Session C1 - Developing an optimization model for reservoir operation on the Connecticut River explicitly including fish flows

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Developing an Optimization Model for Reservoir Operation on the Connecticut River Explicitly Incorporating Fishflows

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Presentation Overview

• Introduction and Overall Study Goals
• Convening the Stakeholder Based Process
• Developing the decision support tools
• Incorporating Flexible Targets for Fish and other Objectives
• Examples of Results
Study Goal

Create a basin-wide decision support tool that allows water managers and other key stakeholders to evaluate environmental and economic outcomes based on various management scenarios.

This goal is being achieved with:

- careful evaluation of current operations,
- interactions with stakeholders, and
- the generation of new operational alternatives that improve overall system performance.
Connecticut River

- Connecticut River
  - Connecticut Lake, NH to the Long Island Sound
  - 11,000 mi²
  - >410 miles long
  - regulated by >70 large dams, 14 USACE
  - 44 major tributaries
  - 3.2 million people
- Once inaccurately called the “most highly regulated sewer in America”
Study History

• TNC has 50 years of involvement CT River
• TNC has purchased over 250,000 acres
• 2004 TNC convened stakeholders and identified major issues:
  • Biodiversity
  • Threats
  • Strategies
• TNC and the USACE hired the Consensus Building Institute (CBI) to conduct a stakeholder engagement process in 2008
### Desired Outputs for Connecticut River Ecosystem Flow Strategy Action Plan (CBI)

<table>
<thead>
<tr>
<th>Output 1</th>
<th>Evaluate operational changes needed to produce measurable environmental benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output 2</td>
<td>Assessment of options to re-operate flood control dams without significant loss of flood protection</td>
</tr>
<tr>
<td>Output 3</td>
<td>Evaluate alternatives to ameliorate the impacts of hydropower peaking</td>
</tr>
<tr>
<td>Output 4</td>
<td>Assessment of options to re-operate private hydropower dams while maintaining most of the current power generation capacity</td>
</tr>
<tr>
<td>Output 5</td>
<td>Evaluate the impact of reservoir operations and assessment of options to manage these water supplies</td>
</tr>
<tr>
<td>Output 6</td>
<td>Provide a basin-wide context to evaluate the cumulative impacts of water management decisions in each state (e.g. major groundwater withdrawals, surface water withdrawals, waste water return flows).</td>
</tr>
<tr>
<td>Output 7</td>
<td>Evaluate the social/economic costs and environmental benefits of implementing these changes in operations</td>
</tr>
<tr>
<td>Output 8</td>
<td>Optimization program that will allow stakeholders to maximize selected functions, such as environmental benefits, while operating within constraints on flood control, power generation, and other water management needs.</td>
</tr>
</tbody>
</table>
Other Stakeholder Engagement

• Kick–off Meeting in 2008
• Interviews with dam owners and operators
• Owner and operator workshop (Nov 2009)
• Resource managers (August 2010)
• Environmental flows and impacts (April 2011)
Developing Decision Support Tools

- Study followed protocols established in early incarnations of shared vision planning (Palmer 1998, Palmer et al 1999, Palmer 2007), particularly in that several different models developed by stakeholders were used to support the process (Ryu et al 2009, Palmer and Werick 2004, Werick and Palmer, 2008).

Shared Vision Planning (SVP) is a collaborative approach to formulating water management solutions that combines three disparate practices: 1) traditional water resources planning, 2) structured public participation and 3) collaborative computer modeling.
Developing Decision Support Tools

- Three different models have been created describing system management
  - RES–SIM – developed by HEC
  - Optimization model – by UMass
  - STELLA simulation model – by UMass
INPUT

HYDROLOGY

- HISTORIC STREAMFLOW (SYE)
- FORECASTED STREAMFLOW
- CLIMATE IMPACTED STREAMFLOW

SYSTEM CONSTRAINTS AND TARGETS

- ECO-FLOW PRESCRIPTIONS
- STAKEHOLDER NEEDS
- HEC-RAS

MODELS

SIMULATION

OPTIMIZATION

Alternative System Operations
Developing Decision Support Tools

- Optimization Model
  - Daily time step—as is simulation
  - Can simulate 5 year operation with weighted objectives including
    - Fish targets
    - Hydropower
    - Water supply
    - Flood Control
Incorporating Fish Flow Targets

• Began with effort to mimic “A Method for Assessing Hydrologic Alteration Within Ecosystems,” Richter et al., 1996

• These measures were being used by TNC in other studies

• This format did not fit well into optimization

• Realized that “natural flows” were sought
Target with “No” Flexibility

Generic Loss Function #2

Penalty in Objective Function

Percent of Natural Flow
Target with “Wide” Flexibility

Generic Loss Function #3

Penalty in Objective Function vs. Percent of Natural Flow
<table>
<thead>
<tr>
<th>Month</th>
<th>All Diadromous Fish</th>
<th>Atlantic salmon</th>
<th>Alosids</th>
<th>Sh. Sturgeon</th>
<th>Eel</th>
<th>Resident Fish - Coldwater</th>
<th>Resident Fish - Warm Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALL YEAR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2 yr unregulated RI flow can occur every 1.5-3 years at unregulated duration (except mid-May - June due to Alosids)</td>
</tr>
<tr>
<td>JAN</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-5%+/+20% Δ in monthly Q50 and 1%/+50% Δ in monthly Q90; Dec. - Feb.‘+/- 5% change in Q30-Q15 (implies unreg freq. and duration) for channel maintenance</td>
<td>-5%+/+20% Δ in monthly Q50 and 1%/+50% Δ in monthly Q90; Dec. - Feb.‘+/- 5% change in Q30-Q15 (implies unreg freq. and duration) for channel maintenance</td>
</tr>
<tr>
<td>FEB</td>
<td>Below 1cfsm=no Δ; b/w 1-2 cfsm 5% Δ; 2-3 cfsm= 10% (Dec-May varies by geog.) - overwintering of redds</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MAR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>APR</td>
<td>MARCH TO OCT: Up to 10% Δ in unreg. subdaily flows (April-July=Salmon; Mar-Oct = Alosids; May-Oct=Eel; May-June= Shortnose) -- migration &amp; spawning index</td>
<td>Q99 to Q90 = 0% daily flow Δ; Q90 to Q50= 10% Daily Flow Δ; Q50 to Q10 =20% daily flow (Starts in March for alewife, ends in June for all) - migration</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>15Δ% change in monthly Q30 - Q15 (implies unreg freq. and duration) for channel maintenance, flushing</td>
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<tr>
<td>MAY</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>30-120 cm/sec @ Turners - for spawning</td>
<td></td>
<td></td>
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<tr>
<td>Month</td>
<td>Mussel Flow recommendation</td>
<td>Macroinvertebrate</td>
<td>Floodplain Low Flow</td>
<td>Floodplain Medium Flow</td>
<td>Floodplain High Flow</td>
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</table>
| ALL YEAR | • eliminate excessive subdaily variation;  
• For very vulnerable mussel species sites, prevent the flood event larger than x cfs / y recurrence interval flood  
• ALSO see flow needs for diadromous and resident (HOST) fish habitat suitability | • 10% Δ to monthly Q10 to Q1; no Δ to mag. or freq., or timing of 2-yr RI; | Very Low Probability Events | Channel Forming Floods | Maintain 1-2 year recurrence interval floods |
| JAN | | | | | |
| FEB | • "Max. sustainable low flow" that will vary by year based on lowest daily November flow that year.  
• Also see "ALL YEAR" recommendations | | | | |
| MAR | | • no Δ to mag. or freq., or timing of 2-yr RI;  
• no increase in mag. or freq. of floods > 2-yr RI | | 10-Year Flow Event | 2-5 Year Flow Event |
| APR | • No change to monthly Q90 or lower flows;  
• +/- 10% daily natural flows: Maintain number of reversals and flashiness metrics within 95% CI for unregulated sites ("preserve the pattern") | | | maintain natural timing & magnitude of 1-2 year recurrence interval spring flood |
| MAY | | | NO FLOOD | NO FLOOD | |
Trade-Offs: What Do the Eco-Flows “Cost”

Cost can be evaluated in sacrificed income from hydropower or deviations from target storage (i.e. how much do they have to change their operations)

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**Eco-Flow Count vs. Storage Target Trade-Off**

- Percent of Eco-Flows Hit
- Average Daily Storage Error for all Dams (acre-ft)

**Eco-Flow (cfs) vs. Storage Target Trade-Off**

- Average Error of Eco-Flows (cfs)
- Average Daily Storage Error for all Dams (acre-ft)
Navigating The Institutional Framework and Implementing Decisions

• In 2002, TNC noted that operation of large dams, particularly those operated for flood control and/or hydropower, resulted in decrease in biodiversity

• Develop relationship with USACE and MOU (Corps being the largest owner of such dams)

• MOU evolved into Sustainable Rivers Project (SRP)

• SRP now has 36 federal dams on 8 rivers in 12 states

• Connecticut River is one of these

• Relationship offers framework for long-term and intimate collaborations
Navigating The Institutional Framework and Implementing Decisions

• Second special framework is Federal Regulatory Commission

• 6 important dams on Connecticut are to be relicensed (are Wilder, Cabot Station, Turner Falls, Northfield Mountain, Vernon, and Bellows Falls)

• Total of 1,245 Megawatts

• Relicensing begins in earnest in 2013

• Anticipate these model can be used to inform this process
Outcomes And Reflections Of Modeling Process

• Current evaluation is being slowed on agreement on streamflows

• Two studies completed to date, impacts of alternative operations on upper third of system (eco-targets and power) and impacts of sub-daily time step on results (“flashiness” due to hourly peaking)

• Results on value of climate informed forecasts on operation

• Stakeholder engagement was started early, is ongoing, and included wide range of participants and involved study personnel at all levels (i.e., outside consultants, study managers, and modelers)
Questions?