Prescriptive Reservoir Modeling and the ROPE

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What is our goal?

- Assist MVP in Upper Miss ROPE Study
  - New operation policy for each reservoir and system
  - Shared-vision approach
  - Optimization and simulation
- Technology Transfer
Study Area

- Central Northern Minnesota
- 6 Primary Reservoirs
- Extends from Lake Bemidji to St. Paul
The function of a reservoir system is to redistribute the natural occurrence of water in time and space.

- **Reservoirs** accumulate and release water to modify the distribution in time
  - *flood storage, water supply storage*

- **Conveyance** modifies the distribution in space
  - *rivers, reservoirs, canals, pipelines, diversions*
Redistribution of Water

- Redistribution is generally a series of decisions on how to operate water control facilities.
- Based on multiple objectives of system
Balancing Multiple Objectives

- Navigation
- Flood Control
- Hydropower
- Fish & Wildlife
- Irrigation
- Municipal Supply
- Recreation

Some of these objectives are **Complimentary**, and some are in **Conflict**.
Two Approaches to Analysis

- Simulation and Optimization modeling
  - A simulation model makes decisions that follow operating rules specified by the user.
  - An optimization model makes decisions to maximize the benefits associated with meeting the objectives of a reservoir system. (Prescriptive)
A simulation model answers “what if” questions

- The model “operates” the water system for a historical period given a set of operating rules.
- Rules can be added, changed or removed in response to “what if” questions, and the model shows how the system would have operated with those changes.
- Many “what if” questions can be asked and answered to explore ideas and suggestions.
Tasks of an Optimization Model

1) Identify the “optimal” solution

Example:

What do these costs represent?
2) Evaluate and quantify the tradeoffs between various objectives
   • ie, how much does it cost one objective if the benefit to another objective is increased?

3) Seek operations (and operating rules) that achieve a reasonable balance between those objectives
   • simulation aids in this task
Optimization and Simulation models play a complimentary role in developing operating rules.

- Optimization models make decisions based on the benefit achieved for system objectives over time, but those decisions are difficult to make in real-time.
- Operating rules that approach those optimal operations can be developed for use in real-time.
- Simulation models demonstrate the outcome of proposed rules, and allow small adjustments to target the outcome achieved by the optimization.
The Bottom Line -- Symbiosis

- Simulation provides a test of operating rules inferred from “optimal” operation.
- Optimization provides a target to aim for with the simulation.
- Optimization also quantifies the expense of one objective as a cost to other objectives (i.e., a trade-off), which is then demonstrated with the simulation.
Data Requirements

- Physical Reservoir Characteristics
  - storage and outlet capacities
  - elevation/capacity/surface area (if consider evaporation)

- Channel or Conveyance Characteristics
  - channel or conduit capacities
  - losses

- Streamflow Time-Series
  - reservoir inflow, incremental local flow, demand

- Unit penalties on streamflow and storage
Reservoir System as a Network

Use flow network to represent a WATER SYSTEM.
Reservoir System as a Network

- Time period t
- Storage link
- Time period t+1
In this problem, the decisions are
(1) whether to divert water (or how much),
and
(2) how much to store or release from a reservoir in each time period
Maximizing Objectives

We want to optimize the objectives of the water system, whatever those might be.

For example,

• for flood control, the objective is to minimize damage due to flooding
• for water supply, the objective is to maximize yield or minimize shortage to existing demand
Articulating Objectives (Penalties)

- We can articulate our values, priorities, and objectives using penalties or benefits.
- Unit-penalties are applied for occurrences we consider detrimental, such as high flow or very high reservoir storage.
- Negative unit-penalties are applied to positive occurrences, such as streamflow needed for navigation or irrigation.
Examples of Penalty Curves

- **flood control**
- **irrigation**
- **hydropower**
- **navigation**
Combined Penalty Curves

The composite penalty curve is applied in each time period for a single location.
Articulating Objectives (Penalties)

- Values can be monetarily based
  - flood damage, price of water, hydropower
- Or, when value cannot be properly stated in dollars, non-monetary based
  - instream use, such as wildlife preservation
- We often set non-monetary penalties to encourage specific operations or an operating preference
  - referred to as “persuasion penalties”
Comparing Economic to Non-Monetary Objectives

Dollar value of other objectives

Non-monetary objective

max value of non-monetary objective

trade-off curve

increment

increment

max value of non-monetary objective
Prioritizing Objectives?

- If one objective is more important than another, can give it a higher priority in the optimization it would be satisfied first.
- Can vary priorities to determine the system’s sensitivity to these assumptions.
Application

- Run model for each objective individually
  - ensure results are consistent with goals
  - provide upper bound on benefits

- Run model for all objectives
  - using composite penalty functions
  - using various weightings of the objectives

- Infer operating rules (look for patterns in output)

- Simulate operating rules to measure performance

then repeat…
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