Light
CBOD (1)
Phytoplankton
Ammonia
Organic Nitrogen
CBOD (2)
Detritus
Dissolved Oxygen
Nitrate
Organic Phosphorus
CBOD (3)
Benthic Algae
Orthophosphate
Salinity
Sediment Diagenesis

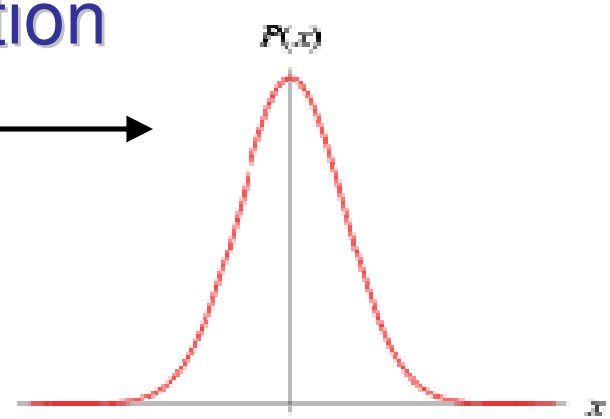
Methodology: Parameter uncertainty

- Kinetic parameters (global and local)

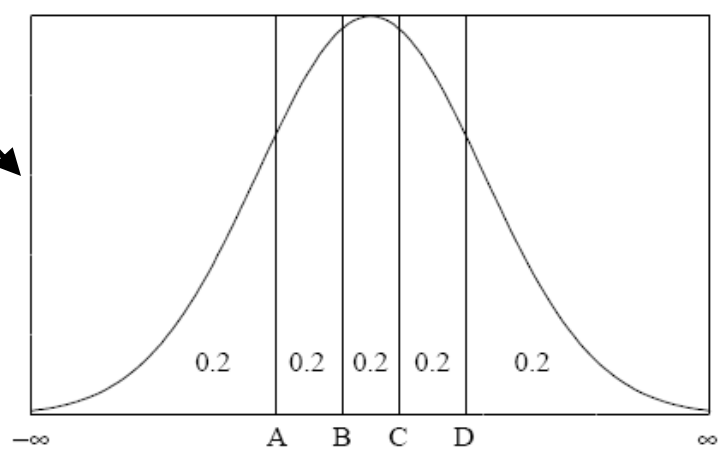


Method Efficiency

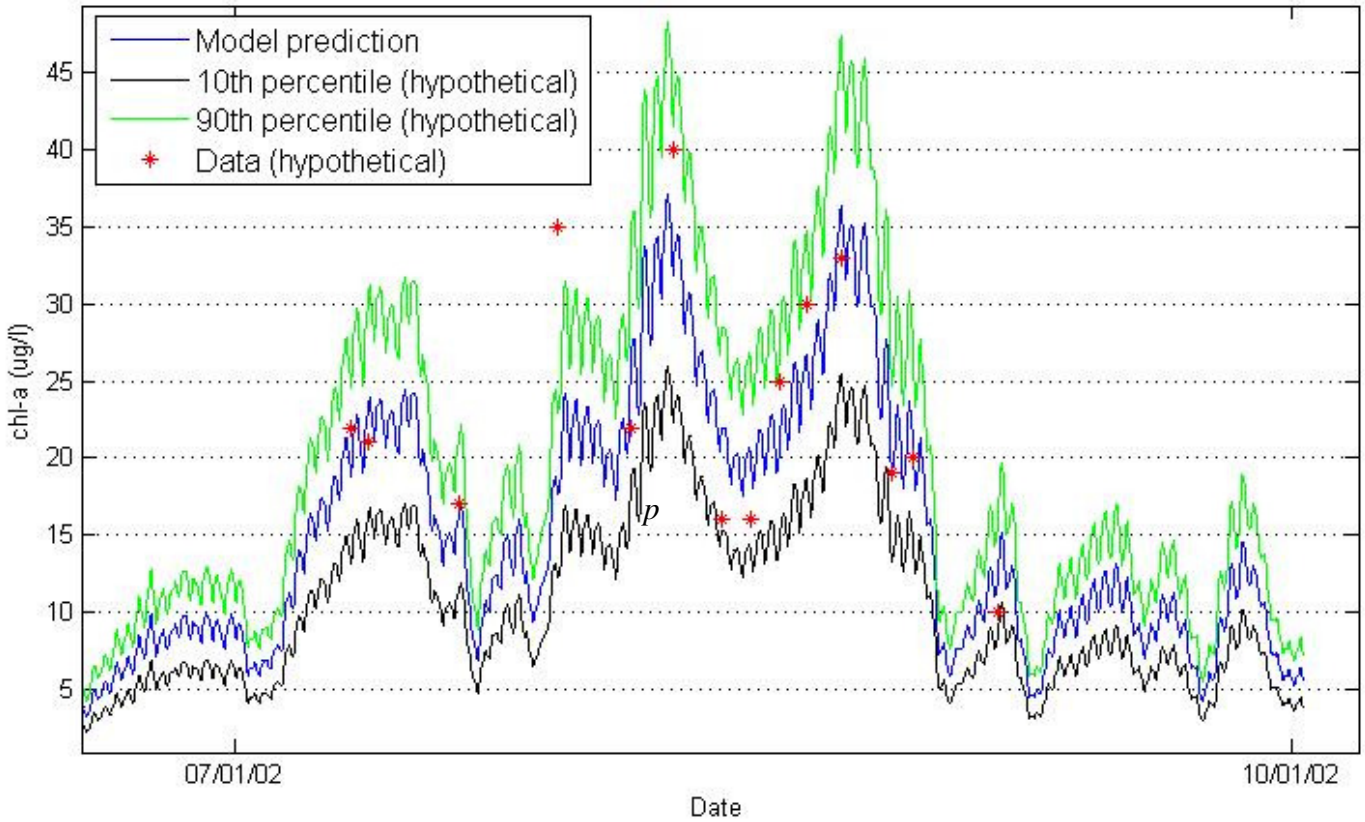
- Two main branches of UA methods
  - First order error approximation
  - Monte Carlo simulation



Latin Hypercube Sampling



Methodology: Credibility of UA



- Example: 13 of 14 observations fall within 80% confidence interval
- How credible is the 80% confidence interval?

Agresti-Coull Confidence Interval tests UA credibility

- Consider each comparison of observation to predicted confidence interval as a trial
- Successful trial = observation is within 80% confidence interval
- Calculate Agresti-Coull confidence interval about the proportion of success (appropriate for small sample sizes)

$$CI_{AC} = \tilde{p} \pm \kappa \frac{\sqrt{\tilde{p}\tilde{q}}}{\sqrt{\tilde{n}}}$$

CI_{AC} = Agresti - Coull Confidence Interval

$\tilde{n}$ = number of independent Bernoulli trials + 4

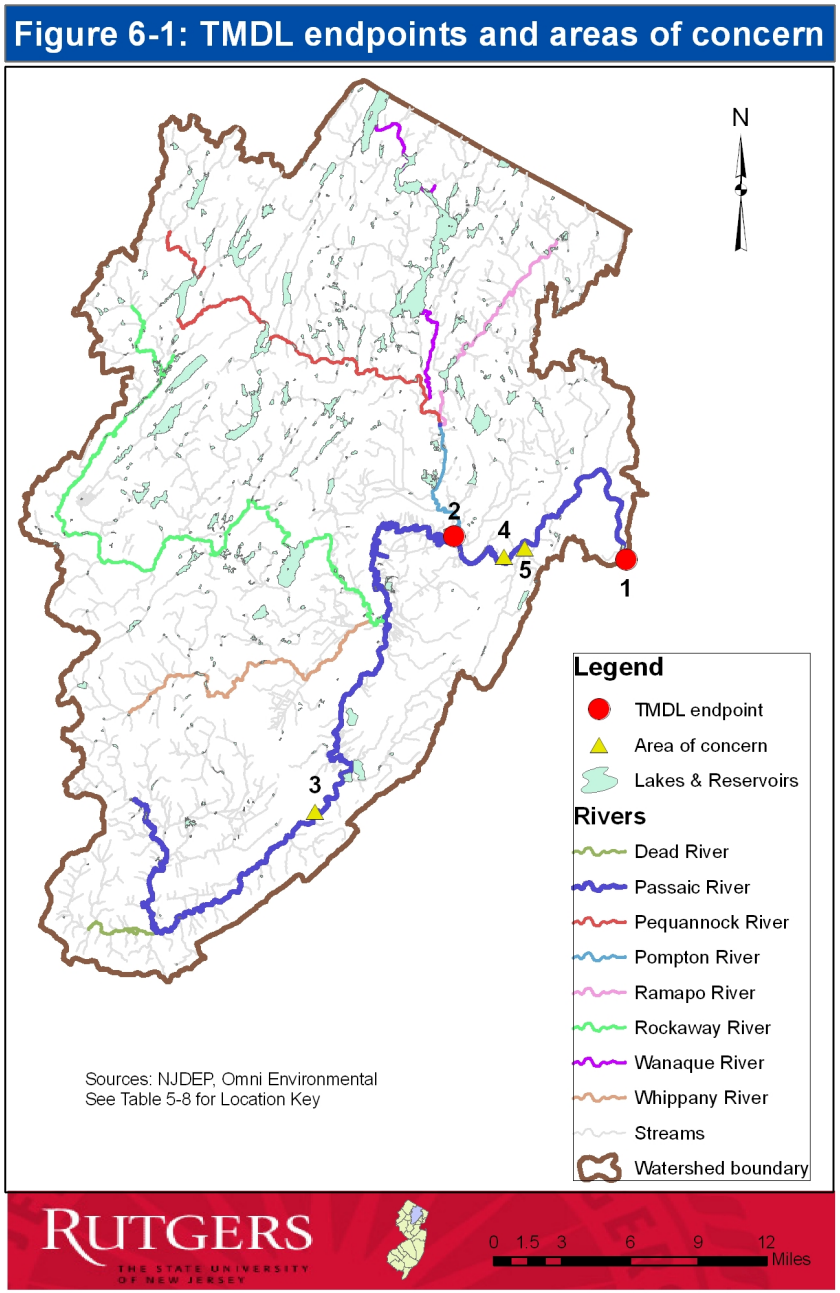
$\tilde{p}$ = (number of successes + 2) / $\tilde{n}$

$\tilde{q} = 1 - \tilde{p}$

$\kappa = z_{\alpha/2} = 1.96$ at 95% confidence.

- In example: $\tilde{n}$ =18, $\tilde{p}$ = 15/18, CI_{AC} = (**0.66, 1.0**)

  → CI_{AC} includes expected p of 0.80 → 80% CI is credible
- Method can detect if predicted 80% CI is too small or too big. Works better with more observations.



Key locations

- *TP*:

Wanaque South intake

Passaic R. near confluence with Pompton R.

Little Falls intake

Chl-a:

Dundee Lake

DO:

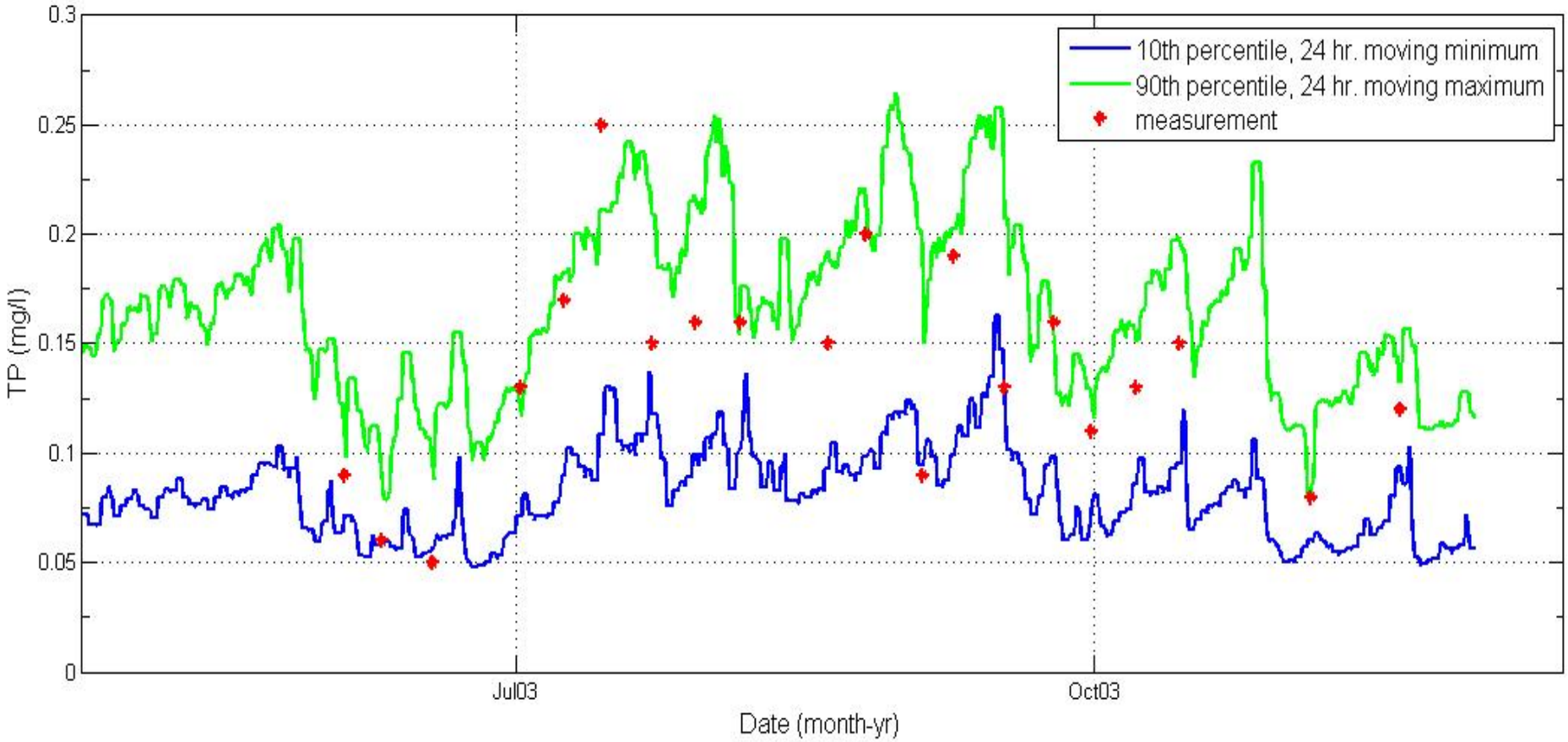
Dundee Lake

Peckman River mouth

Passaic R. near Chatham

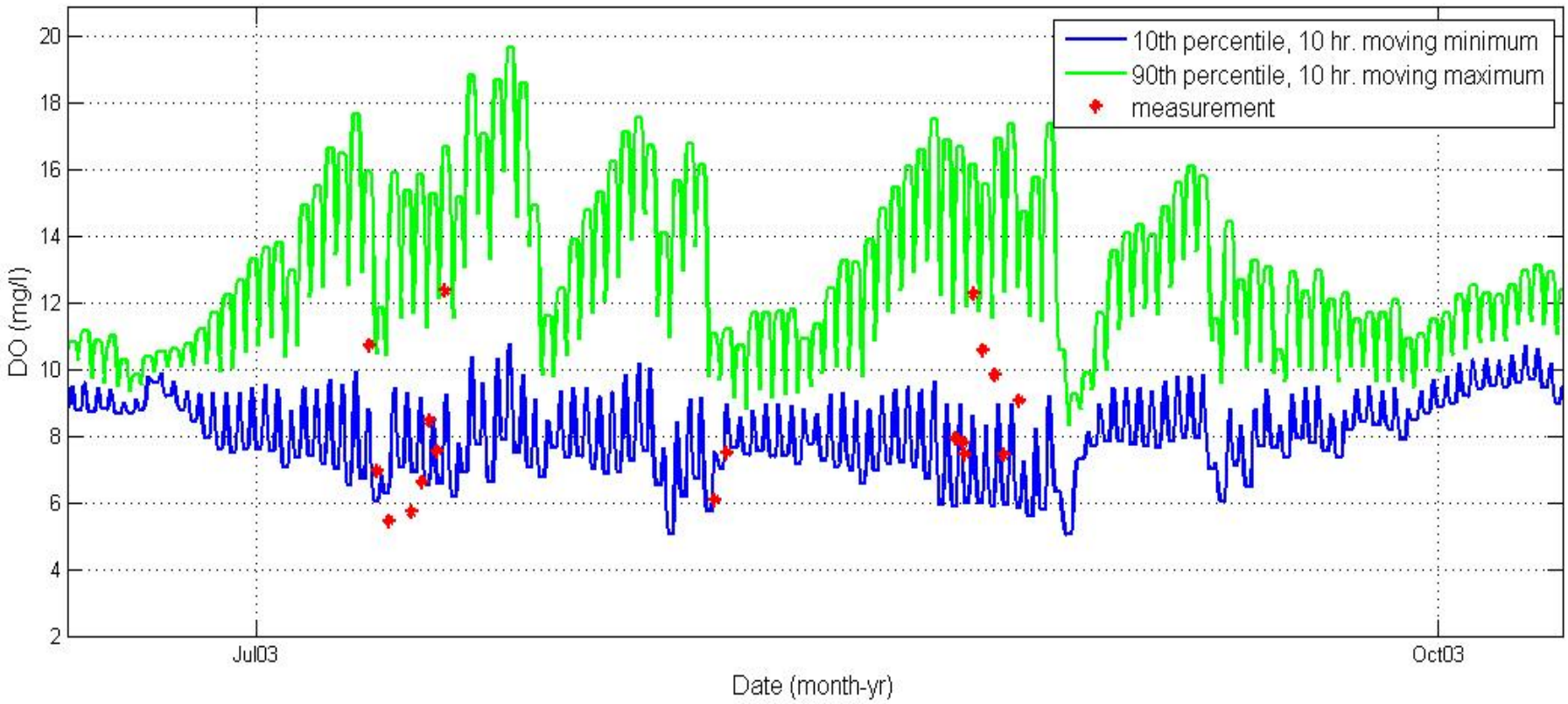
TP at Wanaque South intake

- WY2003
- 20 observations, 15 successes
- 95% AC confidence interval = (0.53, 0.89) → 80% CI is credible



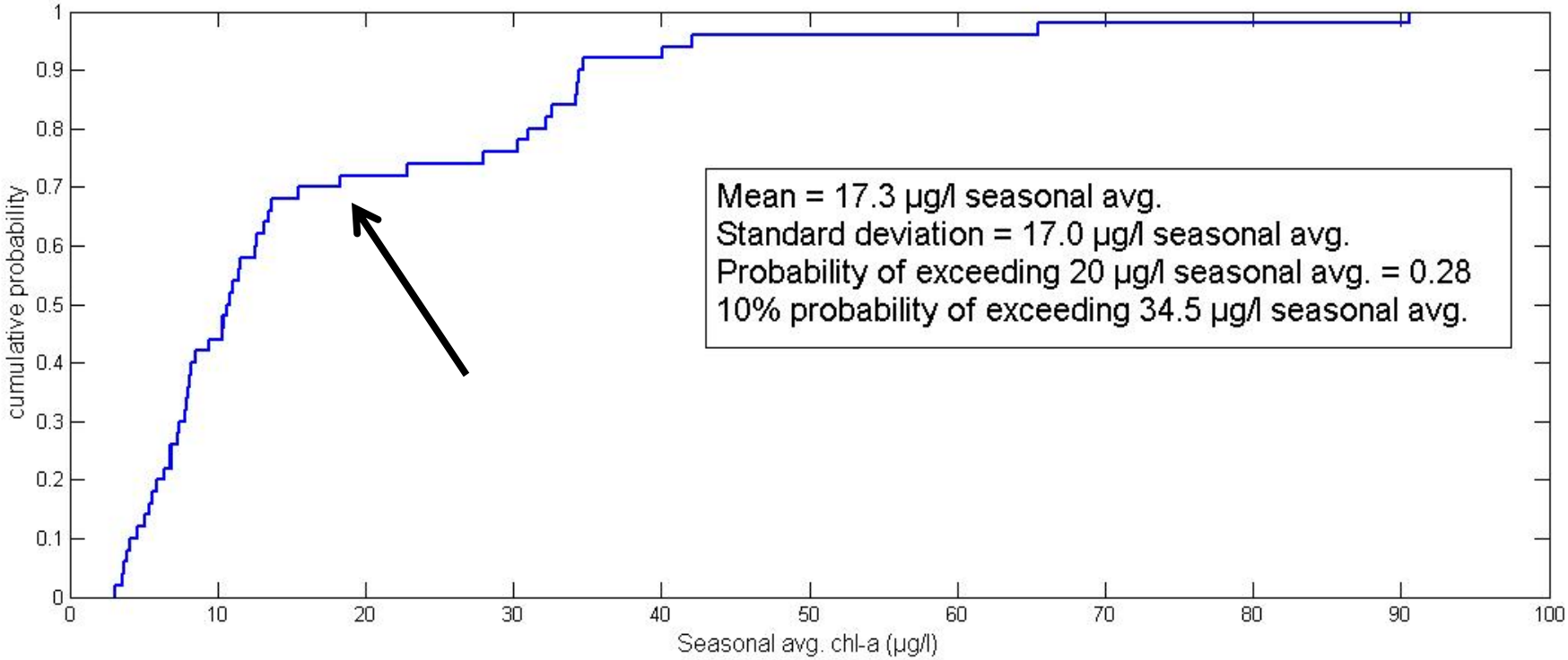
DO at Dundee Lake

- "Summer" 2003
- 18 observations, 13 successes
- 95% AC confidence interval = (0.49, 0.88) → 80% CI is credible



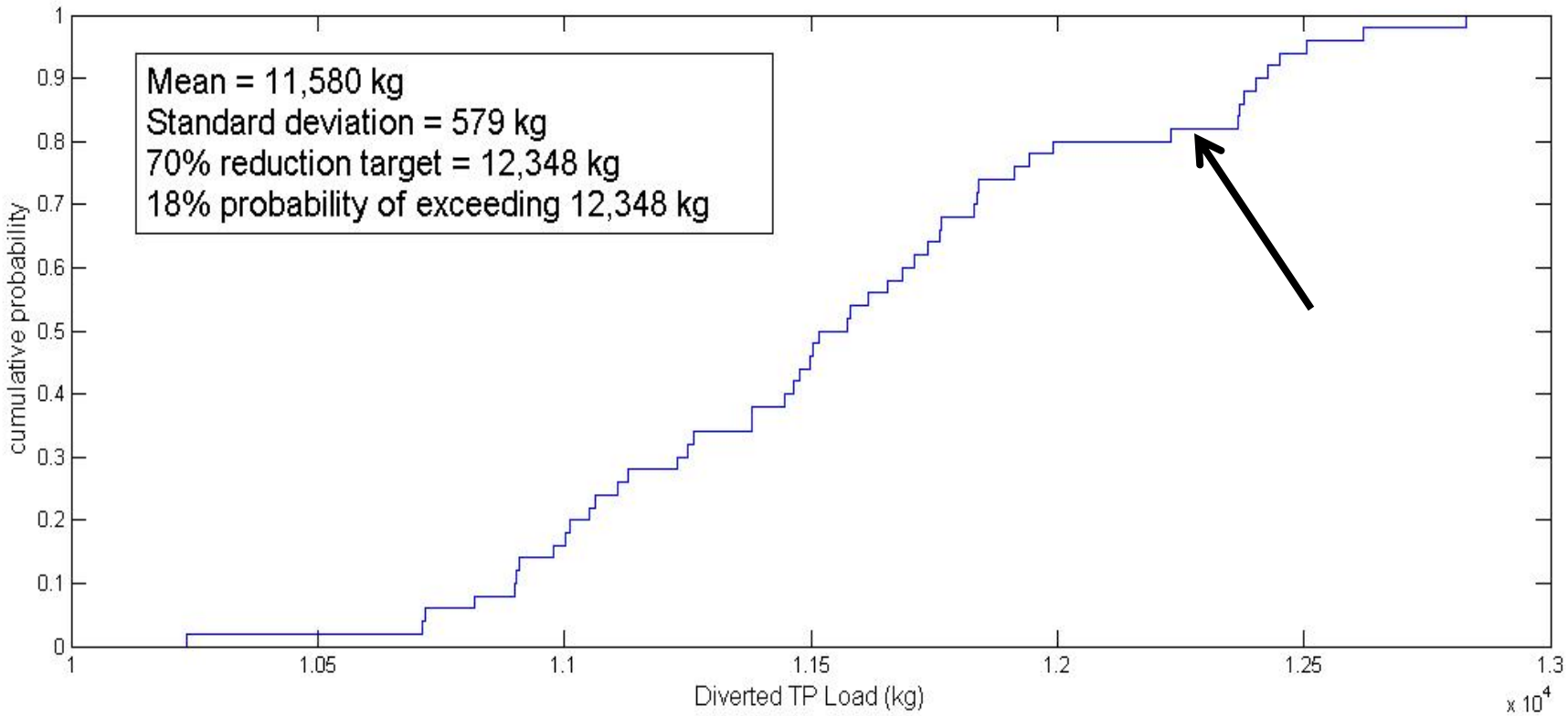
TMDL Scenario: Critical Location 1

- Water quality standard at Dundee Lake is 20 µg/L chl-*a* seasonal avg.
- 28% probability of exceeding chl-*a* standard
- 0 % probability of exceeding DO standards at Dundee Lake

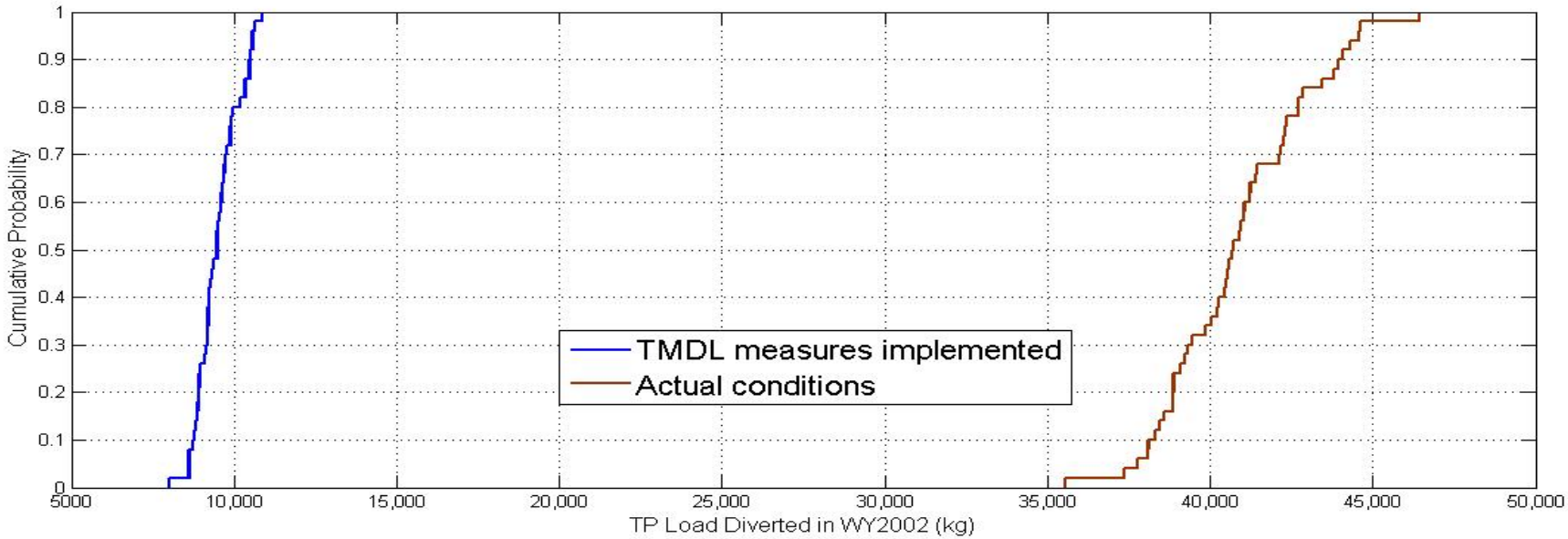


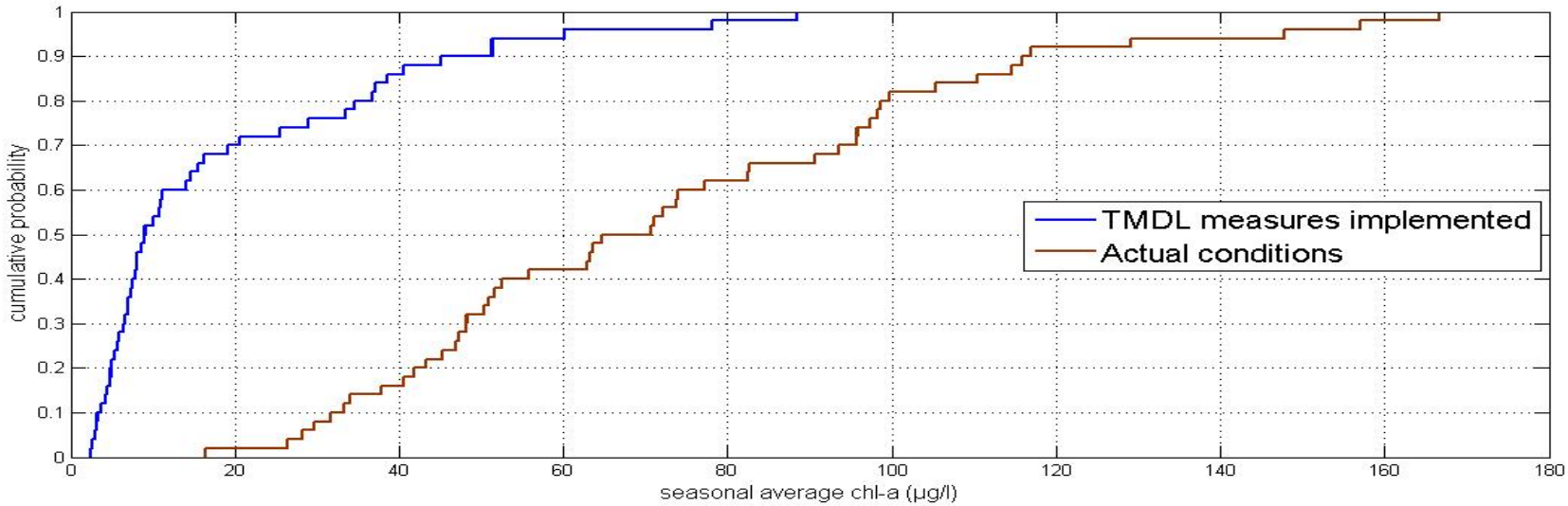
TMDL Scenario: Critical Location 2

- Diverted TP load target of 12,348 kg during critical water year
- 18% probability of exceeding target



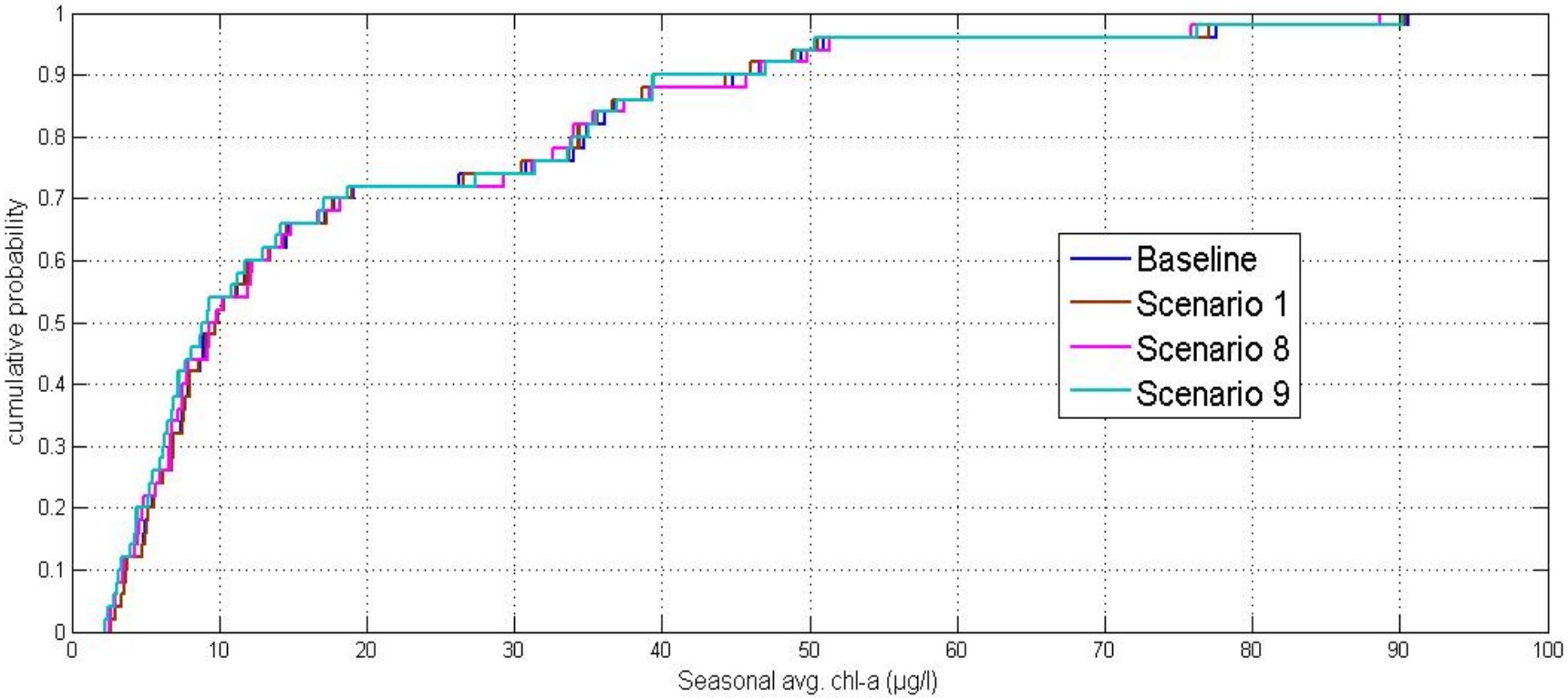
Is TMDL still worth implementing? Yes





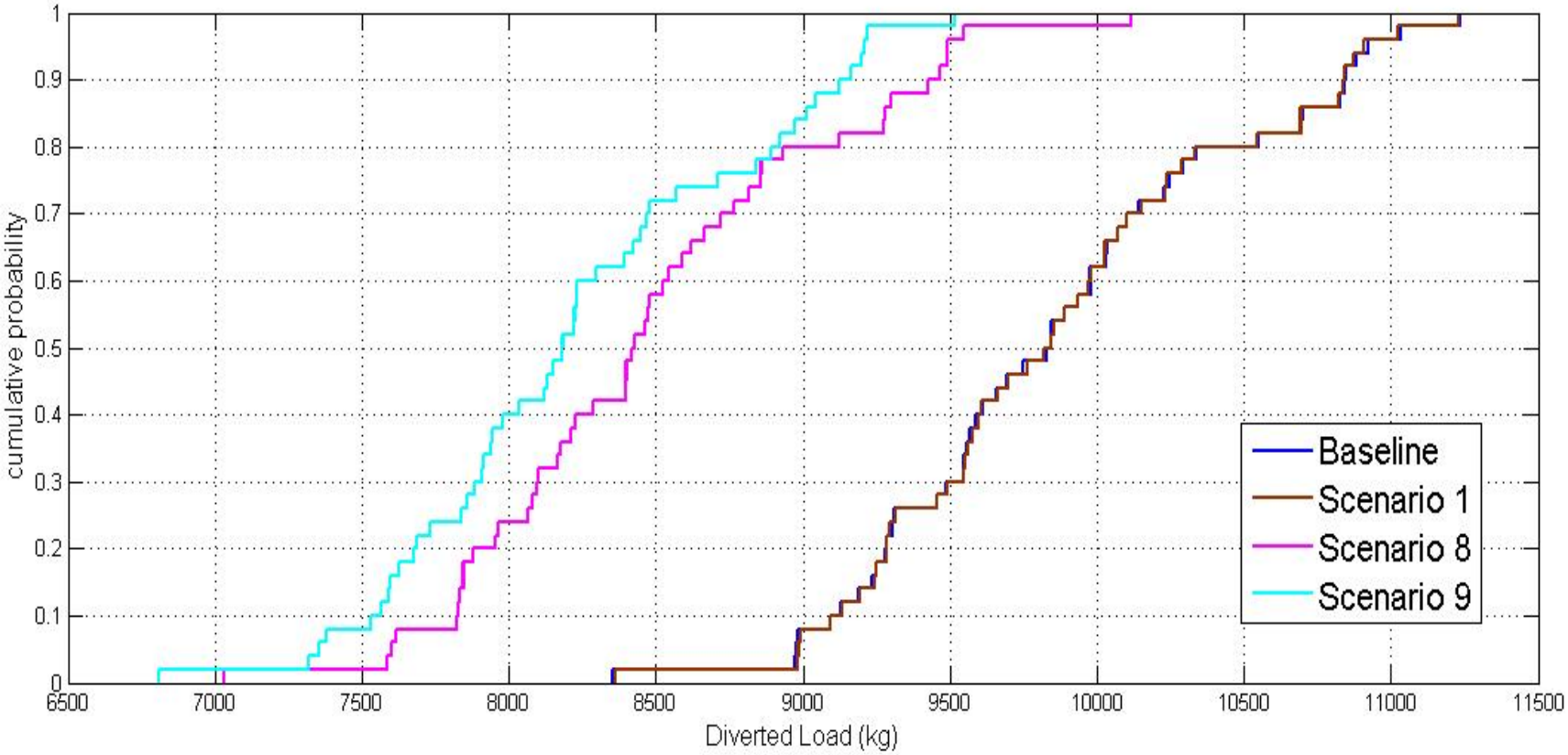
Trading scenarios: Critical location 1

- Compared 3 trading scenarios with baseline no-trade scenario
- No significant difference in probability distributions for seasonal avg. chl-*a* at Dundee Lake
- No significant difference in probability distributions for DO at Dundee Lake



Trading scenarios: Critical location 2

- No significant increase in uncertainty for TP load diverted target to Wanaque Reservoir



Conclusions

- Simple method demonstrated to assess UA credibility
- TMDL has > 10% probability of exceeding chl-a and TP targets at critical locations
- TMDL has 0% probability of exceeding DO target at critical location
- TMDL efficacy demonstrated
- Trading scenarios do NOT have significantly higher uncertainty of attaining WQ targets compared to C&C approach, at all potential hot spots
  - Conservative trading ratios effective in preventing hot spots
  - Point-point source trading; lower bound for uncertainty of WQT *in general* has been established

Future research areas

- Adaptive management tie-in
  - Collect data on key input parameters to reduce model uncertainty
    - Update TMDL and trading scenario uncertainty estimates
  - Communicating model uncertainty to public
- Link to WQ model of Wanaque Reservoir
- Link to economic model to calculate uncertainty of costs and benefits of trading