A Seasonal Operational Model for Water Management within Irrigation Districts

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Project Objectives

1. **Find the best way to manage irrigation district reservoirs and licensed diversions**
   - Achieve “Best Possible Supply” to meet irrigation demands

An example of typical seasonal irrigation demand vs. supply

- **Ideal Demand**
- **Achieved Supply**
- **Best Possible Supply**
2. Extend computer model results from planning studies to real time operation
   - Model irrigation season at weekly time scale
   - Move from “STO” to “MTO” (*multiple time step optimization*)

**Benefit:** Example of reductions in annual irrigation deficits in the WID for STO vs. MTO simulation
A report on our work over the last year:

1. Seasonal runoff projections for Southern Alberta
2. Seasonal Operational Model development
3. Low flow management for City of Calgary
1. Seasonal Runoff Forecasting

**Step 1:** Use snowpack surveys and other indicators to obtain seasonal runoff forecast and the return period of the current hydrological year.

**Step 2:** Break down seasonal forecast into weekly flows by using probability plot of historic weekly natural flows and selecting the same return period as the seasonal forecast for all weeks after May 1st.
Substantial portion of the runoff comes from the mountains.

Prepared three data sets for forecasting:
“S1”: Local observations + climate indices (1981-2014)
“S2”: Longer records, fewer variables (1970-2014)
“S3”: Only climate indices used (1950-2014)

Testing: 65% of record; Validation: 35% of record
Streamflow Forecasting Methods

→ **Models employed**
  - Multiple Linear Regression
  - Support Vector Machines
  - Extreme Learning Machines

→ **Techniques for selecting input variables**
  - High correlation (Pearson)
  - Forward stepwise selection
  - Backward stepwise elimination
  - Principle component analysis (PCA)

→ **Result:** Extreme Learning Machines with PCA yielded the best predictions
## Streamflow Forecasting Results

The table below presents the performance metrics for different models in forecasting streamflows. The models are compared against seasonal (MJJ) average streamflows. The metrics include Mean Absolute Error (MAE), Root Mean Square Error (RMSE), Coefficient of Determination ($R^2$), Nash-Sutcliffe coefficient (NSE), and Index of Agreement ($d$).

<table>
<thead>
<tr>
<th>Model</th>
<th>Mean absolute error (MAE; m³ s⁻¹)</th>
<th>Root mean square error (RMSE; m³ s⁻¹)</th>
<th>Coefficient of determination ($R^2$)</th>
<th>Nash-Sutcliffe coefficient (NSE)</th>
<th>Index of agreement ($d$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ELM</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S1</td>
<td>36.3</td>
<td>42.2</td>
<td>0.81</td>
<td>0.31</td>
<td>0.80</td>
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<tr>
<td>S2</td>
<td>24.8</td>
<td>31.0</td>
<td>0.80</td>
<td>0.59</td>
<td>0.88</td>
</tr>
<tr>
<td>S3</td>
<td>34.0</td>
<td>42.2</td>
<td>0.07</td>
<td>0.03</td>
<td>0.40</td>
</tr>
</tbody>
</table>

Recall: S1, S2, and S3 are the data sets used.

MAE and RMSE are compared against seasonal (MJJ) average streamflows.
Streamflow Forecasting Results

Shown: Average seasonal streamflows (MJJ average)

ELM S2 model and observed streamflow for the training and testing period (1970-2014)

GoF's:
MAE = 24.82
RMSE = 30.98
R^2 = 0.82
NSE = 0.64
d = 0.89
Updated Results (May 23)

**Bow River below Bearspaw Reservoir**

- **Observed**
- **Forecasts**

**GoF's:**
- MAE = 23.2
- RMSE = 29.97
- R2 = 0.83
- NSE = 0.66
- d = 0.9

*ELM S2 model and observed streamflow for the testing period (2000-2017)*

→ **Current prediction for summer 2018 is 218 m$^3$s$^{-1}$**
Next Steps in Stream. Forecasting

- Current ELM S2 model is ready for use
- Testing alternative forecasting methods that rely on sea surface temperatures (SST)
  - Offer possibility of improved results
  - Wavelet Analysis has been used successfully in many other regions
2. Seasonal Operational Model

Characteristics of Seasonal Operational Model

- Optimization model at weekly time step
- Includes all relevant physical constraints
  - Canal and storage capacities, outflow capacities, return flows, etc.
- Includes operational constraints
  - Water license limits (vol. + max. flow), minimum flows, apportionment, deficit sharing agreements
- Runs **Single** or **Multiple** Time Step Optimization
- Can simultaneously find ideal supply releases and demand reductions in dry years
New Model Interface

BASIN MANAGEMENT MODEL (BMM)

- scf.txt
- hbdf.txt
- Select SCF File
- Select HBDF File

- Save Constraints As TXT File
- Save Optimal Solutions As TXT File
- Save Constraints As LINDO File
- Save Reservoir Levels As Volumes

- Seasonal Operation

Start Date: Sunday, January
Number Of Time Intervals: 1
Sensitivity Analysis: 0.0000
Aridity Factor: 1.0000

Calculate | Cancel
The second selection is the number of time intervals:
### Dynamic Model Input

#### Reservoirs Initial Storage Levels

<table>
<thead>
<tr>
<th></th>
<th>Reservoirs Initial Storage Levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Reservoir Name / Num Starting Storage Level</td>
</tr>
<tr>
<td>2</td>
<td>Reservoir 1</td>
</tr>
<tr>
<td>3</td>
<td>Reservoir 2</td>
</tr>
<tr>
<td>4</td>
<td>Reservoir 3</td>
</tr>
</tbody>
</table>

#### Diversion Channels Demands Forecast

<table>
<thead>
<tr>
<th></th>
<th>Diversion Channels Demands Forecast</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Diversion Channel Name / Num Remaining Water To Be Diverted</td>
</tr>
<tr>
<td>2</td>
<td>DiversionChannel 10</td>
</tr>
<tr>
<td>3</td>
<td>DiversionChannel 19</td>
</tr>
<tr>
<td>4</td>
<td>DiversionChannel 15</td>
</tr>
<tr>
<td>5</td>
<td>DiversionChannel 14</td>
</tr>
<tr>
<td>6</td>
<td>DiversionChannel 12</td>
</tr>
<tr>
<td>7</td>
<td>DiversionChannel 17</td>
</tr>
</tbody>
</table>

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Model Result: Projected storage levels and crop application based on seasonal forecasts

Current Date

Simulated Time Series of Component
RESERV 1

Water surface elevation [m]

557
556
555
554
553
552

Time [intervals]

1 2 3 4 5 6 7 8 9 10 11 12

+10 %
-10 %
Next Steps in Model Dev’t

→ Testing and validation
  - Includes development of publishable MTO model benchmark test

→ Setting up the model for Irrigation Districts

→ Porting the model to the web
3. Low Flow Mgt. for Calgary

- Completed hydrometric data “gap-filling” algorithm
  - Produced weekly flow series at 15 stations for 904 years of data
  - Publication of algorithm subject to minor revisions in HSJ

Work based on study with Prof. Sauchyn:

Reconstruction of 904 years of annual flows using tree ring data

Example of 904 years of flows for a single site at weekly scale
The Fifteen Stations in the Study

- Cascade River at Lake Minnewanka
- Bow River Below Kananaskis
- Bow River at Bearspaw Dam
- Bow River at Ghost Dam
- Nose Creek at the Mouth
- Highwood River at the Mouth
- Bow River at Banff
- Spray River at the Mouth
- Spray River at Spray Lake
- Kananaskis River at Barrier Lake
- Kananaskis River at the Lower Kananaskis Lake
- Kananaskis River at the Upper Kananaskis Lake
- Highwood River at High River
- Fish Creek at the Mouth
- Elbow River at Glenmore Dam
Validation of the Gap-Filling Algorithm

Figure 6. Bow River at Ghost Lake - Historic vs Simulated Flows

Historic and in-filled weekly flows (m3/s)

Time (years)

Ilich, Gharib and Davies (HSJ, under revision)
Results for City of Calgary

- Completed Bow River Basin modelling study for City of Calgary
  - Relied on 904 years of weekly natural flows matched with the existing licenses and infrastructure
  - Utilized new operating rules for Glenmore Dam to offset potential deficit at Bearspaw Dam, and also used recently established operating rules for Ghost Dam
  - Utilized higher storage available at Glenmore Dam based on design specs for new spillway gates and revised operating rule curve

- Results showed deficits for the Calgary water supply in only 7 of 904 years

- Study was reviewed and accepted by the City of Calgary

- 904 years of weekly flows (1111 – 2014) are available to other researchers
Conclusion

Our aims are to develop a method that,

- Allocates water more efficiently than the current computer-based tools \( \rightarrow \) more efficient water use
- Improves reservoir operations
- Provides optimal diversion and reservoir releases from week-to-week or month-to-month within a single season, based on actions to date and current hydrological data

Practical Result: Optimization of operations over ~10 week horizon, with updated guidance based on current storage levels and crop demands