SNOW HYDROLOGY OF THE PRAIRIE ENVIRONMENT

D. M. Gray

ABSTRACT

In the discussions, the emphasis is placed on the application of the Heat-Budget or Energy-Budget equation to study the disposition of the Prairie snowpack. In addition, a special attempt is made to point out unique features of the Prairie environment which affect the magnitudes of the heat components of the equation as compared to their evaluation in other regions of the country.

GENERAL

Not unlike many other regions of Canada, on the Prairies, snow represents a main and vital source of the manageable fresh water supply. In these semi-arid regions, about 80-85% of the streamflow in the major river systems and the water stored in prairie dugouts and sloughs comes from the shallow snowpack. Nevertheless, in spite of the importance of "Snow Hydrology" to the water supply and despite the impressive length and severity of the Western Canadian winters, until recently surprisingly few studies have been undertaken or reports written about its snow cover.

SNOWPACK - DATES OF FORMATION, DISAPPEARANCE AND DEPTH

Generally, snowfall over an area tends to be more uniform than rainfall, however, because of its buoyancy, it is affected by wind and thus its accumulation and retention on the ground may be highly heterogeneous. On the Prairies, although the general snowpack depth is fairly uniform, local variations in topography and vegetative cover may cause major departures from this average. Each field therefore, has its own peculiar catch and retention characteristics. This fact, of course, has long been recognized by agriculturalists in that strip cropping is used as much as a moisture conservation practice as a wind erosion control measure. Studies have shown that stubble fields retain as soil moisture, on the average, an amount of water equivalent to approximately 37% of that of the average overwinter pack whereas fallow lands retain only about 9%. Part of this difference can, of course, be attributed to the fact that the stubble will retain snow blown from adjacent fallow strips which under certain conditions may be completely denuded.

In general, because of the expanse of areas of flat or gently rolling topography (<2% - 4%), the sparsity of tall, dense vegetative growth and the continual strong, surface winds (average hourly 10 - 16 mph) severe drifting and redistribution of the snowpack may occur over the winter months. McKay (1964), reports that well-exposed snow courses on the Canadian Plains retain only about 65% of the accumulated snowfall reported from adjacent climatological stations during melt-free winters. The fact that Prairie Snowpacks are highly susceptible to redistribution by wind is of special importance on considering the melt process because,

1. During the erosional process snow particles are often mixed with soil particles and thus the reflective and other properties which affect melting are changed on redistribution.
2. Well-eroded gullies, shelter-belts, buildings etc. act as sediment traps which cause the formation of massive, deep drifts. At the time of melt, the accumulations in the gullies may effectively store runoff from adjacent fields. For example, near Regina in 1966, accumulations in the gullies showed them to contain about 3 1/2 acre-ft. of water (as snow) per thousand feet in length although, up to the time of sampling, no significant runoff had taken place and the adjacent fields were free of snow. This lag effect is extremely important to the prediction of the time-rate of runoff.

Information of the dates of formation, loss and duration of the snowpack and the depths of the snowpack on the Prairies as listed by McKay and Thompson (1967) is given in Figs. 1 - 5 inclusive. As indicated by the authors the estimated return period values of the particular event may be calculated from the simple expression,

\[ x = \bar{x} + k\sigma \]  \hspace{1cm} \ldots (1)

in which

- \( \bar{x} \) = the mean,
- \( k \) = frequency factor, and
- \( \sigma \) = standard deviation.

Assuming the duration, time of formation and disappearance of the snow cover are normally distributed and the snowpack
As pointed out by McKay and Thompson, it should be recognized that the means and standard deviations given for the snow depths (Figs. 4 and 5) should not be considered as the mean and standard deviations as would be obtained from a True Gumbel distribution since a large number of zero values were used in the analysis. That is, the constants should be used merely to fix the location and slope of the straight line given by equation 1. From the data given in the figures it is pertinent to note that over much of the Prairie region the average duration of the snowpack is in the range of 130-140 days, the average date of loss or disappearance usually occurs the last week in March or the first week in April (Day 83 - Day 97) and that at the time of beginning of melt the average depth is in the range of 5 - 15 inches.

Table 1. Frequency factors for specified return periods

<table>
<thead>
<tr>
<th>Return Period (yrs)</th>
<th>Frequency Factor, k</th>
<th>Normal</th>
<th>Extreme Value (N&gt;20)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>0.84</td>
<td>0.92</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>1.28</td>
<td>1.63</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>1.50</td>
<td>2.02</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>1.65</td>
<td>2.30</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>1.75</td>
<td>2.52</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>1.84</td>
<td>2.69</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>2.05</td>
<td>3.18</td>
<td></td>
</tr>
<tr>
<td>75</td>
<td>2.23</td>
<td>3.56</td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>2.33</td>
<td>3.84</td>
<td></td>
</tr>
</tbody>
</table>
DENSITY

Snow depth information alone does not provide a good measure of the potential water on a basin which is available for runoff or recharge. Densities of freshly-fallen snow have been found to range from 0.004 to 0.34, depending to some extent on the location and time of year. Further, as fallen snow ages, it is subjected to climatic elements (heat exchange, pressure changes, wind, etc.) which may cause structural changes in the pack and therefore alter its density. Similarly, during the melt period the density of a snowpack may vary widely because of the preserve or loss of meltwater.

The seasonal change in density of snowpacks located near Regina and in Southern Manitoba are shown in Fig. 5. From these curves it can be observed that the densities change from a value of about 0.2 in early January to about 0.35 at the time of melt.

SUBDIVISION OF PRAIRIE REGION
ACCORDING TO PERMANENCY
OF SNOWPACK AND VEGETATION

Because of the areal extent or the size of the Prairie region, wide variations in climatic, exposure, topographic, vegetative and other conditions which are important to snow hydrology investigations may be encountered. For this reason, the region is frequently divided to smaller zones as shown in Fig. 7.

Zone 1 Snowpack frequently lost in winter

In this area, appreciable melting and evaporation of the snowpack may occur at different times throughout the winter such that under certain conditions the pack may melt completely and disappear. Commonly, this area is referred to as the Chinook belt because it is subjected to the warm, dry foehn-like winds of moderately high velocity (usually from the...
west or southwest) called Chinooks. Chinooks may vary in duration from a few hours to several days and are usually accompanied by abrupt temperature changes of as much as 30°C. Southern Saskatchewan, for example, experiences 5 - 8 periods of Chinook activity each winter.

**Zone 2 Snowpack tends to be permanent throughout the winter – Prairie.**

As shown on Fig. 7, this zone includes the major position of the settled, agriculturally-developed area of the Prairie Provinces. The climatic conditions of this area are those which we normally associate or characterize as the typical Prairie Environment. Representative of the climatic conditions which prevail in this zone during winter are those recorded at Saskatoon (see Table 2). As shown in the Table, the mean monthly temperatures during the winter months are well below 32°F.

**Zone 3 Snowpack tends to be permanent in winter forest.**

This zone, which falls north of the agricultural belt, is a forested region in which the snowpack tends to be permanent in winter.

**HEAT BUDGET OR ENERGY BALANCE**

A simple, vertical-flux, energy-budget or heat-budget equation for a snowpack may be written as,

\[
\Sigma H = H_{rs} + H_{r1} + H_c + H_e + H_g + H_p + H_q + H_m = 0. \quad (2)
\]

in which

- \(H_{rs}\) = absorbed solar (short-wave) radiation,
- \(H_{r1}\) = net long wave radiation exchange between the snowpack and its environment,
Table 2. Climatic statistics for Saskatoon

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Ave. Temp. (°F)</td>
<td>21.1</td>
<td>7.4</td>
<td>0.80</td>
<td>4.6</td>
<td>18.7</td>
<td>38.4</td>
</tr>
<tr>
<td>Ave. Max. Temp. (°F)</td>
<td>51</td>
<td>38</td>
<td>36</td>
<td>38</td>
<td>48</td>
<td>72</td>
</tr>
<tr>
<td>Ave. Min. Temp. (°F)</td>
<td>-10</td>
<td>-28</td>
<td>-37</td>
<td>-31</td>
<td>-19</td>
<td>8</td>
</tr>
<tr>
<td>Ave. Wind Speed (mph)</td>
<td>11.0</td>
<td>10.1</td>
<td>11.5</td>
<td>11.0</td>
<td>11.0</td>
<td>12.4</td>
</tr>
<tr>
<td>Ave. Sunshine, n, (hrs)</td>
<td>94</td>
<td>84</td>
<td>97</td>
<td>123</td>
<td>191</td>
<td>218</td>
</tr>
<tr>
<td>Possible Sunshine, N, (hrs)</td>
<td>270</td>
<td>245</td>
<td>261</td>
<td>278</td>
<td>368</td>
<td>418</td>
</tr>
<tr>
<td>n/N</td>
<td>0.35</td>
<td>0.34</td>
<td>0.37</td>
<td>0.43</td>
<td>0.52</td>
<td>0.52</td>
</tr>
<tr>
<td>Mean Cloud Amounts (%)</td>
<td>64</td>
<td>62</td>
<td>59</td>
<td>58</td>
<td>57</td>
<td>60</td>
</tr>
<tr>
<td>*Relative Humidity, RH, (%)</td>
<td>84</td>
<td>87</td>
<td>86</td>
<td>82</td>
<td>83</td>
<td>68</td>
</tr>
<tr>
<td>*Ave. Vapor Pressure (monthly in mm Hg)</td>
<td>2.9</td>
<td>1.6</td>
<td>1.03</td>
<td>1.25</td>
<td>2.46</td>
<td>5.9</td>
</tr>
</tbody>
</table>

*Regina

Figure 4. Snowpack depth, February 28. (McKay and Thompson, 1967).
\[ H_c = \text{convective heat transfer (sensible heat)}, \]
\[ H_e = \text{latent heat of vaporization released by condensate or used in evaporation}, \]
\[ H_g = \text{conduction of heat from underlying ground}, \]
\[ H_p = \text{heat content of rainwater}, \]
\[ H_d = \text{change in energy content of the snowpack}, \]
\[ H_m = \text{heat equivalent of snowmelt}. \]

In this equation it is customary to express the heat units in calories considering a unit area of 1 cm\(^2\) (1 cal/cm\(^2\) = 1 langley). All heat fluxes directed toward the snowpack are considered positive and those away from the pack negative (the sign being included in the term).

\[ H_{rs} = \text{Absorbed solar (shortwave) radiation} \]

The amount of solar radiation absorbed by a surface depends on the intensity of direct and diffused radiation in the ultraviolet and visible parts of the spectrum received by the surface and its albedo or reflective power. Thus, in equational form,

\[ H_{rs} = I (1 - r) \]

in which

I = insolation received at the earth’s surface, and \( r \) = reflection coefficient. The main factors affecting the amount of insolation received, \( I \), are:

(a) solar altitude and parallax,
(b) extent, distribution and form of cloudiness,
(c) the absolute humidity and the amount of ozone in the atmosphere, and
(d) the amount of dust in the atmosphere.

Of the above factors, the solar altitude and the amount of cloudiness are the most important. The others, for example,
the absolute humidity or the ozone and dust content of the air have relatively little effect on the insolation term, I. This is particularly true for Prairie Conditions where the water and dust content of the air are usually low. There is, however, a trend for the atmospheric transmission coefficient (I/I_0 - I_0 is the insolation received at the outer limit of the earth's atmosphere) to vary seasonally on the Prairies from a maximum of ~ 83% at the summer solstice to a minimum of ~ 70% during the winter solstice. This variation can be explained in part by the fact that because of the northern latitude of the Prairies (~ 50° - 53°N), the zenith distance, and hence the optical air mass the radiation must penetrate, increases during the winter months. Representative values of the average mid-monthly intensity of insolation received at a latitude of 51°N given by Mateer (1955a) are listed in Table 3.

According to Mateer (1955b), the values from Table 3 may be adjusted to take into consideration cloud cover by applying the equation,

\[ I = I_c (0.355 + 0.68n/N) \]

in which

\[ I = \text{insolation received considering cloud cover, } I_c = \text{cloudless day insolation, and } n/N = \text{ratio of the hours of bright sunshine to the maximum (possible) hours of bright sunshine.} \]

One of the major differences in evaluation of the energy-balance components for the Prairie snowpack compared with a deep, mountainous pack is evaluating the time change in reflectivity during the melting period. It is well-documented that the reflectivity of a snowpack is little affected by the type and condition of the ground beneath it provided that the depth of the pack is greater than six inches. From the information given in Figs. 4 and 5 it is evident that on the Prairies, because of the shallow initial depth of the pack, when melting does occur the depth may be quickly reduced to such extent that the absorptive and reflective properties of the underlying surface plays an important role in the energy exchange. When this occurs, melt is greatly accelerated because a greater portion of the insolation received at the surface is absorbed and used to melt both the pack and the soil surface. This effect is strikingly evident from direct observations of the rate of disappearance of snow accumulations from adjacent fallow and stubble fields. Snow disappears first from the fallow lands because of their black color and shallow depth of cover. The rate of decrease in reflectivity from the area increases with time as the surface layer of snow melts to expose dirty layers of wind-blown snow below and as patches of exposed black, bare soil appear on the fallow land. Edge

<table>
<thead>
<tr>
<th>Condition of Snow Surface</th>
<th>Height of Sun (°)</th>
<th>Reflectivity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compact, dry, clean</td>
<td>30.3</td>
<td>86</td>
</tr>
<tr>
<td>Clean, wet, fine grain</td>
<td>34.5</td>
<td>63</td>
</tr>
<tr>
<td>Wet clean granular</td>
<td>33.7</td>
<td>61</td>
</tr>
<tr>
<td>Porous, very wet, greyish color</td>
<td>35.3</td>
<td>47</td>
</tr>
<tr>
<td>Very porous, grey, full of water, sea ice visible</td>
<td>32.8</td>
<td>43</td>
</tr>
<tr>
<td>Very porous, light brown, saturated with water</td>
<td>29.7</td>
<td>31</td>
</tr>
<tr>
<td>Very porous, dirty, saturated with water, sea ice visible</td>
<td>37.3</td>
<td>29</td>
</tr>
</tbody>
</table>

(Kuzmin, 1960 — after Kondrat'ev, 1954)

Table 4. Reflective properties of snow.

|----------|----------|----------|----------|----------|----------|----------|

Using the climatic data given for Saskatoon (Table 2) with equation 4 it is evident that on the average only about 59% of the insolation is received during Dec. (74 ly/day) whereas this percentage increases to 71% at the time of melt (Mar. = 312 ly/day; Apr. = 432 ly/day).

**Reflectivity (albedo) r**

The reflectivity of a snowpack varies over a wide range depending both on the height of the sun and the condition of the surface layers of the pack. Typical values of the reflectivity coefficient for different snowpacks and sun angles are given in Table 4.

Using the values given in the table as a guide, it is obvious that for the Prairies, because of their northern location and the fact that they are usually blanketed with a dry, clean, snowcover the reflection coefficient is very high. It follows therefore, in consideration of remarks made in preceding discussions that the net incoming solar radiation on these regions during the winter months will be very low and at many times less than the nocturnal long-wave radiation loss. This causes the temperature of the snowpack to lower below freezing.
melt around the periphery of these patches accelerates the process. The net result is a rapid melting and disappearance or disintegration of the snowpack which occurs reasonably uniformly from an area except in the gullies and drifted areas.

For deep, well-drained snowpacks it has been shown that during the melting period the change in reflectivity or albedo follows an exponential decay function when related to the number of degree-days above 32°F. Preliminary studies conducted at the University of Saskatchewan have indicated that for the shallow Prairie snowpacks the shape of this curve is ogive. That is, the curve may be divided into two parts.

1. A rather flat, concave-down, segment during which the reflectivity does not change appreciably with the number of degree-days. This result is consistent with the findings of McKay in which he suggested that there is a base temperature, “threshold temperature” below which no melting occurs (see later discussions). Thus, the shape of this segment of the curve probably reflects the condition during which the sub-zero snowpack mainly stores heat to increase its temperature to 32°F. Although the reflectivity of the pack is also high, some melting of the surface may occur.

2. A steep, downward-sloping, concave-upward (which is nearly linear) segment of the curve representing the period during which “active” melt takes place. The slope of this curve is much larger (negatively) than that used for a well-drained deep pack.

Net Longwave Radiation Exchange, $H_{L1}$

In the absence of significant forest cover, such as those conditions encountered on the Prairies, the principal factors influencing the long-wave exchange are:

1. The temperature of the snow surface and air layer close to the ground;
2. The absolute air humidity;
3. The amount and form of cloudiness; and
4. The wind velocity in the air layer close to the ground.

The general equation which expresses mathematically the relative effects of these variables on the exchange process is

$$H = [(a + b \sqrt{e_a}) \sigma T_a^4 - \sigma T_s^4] \left[1 - (1 - 0.024z)N \right] \cdots (5)$$

where

$e_a =$ actual vapour pressure of the air (mb) at air temperature, $T_a$,

$\sigma =$ Stefan-Boltzmann’s constant,

$T_s =$ surface or ground temperature,

$z =$ height of the cloud base in thousands of feet,

$N =$ portion of the sky covered by clouds (decimal fraction), and

$a, b =$ constants of the emissivity function whose values for a melting snow surface over large snow fields are usually taken as 0.74 and 0.0049 respectively.

Winters in Western Canada are characterized by lengthy nocturnal periods of cloudless skies. During these periods, because of the low absolute humidity of the air, thus the large longwave radiation loss, the total net radiation exchange is negative. That is, the outgoing radiation loss during the evening exceeds the gain during the day. Under these conditions the temperature of the pack is lowered. As indicated previously, this aspect has been substantiated by the findings reported by McKay in which he defined a temperature base as a “threshold temperature” or an average air temperature at which under given conditions melting occurs. McKay found that the threshold temperatures of mid-January, mid-February, mid-March and mid-April were approximately 40°F, 39°F, 37°F and 32°F respectively. That is, usually the thermal quality of the snowpack is greater than 100%.

That the net longwave radiation loss, may exceed the short-wave gain on the Prairies during the winter months is easily discernible from the data given in Tables 2, 3 and 4.

Even during the melt period, the nocturnal radiation losses may be sufficient to refreeze all or a portion of the thawed soil and to reduce the temperature of the surface crust below 0°C. Usually, however, this loss does not exceed 15% of the average daily heat input. As the net long-wave radiation exchange is dependent on both air temperature and humidity, this exchange can be greatly altered by a change in magnitude of these variables. It is a generally recognized fact that on the Prairies, appreciable melting of the pack will not occur until the mean daily air temperatures exceed 40°F. It should be pointed out that at the time of melt there is often a reversal in the time of occurrence of maximum cloud cover. That is, the days are often clear whereas clouds form in the evenings (probably caused by evaporation during the day). The obvious effect of the increased cloudiness is to reduce the nocturnal radiation loss and subsequent cooling of the snowpack. Since the shallow Prairie pack responds quickly to daily temperature changes, these conditions are conducive to high melt rates.

Convective-Condensation Heat Transfer, $H_c, H_e$

Usually the transfer of heat to the snowpack by turbulent processes is considered of secondary importance to that supplied by radiation. Although this generalization may be applicable to conditions encountered in Zone 2 (see Fig. 6) it is doubtful whether it is valid for Zone 1, a zone subjected to appreciable Chinook activity in which these may be abrupt temperature changes accompanied by high winds.

In the turbulent exchange the transfer of heat to or from the snowpack is accomplished in two ways, (a) by the direct transfer of heat due to a temperature gradient and (b) by the transfer of heat in the form of the mass exchange of air (water vapour) under the action of a vapour pressure gradient. These processes may be described mathematically by the simple expressions,
\[ H_C = k_C (T_a - T_s) f(u) \] \[ H_E = k_E (e_a - e_s) f'(u) \]
in which

- \( H_C \) = convection heat transfer under a thermal gradient,
- \( H_E \) = heat transfer by condensation or evaporation,
- \( k_C \) = convection coefficient (dependent on the height of measurement of parameters, the specific heat of air, the density of air, the roughness parameter and the mixing length),
- \( k_E \) = condensation or diffusion coefficient (dependent on the height of measurement of the parameters, the specific humidity of air, the density of air, the air pressure, the surface roughness and the mixing length), and
- \( f(u), f'(u) \) = wind functions.

Different forms of equation 6 and 7 presented by Sverdrup (1946), Thornthwaite and Holzman (1939) and the U.S. Corps of Engineers (1956) or the Bowen Ratio may be used to determine the relative amounts of heat transfer by convection or condensation. Since these relationships are reasonably commonplace in the literature, they will not be reproduced herein.

As pointed out by Diamond (1953) it is a common misconception that appreciable evaporation takes place when a warm, dry air blows over a snow surface. Since evaporation can only take place when a vapour pressure gradient exists and since the upper temperature a snow surface can reach is 32\(^\circ\)F at which time the vapour pressure of the air is approximately 6.11 mb, then air at temperatures of 0\(^\circ\)C, 5\(^\circ\)C, 10\(^\circ\)C, 15\(^\circ\)C and 20\(^\circ\)C must have relative humidities less than 99.9%, 70%, 49.7%, 37.5% and 26% before there is a vapour pressure gradient favourable to evaporation. Further, in this process,

a) a heat supply must be available for evaporation or the temperature of the snow surface will be lowered causing a subsequent reduction in the vapour pressure at the surface; and
b) the relative heat quantities required for evaporation and melting for snow at 0\(^\circ\)C are approximately 8.5:1 (680 cals./gm:80 cals./gm).

On the basis of the preceding information it is reasonable to assume that under Prairie conditions:

1. In Zone 1, appreciable melting of the pack may occur due to convective-heat transfer from Chinook winds. It is questionable, however, that these winds will cause direct evaporation and/or sublimation from the pack except at locations close to their source. The disappearance of the pack may therefore be attributed to melting accompanied by infiltration and finally evaporation from a free water surface.
2. In Zone 2, because of the low air temperatures, the amount of evaporation which occurs from a snowpack during winters is negligible.

**Heat Conduction to and from the Soil, \( H_Q \)**

During most winters on the Prairies, the flow of heat within the ground underlying the snowpack is toward the soil surface.

\[ \text{Figure 6. Seasonal variation in average snow density.} \]
\[ \text{(after McKay, 1966).} \]
and thus there is a gradual lowering of soil temperature. In the absence of the occurrence of an early large snowfall, depths of frost penetration of 5 - 7 feet are common. However, because of the low thermal conductivities of the soil (usually at low moisture contents), the relatively small thermal gradients, and the presence of the soil snow interface, it is questionable whether the net transfer is of sufficient magnitude and rate to cause melting of the pack. Most likely this heat partially offsets the net loss through long-wave radiation and thereby resists lowering of the temperature of the pack.

Although, preceding active melt some of the heat conducted to the pack may result in some ripening it is considered that the thermal regime and conductance properties of the soil are of major importance as they affect the amount of infiltration to the soil because

(a) normally, the temperatures of soils underlying the Prairie snowpack at the time of active melt are below 32°F. Thus meltwater released by the pack on entry to the soil is refrozen and forms an effective barrier to
infiltration and the movement downward to deeper depths; and
(b) as pointed out previously, because the snowpacks are shallow, an appreciable amount of the absorbed energy may be absorbed by the soil surface. This supply of heat will induce thermal gradients both in the direction of the pack and downward into the soil.

With reference to item (b) above it has been found in studies of the infiltration characteristics to frozen soils that, assuming isothermal conditions, the volumetric seasonal infiltration amount could be related to the water equivalent of the snowpack and the net heat transfer to the soil, which of course, is governed partially by the thermal properties of the ground. It was observed that the percentage of the heat received at the snow surface which is absorbed by the ground increased exponentially with a decrease in the amount of the above-surface moisture (analogous to the exponential decay of the amount of radiation penetrating a snowpack to different depths-extinction curve). These percentages ranged in value from approximately 10% at the time of beginning of melt to 80% at times just preceding the actual disappearance of the pack.

**Heat Content of Rainwater, $H_p$, and Change in Energy of Snowpack, $H_q$**

The heat supplied to a snowpack by rain is calculable by the standard equation,

$$H_p = (T_r - T_s)P_r$$

in which

- $T_r =$ temperature of rain ($^\circ C$),
- $T_s =$ temperature of snow ($^\circ C$),
- $P_r =$ rainfall depth (cm).

This factor is usually not important to the melting of prairie packs, because of the infrequent occurrence of rain during this period. Needless-to-say, however, if rain does occur during time of melt it will give rise to the rapid release of meltwater and high flood peaks.

As indicated in previous discussions of the melt sequence of Prairie packs, the energy changes of the pack are important during periods preceding the active melt. However, during the melt period, because of the low storage capacity of the pack for heat (shallow), the pack warms quickly in early morning and responds rapidly to changes in climatic conditions. It is thus to be expected that this produces pronounced diurnal fluctuations in the runoff pattern.

**SUMMARY**

Prairie snowpacks are highly susceptible to wind erosion or redistribution by the wind. This process may cause changes in the thermal or reflective properties of the pack in addition to greatly influencing the runoff pattern from an area.

Because of the shallow depth of the pack, the character of the ground underlying the pack plays an important role in the energy exchange. This characteristic is particularly important as it influences the rate of change of albedo during the melting period and heat conduction to the ground which in turn influences the volumetric infiltration amounts.

With the normal climatic conditions which prevail on the Prairies during the winter months:

1. The net energy exchange is negative (outward) resulting in a lowering of the snowpack temperature below freezing ($32^\circ F$).
2. The amount of evaporation from the pack is negligible.
3. The net convective heat transfer to or from the pack is negligible.

The relative importance of these components to the exchange changes at the time of melt or under Chinook conditions.

**REFERENCES**


DISCUSSION I

J.A.S. Milne; I question the siting of the precipitation gauge as shown on the slide being too close to a travelled road, i.e. because of effect of snow plowing, etc.

D.M. Gray; No, I don't think that the position of the gauge (shown on slide) in relation to the road a problem because:

1) No snow blowers are used in the area. When graders are used, the snow is usually pushed into the drainage ditches.
2) Elevated roads in the area are usually swept clean of snow except for localized drifts, and
3) The distance in the slide is misleading. I would guess this gauge is approximately 100 ft. from the road.

G.A. McKay; In the presentation it was indicated that heat was very efficiently transferred from the forest canopy to the snow cover and also that the absorption of energy by the biomass was far superior to that of the snow cover which reflects highly in the visible spectrum. This would suggest that much more of the energy incident on the forest would be available for snowmelt than that in open plains having a similar amount of sunshine; however, this is not the case. Would you care to comment?

W.W. Jeffrey; It is true that wavelength conversion by forest biomass leads to greatly increased longwave radiation input to snowpack in the forest ecosystem. This additional longwave component, however, is not sufficient to compensate for the reduction in shortwave input which results from the interception of solar radiation by the biomass. New snowpack in the open will, of course, reflect strongly in the shortwave range so that much of the gross shortwave input is lost back to the atmosphere. However, with older snow more will be absorbed by the pack, to make for a greater net shortwave radiation input to snowpack in the open.

For instance, from Figure 7 of my paper, net solar radiation in the open is 0.20 ly/minute. Comparably, net longwave input in the first is 0.06 ly/min; net shortwave input is 0.01 ly/min; total radiation input in forest is therefore 0.07 ly/min. Total radiation input in open is 0.20 ly/min. (shortwave) corrected by -0.08 ly/min net longwave budget, total = 0.12 ly/min.

D. Storr; Measurements of net all wave radiation at Marmot Creek, both above the canopy (60 ft spruce) and below at 6 ft above ground, show that the ratio is approximately 5:1. This ratio may vary with the season and is probably less during the winter.

W.W. Jeffrey; The 5:1 ratio is more pronounced than the approximately 2:1 ratio developed by the United States Army Corps of Engineers' work for the closed forest.

M.C. Quick; Is the energy input to open areas increased by surrounding forest areas and is this only qualitative?

W.W. Jeffrey; Forests, through efficient all-wave absorption, heat up and produce large amounts of sensible heat, which can be advected into open areas occurring within the otherwise forested landscape. This means that an additional heat input is available to snowpack in large, open areas in the otherwise forested landscape, in comparison to snowpack in steppe or tundra (non-forested) regions. Other than the work by Miller cited in my paper, I cannot offhand recall any other quantitative measures of this phenomenon.

M.C. Quick; On the Prairies have fences been used to trap the wind blown snow and if so, with what success?

D.M. Gray; Yes, fences are used on the Prairies:

1) Of course by Highway Department, Railways, etc., for protection of respective facilities.
2) By farmers in the form of windbreaks, etc., and snow ridging. The exact value of these procedures in terms of increased moisture conservation and consequent yields is unknown.
3) To assist in the catch or accumulation in depressions used as domestic or livestock water supply reservoirs.

W.W. Jeffrey; Some work has been done in Colorado (Agric. Expt. Station?) on stubble and tall sorghum strips to induce snow accumulation in farm areas. I remember this only vaguely. Perhaps Dr. Meiman could refresh my memory on this work.

J.R. Meiman; The U.S. Agriculture Research Service did some studies in Colorado on effects of stubble on snow accumulation.

Also, the U.S. Forest Service, Rocky Mountain Forest and Range Experimental Station, is researching the use of snow fences to increase water supplies in Wyoming.

W.T. Dickinson; Are you aware of any work that has been done on treating the snowpack as a transient porous media? That is, it absorbs moisture and changes to a point; and then the runoff begins rather quickly and unpredictably. Might a porous media approach be worthwhile?

D.M. Gray; Unfortunately not! In agreement with you, I have given consideration of this approach and indeed believe it is worth investigating. The difficult problem will be in evaluating both transmission and gradient properties in the pack.

G.A. McKay; I am not aware of any study of this nature having been undertaken. Our experience in the Prairies indicates that often the runoff in smaller channels occurs suddenly when spring is advanced, often after all snowcover is removed from the flat prairies. This appears to be the result of the snow stored in gullies becoming suddenly fluid with the
acquisition of a high percentage of liquid water; substantial flows occur quite suddenly.

C.E. Schomaker; What happens to the water from the transitory snowpack in the zone of Chinook Wind? Does it appear as runoff?

D.M. Gray; Your question involves both a 'yes' and a 'no' answer depending on conditions which exist at the time of occurrence of the Chinook. That is,

(1) If the soil temperature is below freezing, or the soil frozen at a high moisture content—or in other words, if conditions favor runoff—then one can get appreciable rates and volume of runoff from Chinook activity.

(2) Conversely, if the snowpack is shallow, the soil unfrozen or having a high infiltration potential, that is, where conditions do not favour runoff, then the pack disappears primarily by infiltration and evaporation and thus very little runoff is visibly evident.

For further information on the subject, I would refer you to the work of Pelton and Campbell at Swift Current, Saskatchewan.

G.A. McKay; Concerning runoff occurrence in the Chinook belt. This does happen frequently in the winter months; reservoirs, gullies, and potholes becoming filled in January when sufficient cover is available prior to the melting period.

Farther east, melt resulting in midwinter thaws usually produces a glaze or ice layer on the surface of the snow cover, leaving the lower snow unchanged, i.e., dry and powdery. This pattern tends to change about mid-February when the melting process is due more to solar radiation; in January it is mainly the result of turbulent transfer. In February the whole pack warms up with insolation penetrating to the ground and melt water then penetrates to the ground and the snowpack ripens.

W.W. Jeffrey; To confuse the situation further, let me briefly mention some work I did in Alberta in low elevation lodgepole pine forests. Snowpack under forest stands was ephemeral. Fall soil moisture measurements followed by soil moisture measurements in the subsequent spring allowed an overwinter soil moisture budget to be made. Results demonstrated overwinter accretion of soil moisture in the upper portion of the mantle. This could be interpreted as representing infiltration of snowmelt water into the soil mantle during the winter. However, measurements of soil moisture throughout the profile showed that spring soil moisture was lower at depth (4 to 8 feet approximately) than soil moisture levels in the previous fall. In some plots, total soil moisture for the instrumented solum was virtually identical in spring and fall. This could be interpreted as indicating thermally-induced soil moisture redistribution overwinter. In this case, there is little supportive evidence for melt water recharge of the soil mantle.

Snowfall in the area is slight, and the water equivalent of overwinter precipitation small. The soil moisture budgets still left unanswered the question of disposition of ephemeral snowpack in Chinook areas.

K.S. Davar; Much is known and has been discussed about the snowmelt component in the synthesis of basin outflow hydrographs. However, most of this discussion has referred to the estimation of basin snowmelt; there are two other important aspects involved in the proper synthesis of snowmelt hydrographs, the storage and transmission characteristics of the basin. Snowmelt is a thermodynamic process, storage and transmission may be considered to be hydraulic phenomena. The entire complex of snowpack, vegetal or humus mat, and soil strata may be viewed as a storage and transmission medium, with the unique distinction that its hydraulic characteristics may vary widely continuously, and in an irregular manner.

A significant observation, based on field information and laboratory tests, is that a snowpack will absorb increments of liquid water until a critical point is reached, at which it will suddenly start releasing its storage of liquid water, as if the hydraulic resistance to emergence had been suddenly overcome at this critical point.

Further investigations are very necessary concerning this phenomenon as it has a very important influence on timing of basin snowmelt releases, commonly referred to as the ripening of the pack.

T. Dickinson; The study of flow in a snowpack as a transient porous media phenomenon would be most interesting, and hopefully fruitful. The question arises with regard to sampling this flow. I would appreciate hearing discussion on this topic during the remainder of the workshop.