Incorporating Large-Scale Climate Information in Water Resources Decision Making

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A Water Resources Management Perspective

Decision Analysis: Risk + Values

• Facility Planning
  – Reservoir, Treatment Plant Size

• Policy + Regulatory Framework
  – Flood Frequency, Water Rights, 7Q10 flow

• Operational Analysis
  – Reservoir Operation, Flood/Drought Preparation

• Emergency Management
  – Flood Warning, Drought Response

Data: Historical, Paleo, Scale, Models
Motivation

- US Bureau of Reclamation (USBR) searching for an improved forecasting model for the Truckee and Carson Rivers (accurate and with long-lead time)

- Forecasts determine reservoir releases and diversions

- Protection of listed species
Outline of Approach

- **Climate Diagnostics**
  - To identify relevant predictors to spring runoff in the basins

- **Forecasting Model**
  - Nonparametric stochastic model conditioned on climate indices and snow water equivalent

- **Decision Support System**
  - Couple forecast with DSS to demonstrate utility of forecast
Data Used

• 1949-2003 monthly data sets:
  • Natural Streamflow (Farad & Ft. Churchill gaging stations)
  • Snow Water Equivalent (SWE)- basin average
  • Large-Scale Climate Variables
Winter Climate Correlations

Carson Spring Flow

500mb Geopotential Height

Sea Surface Temperature
Fall Climate Correlations

Carson Spring Flow

500mb Geopotential Height

Sea Surface Temperature
Physical Mechanism

- Winds rotate counter-clockwise around area of low pressure bringing warm, moist air to mountains in Western US
Climate Indices

- Use areas of highest correlation to develop indices to be used as predictors in the forecasting model
- Area averages of geopotential height and SST

500 mb Geopotential Height

Sea Surface Temperature
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The Ensemble Forecast Problem

- Ensemble Forecast/Stochastic Simulation /Scenarios generation – all of them are *conditional probability density function problems*

\[
f(y_t | y_{t-1}, y_{t-2}, ..., y_{t-p}) = \frac{f(y_t, y_{t-1}, y_{t-2}, ..., y_{t-p})}{\int f(y_t, y_{t-1}, y_{t-2}, ..., y_{t-p}) \, dy_t}
\]

- Estimate conditional *PDF* and simulate (Monte Carlo, or Bootstrap)

- K-NN Approach is Used
Model Validation & Skill Measure

- **Cross-validation**: drop one year from the model and forecast the “unknown” value

- **Compare median of forecasted vs. observed** (obtain “r” value)

- **Rank Probability Skill Score**

\[
RPS(p,d) = \frac{1}{k-1} \left[ \sum_{j=1}^{k} \left( \sum_{i=1}^{n} P_n - \sum_{i=1}^{n} d_n \right) \right]
\]

\[
RPSS = 1 - \frac{RPS(\text{forecast})}{RPS(\text{climatology})}
\]

- **Likelihood Skill Score**

\[
L = \left( \prod_{i=1}^{N} P_{j,i} \right)^{1/N} \left( \prod_{i=1}^{N} P_{c,j,i} \right)
\]
Forecasting Results

**Truckee RPSS results**

<table>
<thead>
<tr>
<th>Month</th>
<th>Median RPSS (all years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nov 1st</td>
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<tr>
<td>Dec 1st</td>
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<td>Jan 1st</td>
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**Carson RPSS results**

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**Truckee Forecasted vs. Observed Correlation Coeff**

- GpH & SWE
- SWE

**Carson Forecasted vs. Observed Correlation Coeff**

- GpH & SWE
- SWE

**Truckee Likelihood Results**

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- Decision Support System
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Seasonal Decision Support System

- Method to test the utility of the forecasts and the role they play in decision making
- Model implements major policies in lower basin (Newlands Project OCAP)
- Seasonal time step
Seasonal Model Policies

- Use Carson water first
- Max canal diversions: 164 kaf
- Storage targets on Lahontan Reservoir: 2/3 of historical April-July runoff volume
- No minimum fish flows (release from upstream reservoir to combat low flows)
Decision Model Flowchart

1. **Ensemble Forecasts**
   - Truckee Forecast
   - Carson Forecast

2. **Is Truckee Forecast > Max Diversion?**
   - No: Truckee Avail for Diversion = Truckee Forecast
   - Yes: Truckee Avail for Diversion = Max Diversion

3. **Is Carson Forecast > Lahontan Target?**
   - No: Diversion Requested = Target – Carson Forecast
   - Yes: Diversion Requested = 0.0 kaf

4. **Is Avail for Diversion > Diversion Request?**
   - No: Truckee Canal Diversion = Avail for Diversion
   - Yes: Truckee Canal Diversion = Diversion Requested

5. **Water Available for Fish**
   - Water Available for Fish = Truckee Fcst – Truckee Canal Diversion

6. **Water Available for Irrigation**
   - Water Available for Irrigation = Carson Fcst + Truckee Canal Diversion

Repeat for each ensemble member.
Decision Variables

• Lahontan Storage Available for Irrigation

• Truckee River Water Available for Fish

• Diversion through the Truckee Canal
Decision Model Results

Dec 1\textsuperscript{st} Forecast

- Irrigation Water
  - Median of Ensemble Irrigation Water (kaf)
  - Perfect Forecast Irrigation Water (kaf)
  - $r = 0.17$

- Canal Diversion
  - Median of Ensemble Diversion (kaf)
  - Perfect Forecast Diversion (kaf)
  - $r = 0.23$

- Water for Fish
  - Median of Ensemble Fish Water (kaf)
  - Perfect Forecast Fish Water (kaf)
  - $r = 0.36$

Feb 1\textsuperscript{st} Forecast

- Irrigation Water
  - Median of Ensemble Irrigation Water (kaf)
  - Perfect Forecast Irrigation Water (kaf)
  - $r = 0.54$

- Canal Diversion
  - Median of Ensemble Diversion (kaf)
  - Perfect Forecast Diversion (kaf)
  - $r = 0.38$

- Water for Fish
  - Median of Ensemble Fish Water (kaf)
  - Perfect Forecast Fish Water (kaf)
  - $r = 0.62$

Apr 1\textsuperscript{st} Forecast

- Irrigation Water
  - Median of Ensemble Irrigation Water (kaf)
  - Perfect Forecast Irrigation Water (kaf)
  - $r = 0.79$

- Canal Diversion
  - Median of Ensemble Diversion (kaf)
  - Perfect Forecast Diversion (kaf)
  - $r = 0.78$

- Water for Fish
  - Median of Ensemble Fish Water (kaf)
  - Perfect Forecast Fish Water (kaf)
  - $r = 0.93$
Dry Year: 1994

- April 1st
  - Truckee Forecast
  - Carson Forecast
  - Storage for Irrigation
  - Canal Diversion
  - Water for Fish

- February 1st
  - Truckee Forecast
  - Carson Forecast
  - Storage for Irrigation
  - Canal Diversion
  - Water for Fish

- December 1st
  - Truckee Forecast
  - Carson Forecast
  - Storage for Irrigation
  - Canal Diversion
  - Water for Fish
Wet Year: 1993

April 1st

February 1st

December 1st

Truckee Forecast

Carson Forecast

Storage for Irrigation

Canal Diversion

Water for Fish
Normal Year: 2003

April 1st
- Truckee Forecast
- Carson Forecast
- Storage for Irrigation
- Canal Diversion
- Water for Fish

February 1st

December 1st
## Exceedance Probabilities

<table>
<thead>
<tr>
<th>Year</th>
<th>Date</th>
<th>Irrigation Water mean value (kaf)</th>
<th>264 kaf Irrigation Water exceedance probability</th>
<th>Fish Flow mean value (kaf)</th>
<th>60.5 kaf Fish Flow exceedance probability</th>
<th>Canal Diversion mean value (kaf)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1994</strong></td>
<td>Apr 1st</td>
<td>94</td>
<td>4%</td>
<td>0</td>
<td>0%</td>
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<td></td>
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<td>161</td>
<td>14%</td>
<td>42</td>
<td>57%</td>
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<td>Dec 1st</td>
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<td>39</td>
<td>58%</td>
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<tr>
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<td>Historical</td>
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<td>50%</td>
<td>199</td>
<td>87%</td>
<td>84</td>
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<tr>
<td><strong>1993</strong></td>
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<td>452</td>
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<tr>
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<td>332</td>
<td>73%</td>
<td>391</td>
<td>99%</td>
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<tr>
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<td>Dec 1st</td>
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<td>138</td>
<td>81%</td>
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<tr>
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<td>264</td>
<td>50%</td>
<td>199</td>
<td>87%</td>
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<td><strong>2003</strong></td>
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<td>Feb 1st</td>
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<td>223</td>
<td>91%</td>
<td>106</td>
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<td>225</td>
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<td>71</td>
<td>69%</td>
<td>108</td>
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Summary & Conclusions

- Climate indicators improve forecasts and offer longer lead time
- Water managers can utilize the improved forecasts in operations and seasonal planning

Grantz et al. (2005) – submitted to BAMS
Acknowledgements

Funding

- CIRES and the Innovative Research Project
- Tom Scott of USBR Lahontan Basin Area Office