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

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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.
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

Average Difference

Temperature = 0.87°C
Dissolved Oxygen = 0.84 mg/L
Water Balance = 0.04 m

Temperature Calibration

Dissolved Oxygen Calibration
Surrogate Model Development for Old Hickory: Elevation Results

**Surrogate Model**

![Surrogate Model Graph]

**Reduced Surrogate Model**

![Reduced Surrogate Model Graph]
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?