Cost of Inflow Forecast Uncertainty for Day Ahead Hydropower Production Scheduling

HEPEx 10th University Workshop
June 25th, 2014
NOAA Center for Weather and Climate

Thomas D. Veselka and Les Poch
Argonne National Laboratory

Water Use Optimization Toolset
- Hydrologic Forecasting
- Seasonal Hydro Systems Analysis
- Environmental Performance
- Day Ahead Scheduling / Real-Time Operations

Argonne National Laboratory
Oak Ridge National Laboratory
Pacific Northwest National Laboratory
Sandia National Laboratories

U.S. Department of Energy
Energy Efficiency & Renewable Energy
Water Power Program
Project Background Information

• The DOE Water Power Program is funding the development and deployment of the Water Use Optimization Toolset (WUOT)
  ➢ Multi-lab effort (ANL, PNL, SNL)
  ➢ Contains several integrated components
  ➢ Objective: Produce more power with the same amount of water

• The day-ahead scheduling and real-time operations tool is named **Conventional Hydropower Energy and Environmental Systems (CHEERS)**

• CHEERS Simultaneously optimizes power and environmental objectives
  ➢ **Power:** Maximize the value of energy production and ancillary services
  ➢ **Environment:** Enhance habitats and improve river functionality
  ➢ **Granularity:** 5 minute to 1 hour time step for 1 to 7 days at the generating unit level
CHEERS Framework

• Describes a system as a network of objects
  – Commodity (water & power) flows
  – Boundary nodes (inflows)
  – Storage nodes (reservoir)
  – Conversion nodes (turbine/generator)
  – Junction nodes (confluence)
  – Links (river, canal, power transport)

• Creates schedules - when, where & how much
  – Water release from storage
  – Power generation
  – Ancillary services (regulation, spin, & non-spin)

• Describes functionality and applies rules
  – For individual objects, groups of objects, and/or the whole system
  – For individual time steps or over specified time periods
The Aspinall Cascade Is a Tightly Coupled System

Black Canyon to Montrose to Rifle

Curecanti Substation

Blue Mesa

Hourly fluctuations & may be turned off for an entire day

Approximately 150 Miles

Uncontrolled Flows

Hourly fluctuations & may be turned off for an entire day
Aspinall Operating Limits Restrict Power Plant Operations

- **Blue Mesa**
  - Maximum elevation
  - Minimum elevation

- **Morrow Point**
  - Seasonal minimum elevations
  - Maximum elevation

- **Crystal**
  - Maximum elevation
  - Minimum elevation
  - Seasonal daily elevation change limit as a function reservoir state
  - Seasonal multiple day change limits

<table>
<thead>
<tr>
<th>Month</th>
<th>Blue Mesa</th>
<th>Morrow Point</th>
<th>Crystal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Minimum Elevation (ft)</td>
<td>Maximum Elevation (ft)</td>
<td>Minimum Elevation (ft)</td>
</tr>
<tr>
<td>Jan</td>
<td>7,393.0</td>
<td>7,519.4</td>
<td>7,143</td>
</tr>
<tr>
<td>Feb</td>
<td>7,393.0</td>
<td>7,519.4</td>
<td>7,143</td>
</tr>
<tr>
<td>Mar</td>
<td>7,393.0</td>
<td>7,519.4</td>
<td>7,143</td>
</tr>
<tr>
<td>Apr</td>
<td>7,393.0</td>
<td>7,519.4</td>
<td>7,143</td>
</tr>
<tr>
<td>May</td>
<td>7,393.0</td>
<td>7,519.4</td>
<td>7,143</td>
</tr>
<tr>
<td>Jun</td>
<td>7,393.0</td>
<td>7,519.4</td>
<td>7,151</td>
</tr>
<tr>
<td>Jul</td>
<td>7,393.0</td>
<td>7,519.4</td>
<td>7,151</td>
</tr>
<tr>
<td>Aug</td>
<td>7,393.0</td>
<td>7,519.4</td>
<td>7,151</td>
</tr>
<tr>
<td>Sep</td>
<td>7,393.0</td>
<td>7,519.4</td>
<td>7,151</td>
</tr>
<tr>
<td>Oct</td>
<td>7,393.0</td>
<td>7,519.4</td>
<td>7,143</td>
</tr>
<tr>
<td>Nov</td>
<td>7,393.0</td>
<td>7,519.4</td>
<td>7,143</td>
</tr>
<tr>
<td>Dec</td>
<td>7,393.0</td>
<td>7,519.4</td>
<td>7,143</td>
</tr>
</tbody>
</table>
Typical Day Ahead
Deterministic Result

- Blue Mesa
  - Capacity of 86.4 MW (2 units)

- Morrow Point
  - Capacity of 173.4 MW (2 units)

- Crystal
  - One unit with a capacity of 28 MW

**Daily Inflow**

- Blue Mesa: 7,233
- Morrow Point: 8,167
- Crystal: 467

**Daily Side Flows**

- Blue Mesa: 1.167
- Morrow Point: 8.633
- Crystal: 9.800

**Crystal**

<table>
<thead>
<tr>
<th>Day</th>
<th>Max Elevation (ft)</th>
<th>Min Elevation (ft)</th>
<th>Daily Elevation Change (ft)</th>
<th>3 Day Elevation Change (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sun</td>
<td>6,763.2</td>
<td>6,760.2</td>
<td>3.0</td>
<td>Max Daily</td>
</tr>
<tr>
<td>Mon</td>
<td>6,763.4</td>
<td>6,761.6</td>
<td>1.8</td>
<td>Max Daily</td>
</tr>
<tr>
<td>Tue</td>
<td>6,763.4</td>
<td>6,761.4</td>
<td>2.0</td>
<td>Max Daily</td>
</tr>
<tr>
<td>Wed</td>
<td>6,763.4</td>
<td>6,761.4</td>
<td>2.0</td>
<td>Max Daily</td>
</tr>
<tr>
<td>Thu</td>
<td>6,763.4</td>
<td>6,761.7</td>
<td>1.7</td>
<td>Max Daily</td>
</tr>
<tr>
<td>Fri</td>
<td>6,763.4</td>
<td>6,760.7</td>
<td>2.7</td>
<td>Max Daily</td>
</tr>
<tr>
<td>Sat</td>
<td>6,763.4</td>
<td>6,760.2</td>
<td>2.7</td>
<td>Max 3-Day</td>
</tr>
<tr>
<td>Week</td>
<td>6,763.4</td>
<td>6,760.2</td>
<td>3.0</td>
<td>Max Daily</td>
</tr>
<tr>
<td>Change</td>
<td>3.2</td>
<td>3.0</td>
<td>3.0</td>
<td>3.16</td>
</tr>
</tbody>
</table>
Power Schedulers Currently Use Persistence to Forecast Short-term Aspinall Side Flows

Flows are more than expected
Flows are less than expected

2009 Crystal Reservoir Day Ahead Side Flow Forecast Error

Total Daily Side Flow Forecast Error (AF)

Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

Blue Mesa 748
Active Reservoir Storage (TAF)
Morrow Point 42
Crystal 13
Inaccurate May 4th Forecast

Day Ahead Schedule

Actual/Real-time Operations

Expensive Balancing Purchases

Aspinall

Interchange

Other Aspinall Generation

STF

LTF

Expensive Balancing Purchases

Inaccurate May 4th Forecast

Expensive Balancing Purchases

Actual/Real-time Operations

Expensive Balancing Purchases
Inflow and Side Flow Forecast Error Computations

Assume persistence forecasting
- Flows tomorrow and thereafter will be identical to yesterday

Use historical data
- Hourly data for the years 1999 through 2010
- Cascade reservoir elevations
- Power and non-power water releases and reservoir elevations

Uncontrolled inflows into the top reservoir and side flows between reservoirs are based on a water mass balance equation and water storage volume-to-elevation curves

Challenges
- Water release rate measurement error
- Reservoir elevation measurement error
- Accuracy of volume-to-elevation curves

Eventually switch to the WUOT Hydrologic Forecasting tool
- Shows promise to reduce daily forecast error
A narrower operating range has power and economics implications.

A Perfect Forecast Range accommodates higher than projected inflows.

A Compliance Scheduling Range accommodates lower than projected inflows.

Max elevation

Min elevation

Head

Water Storage Levels Must Also Accommodate Ancillary Services

CHEERS Uses Buffers to Reduce Reservoir Violations Associated with Inflow Forecast Error
Crystal Water Side Flow Forecast Errors Are Used to Estimate Water Storage Buffer

- Flows are more than expected: Decrease maximum elevation level to accommodate water surplus.
- Flows are less than expected: Increase minimum elevation level to accommodate water shortfall.

Buffer levels are based on scheduler’s risk tolerance.

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard Dev</td>
<td>14.36</td>
</tr>
<tr>
<td>Mean</td>
<td>0.00</td>
</tr>
<tr>
<td>Median</td>
<td>1.00</td>
</tr>
<tr>
<td>Mode</td>
<td>4.00</td>
</tr>
<tr>
<td>Skewness</td>
<td>0.24</td>
</tr>
<tr>
<td>Kurtosis</td>
<td>5.57</td>
</tr>
</tbody>
</table>

Exceedance Probability (%)

Hourly Average Forecast Error (AF)
One Statistical Distribution *DOES NOT* Fit all Situations

**Seasonal differences: monthly distributions**
- Forecast errors in Spring tend to be the highest
- Winter has the most reliable forecast

**Time of day during Spring: night versus day**
- Forecast errors in mid to late afternoon are relatively high
- Nighttime forecasts are more reliable

**Error distributions are dependent on current conditions**
- Low inflow conditions tend to have positively skewed distribution
- High inflow conditions tend to have negatively skewed distribution

**Errors increase with longer projection time**
- Day-ahead scheduling may be up to 4 days or more in advance

**Summer thunderstorms occasionally result in large inflow under predictions**
Separating Data into Different Classes Yields Better Schedules

This approach allows more filling at night and more power production during the daytime when power prices are high.

Decrease the maximum elevation target less during the night.

Increase the minimum elevation target less during the afternoon.
Summary of Economic Impacts on Power

**Perfect Forecast**

- **High Reservoir Condition**
  - Higher power production during low priced hours results in lower on-peak generation
  - Sales of regulation down are reduced or eliminated
  - Down-side generation potential is reduced, limiting responses to increases in variable resource (i.e., wind and solar) output

- **Middle Reservoir Condition**
  - Forecast error has relatively little or no impact

- **Low Reservoir Condition**
  - Lower maximum power production
  - Less power may be produced during the most valuable periods
  - Potential sales of regulation up and contingency reserve services are reduced
  - Up-side generation potential is reduced, limiting responses to reductions in variable resource output

**Imperfect Forecast**

- **High Reservoir Condition**
  - Lower maximum power production during low priced hours results in lower on-peak generation
  - Reduced sales of regulation down are reduced or eliminated
  - Reduced down-side generation potential is reduced, limiting responses to increases in variable resource (i.e., wind and solar) output

- **Middle Reservoir Condition**
  - Forecast error has relatively little or no impact

- **Low Reservoir Condition**
  - Lower maximum power production
  - Less power may be produced during the most valuable periods
  - Potential sales of regulation up and contingency reserve services are reduced
  - Reduced up-side generation potential is reduced, limiting responses to reductions in variable resource output
Thank you for your attention