Prescriptive Reservoir Modeling and the ROPE

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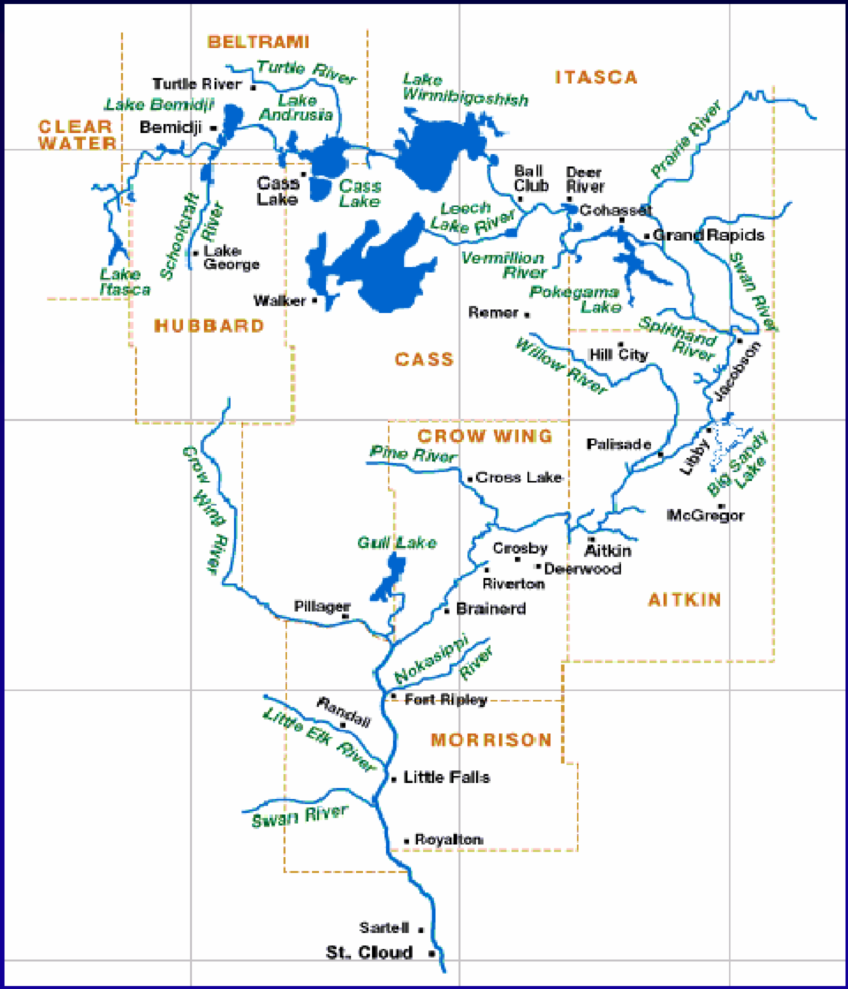
What is our goal?

- 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



Reservoir System Modeling

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 <u>Complimentary</u>, and some are in <u>Conflict.</u>

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)

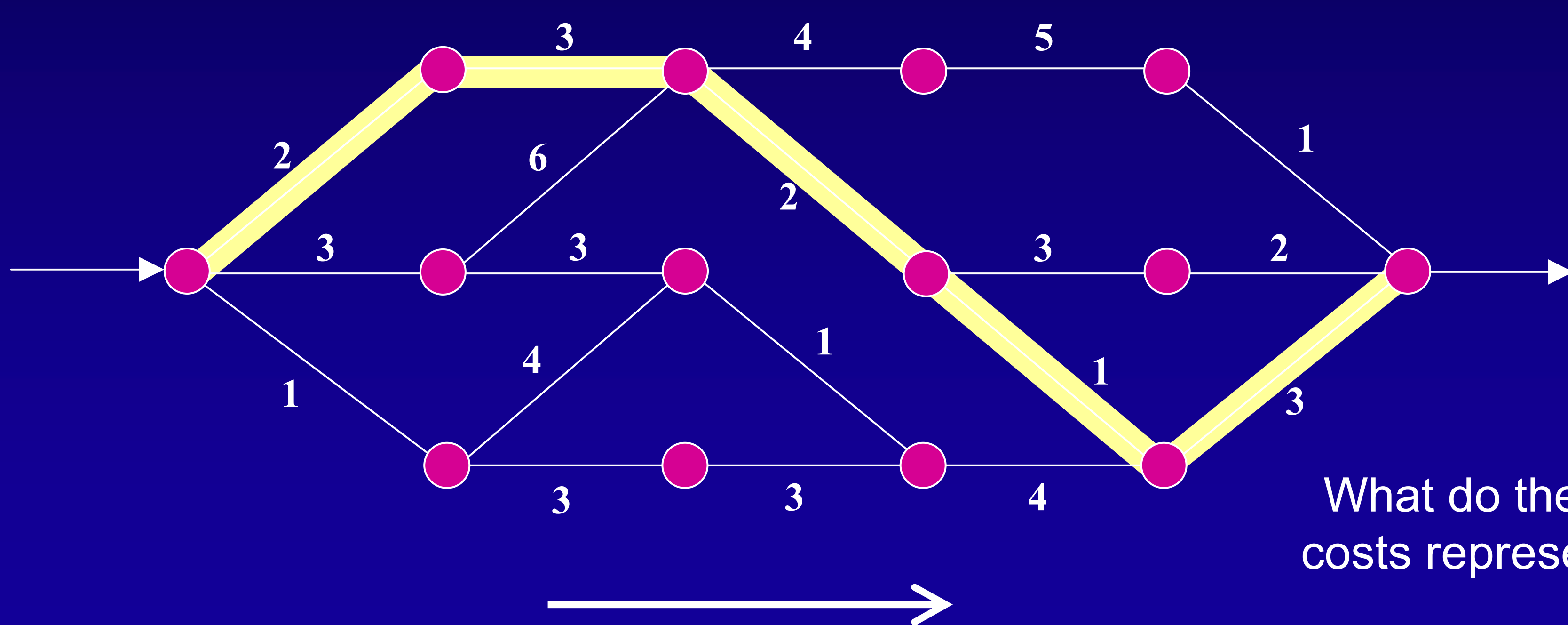
Task of a Simulation Model

- 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 <u>would have</u> 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?

Tasks of an Optimization Model

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

Use of Optimization AND Simulation

- 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.

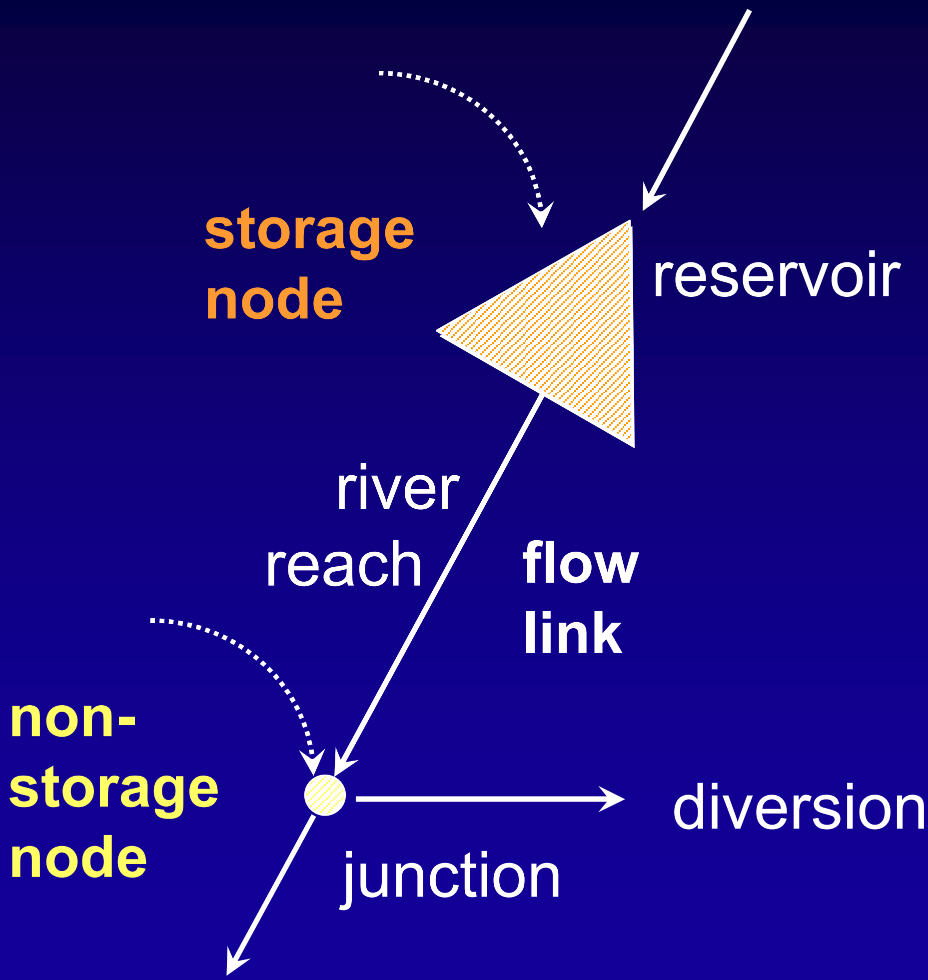
The Bottom Line -- Symbiosis

- 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 (ie, a trade-off), which is then demonstrated with the simulation

Data Requirements

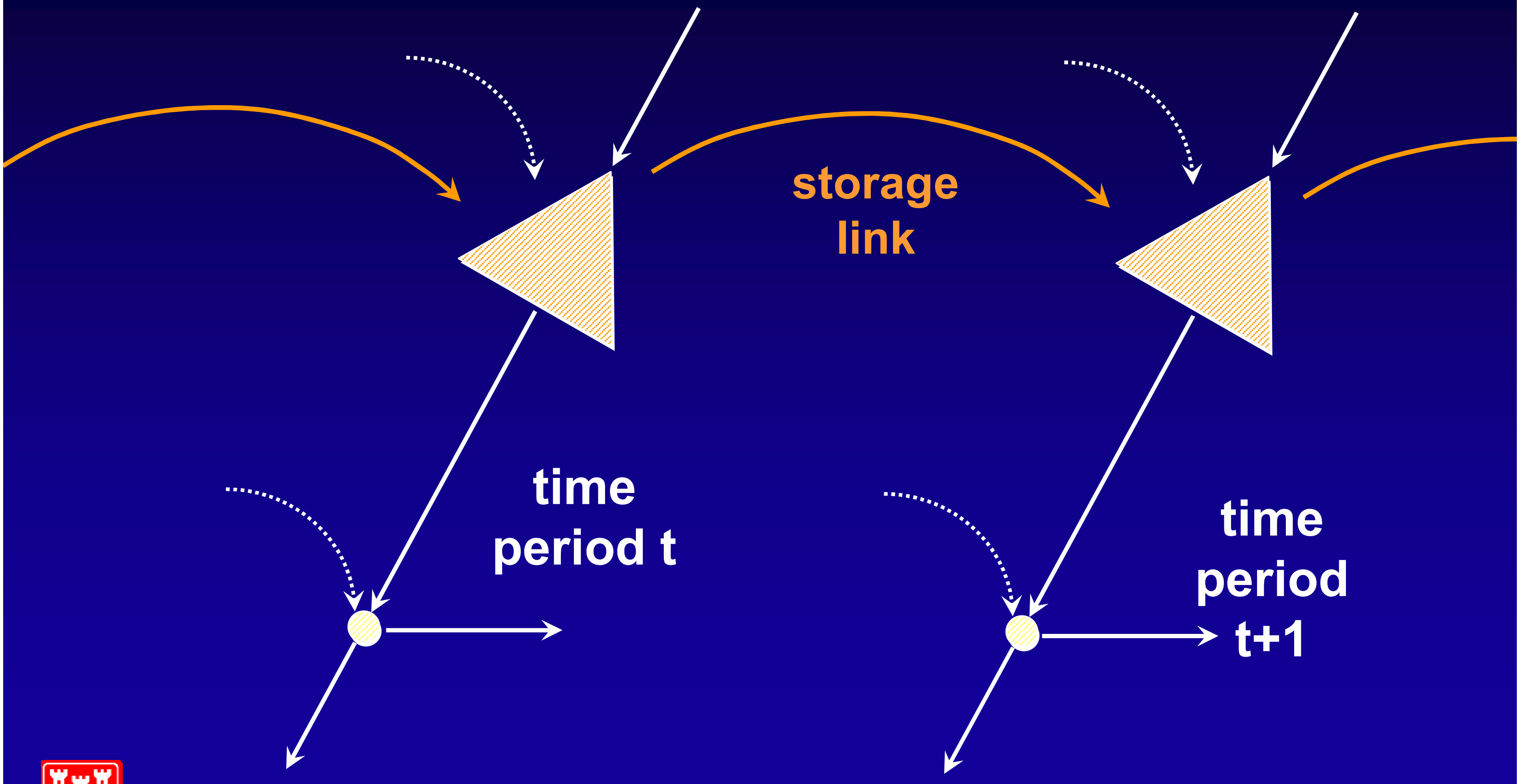
- Physical Reservoir Characteristics
  - storage and outlet capacities
  - elevation/capacity/surface area (if consider evaporation)
- Channel or Conveyance Characteristics
  - channel or conduit capacities
  - losses
- Streamflow Time-Series
  - reservoir inflow, incremental local flow, demand
- Unit penalties on streamflow and storage

Reservoir System as a Network



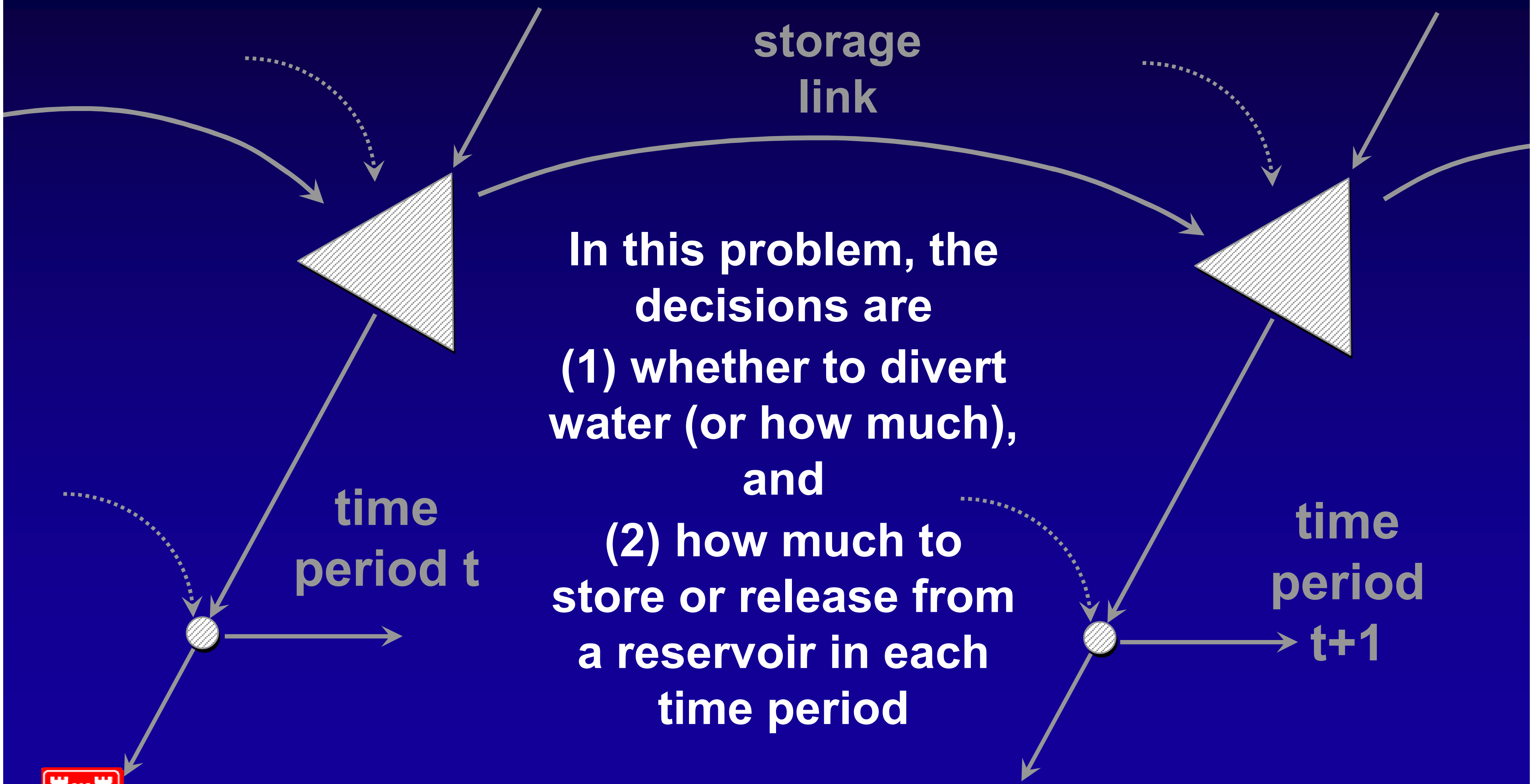
Use flow network to represent a WATER SYSTEM

Reservoir System as a Network



What are the decisions?

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

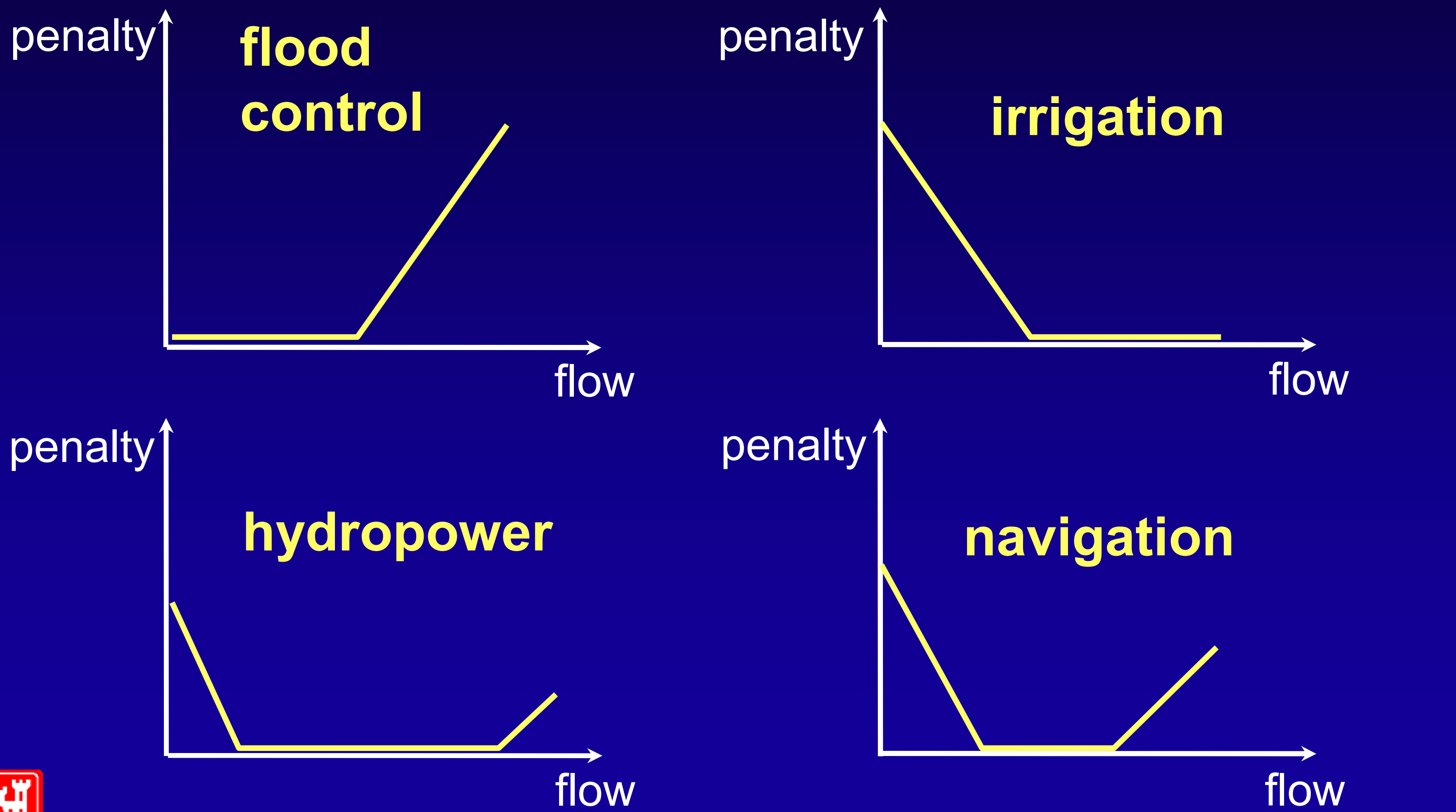
For example,

- 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

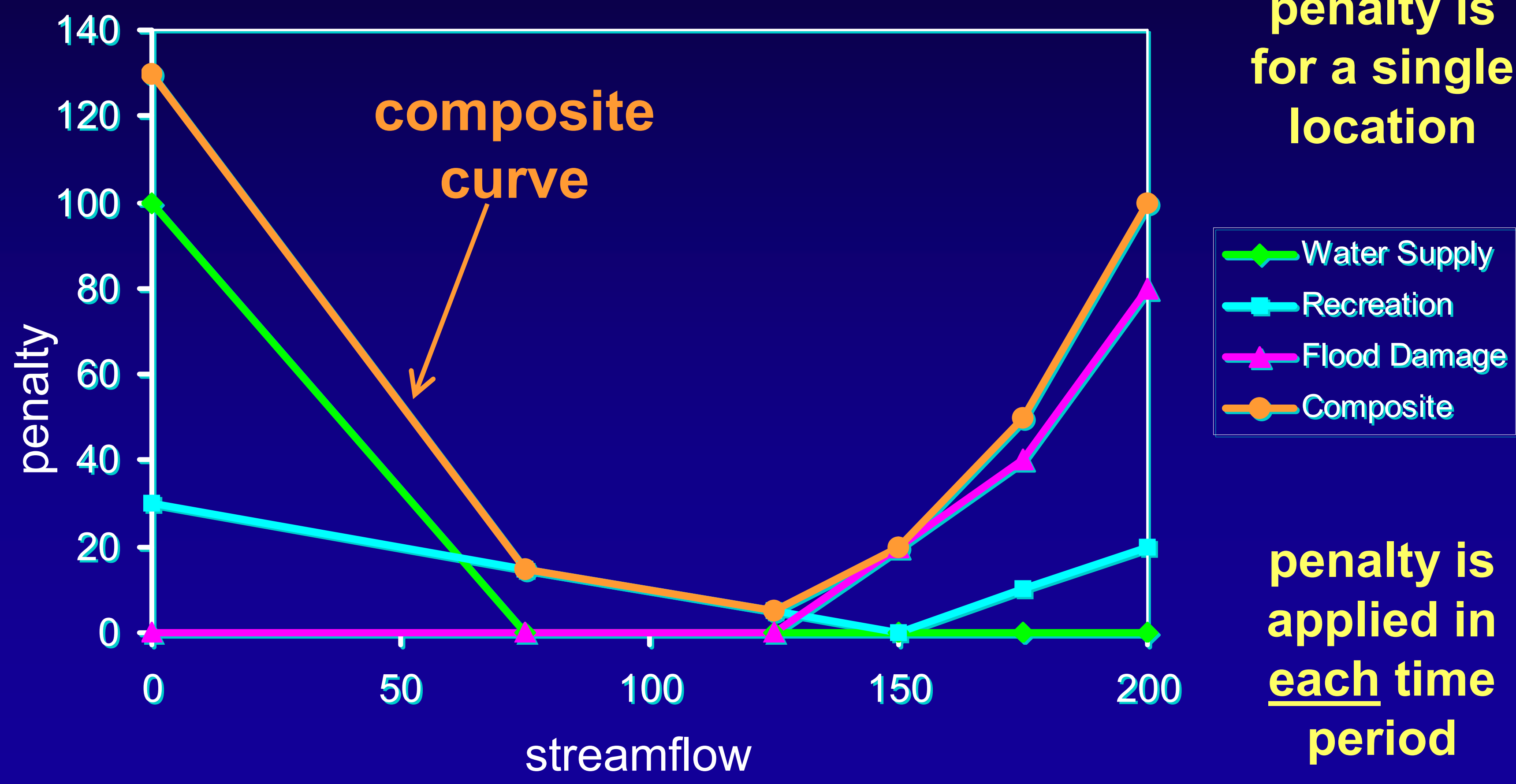
Articulating Objectives (Penalties)

- 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



Combined Penalty Curves



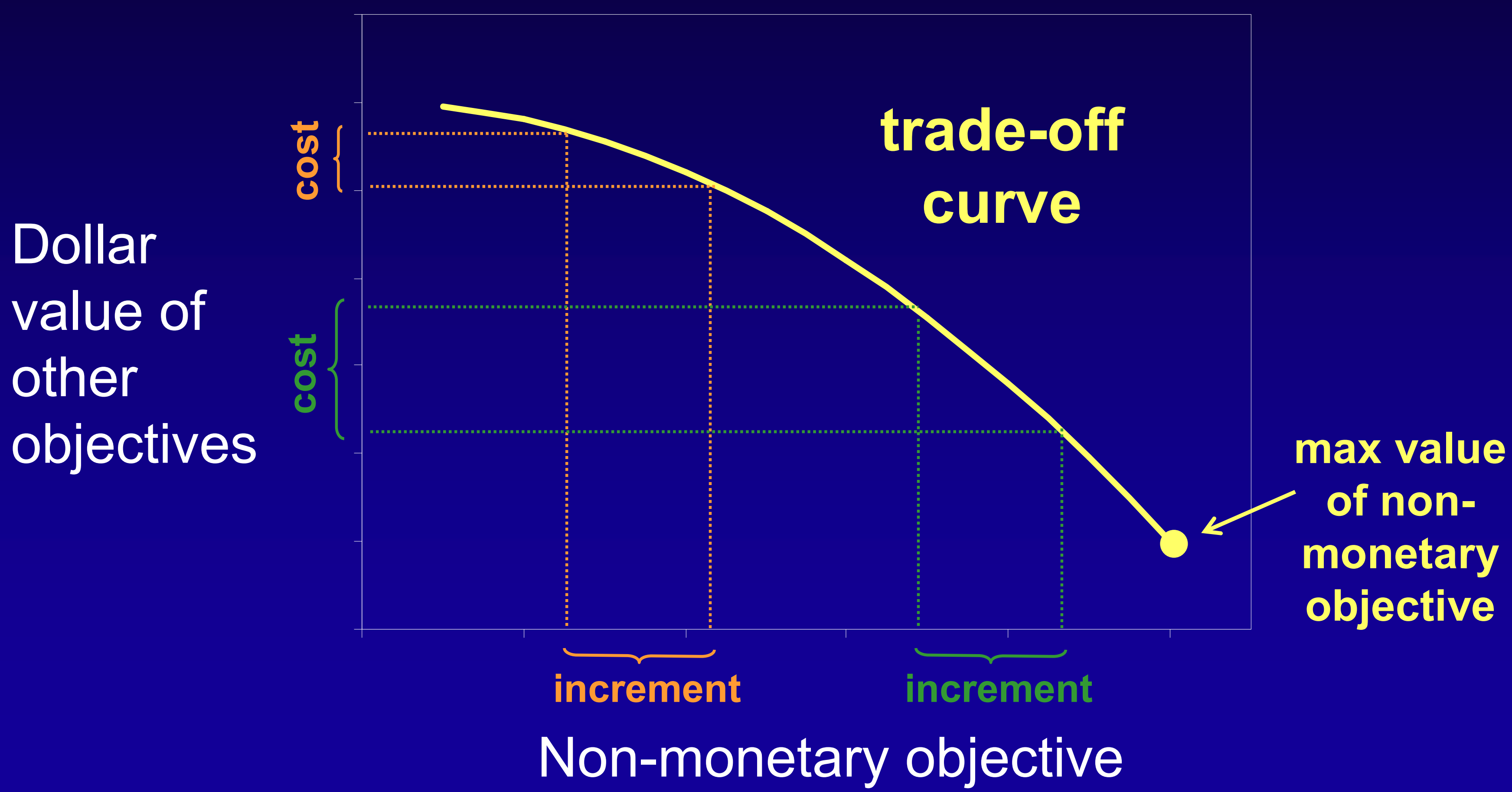
penalty is for a single location

penalty is applied in <u>each</u> time period

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



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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