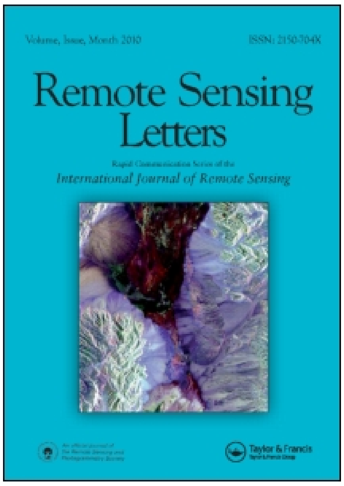

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Effects of classification approaches on CRHM model performance

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Effects of classification approaches on CRHM model performance

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The cold regions hydrological model (CRHM) platform, a physically based hydrological model using a modular and object-oriented structure, has been applied for simulating the redistribution of snow by wind, snowmelt, infiltration, evapo-transpiration, soil moisture balance, surface depression storage and run-off routing. Land use and land cover classification is a preprocessing procedure to provide the required parameters for CRHM. Per-pixel-based and object-oriented classifications are the two major classification approaches currently in practice. The objective of this study is to evaluate whether the more complex object-oriented classification method can significantly improve the performance of the CRHM model in a prairie landscape. The study was conducted in the Smith Creek watershed in eastern Saskatchewan. Two Satellite Pour l'Observation de la Terre (SPOT) multispectral images were used to classify the area into seven classes: cropland, fallow, grassland, wetland, water, woodland and town/road. Both pixel-based maximum likelihood supervised classification method and nearest neighbour object-oriented classification approach were applied to the satellite images for the study area. The parameters derived from both classification methods were input into the CRHM to derive the hydrological response unit (HRU), snow water equivalent (SWE) and basin stream flow. Results indicated that classification results influence the model performance slightly. However, no significant improvement from the object-oriented classification was observed for this specific study.

1. Introduction

Hydrology in the Canadian prairie region is complex and highly varied. Hydrological processes in the prairie region are sensitive to land cover and climate change. Wetlands can be completely dried out when surrounded by native grassland rather than agricultural fields. The cold regions hydrological model (CRHM) platform is the latest prairie hydrological model development and is the 'state-of-the-art' physically based hydrological model for the prairie region. CRHM is based on a modular, object-oriented structure in which component modules represent basin descriptions, observations or physically based algorithms for calculating hydrological processes. The component modules have been developed based on the results of over 40 years of research by the University of Saskatchewan and National Water Research Institute in prairie, boreal, mountain and arctic environments. A full description of CRHM is

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provided by Pomeroy *et al.* (2007). CRHM permits the assembly of a purposefully built model from a library of processes, and interfaces the model to the basin on the basis of a user selected spatial resolution. Current modules in CRHM that are relevant to prairie hydrological processes include (1) prairie blowing snow model (Pomeroy and Li 2000), (2) energy-budget snowmelt model (Gray and Landine 1988), (3) Gray's expression for snowmelt infiltration (Gray *et al.* 1985, 2001), (4) Green–Ampt infiltration and redistribution expression (Ogden and Saghafian 1997), (5) Granger's evaporation expression for estimating actual evaporation from unsaturated surface (Granger and Gray 1989, Granger and Pomeroy 1997), (6) a soil moisture balance model for calculating soil moisture balance and drainage (Leavesley *et al.* 1983) and (7) Clark's lag and route run-off timing estimation procedure (Clark 1945). These modules were assembled along with modules for radiation estimation and albedo changes (Gray and Landine 1987, Granger and Gray 1990) into the CRHM. As new components, additional modules that incorporate wetland/lake storage and spill and dynamic drainage network were added into the CHRM recently (Fang *et al.* 2010).

As land cover and land use play a critical role in prairie hydrology, the CRHM model's performance is based on the accuracy of land cover and land use classification. There are many established land use/land cover classification approaches. Research has indicated that the object-oriented classification method is superior to other classification methods because of the consideration of non-spectral information, such as shape, texture and topography (Guo *et al.* 2006). Therefore, the purpose of this study is to evaluate the model performance based on different classification approaches. More specifically, the objectives are to (1) classify the study area using both pixel-based and object-oriented classification methods, (2) run the CRHM model with the classification results from both methods and (3) compare the model results.

2. Study area

The study area is in Smith Creek, which is located in east-central Saskatchewan, Canada. This is a high-priority area for conservation programme delivery of the Prairie Habitat Joint Venture (PHJV) and the North American Waterfowl Management Plan. Water flows south and east from these sub-basins into the Assiniboine River Watershed of both Saskatchewan and Manitoba. In its current state, the watershed is dominated by cropland with extensive areas of wetland drainage; however, significant concentrations of natural features still exist. The study area was subdivided into five sub-watersheds (figure 1). A weather station and some rain gauges as well as water-level transducers were installed in the study area.

3. Image acquisition and classification

Two Satellite Pour l'Observation de la Terre (SPOT) 5 10-m multi-spectral images were acquired on 5 July 2007 and 1 October 2008. Summer images are good for separating vegetation and non-vegetation features while fall images are good for cropland and natural vegetation separation. Field data were collected in the summer of the same year. Additionally, over 500 field samples were obtained from Ducks Unlimited Canada (DUC), a Non-Government Organization of Wetland and Wildlife Conservation in Canada. The images were radiometrically and geometrically corrected and were clipped for the study area. One normalized difference vegetation index (NDVI) layer was created in the summer image to aid in the classification.

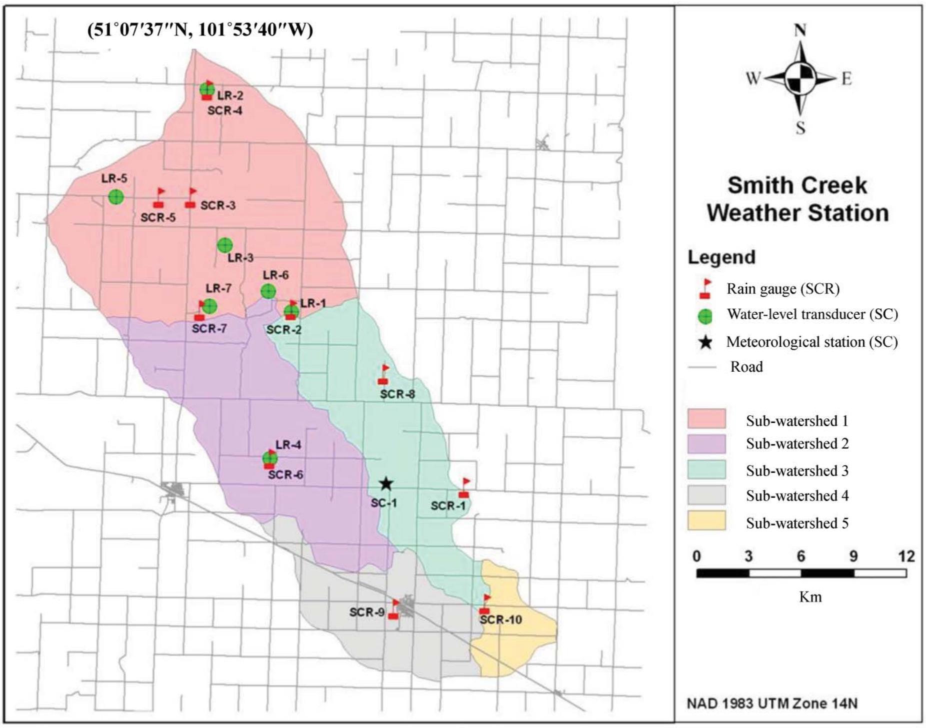

Figure 1. The study area showing subdivisions and the installed rain gauges and weather station.

Two classification methods were applied. Supervised pixel-based classification was implemented using PCI Geomatics and the object-oriented classification by eCognition. The seven class schemes were cropland (fallow), cropland (stubble), grassland/pasture, wetland (shrubs), open water, woodland (tree) and town/road. For the object-oriented classification approach, two steps were applied: segmentation and classification. The scale is a critical parameter on classification as it determines how much detail in the landscape will be fragmented. Based on a comparison of different scale levels (3, 5, 8 and 10), a scale of 5 was selected as it could identify small wetlands and kept the landscape in a uniform pattern.

For the object-oriented classification, before applying the training points to the classification, three rules were set up: (1) open water: digital number in near-infrared band $\leq$66; (2) cropland stubble: hue $\leq$0.7 and (3) town/road: grey-level co-occurrence matrix contrast of digital number of red band in all directions $\geq$110 for the summer image. All samples were applied to both summer and fall images to separate the other land cover types. Both classified thematic maps were entered into the CRHM model as inputs for deriving hydrological parameters, including hydrological response units (HRUs) and basin stream flow. Snow water equivalent (SWE), a measure of the amount of water contained within the snowpack, then was simulated in each HRU and the daily discharge of the stream flow was also simulated using the CRHM model.

4. Results and discussion

4.1 *Classification results*

Classified maps from the pixel-based supervised classification and object-oriented methods showed that the pixel-based classification map had more woodland and the object-oriented classification map had more grassland (figure 2). A close look at a small area indicated that the object-oriented classification identified small wetland features better (figure 2(*c*) and (*d*)). Wetland, which is misclassified as open water in the pixel-based classification, can be well identified using the object-oriented classification approach, which is further substantiated in the following section about HRUs.

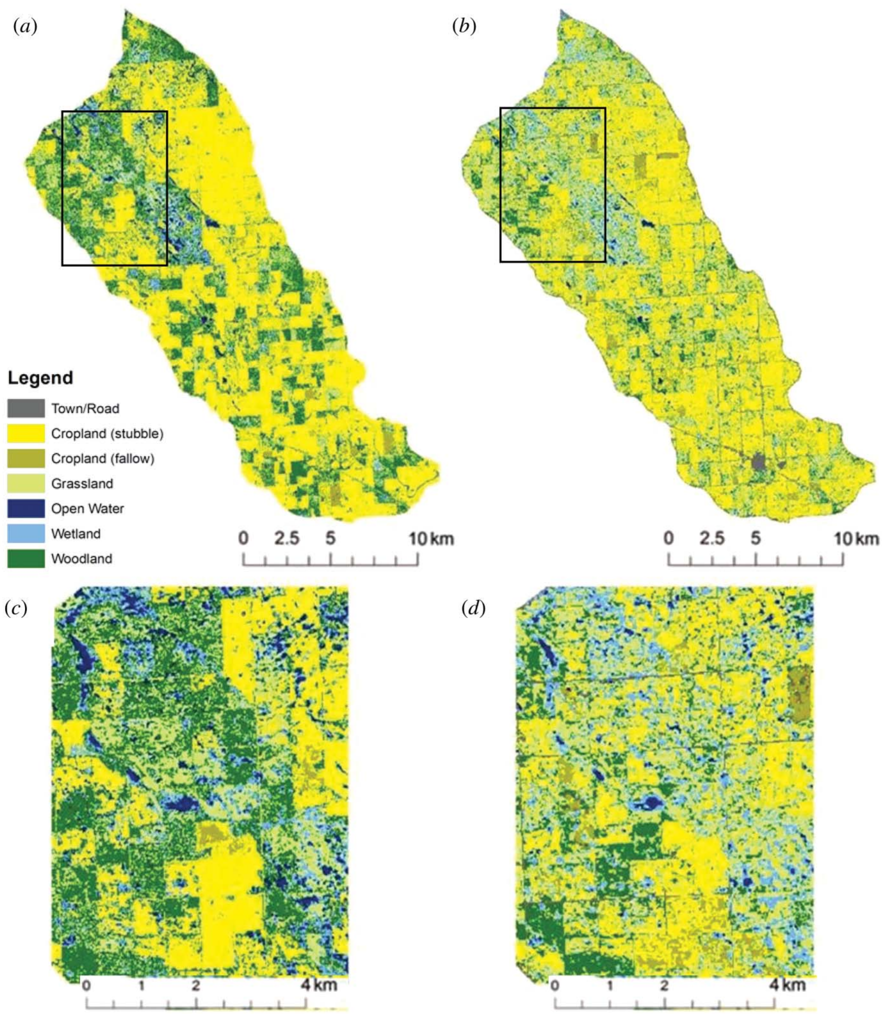

Figure 2. Classified maps (sub-basin 1) from (*a*) pixel-based classification method and (*b*) object-oriented classification method, as well as a close look for both classification maps ((*c*) pixel-based and (*d*) object-oriented).

4.2 *Hydrological response units*

The HRU areas (km^2) used in CRHM modelling were derived from both pixel-based and object-oriented classifications (table 1). HRUs were created from the land use classes by a generalization processes. The two classified maps show similar land cover areas for fallow cropland and stubble cropland. The river channel areas from both land cover classifications are identical, because both were derived from the DUC Geographic Information System (GIS) database. However, both classified grassland and wetland areas from the object-oriented classification are significantly larger in each sub-watershed. On the contrary, the classified woodland area using the object-oriented classification approach is significantly smaller. The open water area is smaller for object-oriented classification as well. The better-identified wetland from object-oriented classification may be due to the fact that its segmentation minimizes the heterogeneity within classified land covers (Guo *et al.* 2006). The same reason can explain the smaller area of classified woodland from object-oriented classification.

4.3 *Snow water equivalent*

SWE during pre-melt and melt periods was simulated on the basis of the HRUs defined from both pixel-based and object-oriented classification approaches. The comparisons show similar results in all sub-watersheds. The differences in simulated SWE values based on the two classification approaches are small in the fallow cropland, stubble cropland, open water and river channel, although there are differences between the simulated and observed SWE values. Therefore, only the comparisons of the simulated and the observed SWE in open water, grassland, woodland and wetland in sub-watershed 1 are illustrated (figure 3). The simulated SWE in open water HRU based on the two classification approaches is almost always the same during the simulation time, although pixel-based classification yields a larger open water area. The differences between the simulated SWE from the two classification approaches are greater in grassland, woodland and wetland HRUs than in open water. Generally, in the grassland HRU, the differences between the observed and simulated SWE from the object-oriented classification are smaller than the differences between observation and simulation based on pixel-based classification. However, the differences between

Table 1. Areas of the HRUs (km^2) derived from the classified land covers in each sub-watershed (Subw).

	Subw1		Subw2		Subw3		Subw4		Subw5		Total	
HRU name	Pb	Oo	Pb	Oo	Pb	Oo	Pb	Oo	Pb	Oo	Pb	Oo
FC	5.1	5.1	3.3	3.3	2.3	2.3	4.1	4.1	0.6	0.6	15.3	15.3
SC	81.2	83.0	61.1	60.6	54.7	55.7	34.2	36.0	10.7	11.3	242.0	246.5
G	19.2	39.4	6.5	21.1	7.3	13.8	2.4	8.1	1.1	3.2	36.5	85.6
W	16.9	24.0	9.7	11.4	3.6	5.1	2.5	3.3	1.0	1.3	33.7	45.1
WO	41.4	18.5	27.0	12.8	16.0	7.3	12.4	4.3	5.1	2.2	102.0	45.1
OW	9.1	2.9	3.3	1.7	0.7	0.5	0.5	0.4	0.1	0.0	13.7	5.5
RC	0.6	0.6	0.3	0.3	0.6	0.6	0.4	0.4	0.1	0.1	2.0	2.0

Note: HRU, hydrological response unit; Pb, pixel-based classification; Oo, object-oriented classification; FC, fallow cropland; SC, stubble cropland; G, grassland; W, wetland; WO, woodland; OW, open water; RC, river channel.

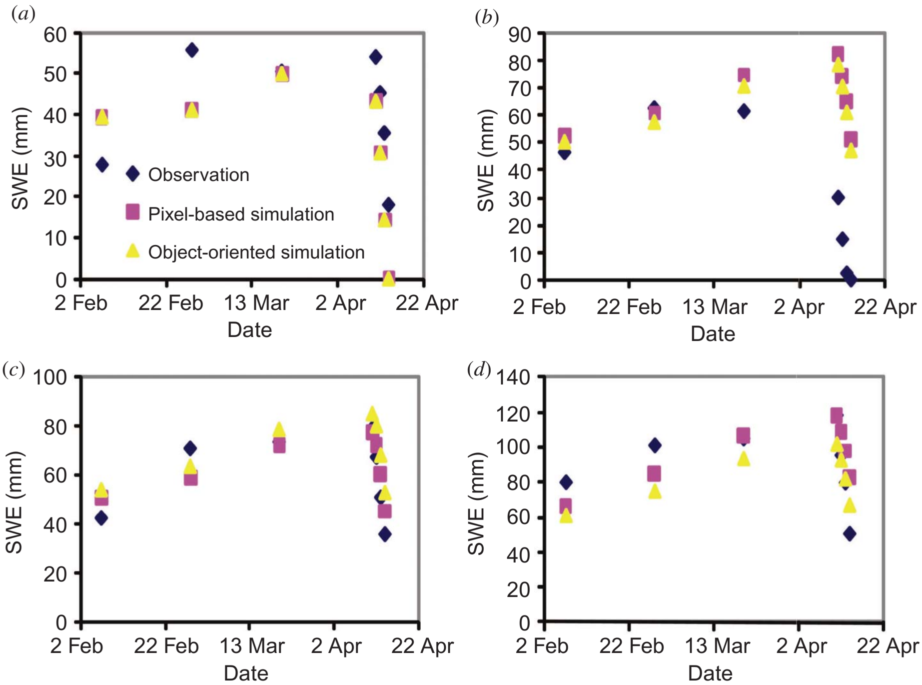

Figure 3. The observation of snow water equivalent (SWE) and the simulated SWE in (*a*) open water, (*b*) grassland, (*c*) woodland and (*d*) wetland HRUs in 2008 based on pixel-based and object-oriented classifications in sub-watershed 1.

observed and simulated SWE from the object-oriented classification in woodland and wetland areas are relatively larger on most simulation days.

The deviations of the simulated SWEs from the observations were quantified by the root mean square difference (RMSD) (table 2). This table shows only the results of sub-watershed1, but other sub-basins have similar RMSD values. The RMSD values

Table 2. Root mean square difference (RMSD) of the simulated SWE from the observed SWE in sub-watershed 1.

	RMSD for simulation of SWE (mm)	
HRU name	Pb	Oo
FC	2.7	2.7
SC	3.4	3.4
G	16.3	15.1
W	6.4	6.0
WO	2.9	4.4
OW	5.5	5.5
RC	17.5	17.5

Note: HRU, hydrological response unit; Pb, pixel-based classification; Oo, object-oriented classification; FC, fallow cropland; SC, stubble cropland; G, grassland; W, wetland; WO, woodland; OW, open water; RC, river channel.

resulting from pixel-based and object-oriented classifications are the same in the fallow and stubble croplands, river channel and open water. However, RMSD values from object-oriented classification are consistently lower in other land covers except woodland. The differences of SWE simulations based on the two classification approaches are relatively larger in grassland and woodland HRUs, which can be explained by the difference of areas of grassland and woodland classified by the approaches.

4.4 *Basin stream flow*

Springtime stream flow in 2008 was simulated based on the pixel-based and object-oriented classifications and the simulated discharge values were compared with the observed discharge values (figure 4). The simulated daily stream flow discharge from the object-oriented classification is evidently different from the simulation from the pixel-based classification on most days during the simulation period, with one real and two spurious peaks. On the other days, differences in the simulations based on the two classification approaches are small, although the differences between simulated and observed values are relatively large. The difference between the observed stream flow discharge and the simulated discharge from object-oriented classification is larger than that between observation and simulation from pixel-based classification during the period 9 April to around 24 April. After that, the simulated stream flow discharge based on object-oriented classification is more comparable to the observed values than the simulation from pixel-based classification.

The observed cumulative spring discharge, peak daily discharge and peak discharge dates were compared with the simulated values from pixel-based and object-oriented classification approaches (table 3). Compared with the simulations from the object-oriented classification, the simulations from the pixel-based classification demonstrate a smaller difference in the cumulative discharge and peak daily discharge.

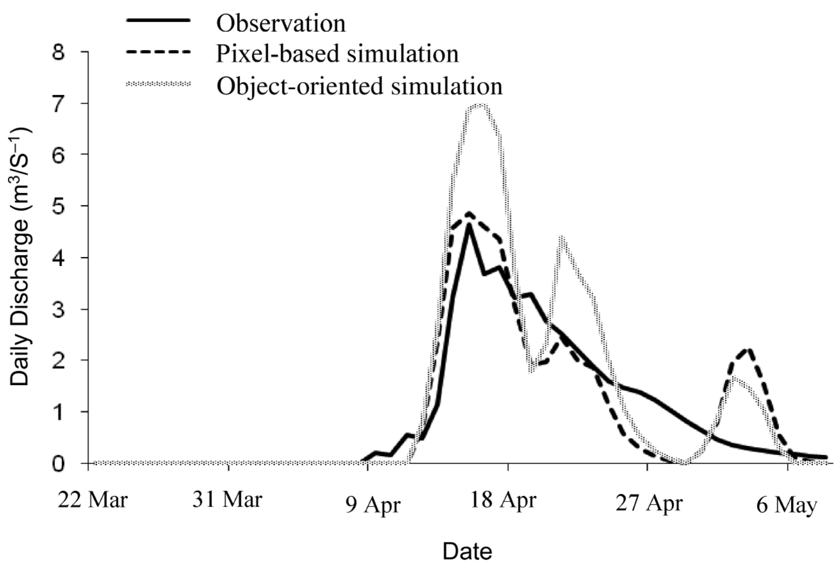

Figure 4. Observed and simulated stream flow in spring of 2008 based on pixel-based and object-oriented classifications.

Table 3. The cumulative spring discharge, daily peak discharge and peak discharge date of the observation and simulation from the pixel-based and object-oriented classifications in 2008.

Methods	Cumulative spring discharge ($m^3 s^{-1}$)	Peak daily discharge ($m^3 s^{-1}$)	Peak discharge date
Observation	43.9	4.7	15 April
Pixel-based simulation	44.3	4.9	15 April
Object-oriented simulation	57.6	7.0	16 April

In addition, the observed peak discharge date is the same as the simulation based on the pixel-based classification; however, a 1-day difference from the simulation based on the object-oriented classification is noticed. The larger amount of the simulated spring discharge resulting from the object-oriented classification can be explained by the classified land covers having larger area of grassland and smaller area of woodland compared with the pixel-based classification, and the fact that the woodland has more surface storage capacity than the grassland has.

5. Conclusions

The simulated SWE in the HRUs generated from object-oriented classification is closer to the observed SWE, compared with the HRUs from the pixel-based classification, although the simulations are the same from the two classification approaches in some HRUs. Relatively larger differences of the simulated SWE from the two classifications are observed in grassland and woodland HRUs, which is a result of differently classified land covers.

The discharge of spring stream flow was also simulated on the basis of the classified land covers from the two classification approaches and was compared to the observational discharge. Simulations from the object-oriented and pixel-based classifications overestimated the spring basin discharge by 0.8% and 35%, respectively. The large differences of simulated stream flow discharge based on the two classification approaches may be attributed to different areas of grassland and woodland between the two classifications and the different surface water storage capacity of grassland and woodland.

Overall, the object-oriented classification leads to a somewhat better simulation of snow accumulation in some HRUs during the snow pre-melt and melt season, but a slightly worse simulation of SWE in woodland and wetland HRUs. The spring stream flow discharge is based on the object-oriented classification in the CRHM model than that from the pixel-based classification. This confirms that the classified land covers have some impacts on the performances of a hydrology model. However, it is hard to draw a conclusion about which classification approach is superior to the other.

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