

## **Enhanced Indicators of Land Use Change and Climate Variability Impacts on Prairie Hydrology Using the Cold Regions Hydrological Model**

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### **ABSTRACT**

The Cold Regions Hydrological Model has proven to be a useful research tool in assessing the impacts of land use and climate variability on water balance and streamflow. The results are useful in making recommendations for improved land management practices. The model is based on a modular, object-oriented structure in which each module represents a physically based algorithm that has been derived from recent process-based research. The user selects modules from a library to be compiled by the model, according to the hydrological needs of the investigation and watershed. Enhanced, quantitative indicators of hydrological response have been developed with the intent of evaluating the sensitivity of the prairie water balance to land use change and climate variability. The indicators focus on the hydrological processes of snow accumulation, snowmelt, evapotranspiration and runoff generation.

Development and testing of the indicators use data from a sub-basin in the upper reaches of the Little Bow watershed located north of Lethbridge, Alberta over a series of wet/cool and dry/warm years. This area has cropping and grazing practices and topography and drainage features that are typical of the Canadian prairies. Seasonal runs of the model were performed for 1997/98 and 1999/2000 during the winter, spring and summer months. Snow accumulation, snow ablation, infiltration into frozen soils and the summer water and energy balance were modelled. The response of the model and enhanced indicators to variations in land cover and climate variability is demonstrated and discussed.

Key words: Hydrological model, land use, quantitative indicators

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## **INTRODUCTION**

An integrated assessment of land use impacts on water balance and streamflow is necessary in order to make sound recommendations for improved land management practices. To achieve this, the results from recent process-based hydrology research have been integrated into a numerical Cold Regions Hydrological Model (CRHM). The model provides the user with advanced techniques for the calculation of water balance and streamflow. For over 30 years, hydrological models have been developed, improved and evaluated by the Authors. This experience has recommended the following considerations for modelling Cold Region environments:

1. Coupled flow of water in liquid, vapour and frozen states,
2. Coupled mass and energy balance controls on process rates,
3. Phase change in soils (frozen soils),
4. Snow and rain interception in forest canopies,
5. Consideration of hillslope and aspect on “vertical exchange processes”,
6. Episodic flow between soil moisture, groundwater and base flow.

The objective is to develop a model that is sensitive to the impacts of land use and climate change.

## **COLD REGIONS HYDROLOGICAL MODEL**

CRHM has a modular, object-oriented structure. Each module represents a physically-based algorithm. The user selects modules from a library to simulate the physical processes appropriate to the basin and investigation. Spatial information is incorporated using a GIS interface.

### **Data Component**

In this component of the model, spatial and meteorological data is prepared for CRHM. Time-series meteorological data include air temperature, humidity, windspeed, precipitation and radiation, etc. Spatial data (e.g. basin area, elevation, and cover type) is analyzed using a GIS interface tool that assists the user in basin delineation, characterization and parameterization of Hydrological Response Units (HRUs). HRUs are subdivisions of the basin characterized by the operator from an understanding of the hydrological processes and land use.

### **Model Component**

CRHM utilizes a Windows-based series of pull-down menus linked to the system features. Modules are selected from the library and grouped together by the CRHM processor. Modules have a set order of execution with common variables and constants; certain variables and constants are retrieved from specified modules for use in the calculations within a module. Modules are created in C++ programming language.

### **Analysis Component**

The Analysis Component is used to display, analyze and export results. Statistical and graphical tools are used to analyze input data and model performance. Sensitivity-analysis tools are provided to optimize selected model parameters and evaluate their effects on simulation results.

## **LITTLE BOW WATERSHED**

The Little Bow watershed is located 40 km north of Lethbridge, Alberta, Canada at approximately 50.11°Lat. 112.71°Long. Only the upper reaches (sub-basins 41 & 42) of the Little Bow basin were analyzed. Approximately 62.5% of the total basin area (127.35 km<sup>2</sup>) is native grass. The landscape is predominately rolling and undulating topography with glacial and lacustrine soil. Climate data was retrieved from meteorological stations located near Lethbridge and Vauxhall, Alberta for 1997 to 2000. The Lethbridge Research Centre provided basin precipitation and streamflow data.

## MODEL RESULTS

### Water Balance / Land Use Scenarios

CRHM is used to calculate basin water balance and model land use scenarios. Figure 1 displays the water balance outputs generated from CRHM that were used to determine the snow accumulation efficiency and runoff efficiency results. Table 1 summarizes the effect of modifying the HRU content within the basin. With a reduction in native grassland and increase in stubble, the runoff and sublimation increases while infiltration decreases.

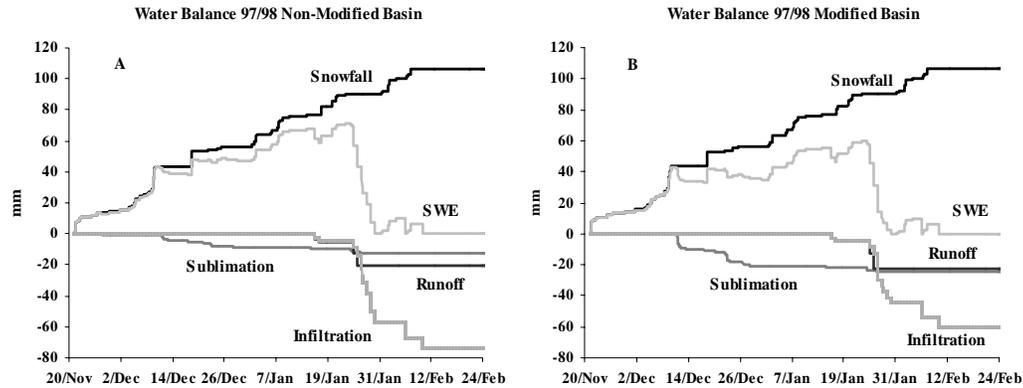


Figure 1. Modelled water balance results for the Little Bow watershed, sub-basins 41 and 42 for original (A) and modified (B) HRU scenarios.

**Table 1. Water balance for Little Bow sub-basins 41 and 42.**

|                | fallow | stubble | native | riparian | snowfall | runoff  | infiltration | sublimation |
|----------------|--------|---------|--------|----------|----------|---------|--------------|-------------|
| Basin as is    | 12.18% | 16.80%  | 62.47% | 8.54%    | 106.5 mm | 20.8 mm | 73.5 mm      | 12.2 mm     |
| Basin Modified | 12.18% | 75.35%  | 3.93%  | 8.54%    | 106.5 mm | 22.5 mm | 59.8 mm      | 24.2 mm     |

### Hydrological Indicators

Three Hydrological Indicators were developed using CRHM outputs.

1. Snow Accumulation Efficiency (S-Ratio: SWE/Snowfall) - use outputs from Prairie Blowing Snow Model (PBSM) (Pomeroy and Li 1997) to show variations between HRUs and the effect of land-use change simulations on entire basin snow water equivalent (SWE).

2. Runoff Efficiency (R-Ratio: Runoff/SWE) - use outputs from PBSM and Infiltration (Gray et al. 1985) modules to show variations between HRUs and the effect of land-use change simulations on entire basin snow water equivalent.

3. Evapotranspiration Efficiency (E-Ratio: LE/Rn) - use outputs from Evaporation (LE) (Granger and Gray 1989) and Radiation (Rn) (Granger and Gray 1990) modules to show variations between HRUs and the effect of climate variability by comparing wet and dry years (Figure 2).

A summary of indicator results that shows the sensitivity of the Little Bow basin water balance to land use change and climate variability is displayed in Figure 3.

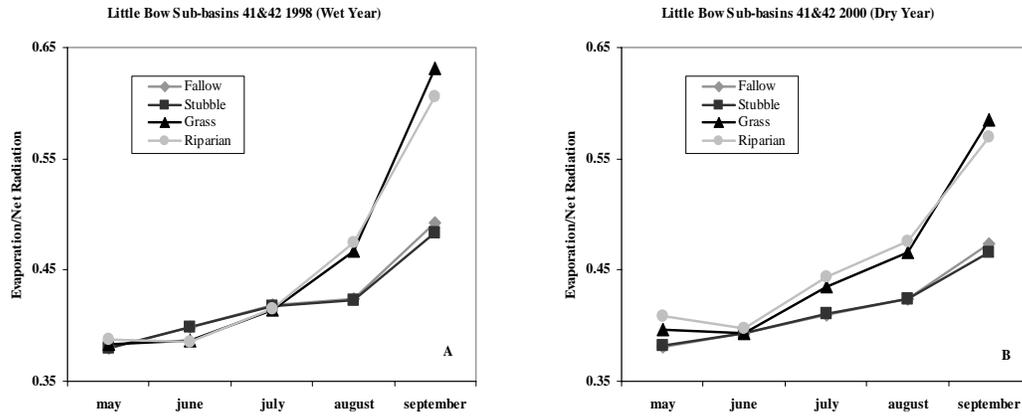


Figure 2. Evapotranspiration Efficiency (E-Ratio) determined for wet (A) and dry years (B) for the Little Bow watershed sub-basins 41 and 42. The larger the  $LE/R_n$  the more 'productive' the vegetative cover.  $LE/R_n$  is lowest in May and greatest in September as the ground warms.  $LE/R_n$  is similar in Spring for both years but is higher in the wet year by the end of Summer.

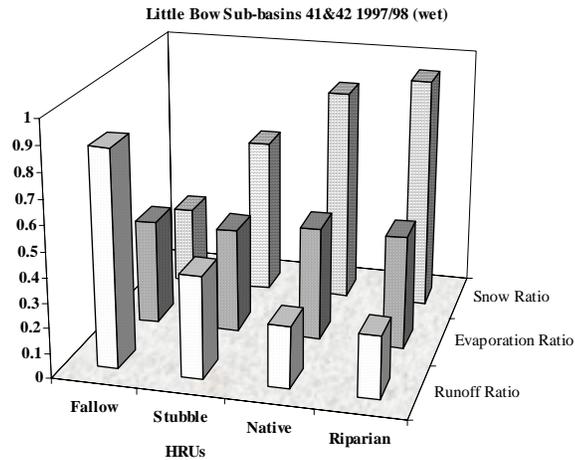


Figure 3. Combined graph showing S, R, and E-Ratio Indicators for 1997/98. The S and R-Ratio Indicators respond to the change in HRU type. The E-Ratio Indicator response is limited by temperature and relative humidity interpolation constraints.

## CONCLUSIONS

Modular, process-based, distributed, hydrological modelling has been developed for cold regions. Hydrological process simulations can show the direct result of land use cover and configuration in a basin on phenomena such as snow accumulation, evapotranspiration, melt and Spring streamflow. Scenarios corresponding to 'virtual' landcover patterns can be considered and the impacts of changes to existing land use on the peak snowmelt discharge anticipated.

## FUTURE WORK

The aim is to extend CRHM to include the full hydrological year and greater range of land use and environments. Modules will be added to include forest and tundra hydrological processes. Improved consideration of slope and aspect effects on processes will be incorporated. Other work

in progress includes fully incorporating a GIS interface and water quality module. And continued sensitivity analysis of model performance with field data.

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