Using Field Surveys and LiDAR to Derive Parameters for Uncalibrated Spring Streamflow Prediction Using the Cold Regions Hydrological Model

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Background and Research Objectives

❖ Snow redistribution, snowmelt and infiltration to frozen soils are important hydrological processes in generating runoff in the Canadian Prairies. Snowmelt produces not only the majority of annual streamflow but also the peak annual flow event.

❖ The eastern Canadian Prairies are characterized by cropland, pasture, woodland and wetlands, with poorly developed drainage over impermeable post-glacial till. The contributing area for streamflow is highly variable and controlled by antecedent depressional water storage.

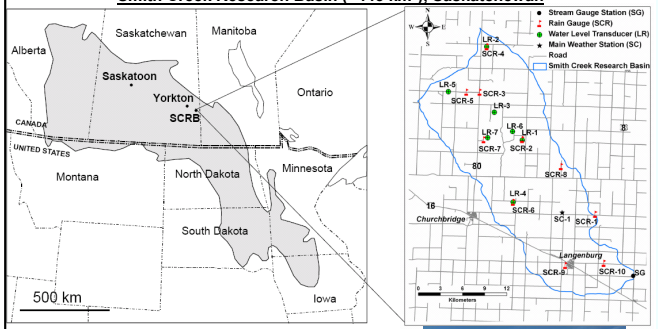
❖ Simulating streamflow in river basins with varying contributing area is challenging due to uncertainty in estimation of surface storage in small depressions and wetlands. This is particularly difficult in droughts when storage and contributing areas are very small.

❖ This study focuses on the development of a physically based, modular hydrological model that is suitable for a Canadian Prairie wetland environment. This study also sets up and compares calibrated and uncalibrated hydrological modelling approaches as well as examines the possibility of uncalibrated prediction for ungauged basins.

❖ Specific objectives are to evaluate the model performance in simulating winter redistribution of snow by wind, snowmelt, soil moisture states during spring snowmelt period, and spring basin streamflow.

Study Site and Field Observation

Smith Creek Research Basin (~445 km²), Saskatchewan



❖ Meteorology, radiation, snow depth, soil moisture, precipitation at a central weather station.

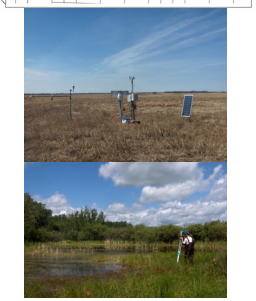
❖ Rainfall from 10 stations; wetland water level from 7 stations.

❖ Basin streamflow discharge measurement at basin outlet Water Survey of Canada station.

❖ Coarse resolution (25-m) topographic map based DEM and fine resolution (1-m) LiDAR-derived DEM, SPOT 5 (10-m) multispectral images, basin drainage and wetland GIS inventory.

❖ 14 detailed wetland bathymetric surveys.

❖ 18 snow survey and soil moisture transects (total length 2010 m).



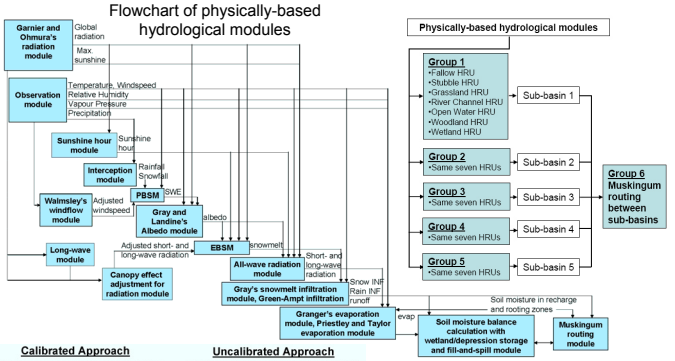
Model Description and Parameterization

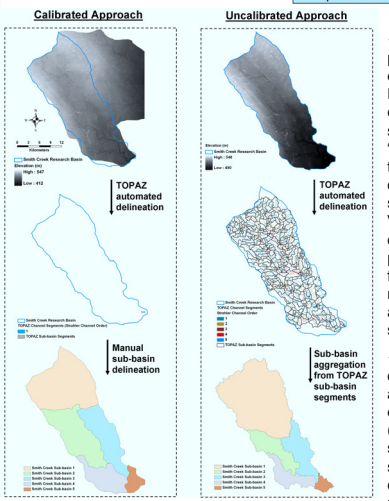
❖ The Cold Regions Hydrological Modelling platform (CRHM) (Pomeroy et al., 2007) is a physically based, modular, object oriented model assembly system. Within CRHM, component modules can be selected to represent basin descriptions, observations and physically based algorithms for simulating the hydrological cycle. A pre-processing procedure involving two modelling approaches: calibrated and uncalibrated was used to estimate values of model parameters.

❖ Both modelling approaches divided Smith Creek basin to five sub-basins. In the calibrated approach, sub-basins were manually delineated from examination of drainage networks and a coarse resolution DEM. In the uncalibrated approach, a LiDAR derived fine resolution DEM was used to delineate the drainage network and sub-basins were aggregated from TOPAZ sub-basin segments to a total area of 393 km². 'Groups' of HRU were set for each sub-basin and a Group was set up to connect HRUs.

❖ Physically based hydrological modules were assembled and simulations were carried out on 'Hydrological Response Units' (HRUs). Within each sub-basin, seven HRUs: fallow, stubble, grassland, river channel, open water, woodland, and wetland were derived from supervised classification of SPOT 5 imagery.

Flowchart of physically-based hydrological modules

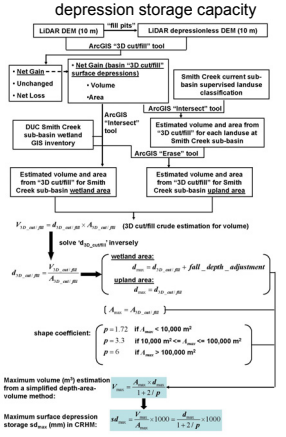


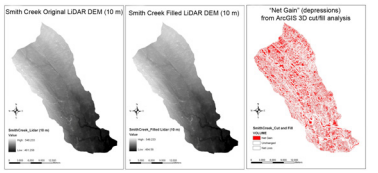


❖ In both modelling approaches, sub-basin physiographic characteristics (ground slope, elevation) were determined from DEM and HRU areas were derived from a supervised classification of the SPOT 5 image. Blowing snow fetch distance was estimated using "FetchR" program (Lapen and Martz, 1993); the blowing snow distribution factor was decided from prairie landscape aerodynamic sequencing (Fang and Pomeroy, 2009). Vegetation height and fall soil moisture were determined from field surveys. Routing parameters (channel length, longitudinal friction slope, hydraulic radius, Manning's roughness coefficient) were derived from GIS analysis of the drainage networks and field surveys of channel conditions.

❖ In the calibrated approach, the surface depression storage capacity in the wetland areas (wetland and open water HRUs) was estimated using a volume-area relation (Wiens, 2001); for the upland area (fallow, stubble, grassland and woodland HRUs), the surface depression storage capacity was calibrated by so that simulated closely matched observed hydrographs.

Flowchart of an automated procedure for depression storage capacity





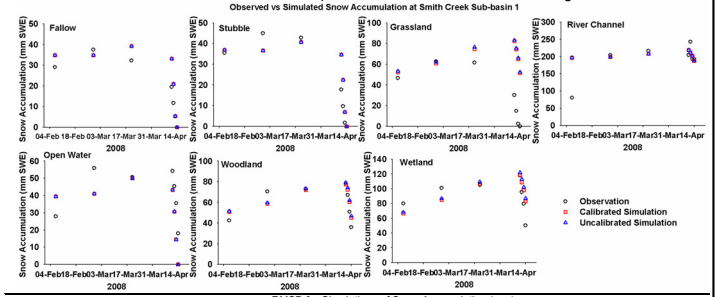
❖ In the uncalibrated approach, an automated procedure involving LiDAR DEM and various ArcGIS tools was used to extract initial depth, area and volume of surface depression. In turn, they were input into a simplified depth-area-volume relationship (Brooks and Hayashi, 2002). Values of the depression storage capacity were estimated for both wetland and upland areas.

❖ The shape coefficient value for small depressions (A_{max} < 10,000 m²) was estimated from the analysis of wetland bathymetric survey data (Minke et al., 2009); for the larger depressions, the value reported by Hayashi and van der Kamp (2000) was used.

Model Performance Evaluation

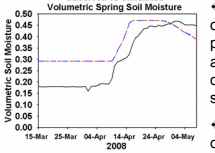
❖ Simulations of snow accumulation (SWE) during the winter 2007-08 were evaluated against snow survey observations from the pre-melt and melt periods for both calibrated and uncalibrated modelling. The calibrated and uncalibrated simulations had very similar results and both were generally in good agreement with the observations for most HRUs. The exception is for fallow, stubble, grassland and open water HRUs during the melt period.

❖ The root mean square difference (RMSD) was very close between the calibrated and uncalibrated simulations for HRUs in all sub-basins except for wetland HRU in sub-basins 2 and 3 due to the difference in the delineated sub-basin size. The RMSD ranged from 1.7 to 7.9 mm for fallow, stubble, open water and woodland HRUs, indicating generally good performance. Larger RMSD were found for grassland, river channel and wetland HRUs, ranging from 7.1 to 25.2 mm. The general sequence of wind redistribution of snow was well simulated: snow was relocated from fallow fields to channels and wetlands and provided the source water for runoff generation.

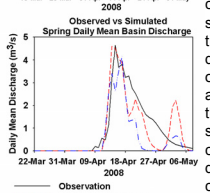


RMSD for Simulations of Snow Accumulation (mm)

	Sub-basin 1		Sub-basin 2		Sub-basin 3		Sub-basin 4		Sub-basin 5	
HRU Name	Calibrated	**Uncalibrated**	Calibrated	**Uncalibrated**	Calibrated	**Uncalibrated**	Calibrated	**Uncalibrated**	Calibrated	**Uncalibrated**
Fallow	2.6	**2.6**	1.8	**2.6**	2.7	**1.9**	2.6	**1.9**	1.7	**1.7**
Stubble	3.3	**3.3**	3.3	**3.3**	7.0	**6.9**	6.8	**6.8**	6.1	**6.1**
Grassland	16.3	**16.6**	16.7	**19.2**	14.9	**16.3**	18.1	**19.9**	15.9	**16.6**
River Channel	17.4	**17.4**	17.4	**17.4**	12.7	**10.3**	13.4	**17.2**	15.4	**10.0**
Open Water	5.4	**5.4**	5.4	**5.4**	5.5	**5.5**	5.5	**5.5**	7.9	**7.9**
Woodland	2.9	**3.1**	3.0	**3.1**	2.9	**2.7**	2.8	**2.8**	2.7	**2.7**
Wetland	6.4	**7.1**	9.6	**25.2**	17.3	**12.3**	17.9	**16.7**	10.8	**11.5**



❖ The simulated volumetric soil moisture was tested against observations from the main weather station during 2008 spring melt period. Both calibrated and uncalibrated simulations were similar. There are some discrepancies between the simulated and observed values; on average, the difference between simulated and observed volumetric soil moisture was about 1% .



❖ Model performance in simulating basin streamflow was evaluated by comparing simulated and observed daily discharge at the basin outlet in spring 2008. Both calibrated and uncalibrated simulations had good timing for the peak discharge, with very comparable magnitudes of peak discharge to the observation. The RMSD between daily discharge observations and simulations were 0.09 and 0.11 m³/s for the calibrated and uncalibrated simulations, respectively. Both simulations predicted the same duration of 27 days for the spring streamflow, three days shorter than the observed one. Based on the model bias (MB), the calibrated and uncalibrated simulations underestimated the total basin discharge by 7% and 38%, respectively. The calibrated simulation calibrated the upland area surface depression storage by comparing to the observed hydrograph, resulting in better overall performance.

	RMSD		MB	Peak Discharge	Duration
	Volumetric Soil Moisture	Basin Discharge (m³/s)	Basin Discharge	(m³/s)	(Day)
Observation	N/A	N/A	N/A	4.65	30
Calibrated Simulation	0.012	0.09	-0.07	4.61	27
Uncalibrated Simulation	0.012	0.11	-0.38	4.17	27

Conclusions

❖ Prairie spring streamflow was simulated by assembling the major hydrological processes in the Cold Regions Hydrological Modelling platform (CRHM). Calibrated and uncalibrated modelling were set up; uncalibrated modelling employed an automated parameter estimation procedure using field surveys and LiDAR DEM. Comparisons were made among the observations, and calibrated and uncalibrated simulations. The simulations showed a generally good ability to predict wind redistribution of snow, snowmelt, soil moisture, peak discharge volume and timing.

❖ Compared to the calibrated modelling, the uncalibrated modelling had slightly poorer performance in predicting the cumulative spring basin discharge but is still within a satisfactory range. The uncalibrated modelling generated an parameterization procedure that can be useful for modelling an ungauged basin if adequate information on basin physiography, meteorological and landcover is available.

Acknowledgements

Financial support was provided through the CFCAS Drought Research Initiative (DRI) network, Prairie Habitat Joint Venture Policy Committee, Agriculture and Agri-Food Canada, Prairie Provinces Water Board, Saskatchewan Watershed Authority and the Canada Research Chairs Programme. Michael Solohub, Adam Minke, and Nathalie Brunet provided field support.