Ensemble Optimization for Hydroelectric Operations

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Powell River BC Basin
How to improve the relationship between water and power generation?

Average Annual Inflow: 4,151 cfs
Average Annual Generation: 514,863 MWh (1978-1997)

\[ MWh = 62.289 \times cfs + 256,106 \]
\[ R^2 = 0.759 \]
The Application

The paper mill’s electricity requirements normally exceed the capability of the two hydroelectric plants.

The objective is to minimize the cost of electricity purchases.

A key constraint in operating the dams is to guarantee minimum generation of 20 Mw at all times.
Since 1989 a decision support system has been used for optimizing electricity purchase decisions.

The decision support system consists of:

• a hydrologic ensemble forecast model,

• an ensemble optimization reservoir model,

• an generator optimum loading model.
The inputs are weekly hydrologic ensemble forecasts and seasonal energy prices.

The one year time horizon reservoir operations model is a non-linear optimization.

The recommendation is the specific optimum power generation for this week.

The result is the week by week probability distributions for future power and reservoir states.
Operation Before Ensemble Optimization

Limited storage operating range: Frequent spill

Long term ave.

Power & Spill

Inflow
Limited storage operating range: Frequent spill
Conceptual Modeling: Hydrology

Historical Weather Data Inputs

Hydrologic model outputs: snow at elevation bands

Weather → Model → Inflow Forecast
Hydrologic model outputs: daily inflow hydrographs

- Daily Precipitation
- Temperature Daily Maximum & Minimum
- Flow: Model, Measured

Weather → Model → Inflow Forecast
Inflow probability depends on present conditions.

Forecast with weather from each year, e.g. 1955

Cumulative Inflow

Ensemble Forecasts

Initialization Period: Oct. 1 1993 to Sep. 1 1996
Now Simulating: Aug 21, 1995
Meteorological Data File: C:\JOBS\9218MUD\DATAMGR\DATA\HDMKPP.DBF
Watershed Parameter File: C:\JOBS\9218MUD\DATAMGR\DATA\MOH.PAR
Reliability of minimum generation

Truncate the hydrologic ensemble forecast at an appropriate probability level.

For example, the recommended generation may go to the lower bound (20 Mw minimum generation) in at least one of the hydrologic sequences provided in the input.

The driest sequence controls the reliability.
The Annual Storage Model has successfully optimized powerhouse releases for the planning horizon.

**Next Week**

Recommended average releases (cms) and the corresponding average generation (MW) for the week starting February 26, 2004:

<table>
<thead>
<tr>
<th>Powerhouse</th>
<th>Discharge (cms)</th>
<th>Generation (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Powell Plant</td>
<td>118.00</td>
<td>46.6</td>
</tr>
<tr>
<td>Lois Plant</td>
<td>40.00</td>
<td>39.3</td>
</tr>
<tr>
<td>Total</td>
<td>158.00</td>
<td>85.9</td>
</tr>
</tbody>
</table>

**Next Year**

Expected value of total generation (MWh) for the planning horizon from February 26, 2004 to February 23, 2005:

<table>
<thead>
<tr>
<th>Powerhouse</th>
<th>Generation (MWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Powell Plant</td>
<td>402,176</td>
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<tr>
<td>Lois Plant</td>
<td>339,956</td>
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<tr>
<td>Total Generation</td>
<td>742,132</td>
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</tbody>
</table>
Operation After Ensemble Optimization

Aggressive storage operating range: Reduced spill

More Power
Recommended release for 1st week

Probabilistic outcomes for subsequent weeks
Probabilistic outcomes for subsequent weeks
Hydrologic Ensemble Optimization

Actual Hydroelectric Benefits.

<table>
<thead>
<tr>
<th></th>
<th>1989</th>
<th>1990</th>
<th>1991</th>
<th>GwH/Year</th>
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</thead>
<tbody>
<tr>
<td>Actual operation with software</td>
<td>269</td>
<td>392</td>
<td>265</td>
<td>295</td>
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<tr>
<td>Theoretical optimum</td>
<td>268</td>
<td>309</td>
<td>334</td>
<td>304</td>
</tr>
<tr>
<td>Rule Curve Operation</td>
<td>263</td>
<td>289</td>
<td>313</td>
<td>288</td>
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</tbody>
</table>

2-percent improvement over Rule Curve was experienced.

Payback was less than one year

Up to 5-percent improvement over Rule Curve is possible if future operations follow recommendations more closely.
Hydrologic Ensemble Optimization

Remaining Potential Hydroelectric Benefits.

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</thead>
<tbody>
<tr>
<td>Actual operation</td>
<td>269</td>
<td>292</td>
<td>325</td>
<td>302</td>
<td>242</td>
<td>307</td>
<td>344</td>
<td>330</td>
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<td>optimum</td>
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Overall possible improvement of 3-percent remains if the optimal recommendations can be followed more closely in practice.

This comparison provides a performance measure for ongoing operations.
Thank you for your attention

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