Simulation and Optimization of Large-Scale Controlled Reservoir System Constituent Response to Power Generation Activities

Dr. Gene LeBoeuf, Ph.D., P.E., BCEE
Dr. Mark McDonald, Ph.D.
Heather Smith Sawyer, P.E.
Amy Shaw

Vanderbilt University
Department of Civil & Environmental Engineering
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Outline of Presentation

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Introduction & Motivation

- Hydropower historically has been used to supplement thermal power during peak electricity use periods.
- “Peaking” operations result in significant fluctuations of stream flow, which can adversely impact downstream aquatic ecosystems.
- Recent regulations are trending toward new flow requirements, including shifts from “peaking” operations to “base-load” operations, resulting in adverse effects on power generation, especially during the high energy cost “peak” periods.
- Operators need additional tools to determine the best trade-off between power production and environmental conservation.

Background

- Various decision support systems (DSS) have been developed for hydropower generation optimization, but have a combination of drawbacks:
  - Application to only one reservoir
  - Do not incorporate environmental performance in constraints
  - Generalized packages with limited capabilities for site-specific systems
  - Lacking fidelity: typically one-dimensional with coarse spatial and temporal grids
- CE-QUAL-W2 is a high fidelity hydrodynamic water quality model that has been extensively studied and verified.
  - Ideal for long, narrow reservoirs and riverine segments
  - Can be used as a decision support tool to assist dam operators in planning releases and modeling potential release impact on riverine conditions
  - Due to computational requirements, W2 is not well-structured to support everyday decision-making, nor evaluation of optimal dam release performance subject to constraints

Project Goal and Objectives

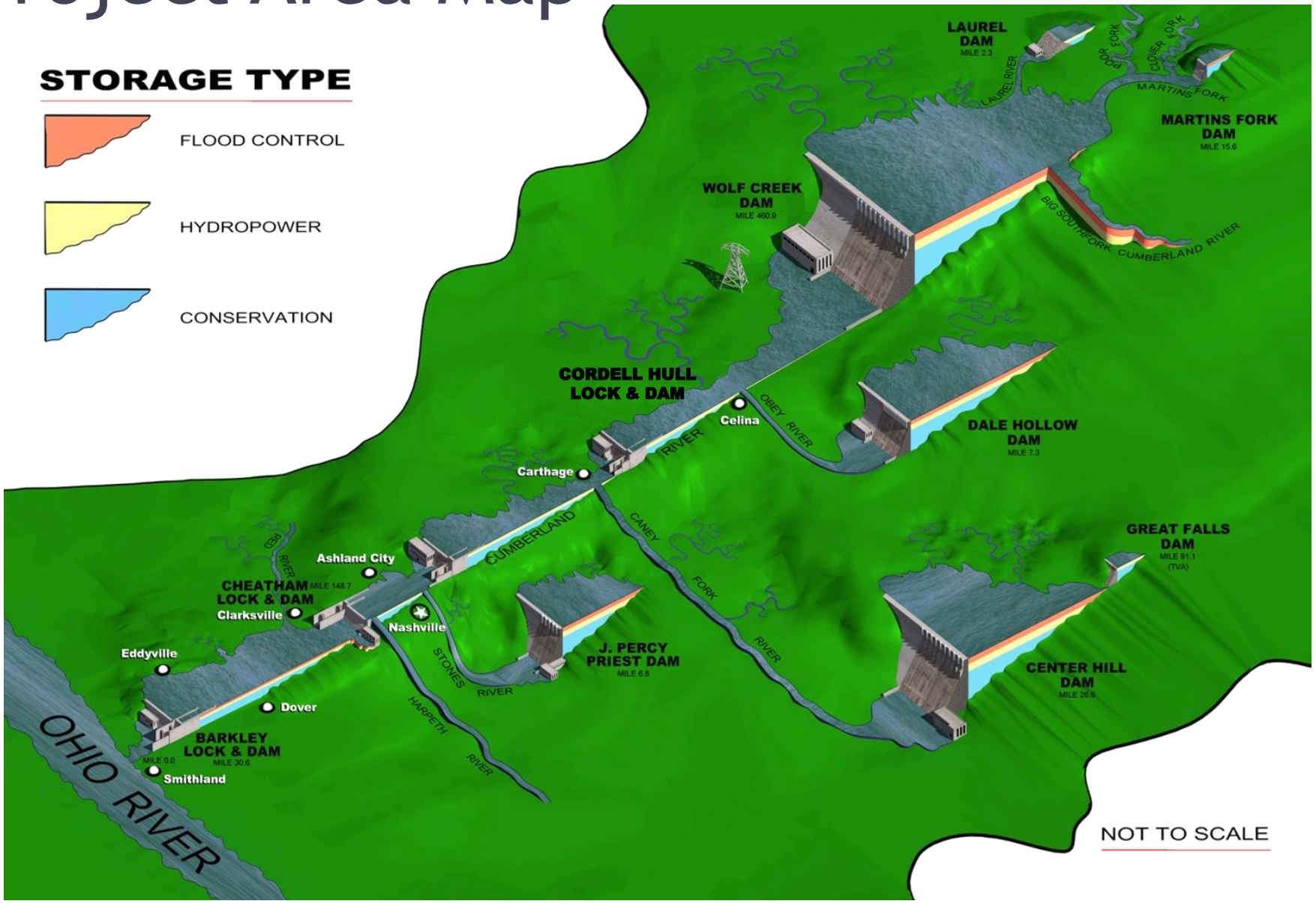
- ***Overarching Goal:*** *Apply state-of-the-art mathematical and modeling approaches for model reduction and multi-objective optimization to multi-system hydropower operations that maximize energy production while minimizing environmental impacts.*

- Develop a DSS for optimal hydropower generation subject to environmental constraints for a multiple reservoir system comprised by a well-modeled section of the Cumberland River, namely the Cordell Hull and Old Hickory reservoirs.

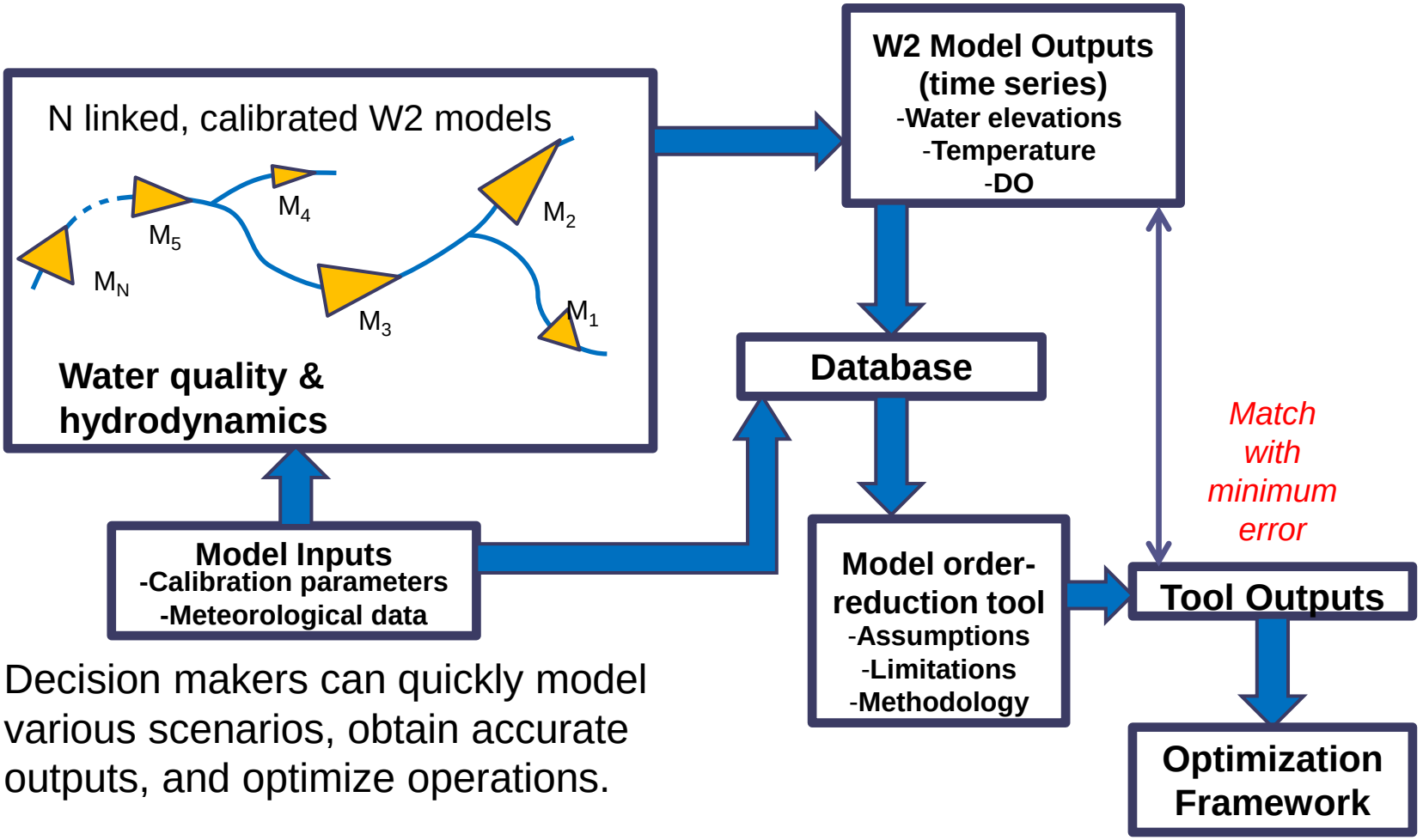
Overview of Approach

- Perform model order reduction through surrogate modeling methods to reduce the cost of simulating the system
- Effectively link two reservoir systems and simultaneously couple with control optimization under various constraints determined by stakeholders, including:
  - Balance of basin-wide hydrologic inflows and outflows.
  - Maintenance of water quality, to include dissolved oxygen and temperature, as close to optimal conditions as possible.
  - Maintenance of required navigation depths
  - Minimization of downstream water elevations during flood events.
  - Allocation of water releases in summer and early fall to provide supplemental flows for water quality and cooling water for power generation.
- *No known prior systems have employed such techniques to maximize hydropower operations and minimize environmental impacts while maintaining high fidelity hydrodynamic and water quality information for effective prediction of multi-reservoir system influences.*

Project Area Map



Methodology



- Decision makers can quickly model various scenarios, obtain accurate outputs, and optimize operations.
- Calibrated reservoir models can be used to “train” the new model once.

Results to Date

- Updated (to version 3.6) CE-QUAL-W2 models for Cordell Hull and Old Hickory reservoirs, and calibrated for DO and temperature
  - → Completed 1/27/12
- Developed elevation, temperature, and DO surrogate models for 2 reservoirs
  - → Cordell Hull completed 6/30/13
  - → Old Hickory completed 7/15/13
- Developed optimization model constraints for 2 reservoirs
  - → Completed 12/15/13

CE-QUAL-W2 Model Calibration for Old Hickory Reservoir

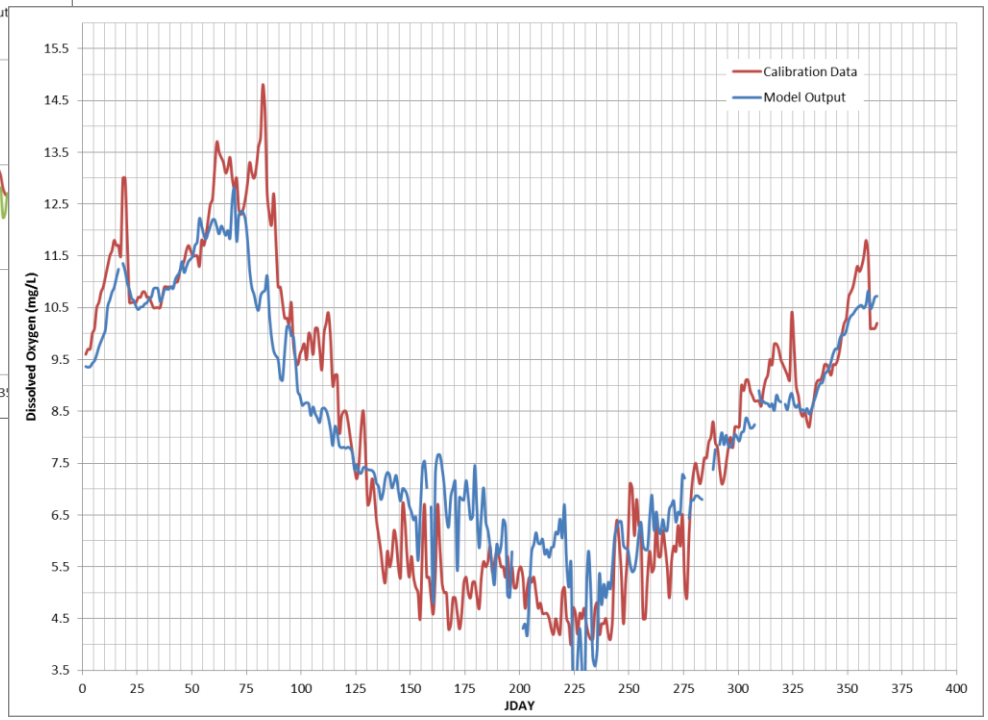
Temperature Calibration

Average Difference

Temperature = 0.87°C

Dissolved Oxygen = 0.84 mg/L

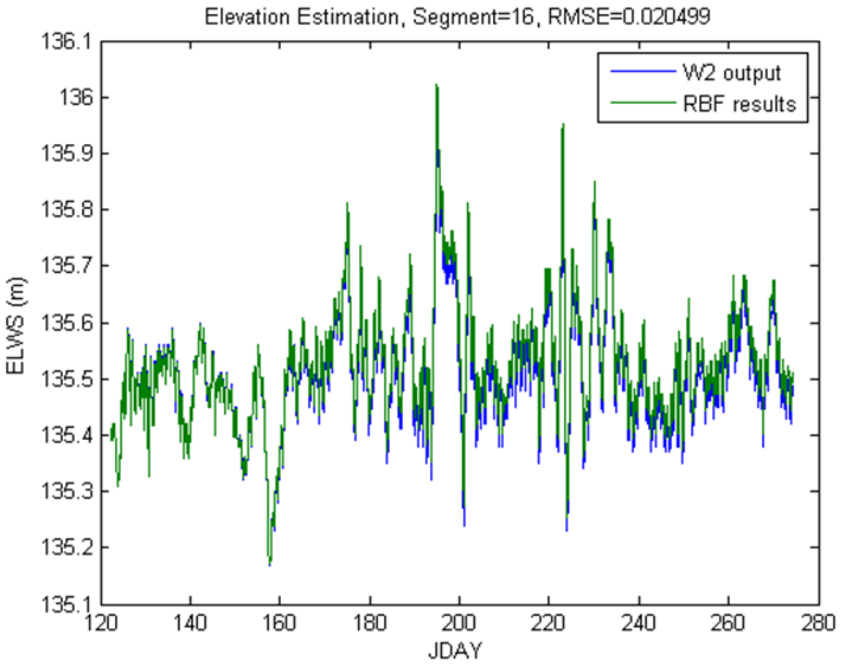
Water Balance = 0.04m



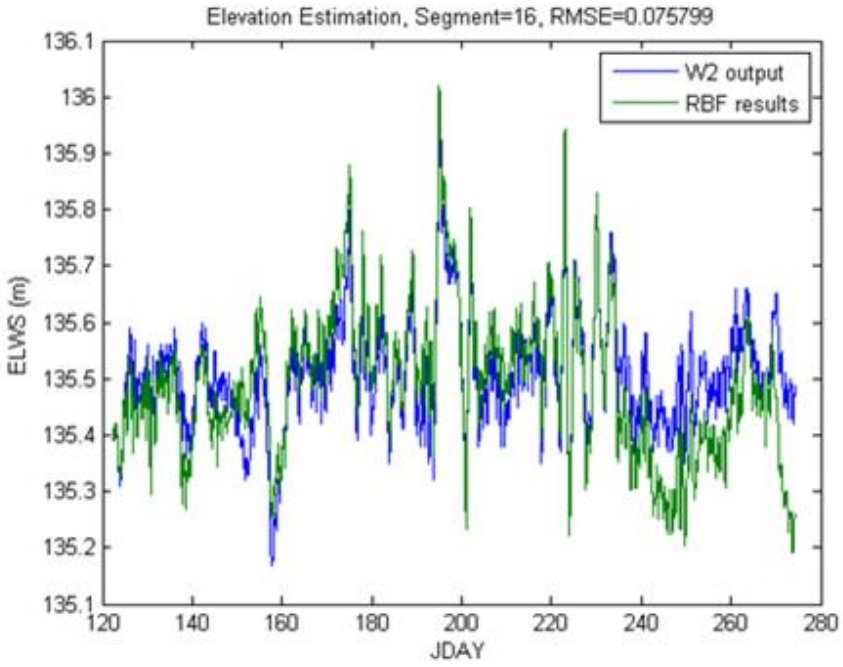
Dissolved Oxygen Calibration

Surrogate Model Development for Old Hickory: Elevation Results

Surrogate Model

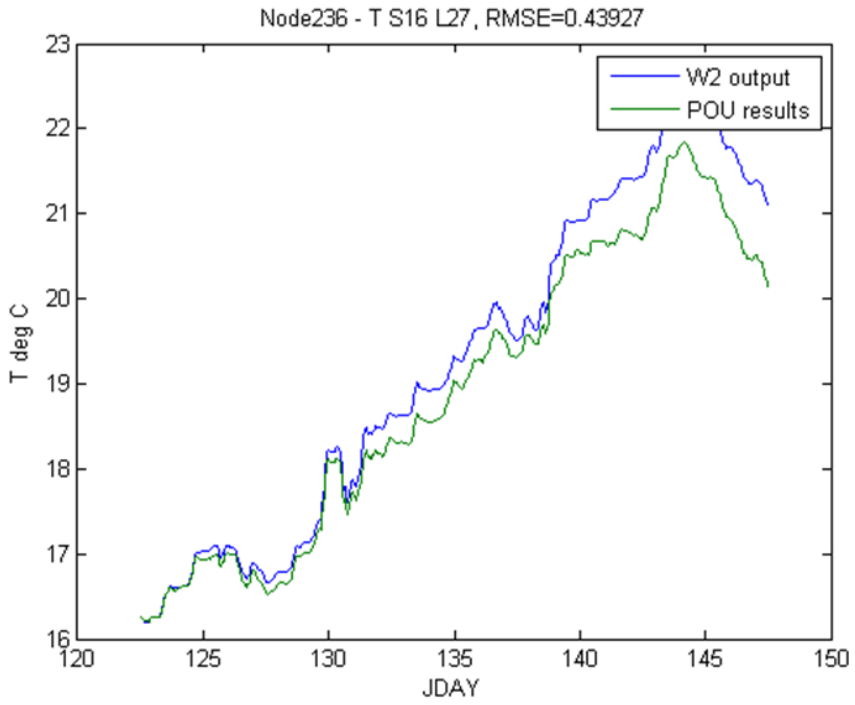


Reduced Surrogate Model

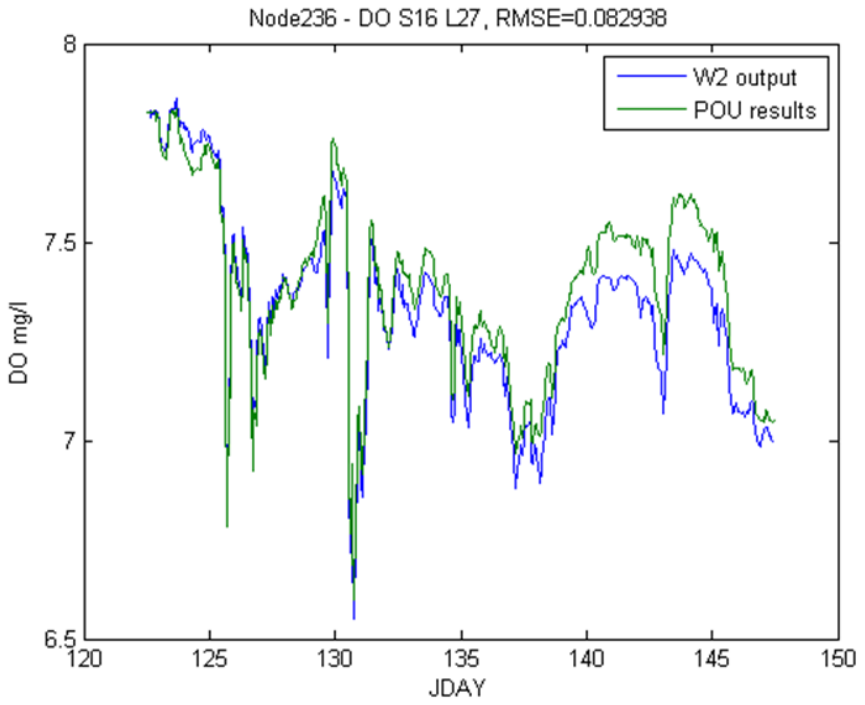


Surrogate Model Development for Old Hickory: Temperature & DO Results

Temperature at Turbine Discharge



Dissolved Oxygen at Turbine Discharge



Deliverables & Management Schedule

- Apply optimization techniques for both centralized (global) and localized (reservoir specific) control strategies
- Validate reduced model systems for Cordell Hull and Old Hickory reservoirs through comparison of model results with seconds set of simulation data
- Validate reduced model system through comparison of model results with actual linking of two reservoir CE-QUAL-W2 models as well as actual measured system results
- Provide validated optimizable, prototype system to U.S. Army Corps of Engineers Nashville District Water Management and Hydropower Operations personnel

Questions?