Accounting for Human Intervention in Streamflow Forecasting

Presentation to HICs Workshop

Silver Spring, MD

Andy Chang, Bob McCormack
Lawrence Wolpert

February 16, 2010
Agenda

- Who are we?
- What do we do?
- What’s the issue?
- What’s the problem?
- What’s the solution?
- What are the next steps?
- Questions – as if these are not enough!
Who are we?
Aptima, Inc.

Interdisciplinary Small Business
- 100+ staff (80% graduate degrees)

- Founded in 1995; consistent annual growth (43% CAGR)
- Serving government and commercial clients
- 300+ contracts with the DoD
- Offices
  - Woburn, MA, (HQ)
  - Washington, DC
  - Dayton, OH
  - Ft Walton Beach, FL

© 2008, Aptima, Inc.
What’s the issue?
Streamflow Forecasting

- NWS is responsible for providing weather, hydrologic, and climate forecasts and warnings
  - provides web-based Advanced Hydrologic Prediction Services (AHPS) through 13 regionally-based River Forecast Centers
  - AHPS uses computer models that simulate river flow, rainfall, etc. to generate predictions and these are conveyed to users

- Predictions are filled with uncertainty, which is difficult to convey
  - Human behavior, which directly impacts the water levels and flood conditions, remains one of the chief sources of uncertainty in hydrology forecasts

- Current models do not explicitly account for behavior of the humans in the loop (forecasters, WRMIs)
  - River regulation complicates streamflow forecasting due to lack of human influences
Visual Display Design

- Support EMs’ decision making regarding courses of action.
  - Visualizations of river forecasts with uncertainty
  - Visualizations of “impact” of various flooding scenarios

- Visualization of uncertainty model inputs for clear understanding of “why” predictions are what they are.

- Allow for local knowledge to be incorporated into predictions

- Fusion / organization of information for clear understanding of relationship to one another and enhanced orientation.
What’s the problem?
What’s the solution?
Objectives

Understand Influences and Actions of Water Resource Managers

Develop Models which Account for Human Behavior

Link Hydrology Forecasts To Human Models

Incorporate Human Behavior Forecasts Into Hydrology Predictions
What do we do?

Human-Centered Engineering

- Technology Capabilities
- Social & Organizational Structures
- Mission, Tasks & Work Processes
- Human Agents

Congruence or ... Disruption
SME Interviews

- Northeast RFC – Taunton, MA
- Development and Operations Hydrologists (DOH Workshop in SS)
- US Army Corps of Engineers – Reservoir Control
- First Light Power Resources – New Milford, CT
- California-Nevada RFC – Sacramento, CA
  - NWS, USACE, SMUD, PG&E, SFWATER, USBR, CA Water
[Decision Ladders]
Decision Ladder Structure

Monitoring Reservoir Inflow Conditions
Monitoring Reservoir Conditions
Monitoring Downstream Conditions
Water Release Planning

CALIFORNIA HYDRO POWER DECISION LADDERS
## Monitoring Regulations/Rights

<table>
<thead>
<tr>
<th>Task Description</th>
<th>Ladder Code</th>
<th>Role</th>
<th>Combination of Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observe dam conditions and inputs</td>
<td>3</td>
<td>Observe information and data</td>
<td>Hydropower Water Resource Manager</td>
</tr>
<tr>
<td>Perception dam conditions and inputs</td>
<td>4</td>
<td>Observations</td>
<td>Hydropower Water Resource Manager</td>
</tr>
</tbody>
</table>
## Decision Ladder Details

### Planning

<table>
<thead>
<tr>
<th>Task Description</th>
<th>Ladder Code</th>
<th>Role</th>
<th>Combination of Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Integrate system states from monitoring activities to obtain “pattern”</td>
<td>5</td>
<td>Hydropower Water Resource Manager</td>
<td>SUBSYSTEMS: System state of Reservoir Inflow Conditions, System state of Reservoir Conditions, System state of Operational Conditions, System state of Downstream Conditions, System state of Regulations and Rights, System state of Power Demands/Costs</td>
</tr>
<tr>
<td>Comprehend current state of river/power system in terms of</td>
<td>6</td>
<td>Hydropower Water Resource Manager</td>
<td>Trends of power demands over time, Trends in power prices over time, Optimal times in 24 hour period for generating power, Optimal times “long term” for human consumption pattern</td>
</tr>
<tr>
<td>Evaluate and compare options</td>
<td>9</td>
<td>Hydropower Water Resource Manager</td>
<td>Release (e.g., ability to make immediate profit, ability to come in lines with downstream regulations / height, ability to come in lines with downstream recreational regulations / height, ability to bring reservoir in lines with goal levels when over goal height, ability to bring dam in lines with integrity limits when above limits, ability to accept anticipated inputs, ability to reduce height of river upstream and have associated impacts on quality variables upstream, ability to change quality levels at reservoir by reducing water, ability to generate power that is in lines with power demands) vs. Storing water (e.g., ability to provide long term power generation during peak seasons, ability to come in lines with regulations at reservoir when under regulation height or storing will impact quality in appropriate manner, ability to bring reservoir in lines with goal levels when under goal height, ability to continue to provide power if anticipated inputs do not come to fruition, reduce flooding downstream that may already be occurring, ability to increase height of river upstream and have associated impacts on quality variables upstream, ability to change quality levels at reservoir by reducing water, operate within “ancillary” market, maintain minimum levels needed for generating power, wait to produce power when profit out ways cost)</td>
</tr>
</tbody>
</table>

- **Spill** (schedule maintenance to optimize power generation capability long term, working within “ancillary” market, movement of water to downstream power generation houses while in “ancillary” market, minimizes impact to downstream area that is already high) vs. **Release** (produce power at reduced efficiency to reduce spill, produce power when no other power houses can use water if spilled, work outside “ancillary” market, push more water downstream when able to take it).

- **Achieve Regulation** (meet stringent regulation that has large fine associated with it) vs. **Breach Regulation** (go against a regulation that is not stringent, does not have a heavy penalty, can easily be rectified later).

- **Produce Power** (generate profit when cost effective) vs. **Purchase Power/Produce**
Model Approach

Data
- Environmental
- Human

Human Model
- Finite State Automata
- Bayesian Inference

Visualization

Forecasts

© 2009, Aptima, Inc.
Initial Model: Finite State Automata
Bayesian Model

- Representation of information and influences
- A Bayesian Network is a directed acyclic graph with an associated set of random variables
  \[ B = (V, E) \quad \{X_v\}_{v \in V} \]
- Joint probability distribution
  \[
P(X_1 = x_1, \ldots, X_n = x_n) = \prod P(X_i = x_i \mid X_j = x_j, j \in \text{pa}(i))\]
- We use the Bayesian Network to calculate the likely actions based on the observed information
Finite State Automata based on Decision Ladders

- Prune Nodes
- Adjust Conditional Probabilities
- Insert Known Prior Distributions

Integrated Model
How do we model the actions of “non-cooperative” water resource managers, i.e., those individuals who don’t share their operational plans, schedules, etc.?

The Bayesian model can learn the conditional probability distributions based on observed data.
Contact information

- Lawrence Wolpert (PM)
  lwolpert@aptima.com
  617.913.5399

- Bob McCormack (PI)
  rmccormack@aptima.com
  781.496.2476

- Andy Chang
  achang@aptima.com
  781.496.2447
[ACE]
USER POPULATION: Army Corps of Engineers Water Resource Manager

TITLE: Monitoring Dam Inflow

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Alert</td>
</tr>
<tr>
<td>2</td>
<td>Activate Attention</td>
</tr>
<tr>
<td>3</td>
<td>Observe Information &amp; Data</td>
</tr>
<tr>
<td>4</td>
<td>Observations</td>
</tr>
<tr>
<td>5</td>
<td>Identify Present System State</td>
</tr>
<tr>
<td>6</td>
<td>System State</td>
</tr>
<tr>
<td>7</td>
<td>Interpret Consequences</td>
</tr>
<tr>
<td>8</td>
<td>Options</td>
</tr>
<tr>
<td>9</td>
<td>Evaluate Observe Options</td>
</tr>
<tr>
<td>10</td>
<td>Selected Option</td>
</tr>
<tr>
<td>11</td>
<td>Goal State</td>
</tr>
<tr>
<td>12</td>
<td>Define Task</td>
</tr>
<tr>
<td>13</td>
<td>Task</td>
</tr>
<tr>
<td>14</td>
<td>Formulate Procedure</td>
</tr>
<tr>
<td>15</td>
<td>Procedure</td>
</tr>
<tr>
<td>16</td>
<td>Execute</td>
</tr>
</tbody>
</table>

Identification of the current inflow and impact of reservoir height, as well as the evaluation of predicted weather and river forecasts for identification of future inflow levels and impact on future reservoir heights.
USER POPULATION: Army Corps of Engineers Water Resource Manager

TITLE: Monitoring Dam Operational Conditions

Scenario: With input from the "Monitoring Dam Inflow", the WRM monitors current and expected reservoir heights in relation to the gates conditions for release rates and the dam's operational capacity (if reservoir is going to, or does, exceed safety conditions, "Alert" is triggered).
USER POPULATION: Army Corps of Engineers Water Resource Manager

TITLE: Monitoring Downstream Conditions

Water resource managers monitor downstream conditions in terms of current conditions (from gauges) and expected conditions (from river forecasts and expected releases) to identify the state of the system downstream. If downstream conditions are changing below a hydropower dam that are not in line with expected patterns from their release schedules, an Alert may be triggered.
Scenario: See that the water gauge under a Hydropower Dam is raising while ACE was releasing water to a stream they had not anticipated rising. See that the height of a reservoir at a Dam is approaching or exceeding the limits set for it to be operating at a safe level.
**USER POPULATION:** Army Corps of Engineers Water Resource Manager

**TITLE:** Water Release Planning

Upon understanding the entire system, planning is conducted on when to release water (long term, and short term) where options are evaluated and a selected goal defines the course of action to take. Alerts can trigger re-planning activities.