Evaluating Forecasts in Reservoir Operations: The Role of Reforecast Products in Examining Extremes

Rebecca Guihan
Dr. Austin Polebitski, Dr. Richard Palmer

February 26, 2014
I have a cool hydrology model!

I have a cool climate model!

When should I plant my corn? Should I buy crop insurance?

Will our reservoir refill completely this year?

Should we initiate flood stage protocol or not?
When should I plant my corn?

Should I buy crop insurance?

Will our reservoir refill completely this year?

Should we initiate flood stage protocol or not?

I have a cool climate model!

I have a cool hydrology model!

When should I plant my corn? Should I buy crop insurance?
NOAA SARP

Private/Consulting

End Users

Federal, State, Local Agencies

Academia/University

NOAA SARP
Project Goals

Demonstrate the potential usefulness of climate forecasts and create an appropriate framework for their application

- Co-generate knowledge concerning system operations between researchers and water managers
- Generate ESP streamflow using reforecasts at partner locations
- Evaluate skill of GFS and CFSv2 and corresponding streamflow in the context of decision making
- Disseminate data, case studies, and recommendations to the broader water community
Project Partners - Case Studies

Salt Lake City
Parley’s System:
Drinking Water, Flood Control

Snohomish County PUD
Jackson Hydropower System:
Multi-purpose
Project Partners - Case Studies

PacifiCorps Bear Lake: Irrigation Supply, Flood Control

Dallas Water Utilities System: Drinking Water
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Workshop
<table>
<thead>
<tr>
<th>Partner</th>
<th>Hydropower</th>
<th>Water Supply</th>
<th>Environmental Flows</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dallas</td>
<td>None</td>
<td>• Firm yield</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Frequency of instituting voluntary or mandatory restrictions</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Total revenues generated</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Minimum storages in reservoirs</td>
<td></td>
</tr>
<tr>
<td>PacifiCorp</td>
<td></td>
<td>• Volume of water provided to irrigation</td>
<td>None</td>
</tr>
<tr>
<td>Bear Lake</td>
<td></td>
<td>• Annual allocation of water</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Accuracy of forecast of water to be allocated</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Irrigation supply lost</td>
<td></td>
</tr>
<tr>
<td>Salt Lake City</td>
<td>• None</td>
<td>• Appropriate storage level at the beginning of water supply season</td>
<td>Cannot divert into pipeline until &gt;5 cfs at Lamb’s Diversion</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Balancing water sources and supplies</td>
<td></td>
</tr>
<tr>
<td>SnoPUD</td>
<td>• Mega-watts hours</td>
<td>• Water provided to Everett</td>
<td>• Number of times fish flows are unmet</td>
</tr>
<tr>
<td></td>
<td>produced per year,</td>
<td>• Need to implement curtailments</td>
<td>• Minimizing peak releases that harm fish</td>
</tr>
<tr>
<td></td>
<td>• Total avoided costs from other purchases</td>
<td>• Provide “flushing flows” to move fish down stream</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Annual energy value</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Partner</td>
<td>Hourly/Daily</td>
<td>Weekly</td>
<td>Monthly</td>
</tr>
<tr>
<td>-----------------</td>
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<tr>
<td>PacifiCorp</td>
<td>• None</td>
<td>• Flood Control Decisions</td>
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<tr>
<td>Bear Lake</td>
<td></td>
<td>• Flood Mitigation</td>
<td>• Irrigation Allocations</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Drinking Water Deliveries</td>
<td>• Drought</td>
</tr>
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<td>Salt Lake City</td>
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<td>SnoPUD</td>
<td>• Hydropower Generation</td>
<td>• Drinking Water</td>
<td>• Refill/Drafting Rates</td>
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<td>• Channel forming flows</td>
<td>• Hydropower Scheduling</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>• Flood Control</td>
<td></td>
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# Types of Streamflow Forecasts Used

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<th>Type of Forecast</th>
<th>Forcings</th>
<th>Streamflow</th>
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<td>ESP/Climatology</td>
<td>Historic</td>
<td><img src="image1.png" alt="Climatology" /></td>
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<tr>
<td>HEFS</td>
<td>GEFS and Climatology</td>
<td><img src="image2.png" alt="GEFS and Climatology" /></td>
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<tr>
<td>HEFS</td>
<td>GEFS and CFSv2</td>
<td><img src="image3.png" alt="GEFS and CFSv2" /></td>
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- ESP – Ensemble Streamflow Prediction
- HEFS – Hydrologic Ensemble Forecast System
- CFS– Climate Forecast System
- GEFS – Global Ensemble Forecast System
## Types of Streamflow Forecasts Used

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- **ESP**: Ensemble Streamflow Prediction
- **HEFS**: Hydrologic Ensemble Forecast System
- **CFS**: Climate Forecast System
- **GEFS**: Global Ensemble Forecast System

**Expectation:** Variability decreases
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CFS Forecast vs. Observed Temperature (°C)

Day One

Day Three

$R^2 = 0.842$

$R^2 = 0.8418$

Day Five

Day Ten

$R^2 = 0.8027$

$R^2 = 0.6475$

Day Thirty

Day Sixty

$R^2 = 0.49$

$R^2 = 0.4805$
CFS Correlations by Lead Day

Correlation of CFS and Observed Temperature Data

Correlation of CFS and Observed Precipitation Data
Snowpack as a Crude Forecasting Method: SLC

Annual April-July Inflow Volumes - Salt Lake City (1984-2010)
Additional skill when using ESP forecast
Additional skill when using HEFS forecast
Summed April-July HEFS Inflow (Little Dell)
Means of ESP and HEFS (kaf)

\[ R^2 = 0.9855 \]
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Proof of Concept - Method

Do this for each week, for 52 weeks to determine the benefit of 60 day forecasts.
Proof of Concept - Results

- Use DSS to evaluate revenue gains in three hydrologically different years
- Compare the use of forecast information against ‘perfect knowledge’

<table>
<thead>
<tr>
<th></th>
<th>Annual Inflow (AF)</th>
<th>Average Energy Price</th>
<th>Standard Deviation In Energy Prices</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001-2002</td>
<td>697,800</td>
<td>$25.93</td>
<td>$13.44</td>
</tr>
<tr>
<td>2002-2003</td>
<td>522,489</td>
<td>$31.07</td>
<td>$13.29</td>
</tr>
<tr>
<td>2003-2004</td>
<td>554,374</td>
<td>$39.49</td>
<td>$6.70</td>
</tr>
</tbody>
</table>
Proof of Concept - Results

Cumulative Avoided Cost From Hydropower Production (2001-2002)

- Forecast x 2
- PerfS_ForeE
- ForeS_PerfE
- Perfect x 2
- Actual Avoided Cost
- Rule of Thumb
- Optimal
Proof of Concept - Results

Cumulative Revenue Relative to Rule of Thumb Operations

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Wet Year</th>
<th>Dry Year</th>
<th>Average Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual Avoided Cost</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forecast x 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forecast Energy, Perfect Streamflow</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forecast Streamflow, Perfect Energy</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Perfect x 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Optimal</td>
<td></td>
<td></td>
<td></td>
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</table>
Current Operations and Forecast Use
Current Operations and Forecast Use
Incorporating Forecasts

Simulation Model – Stella or R

• Simulates system operations

• Calculates how water is routed through the system
Incorporating ESP Forecasts: Parley’s System

- Operated by Salt Lake City
- Releases to supply drinking water
- Releases for flood management
Incorporating Forecasts: Salt Lake City

For today’s example:
1. ESP traces used as inflow to the model
2. Static Rule Curve based on the median historic storage determines how releases are made

\[ \text{Inflows} \quad \rightarrow \quad \text{Reservoir Storage} \quad \rightarrow \quad \text{Releases} \]
## Potential Benefits of Using Forecast

<table>
<thead>
<tr>
<th>Critical Period</th>
<th>Concern</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low inflow or low pool elevation</td>
<td>Not providing enough water</td>
<td>How much releases should be reduced</td>
</tr>
<tr>
<td>High inflows or high pool elevation</td>
<td>Spilling, flooding</td>
<td>Chance of spilling, potential peak inflows</td>
</tr>
</tbody>
</table>
Summed April-July ESP Inflow (Little Dell)

Forecast Year


Summed April-July Inflow (kaf)
Example of Results: High Flow Year

Peak Inflows 1997

Peak Inflow (cfs)

Calendar Month

Apr Jun Jul Aug Oct Dec Feb
ESP Streamflow – High Inflow Year

January 1, 1984 (Little Dell)

April 1, 1984 (Little Dell)

June 1, 1984 (Little Dell)
ESP Streamflow – Low Inflow Year

January 1, 2001 (Little Dell)

April 1, 2001 (Little Dell)

June 1, 2001 (Little Dell)
January ESP – Operational Output (af)
April ESP - Operational Output (af)

Combined Storage

Day

0
100
200
300
Mar 31

Index

1984

Simulated Storage
Rule Curve

Release

Day

0
100
200
300
Mar 31

Index

Simulated Release

Water Releases

Day

0
50
100
150
300
Mar 31

Index

Simulated Culinary Release
Ideal Water Demands
January ESP - Operational Output (af)
April ESP - Operational Output (af)
Iterative Process Getting New Tech Into Ops

We’re Operational Hydrologists!

Floods are our priority

We’re Research Hydrologists!

Our new models are awesome, let’s use them!

How come you are not using X at an X frequency?
We’re Operational Hydrologists!

Flooding is our priority

Our new models are awesome, let’s use them!

NOAA SARP

How come you are not using X at an X frequency?

We’re Research Hydrologists!
Final Thoughts and Future Work

- ESP and HEFS/CFSv2 traces applied in operational framework will provide benefits,
  - we are finishing evaluating at what scales and for what decisions, final evaluations completed by September

- Generating hindcast data for evaluating system in existing framework is iterative process
  - generating data, processing through system, trouble shooting...

- Matching End User needs (update frequency, forecast length, etc.) must be priority in beginning of process
Acknowledgements

- NOAA SARP – Nancy Beller-Simms
- Advisors: Dr. Austin Polebitski, Dr. Richard Palmer
- CBRFC: Kevin Werner, Ashley Nielson
- Dr. Andy Wood
- Case Study Partners: Bruce Meaker, Connely Baldwin, Jeff Niermeyer, Tracie Kirkham, Denis Qualls
Thank You!

Questions?
Project Goals

- Analyze the quality of climate forecast products,
- Work with study partners to develop ways to use products in reservoir operations.
Future Work

• Quantitatively compare the results against perfect forecast information

• Is this a useful seasonal prediction tool?
  • Does including the GEFS forecast improve the regular ESP forecast?
  • What benefits do CFS model provide?

CONCLUSION: Preliminary analysis of these data suggest that climatological skill between the ESP and CFS are similar. More work is needed as the data are still very new.
Example of Results: High Flow Year

![April 1, 1997 ESP Releases Forecast](image)

- **BL Releases (Cfs)**
- **Date**

- **May**
- **Jul**
- **Sep**
- **Nov**
- **Jan**
- **Mar**
Example of Results: High Flow Year

*9/30 expected releases would exceed 1500 cfs for an average of 19 days*
Summed April-July ESP Inflow (Lamb)

Forecast Year


Summed April-July Inflow (kaf)
Summed April-July HEFS Inflow (Lamb)

Forecast Year

Summed April-July ESP Inflow (Little Dell)
Example of Results: High Flow Year

**Peak Inflows 1997**

- **Y-axis**: Peak Inflow (cfs)
- **X-axis**: Calendar Month

- **April**
- **June**
- **July**
- **August**
- **October**
- **December**
- **February**

The box plots show the distribution of peak inflows for each month in 1997.
Example of Results: High Flow Year

April 1, 1997 ESP Elevation Forecast

- Max Storage
- Critical Flood Threshold
- Target Range
- Min Storage

Date

Mean
Median
25% / 75%
Max/Min
Example of Results: Low Flow Year

April 1, 2004 ESP Releases Forecast

BL Releases (Cfs)
Example of Results: High Flow Year

<table>
<thead>
<tr>
<th>Year</th>
<th>Max Storage</th>
<th>Min Storage</th>
<th>Target Range</th>
<th>Critical Flood Threshold</th>
</tr>
</thead>
<tbody>
<tr>
<td>1997</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**April 1, 1997 ESP Elevation Forecast**

- **Max Storage**
- **Critical Flood Threshold**
- **Target Range**
- **Min Storage**

**Graph Details**
- Scale: Pool Elevation
- Dates: May to March
- Lines indicate mean, median, 25% / 75% and Max/Min