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Seasonal-Scale Optimization of Conventional Hydropower Operations in Blue Mesa Reservoir

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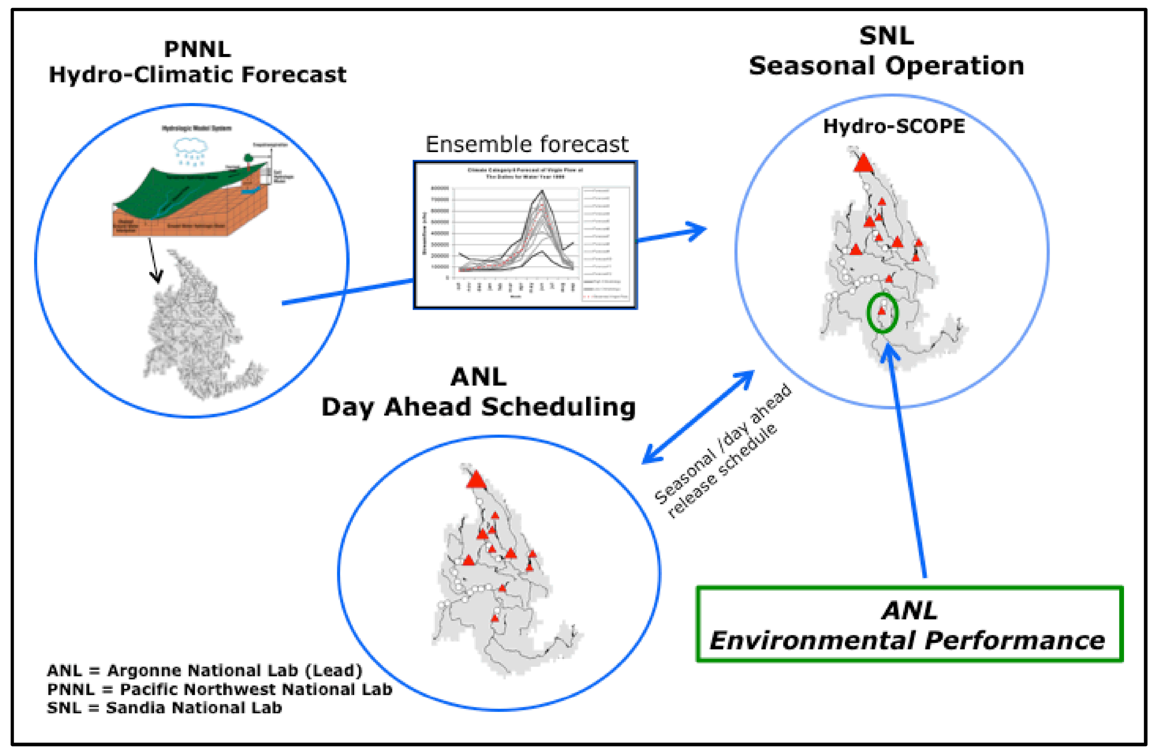
Water Use Optimization

This project is part of a multi-laboratory project funded by Department of Energy, Energy Efficiency & Renewable Energy, Water Power Program. The project includes five sub-projects:

- Hydrologic forecasting (Pacific Northwest National Laboratory)
- Unit and plant efficiency (Oak Ridge National Laboratory)
- Environmental performance (Argonne National Laboratory)
- Day-ahead and real-time optimization (Argonne National Laboratory)
- Seasonal, systems-scale optimization (Sandia National Laboratories)

Goal: To create tools that can help to manage hydropower operations to increase efficiency while considering environmental and other water resource issues.



Demonstration Site: Upper Colorado River Basin

We plan to apply this tool set to a 6-reservoir system in the Upper Colorado Basin. We are beginning with the Aspinall Unit, which is operated by the Bureau of Reclamation and consists of a series of three reservoirs:

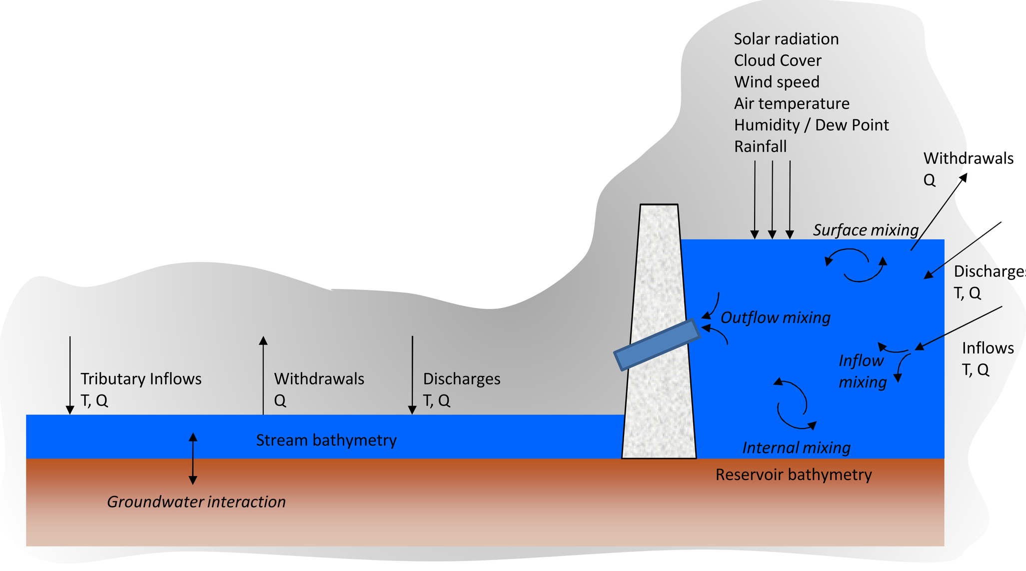
Blue Mesa
↓
Morrow Point
↓
Crystal

The work presented here considers the first reservoir in the Aspinall Unit, Blue Mesa, using historical input data and a four month time horizon.

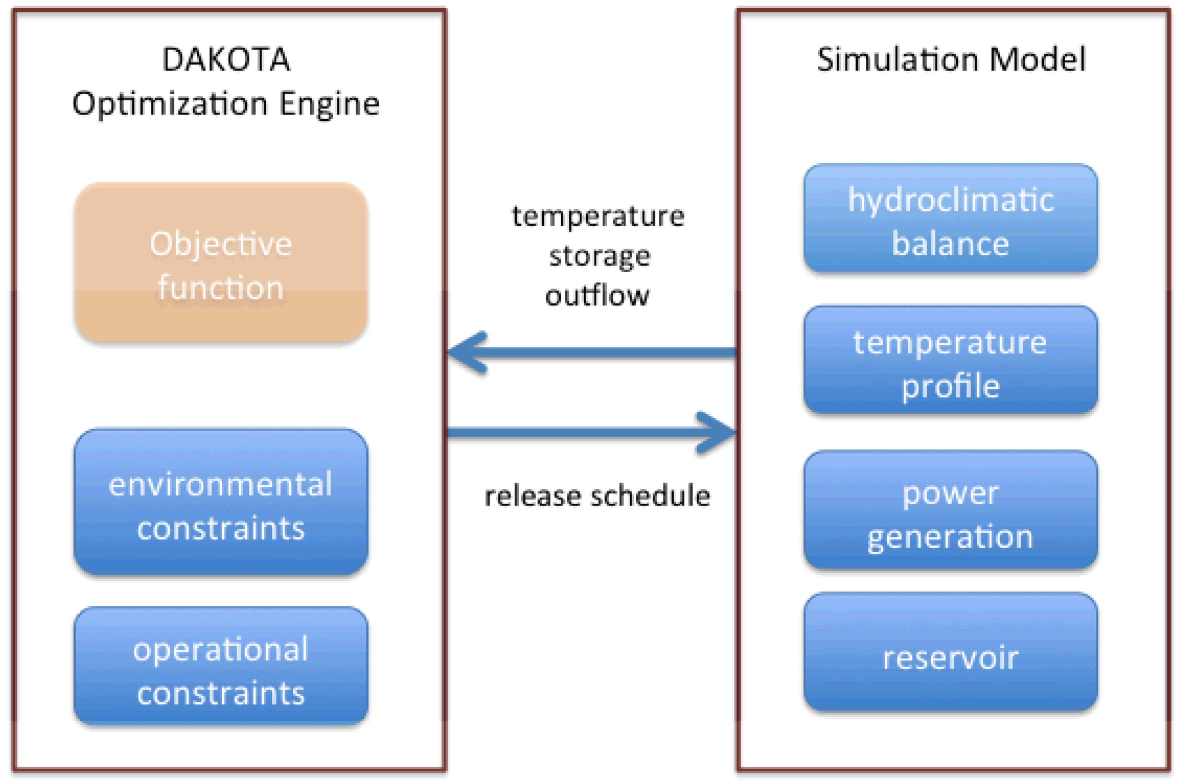
We are using this case to explore optimization strategies and find ways to understand and interpret the results of different operational approaches. This application of this tool set will eventually be expanded to include the entire Upper Colorado River System.

Hydro-SCOPE

The goal of Sandia's sub-project is to create a tool for exploring alternative management strategies over a long time scale, considering the different water uses in the system of interest. The seasonal-scale, systems-scale optimization tool being developed for this purpose is called Hydro-SCOPE (Hydropower Seasonal Concurrent Optimization for Power and the Environment). It is an integrated simulation and optimization tool that can be adapted to any hydrologic system. The simulation portion of Hydro-SCOPE consists of a one-dimensional reservoir model that is coupled with a river routing model. It simulates hydrology, reservoir and river temperatures, power production and revenue, and downstream river conditions based on inflows, meteorological conditions, and power and water demand.



An optimization engine run by Sandia's open source DAKOTA (Design Analysis Kit for Optimization and Terascale Applications) software wraps around the simulation model. Objectives and constraints are defined, and Dakota chooses a release schedule to feed to the simulation model. The model determines hydrologic, water quality, and other conditions created by that release schedule and sends results back to Dakota. This loop runs many times until Dakota finds the (set of) optimal release schedules. We use this process to determine optimal daily water releases for the next week, considering simulation results through season or year.



To ensure flexibility and make Hydro-SCOPE as useful as possible, we are incorporating the ability to use both single- and multi-objective optimization strategies. Multi-objective optimization is useful for understanding trade-offs between objectives, but has longer calculation times. Single-objective optimization is quicker, and objectives can be formulated using insight gained from multi-objective optimization. Single-objective optimization also has results that are easier too interpret than those of multi-objective optimization, and those results can be fed directly to Argonne National Laboratory's day-ahead scheduling tool.

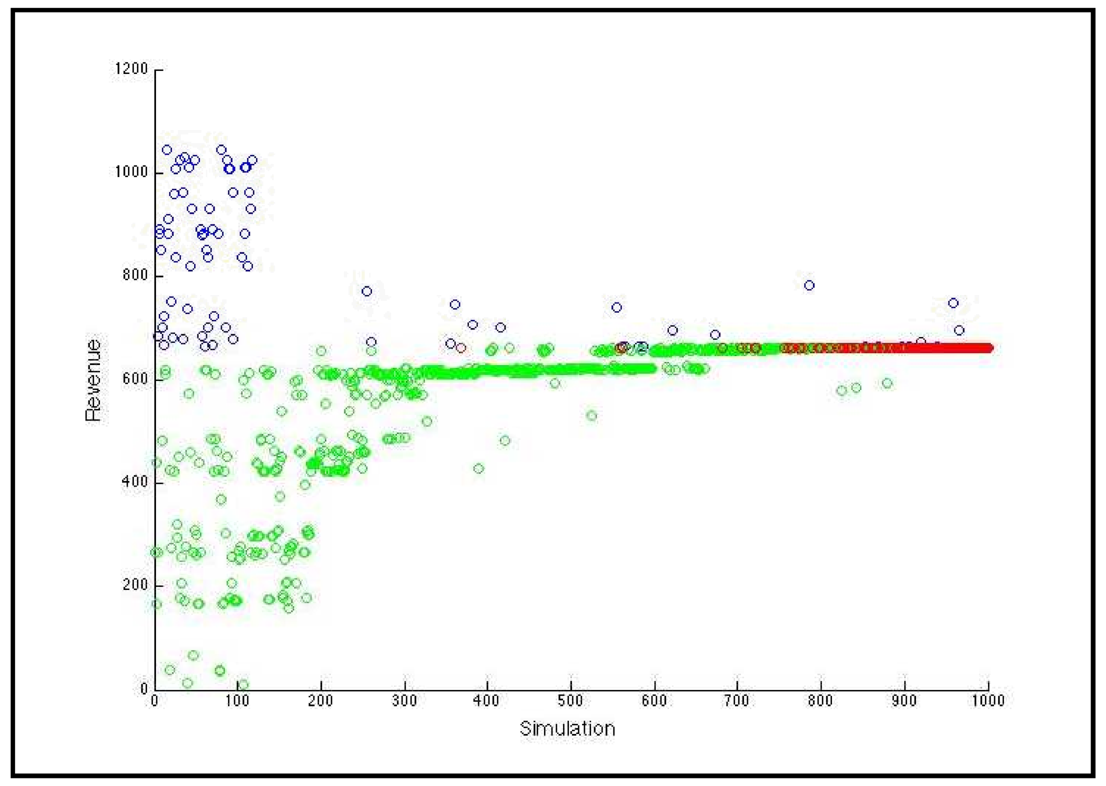
Optimization Strategy

The optimization framework for this project is flexible, with capability for both single-objective and multi-objective optimization using various algorithmic methods. The goal of this optimization is to find long-term operational schedules or strategies that can be used to meet the objectives and constraints specific to the reservoir system being modeled. Considerations are likely to include power generation, revenue, environmental concerns, long-term water allocation issues, and the trade-offs between each of these. A potential scheme for the Upper Colorado system might include:

Blue Mesa Reservoir	
Objectives	Maximize revenue from power generation (Environmental objective is incorporated downstream at Crystal)
Constraints	Elevation at end of time horizon must be at least equal to historical
Aspinall Unit (Blue Mesa, Morrow Point, and Crystal)	
Objectives	Maximize revenue from power generation Maximize environmental indicator (using strategy being developed at Argonne National Laboratory)
Constraints	Minimum and maximum flows below each reservoir Maximum ramping rates downstream of Crystal Base flow downstream of the system
Upper Colorado River System (Aspinall Unit plus Flaming Gorge, Navajo, and Glen Canyon)	
Objectives	Maximize revenue from power generation Maximize environmental indicator (using strategy being developed at Argonne National Laboratory) Maximize satisfaction of water use needs in the basin
Constraints	Minimum and maximum flows below each reservoir and at other key sampling points Maximum ramping rates at key environmental points Comply with operational restrictions Rule curve restrictions for flood control and water use

Initial Results

We are beginning this analysis by optimizing operations at Blue Mesa Reservoir, the most upstream reservoir in the Aspinall Unit. The single objective is to maximize revenue from power generation, and the single hard constraint is that the reservoir elevation at the end of the time horizon must equal the historical elevation. We use a genetic algorithm, and run the analysis for 118 days beginning in June, using historical data (forecast data will be incorporated later in the project). The figure below shows initial results (blue dots do not meet the constraint, red dots are optimal).



National Nuclear Security Administration

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