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
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
Methodology: Parameter uncertainty

- Kinetic parameters (global and local)

![Probability Distribution: Phytoplankton max growth rate](image)

- **μ** = 1.25
- **σ** = 0.1875
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)

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

\(\tilde{p}\) = (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 \(\rightarrow 80\% \text{ CI is credible}\)

- 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

Mean = 17.3 µg/L seasonal avg.
Standard deviation = 17.0 µg/L seasonal avg.
Probability of exceeding 20 µg/L seasonal avg. = 0.28
10% probability of exceeding 34.5 µg/L seasonal avg.
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