System dynamics modeling of water-energy-fish-carbon tradeoffs under various dam decision scenarios

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Introduction

Overall objectives

- Apply a systems thinking approach to analyze various dam management practices
- Simulate interactions and synergies among water storage, hydropower generation, fish population, and GHG emissions for both run-of-river and reservoir-based dams using System Dynamics modeling (SDM)
- Search the optimal dam management alternatives by linking the model with the optimization analysis

Dam decision scenarios

- **Retrofitting dams** (e.g., install fish passage systems, add turbine facilities)
- **New dam building**
- **Dam removal**
- **Dam/Impoundment management** (period shut down turbines, impoundment primary used for flood control, recreation, energy generation)

Methodology

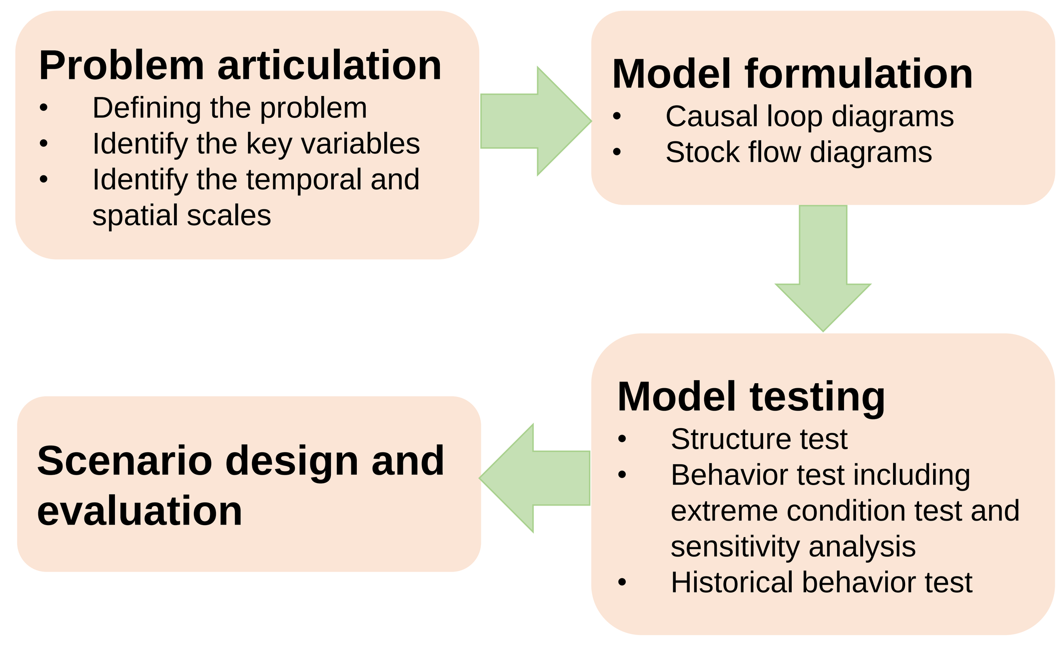
Software

- VensimDSS

System Dynamics Model (SDM)

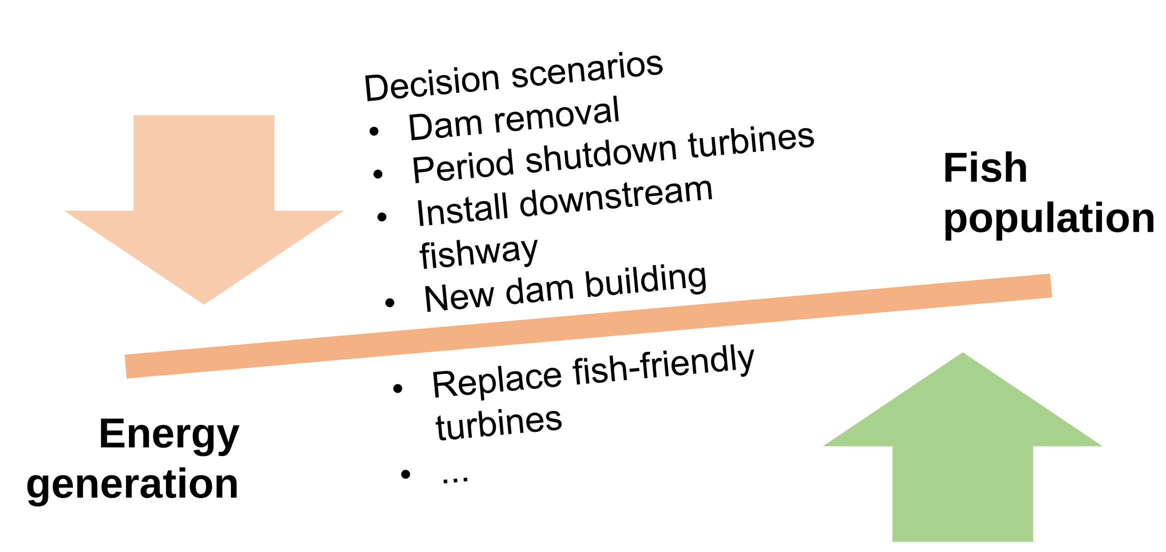
SDM is a modeling and simulation approach to represent the whole problem as a connection between different elements and to model the involved linkages and dependencies

➢ A four-step process to build the model



Optimization analysis

- Conflicted objectives



Data sources

- National inventory of dams, USACE
- Data discover center, UNH
- National Water Information System (NWIS), USGS
- National Hydrography Dataset Plus (NHDPlus), EPA/USGS
- US Energy Information Administration (EIA)
- Peer-reviewed papers
- Dam project reports

Water-energy-fish tradeoffs

Study design:

Short-term (few months) simulation

[SDM & Optimization analysis]

Purposes
- Test the effectiveness of commonly used methods to improve the chances that Alewife reach the ocean and their impacts on energy generation
- Search for the optimal dam management alternatives by linking SDM to optimization analysis

Long-term (50 years) simulation

[Time series analysis]

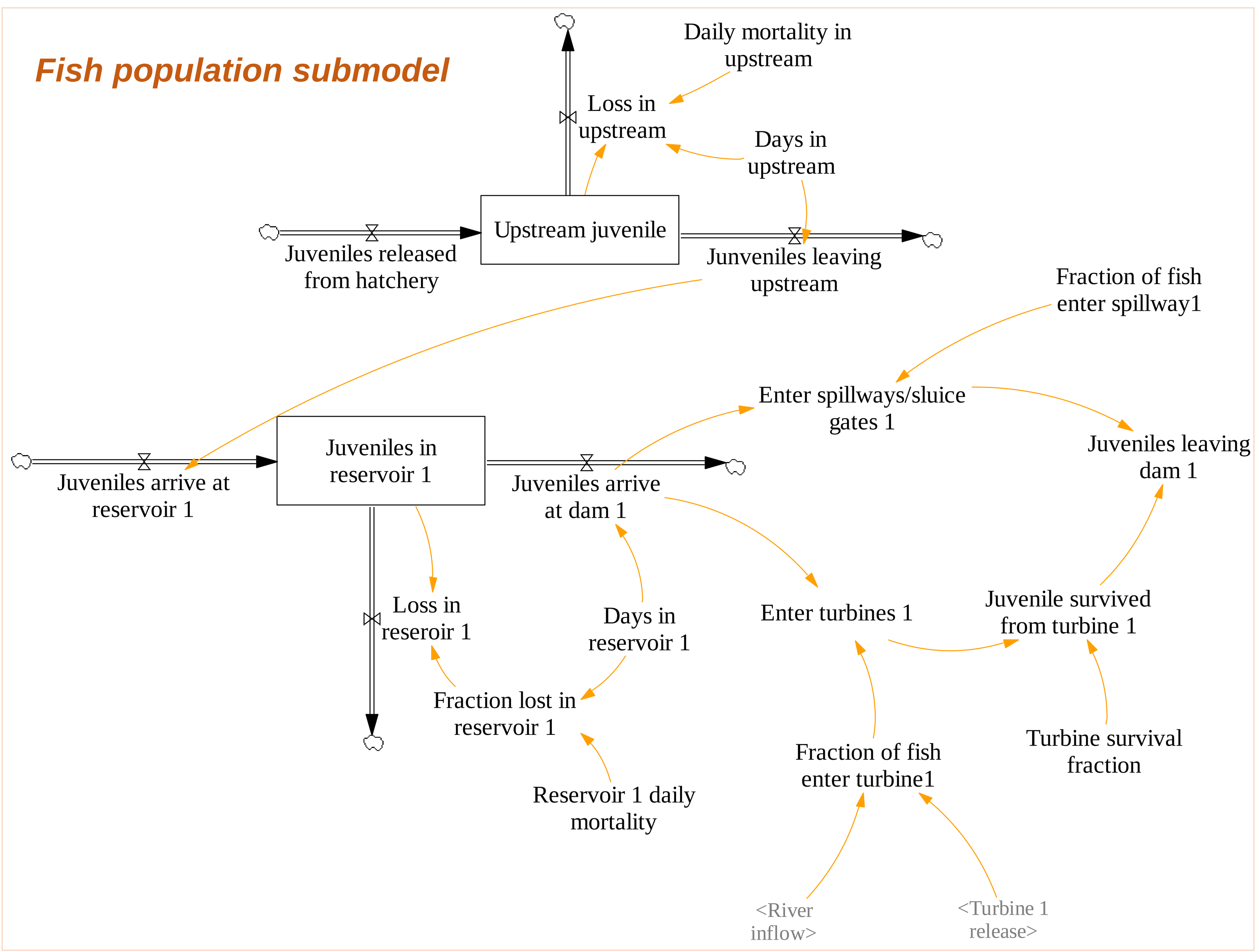
Purposes
- Simulate the performances of the long-term fish population under situations that apply the optimal dam management alternatives or not
- Analyze the impact of dam development and habitat fragmentation on fish population

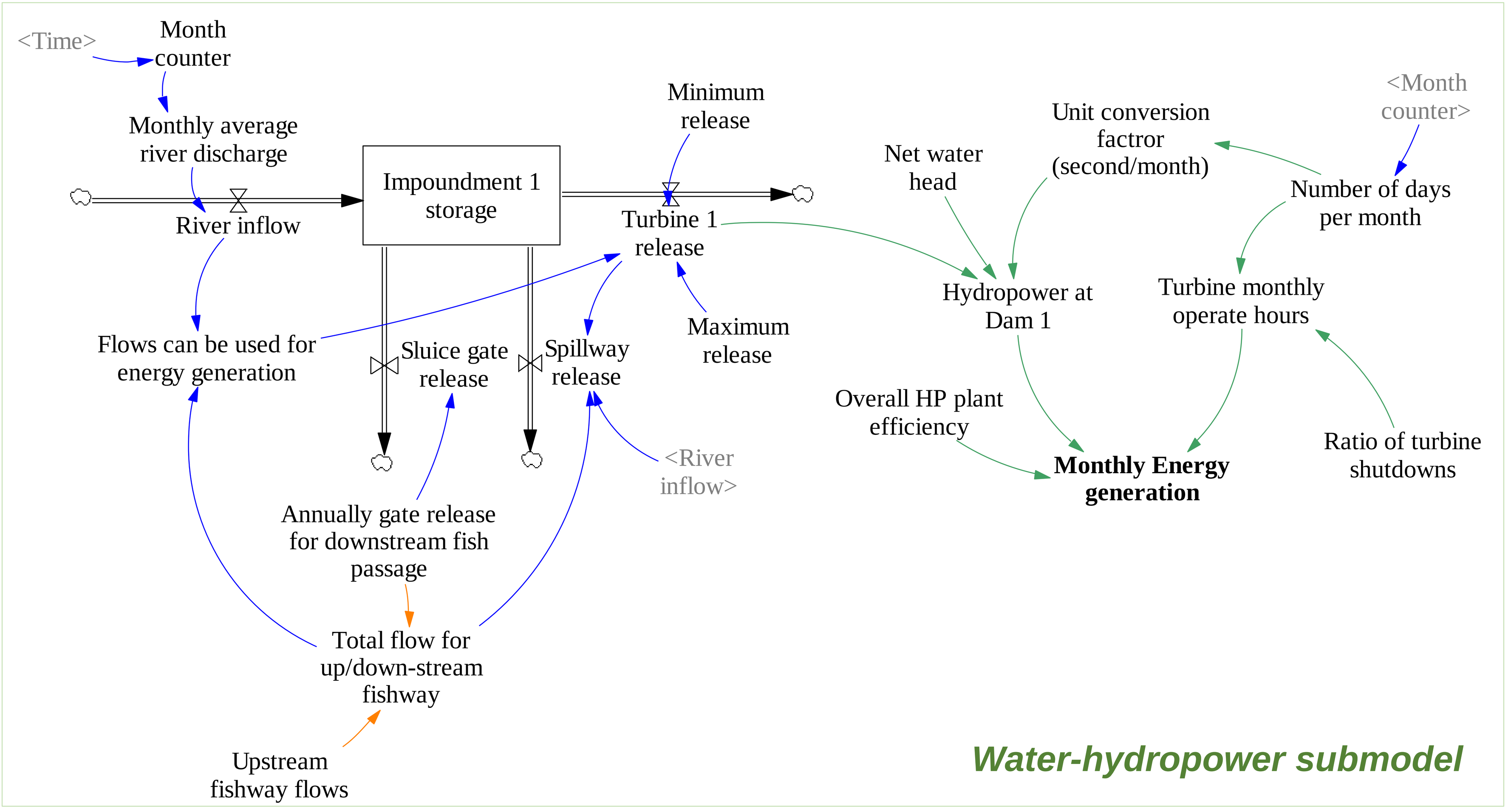
Case study

- Five dams located in the main stem of Penobscot River, Maine
- All dams are run-of-river dams with impoundments behind

Scenario design and evaluation

1) Turbine
   - Energy and fish conflictions may happen when increase (e.g., add turbine facilities in dams) or decrease turbine release (e.g., period shutdown turbines). In this case, more fish will potentially enter turbine and reduce fish population return to the river
2) Dam retrofitting
   - Potential methods to mitigate the conflictions (e.g., install narrow-spaced bar racks and fish friendly turbines)
3) Dam removal or new dam building
   - Extreme conditions for both fish and energy generation





Next steps

- Build the water-energy-fish model for **reservoir-based dams**
- Add the element of **GHG emissions** into the water-energy-fish model and test the possibility of **combining life cycle assessment and SDM** to analyze GHG emissions from dam structure and reservoir during the model's time scale
- Add related economic and social values to the water-energy-fish-carbon model
- Build a **user friendly interface** and study environmental and socioeconomic tradeoffs for dams in the watershed scale

Acknowledgement

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