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PBS-SLURP MODEL

Prepared for
SaskWater and the Upper Assiniboine River Basin Study

NHRI Contribution Series No. CS-98003

Executive Summary

In September, 1997 SaskWater contracted NHRI to provide an enhancement of NHRI's SLURP Hydrological Model that would be appropriate for modelling the hydrological impacts of land use change in Upper Assiniboine River Basin. NHRI scientists identified snow redistribution, evaporation and infiltration into frozen soils as the hydrological processes for which SLURP was in most need of enhancement for application to the prairie environment. Dr. Geoff Kite of NHRI developed and provided SaskWater with SLURP-11 code and manual in October, 1997; SLURP-11 contains NHRI's Granger Evapotranspiration Model.

This final report details the work in coupling NHRI's Prairie Blowing Snow Model (PBSM), a frozen soil infiltration routine and other modifications to SLURP. The coding and simulations were performed by Mr. Tom Brown, P.Eng., of Rowan Systems and formerly of the Division of Hydrology, Univ. of Saskatchewan. The completed model is substantially changed from SLURP-11 and is called PBS-SLURP. PBS-SLURP is demonstrated using data from the Bad Lake International Hydrological Decade basin. It shows snow accumulation, snow melt, infiltration and runoff characteristics are strongly influenced by land cover (fallow, stubble, coulees) and that substantial errors in spring snowmelt runoff calculations would accrue from assuming an even snowcover and infiltration characteristics. The authors recommend however, that further enhancements to PBS-SLURP may be necessary for general application in the Prairies. These enhancements are specific to snowmelt energetics and soil moisture accounting. The next phase of this project will involve SaskWater applying PBS-SLURP in the Upper Assiniboine Basin with the advice and input of NHRI scientists.

INTRODUCTION.

Hydrological modelling in the Canadian Prairie environment is notoriously difficult because of poorly-defined drainage basins, low slopes, intermittent streamflow, land use changes and often dramatic seasonal and interannual variations in precipitation and temperature. Prairie hydrology is also distinctive because of the cold and dry continental climate. Roughly one-third of annual precipitation arrives as snowfall yet roughly 80-90% of annual runoff occurs during the snowmelt season. Hydrological processes that are important in the Prairie environment, yet not normally included in hydrological models, are associated with seasonally-frozen soils, wind redistribution of snowfall, river ice, snowmelt, evaporation from cold soils, and aspects of soil moisture retention in agricultural soils. Research over the last 30 years at the National Hydrology Research Centre and the Division of Hydrology, University of Saskatchewan has attempted to address deficiencies in the understanding of prairie hydrology processes and to develop physically-based algorithms describing these processes.

This report details the incorporation of certain key prairie hydrological process algorithms into a well-known hydrological model, SLURP. SLURP is a semi-distributed hydrological model that has been in continuous development at Environment Canada since its initial conception in the 1970s (Kite, 1978). SLURP has been extensively tested and calibrated in the mountain environment of British Columbia, and used in varied environments such as the Mackenzie River (Kite, 1994). By treating the river basin as a series of sub-catchments, or ASA[3], each with a distinctive arrangement of land covers, SLURP effectively distributes hydrological fluxes and is therefore sensitive to land use and the spatial arrangement of land cover within a basin. Water balances are generated in each ASA and then routed through the basin. The routing and certain hydrological coefficients are optimised for an environment using a calibration from known discharge data for the basin and subcatchments (if available). For application to the Prairies, specifically for the Upper Assiniboine Basin, it was considered appropriate to modify SLURP to take

[3] Aggregated Simulation Area.

advantage of the advances in understanding of prairie hydrological processes that have occurred since its inception, thus improving its physical basis. With an improved physical basis for key prairie hydrological processes, it is felt that SLURP can more confidently predict changes to prairie hydrology due to land use and climate change.

The changes to SLURP detailed here are extensive and deal with phenomena that influence snowmelt runoff generation:

1. winter evaporation and soil drainage,
2. infiltration to frozen soils and
3. wind redistribution of snow.

Snowmelt produces the annual peak flow in most prairie basins, and can produce extreme flood events, such as the Red River Flood of 1997. Snowmelt runoff is extremely variable from year to year because of changes in spring snow water equivalent (SWE) over the basin and variation in the amount of meltwater that infiltrates soil and recharges soil water supplies versus that which runs off to channels and contributes to streamflow. In order to calculate snowmelt fluxes and runoff, it is necessary to know: correct snowfall, evaporation from snowcover, overwinter soil moisture drainage, redistribution of snow by blowing snow, sublimation of blowing snow, and infiltration of meltwater into soils. The following sections discuss the coupling of SLURP and prairie hydrology process algorithms that permit a more process-based calculation of snowmelt runoff using what is effectively a new model PBS-SLURP. The changes permit PBS-SLURP to assess the impact of land use on snow accumulation, infiltration and snowmelt runoff, and demonstrate the strong role land cover has in controlling runoff generation on the Prairies.

HYDROLOGICAL PROCESSES FOR THE PRAIRIES

Pomeroy and Gray (1995) detailed the influence of wind redistribution on prairie SWE, showing that from 1.6 to 39.4 Mg of snow per metre width of field can be relocated from fields to drift areas (shelterbelts, coulees, sloughs) in the Prairie Provinces. Depending on fetch and local climate, an amount of snow from 1.0 to 2.6 times that transported off the field is sublimated (evaporation direct from snow to vapour) and is therefore not available for melt in the spring. The calculation of blowing snow transport and sublimation involves a complex simulation of snowfall correction, snowpack mass balance, mid-winter snowmelt, wind erosion of snow, snow particle transport and heat and mass transfer to the blowing snow particles. The calculation procedure has been coded into a computer model, called the Prairie Blowing Snow Model, PBSM (Pomeroy, 1989; Pomeroy et al., 1993; Pomeroy and Li, 1997), which has been developed at Environment Canada since that time. For application with SLURP, a technique was developed to use PBSM to relocate snow from land cover to land cover within an ASA, based on the roughness of land cover (i.e. from fallow to stubble to brush to wooded land covers). Fig. 1 shows daily measured snow accumulation and simulations of blowing snow transport, sublimation, melt and snowcover accumulation for fallow land at Bad Lake, Sask. using PBSM. Fig. 2 shows monthly snow mass balances compared to surface measurements for several stations on the Prairie Provinces. The results indicate generally good correspondence between PBSM and measurements and suggest that it can provide a useful simulation of snow accumulation for the prairie environment.

Fig. 1. PBSM simulation of snow accumulation for Bad Lake Fallow.

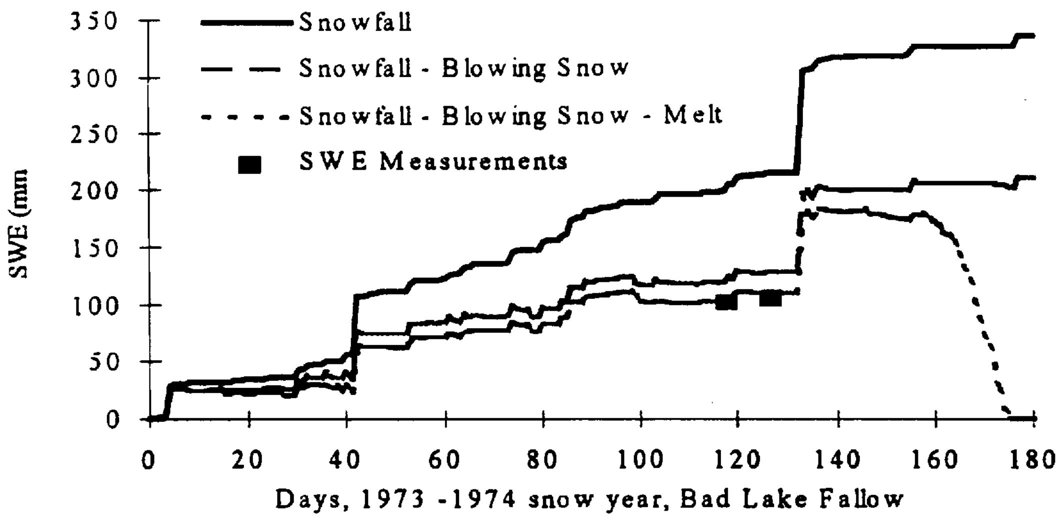
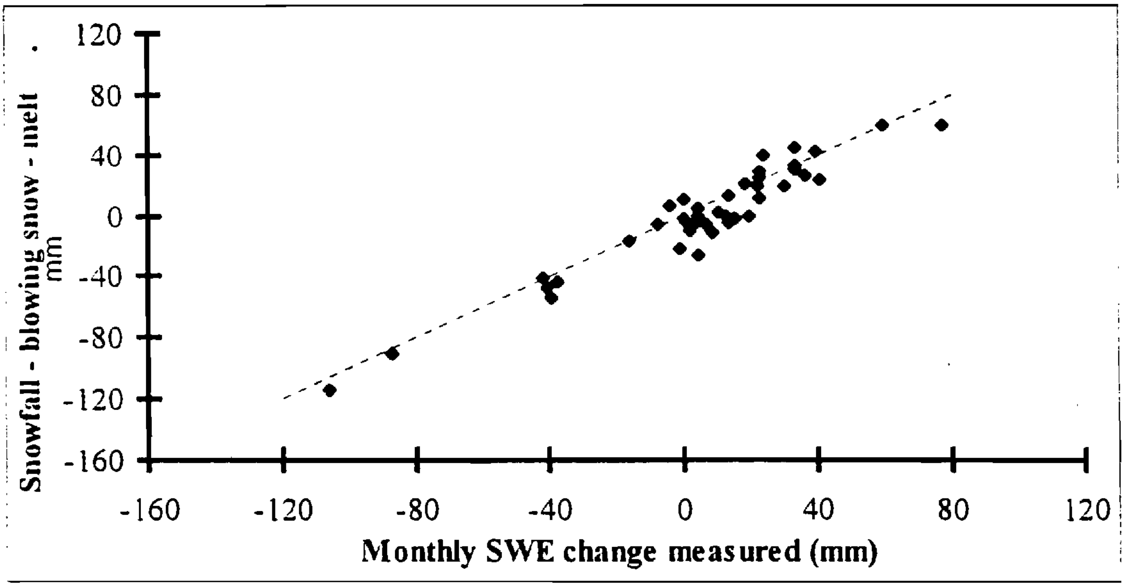


Fig. 2. Comparison of monthly snow mass balances calculated with PBSM and measured at stations in the Prairie Provinces.



SLURP-11 can permit its internal evaporation schemes to operate over the winter period. This was considered inappropriate for the prairie environment, because,

1. soils are frozen in winter,
2. PBSM calculates sublimation of blowing snow and
3. direct evaporation from open snow surfaces is minimal before the snowmelt period (Gray and Male, 1981).

Evaporation schemes in SLURP were therefore disabled over the snow-covered period, until the time of active snowmelt.

Infiltration to frozen soils can vary from zero to the maximum water available from snowcovers on the Prairies, depending on soil characteristics, mid-winter melts and the degree of pore saturation in the upper soil layers (Granger et al., 1984). Gray et al. (1986) classified the infiltration characteristics of frozen prairie soils as restricted (no infiltration), limited (variable infiltration with pore saturation) and unlimited (complete infiltration). Simple algorithms were developed to describe and predict the infiltration characteristics of prairie soils; the algorithms describe extensive field results quite well. When these algorithms were used to modify the US National Weather Service Runoff and Forecasting Simulation, predicted snowmelt runoff from agricultural basins in south-central Saskatchewan increased from negligible to the large snowmelt freshet normally observed (Gray et al., 1986). This result demonstrates the degree of simulation improvement that can be expected by incorporating frozen soil infiltration routines into a hydrological model.

In implementing the infiltration routines in SLURP, soil drainage and runoff generation from upper soil layers were restricted during the winter period when soils are frozen. During snowmelt, soils are classified into one of three infiltration classes, restricted, limited or unlimited, based on soil texture, fall moisture content and mid-winter melt. Meltwater generation in excess to that which can infiltrate is directed as runoff.

The next section in this report details the coupling of PBSM-SLURP and infiltration to frozen soil routines to create PBS-SLURP. Further sections describe PBSM, SLURP and Infiltration to frozen soil sub-models. Appendix A lists the input requirements of PBS-SLURP, Appendix B shows program changes in creating PBS-SLURP from SLURP-11, Appendix C shows model runs of PBS-SLURP for Creighton Tributary of Bad Lake Basin and Appendix D lists the PBS-SLURP code.

PBS-SLURP MODEL FEATURES

SLURP-11

The SLURP model is a complex model which has been under continuous development since its inception in 1978 (Kite, 1978). As such, any refinements have to be integrated into the existing program structure even if this is not the optimum method. The alternative is an extensive and very time consuming rewrite and the risk of altering the accepted operation of the model. SLURP is described in documentation provided with Version 11 (Kite, Oct. 1997) and in several papers by Kite. The following is a description of those aspects of SLURP that are important for integration with blowing snow and frozen soil routines.

The SLURP program operates sequentially through the land delineations in the following order:

1. Sequentially through every ASA, (i.e. sub-basin),
2. Sequentially through every land cover type within an ASA.
3. Sequentially through the land cover for the entire run time period.

The ASA's have to be ordered by drainage sequence. Upstream ASA's which drain into a downstream ASA must appear first in the ASA list. There is no such requirement for land covers in the original SLURP model.

Each element of the (ASA*land cover) matrix is simulated by four nonlinear reservoirs representing canopy interception, snowpack, fast runoff (may be considered as a combined surface storage and top soil layer storage) and slow runoff (may be considered as groundwater). The storage areas affected by the addition of the routines to handle snow transport and infiltration into frozen soil are the snowpack and fast storage. The snowpack operates as one would expect, starting at zero in the fall and gradually increasing in depth with snowfall and snow transport or decreasing with sublimation and melt.

Fast storage is handled as a linear tank filled by precipitation and melt. All water is free to empty through evaporation and drainage. Fast storage does not, however, accurately represent physical soil moisture regimes. One of the parameters for fast storage is its maximum capacity. This would imply that if a soil layer depth is associated with fast storage then soil moisture would be represented. The potential evaporation is determined by the selected evaporation method (Morton, Granger or

Spittlehouse/Black) and as long as there is sufficient water in fast storage, the evaporation demand can be satisfied. However, as soon as fast storage content is drawn down to zero, it is the lack of moisture which is the controlling influence in the model, rather than the evaporation method selected. The drainage mechanism is similar and again can empty fast storage.

Snowfall Corrections

Snowfall undermeasurement due to wind effects, wetting losses and unrecorded trace events have been subject to extensive investigation (Pomeroy and Goodison, 1997). For Canadian measurements Nipher-shielded cylinders are often used to collect snowfall with measurements of accumulated snowfall made every six hours. The Nipher shield reduces undermeasurement due to wind compared with an unshielded gauge but corrections are still required. A correction procedure published by Goodison was incorporated into PBS-SLURP to allow the use of uncorrected AES precipitation data.

Blowing Snow Modelling

Coupling of PBSM and SLURP is made possible by the following modelling features, developed based on 15 years of study of the blowing snow phenomenon in the prairies (Pomeroy and Li, 1997) and experiences in distributed modelling of blowing snow in the Arctic (Pomeroy et al., 1997):

1. There is no snow transport between ASA's.
2. Daily snowfall is added to the snowcover once per day at midnight.
3. Snow transport from land covers with lower roughness is added to the snowpack of land covers with greater roughness once per day at midnight.
4. Transport and sublimation of blowing snow for a land cover are calculated every hour using the hourly wind speed, air temperature and dewpoint. Snow transport is summed over the day and passed on to the subsequent land covers of lower roughness height.
5. No transported snow enters the lowest roughness land cover (normally fallow).
6. All transported snow not distributed onto low roughness land covers is added to the snowpack of the roughest land cover.

7. When the vegetation height is full, no further snow is deposited but transport continues to the next roughest land cover.
8. Snowfall and incoming snow transport are added to snowcover at midnight and then daily snow transport output and sublimation loss are calculated using a one-hour time increment.

In SLURP, a land cover in a particular ASA is processed through the entire run time period before starting on the next land cover. This feature makes it difficult to couple PBSM and SLURP because the snow transport between land covers occurs concurrently. The problem is handled by requiring the land covers to be ordered sequentially by increasing roughness (crop or vegetation height). That is, the land covers are ranked by increasing roughness such that the first land cover on the list fills with snow to capacity quite early in the season, followed by the second etc. The last land covers are the ones which fill later in the season and the very last will never fill at all and is considered to be an infinite sink for wind transported snow (e.g. coulees, river channels, large wooded areas).

It is assumed that there is no net snow transport between ASA. This assumption is quite reasonable for ASA with land covers near the perimeter of short grass or cultivated fields, and fetch length for this land cover of 1 km or more. The assumption is based on the concept of steady state flow, which develops over low roughness land covers early in the season and takes from 300-1000 m to develop. As most prairie catchments have stream channels, sloughs or coulees in the centre rather than on the perimeter and many catchments have extensive grass or cultivated plains around the basin boundaries, this assumption is considered good.

There is little or no snow transport out of a land cover until the vegetation cover is filled to capacity i.e. the snow accumulation is greater than or equal to the crop height. When this happens, snow transport out of the land cover is saved daily. When the entire time period is simulated using that land cover, the program progresses to the next land cover in the ASA, calculating its daily transport and sublimation using the snow transported from the previously processed land cover in the ASA. The transport out of a land cover is deposited over the remaining land covers using the deposition parameters specified by the user in the *.PBS file. To determine the deposition parameters, the user of the model examines a map of the ASA area showing crops and farmland practices in the fall, topography, vegetation, together with the prevailing winter winds to determine the distribution of drift from fallow to the other land classes in the ASA, e.g. stubble, grass, gullies, river channels, forest etc. It is recommended that model users consult the NHRI Science Report No. 7, *Snow Accumulation, Redistribution and Management* by J.W. Pomeroy and D.M. Gray, for principles and techniques for classifying landscape with respect to snow redistribution by blowing snow and to determine prevailing snow transport directions for various locations in the Prairie Provinces.

Winter Evaporation Modelling

Gray and Male (1981) provided information that demonstrates overwinter evaporation from snow covers in cold periods is minimal. PBS-SLURP has been adjusted to reflect this. The following adjustments are made for selected condition.

1. No Snow Cover-

   Use Slurp Evaporation Methods as given (Morton/Granger/Spittlehouse-Black).

2. Snow Cover-

   - Air Temperature greater than 0°C

     Use selected evaporation model.

   - Air Temperature less than or equal to 0°C

     Use only PBSM sublimation

   - Plant canopies

     Use SLURP evaporation at any temperature

Frozen Soil Infiltration Modelling in PBS-SLURP

In SLURP-11, the ratio of current stored water content to its maximum water content has no direct relationship to soil water status and cannot be used as an indicator of soil moisture, however this ratio is important for spring runoff generation. There is no mechanism in the model to reduce or terminate soil drainage when the ground is frozen. A reasonable adjustment for the prairie environment is therefore to stop all drainage between fall and the spring snow melt. In the spring, melt thaws the frozen soil. This change has been implemented in PBS-SLURP.

Based upon 15 years of study of the snow hydrology of the Prairie region and results reported in the former USSR, the Division of Hydrology (Granger et al. 1984;

Gray et al., 1986), postulated that the infiltration potential of frozen soils may be grouped in three broad categories, namely, restricted, limited and unlimited.

Restricted - Infiltration is impeded by an impermeable layer, such as an ice lens on the soil surface or within the soil close to the surface. For all practical purposes, the amount of meltwater infiltration can be assumed to be negligible and that the melt goes directly to runoff and a little to evaporation.

Limited - Infiltration is governed primarily by the snow-cover water equivalent and the frozen water content of the top 30 cm. of soil.

Unlimited - A soil with a high percentage of large, air-filled macropores at time of melt. Examples of soils having these properties are dry, heavily cracked clays and coarse, dry sands.

In SLURP there is not sufficient information to determine these classifications automatically and as a result the operator is required to specify these properties for each land class every fall and input this information to the model. The one case the model does handle is when there is an early melt and the subsequent refreezing causing an ice lens to form. This will change both *Limited* and *Unlimited* to *Restricted*. Implementation of the infiltration to frozen soils routines is described below.

Definitions

1. Index = INF/SWE where $INF=5(1-\theta_p)SWE^{0.584}$
2. Potential = INF/6
3. MELT_THRESHOLD=10mm. Minimum daily meltwater at which the melt routine is enabled. Lower meltwater levels are not counted as one of the six major melt events.
4. Major melt is a day when the meltwater is greater than the MELT_THRESHOLD
5. 6 major daily melts are allowed before the infiltration category is changed to *Restricted*.

The Frozen Soil Infiltration routine

1. The Frozen Infiltration routine will be enabled to start any time after November 1.
2. It will be triggered into operation by the first major melt. At this time, Index and Potential are calculated from the soil moisture (θ_p) and the SWE of the snowpack.

Index and Potential will only be recalculated if another major melt occurs with a greater SWE.

3. The Frozen Infiltration routine will be disabled when the SWE of the snowpack is less than 5mm and a major melt has occurred.
4. Disabling the frozen infiltration routine at a SWE of 5mm is reasonable for shallow snowpacks which melt rapidly but is not satisfactory for deeper accumulations. However, since the meltwater from deeper snowcovers tends to runoff to adjacent areas and the ground does not freeze as deeply under deeper snowpack, it is reasonable to assume that the frozen infiltration routine should be disabled for all land covers at the same time.

The three frozen soil categories are described below

LIMITED

1. Only six major over-winter snowmelt events are possible before the infiltration potential is set to *Restricted*.
2. Meltwater amounts less than the MELT_THRESHOLD are allowed to infiltrate into the soil using unfrozen soil infiltration routines. Once MELT_THRESHOLD has been exceeded (normal spring snowmelt) only the amount of meltwater equal to MELT*Index will infiltrate and the remainder will be handled as runoff. That is, after a major melt the normal fast storage infiltration limits for unfrozen soil are suppressed and the frozen soil routines take over.
3. If the temperature the day after a major melt event is colder than -10°C, the category is changed from *Limited* to *Restricted*.

UNLIMITED

1. All meltwater is allowed to infiltrate after a major snow melt event. Prior to this infiltration is handled by the normal Slurp infiltration routine.
2. If the temperature the day after a major melt event is less than -10°C, the category remains unchanged and all melt water still infiltrates into the soil.
3. *Unlimited* is ended when the model returns to its normal infiltration routine at the end of melt in spring.

RESTRICTED

1. No meltwater is allowed to infiltrate.
2. When the SWE of the snowpack is less than 5mm, the category is no longer applicable as the Frozen Infiltration routine is no longer operational in the program. The Slurp program will thereafter use its normal unfrozen soil infiltration routines.

Snowmelt

SLURP implements two melt routines. The first is a simple degree-day approach using the positive difference between the daily average temperature and parameter(10). The melt rate R_l uses a parabolic correction from January and July minimum and maximum values. The second is a simplified energy budget method proposed by Kustas et al. (1994), which also includes the above simple degree day term.

PBS-SLURP TESTING AT BAD LAKE, SASKATCHEWAN

PBS-SLURP was run for the Creighton Tributary of Bad Lake basin for the winters 1973-74 and 1974-75. Creighton Tributary was chosen because of its comprehensive hydrology and land cover dataset, collected during the International Hydrological Decade during a high snowfall and normal snowfall year. A simple division of the basin into fallow, stubble and drift land cover classifications was used.

- "Drift" land cover was selected for steep shrub-covered slopes, coulee bottoms, farm yards.
- "Fallow" and "stubble" land cover were selected based on land use surveys of summer-fallowed and grain stubble or pasture lands respectively.

The percentage areas of the three land covers is 40% fallow, 50% stubble, 10% drift.

The redistribution of snow by the model between the different land covers is illustrated in Fig. 1 & 2. SWE accumulation for the three land covers for the two years, together with the corrected snowfall and measured SWE from field surveys is given. The resulting ratios of fallow, stubble, drift accumulation are in the ranges predicted from the snow surveys reported by Pomeroy and Li (1997). This suggests from a regional mass balance that the ratio of blowing snow transport to sublimation is reasonable. However modelled snow accumulation is substantially more than that measured. This is not considered to be due to underestimation of blowing snow erosion as this would make the overestimation of drift accumulation worse, but to an underestimate of mid-winter melt. PBS-SLURP does not allow its simple degree-day melt algorithm to operate when the daily mean temperature is below the value set in parameter(10). When parameter(10) is set to 0 C, there is very little mid-winter melt as the <u>average</u> daily temperature on the prairies between November and March is normally below 0°C despite afternoon temperatures which can be over 0°C. Shook (1995) has demonstrated that significant melt can occur on the Prairies when daily mean temperatures are below freezing, and model that use the daily mean temperature for estimating melt can be up to several weeks late in predicting the onset of melt.

The output from the original PBSM produces more melt during February and March simulating prairie conditions more closely, and matches the observed field measurements better (see Pomeroy and Li, 1997). One reason for this is that degree-day melt in PBSM was implemented using the <u>maximum</u> daily temperature, a more

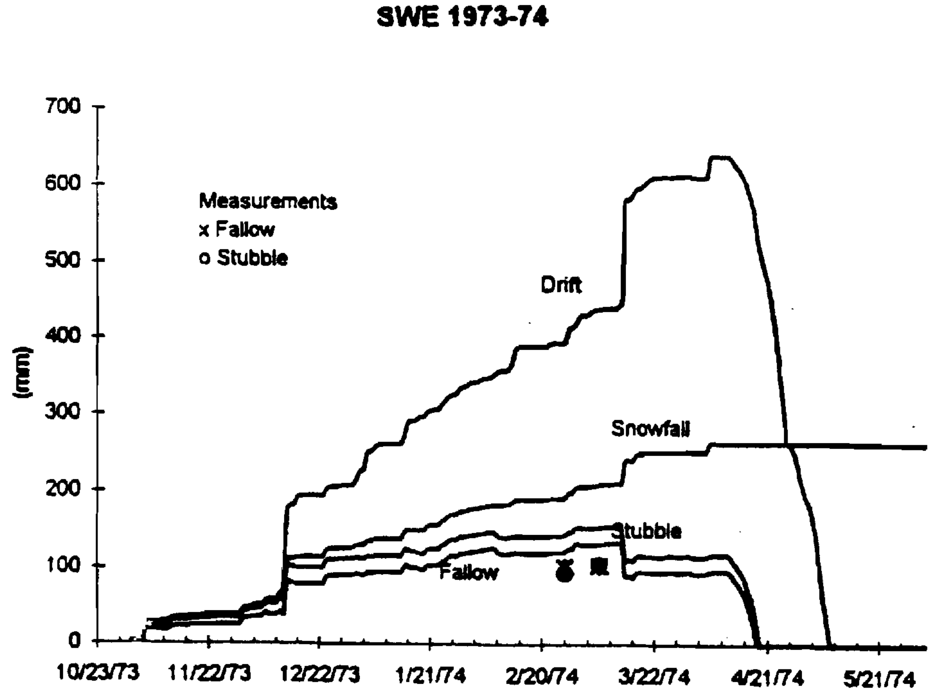


Figure 1. Snow accumulation modelled using PBS-SLURP for 3 land cover types in Creighton Tributary, Bad Lake, Sask. 1973-74 along with measured snowfall and measurements of snow accumulation from snow surveys in fallow and stubble fields.

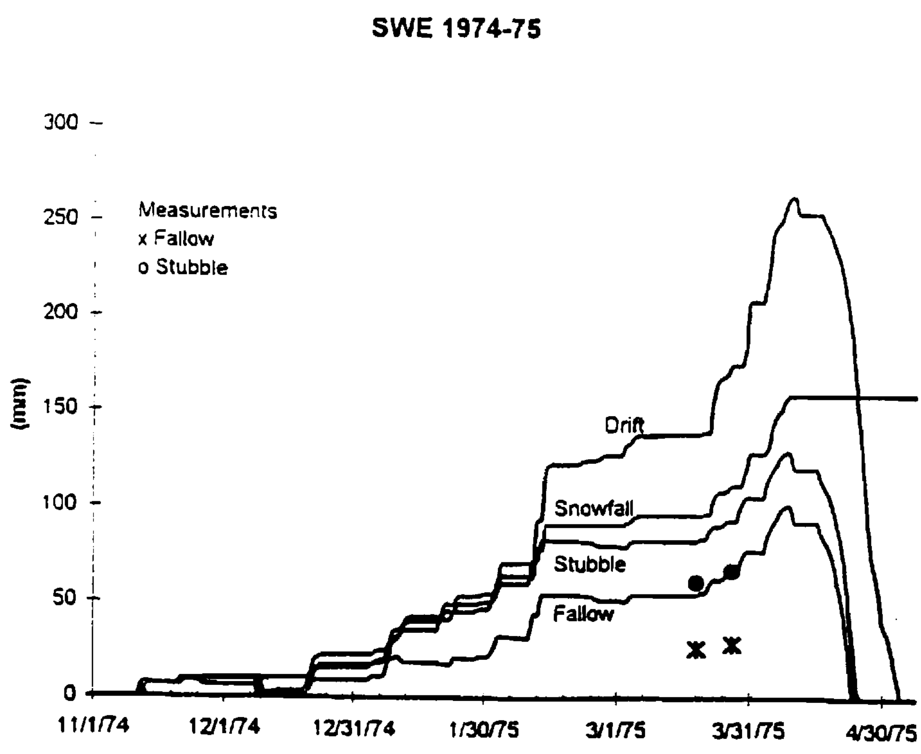


Figure 2. Snow accumulation modelled using PBS-SLURP for 3 land cover types in Creighton Tributary, Bad Lake, Sask. 1974-75 along with measured snowfall and measurements of snow accumulation from snow surveys in fallow and stubble fields.

appropriate parameter. It is not possible to appropriately calibrate PBS-SLURP in its present form to overcome this difficulty, without causing more of the precipitation being handled as rain instead of snow. Parameter(10) which sets the daily mean temperature at which melt begins, also sets the dividing temperature between rainfall and snowfall. Lowering this parameter to correct for meltwater production in mid-winter would also cause the model to predict rainfall at below freezing temperatures.

The transport and sublimation losses from the different land covers together with surface SWE and snowfall are given in Fig. 3 through 6. The sequences show that all land covers act as snow sinks early in the winter season, and accumulation tracks well with snowfall. As roughness elements fill, land covers become blowing snow sources and contribute snow to rougher land covers. In the heavy snowfall season of 1973-74 all land covers track reasonably well with snowfall until early December 1973, after that drift exceeds snowfall and fallow and stubble are substantially less than snowfall. In the moderate snowfall season of 1974-75 all land covers track well until late December 1974, after which fallow has substantially less accumulation than snowfall or accumulation at other sites. Drift exceeds snowfall starting in early February 1975, whilst stubble tracks snowfall fairly well with snowfall until late March.

Snowmelt runoff for each land cover and basin streamflow runoff for PBS-SLURP are shown in Fig, 7 & 8. The melt sequence in all years is fallow, stubble, drift, with drift becoming snow-free up to 3 weeks later than the other land covers. It is seen that the agricultural field snowmelt occurs for only a few days at the start of melt and that melt from the drift areas form a larger component of runoff than would be expected from the relatively small area of the basin covered with snow drifts. In the heavy snow year (1974), peak melt fluxes from the three land covers occur sequentially, prolonging and attenuating the amplitude of the basin runoff peak. In the moderate snow year (1975), fallow and stubble melt at similar times, resulting in a sharp runoff peak that is much greater than the peak for each land cover. These may be compared with the measured streamflow from snowmelt on the Creighton Tributary collected by the Division of Hydrology. There is good correspondence for spring of 1974. The peak is too high for spring 1975; this may be due to the model not melting sufficient snowcover during the winter months of February and March or to a problem in the timing of the melt peaks. The peak is also delayed by 2 days but again this can be explained by the melt routines shortcomings.

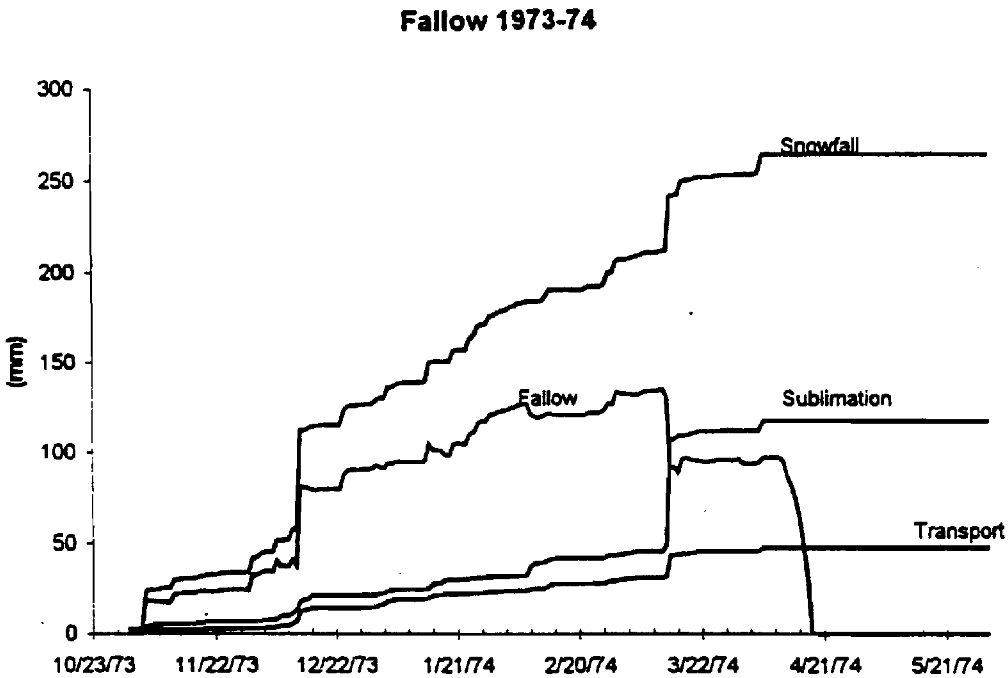


Figure 3. PBS-SLURP simulations of sublimation, drifting from land cover (transport) and snow accumulation, for Fallow land cover, 1973-74, Creighton Tributary, Bad Lake, Sask.

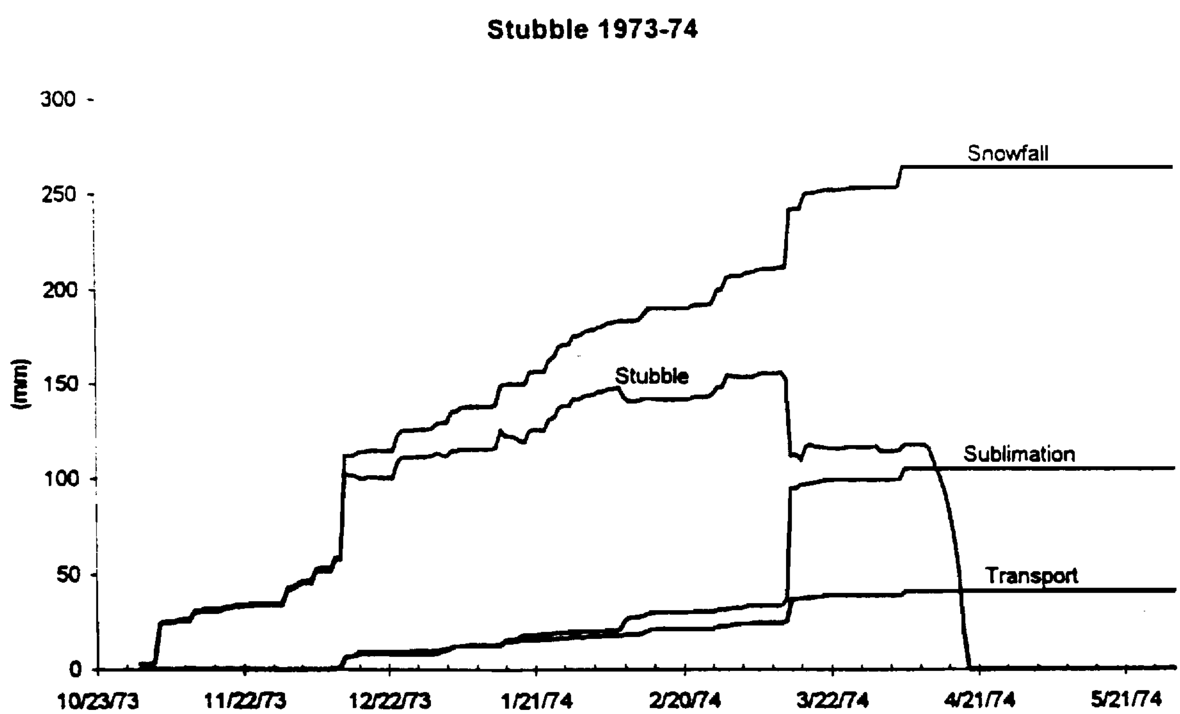


Figure 4. PBS-SLURP simulations of sublimation, drifting from land cover (transport) and snow accumulation, for Stubble land cover, 1973-74, Creighton Tributary, Bad Lake, Sask.

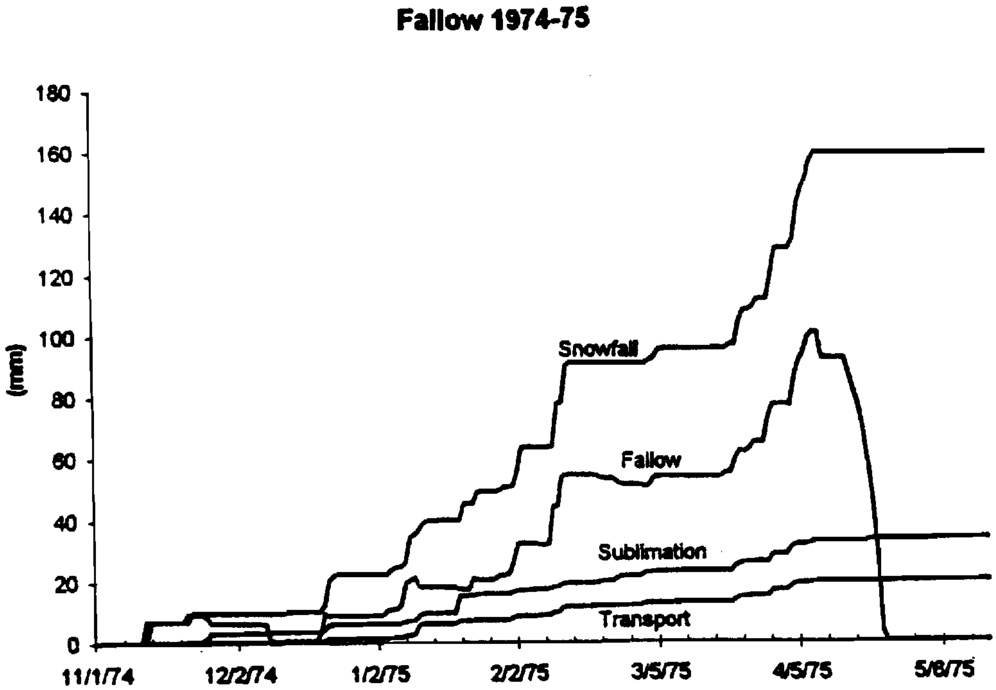


Figure 5. PBS-SLURP simulations of sublimation, drifting from land cover (transport) and snow accumulation, for Fallow land cover, 1974-75, Creighton Tributary, Bad Lake, Sask.

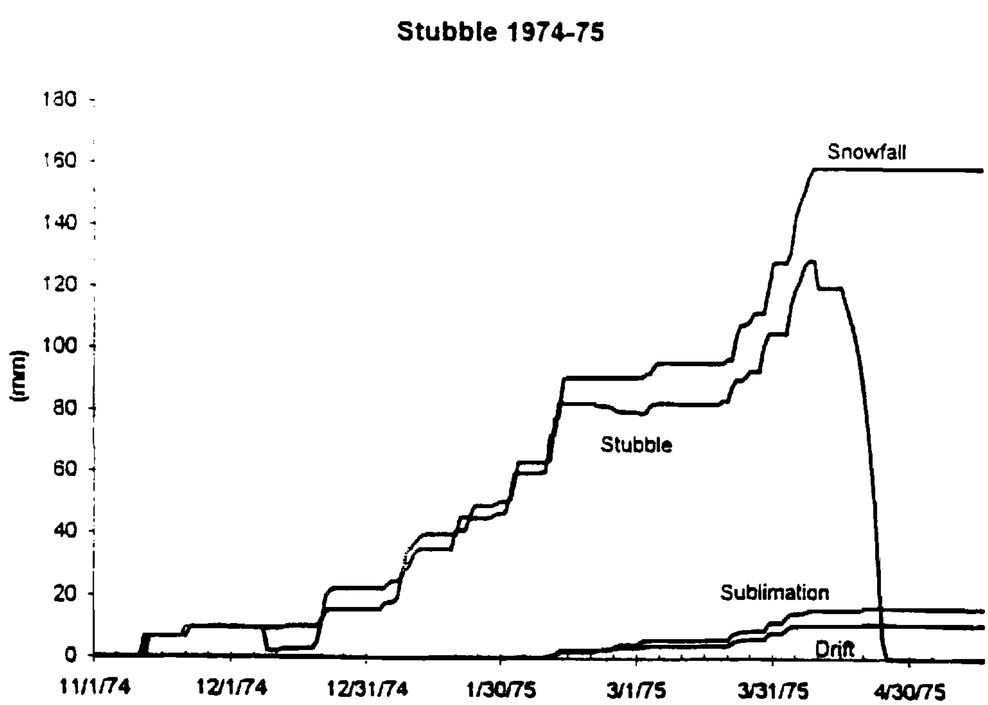


Figure 6. PBS-SLURP simulations of sublimation, drifting from land cover (transport) and snow accumulation, for Stubble land cover, 1974-75, Creighton Tributary, Bad Lake, Sask.

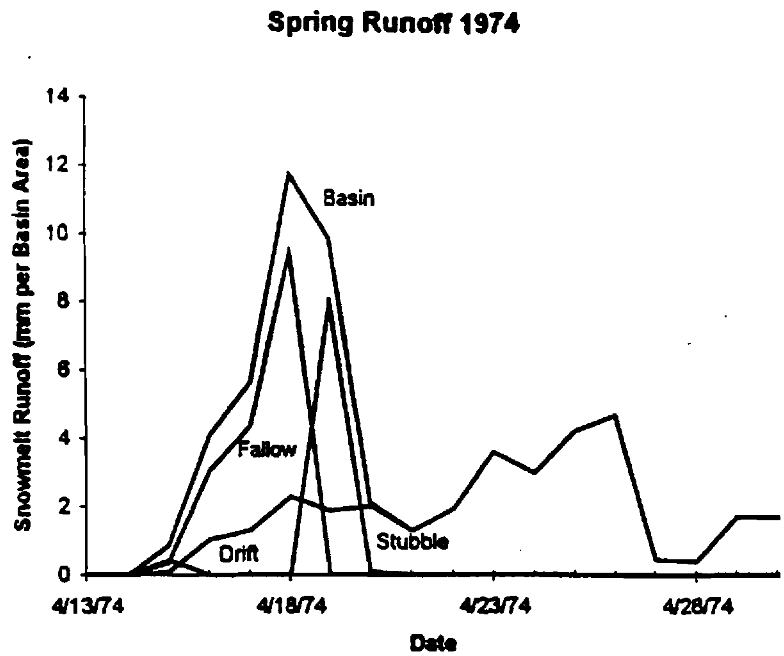


Figure 7. PBS-SLURP simulated runoff (expressed as mm per unit area of basin) for whole basin and contributions from individual land covers – Creighton Tributary, Bad Lake, Sask. 1973-74

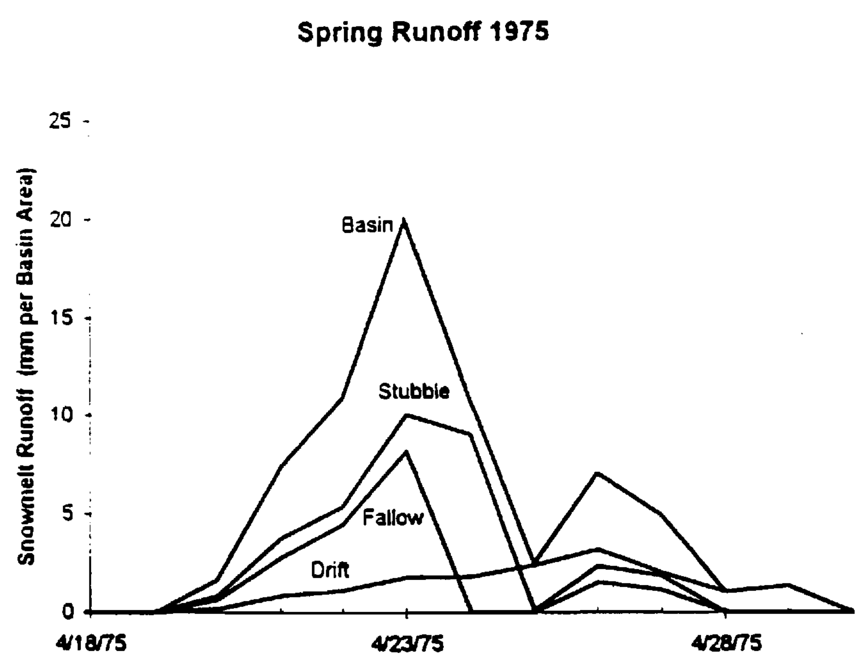


Figure 8. PBS-SLURP simulated runoff (expressed as mm per unit area of basin) for whole basin and contributions from individual land covers – Creighton Tributary, Bad Lake, Sask. 1974-75

Table 1 shows the seasonal fluxes due to sublimation, blowing snow transport, the maximum snow water equivalent, meltwater runoff per land cover and meltwater discharge generation per land cover type.

	Fallow	Stubble	Drift	Basin
73/74				
Sublimation mm/m²	**-117**	**-106**	**0**	**-100**
Transport mm/m²	**-120**	**-44**	**+380**	**-32**
Max SWE mm/m²	**135**	**156**	**640**	**196**
Melt Runoff mm/m²	**60**	**52**	**545**	**105**
Spring Runoff mm/basin	**31**	**32**	**56**	**119**
74/75	Fallow	Stubble	Drift	Basin
Sublimation mm/m²	-34	-16	0	-22
Transport mm/m²	-50	-6	+110	-12
Max SWE mm/m²	101	129	264	131
Melt Runoff mm/m²	55	76	187	78
Spring Runoff mm/basin	22	38	19	79

Table 1. PBS-SLURP seasonal Simulations for Creighton Tributary, Sask.

Recommendations

PBS-SLURP has provided a good initial model for incorporation of distinctive and important Canadian prairie hydrological processes in calculation of streamflow runoff. To take full advantage of improvements in snow accumulation and infiltration routines, model requires further improvements in the snowmelt energetics routine. To make calculation of spring soil moisture and hence snowmelt infiltration more automated and less subjective, developing a more physically-based soil moisture routine in SLURP should be considered.

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