WINTER AND SPRING RUNOFF REGIME ON AN EXPERIMENTAL WATERSHED

H.D. Ayers[1]

The winter snow regime in peninsular Ontario, immediately north of Lakes Erie and Ontario is one of intermittent melt combined with occasional rain or freezing rain during the November - March period. Large accumulations of snow are rare. The soil-snow interface is a plane of significant hydrologic activity. Study of the hydrologic regime on upland watersheds provides a better understanding of river behaviour in this region of Canada.

Geology and Land Use

Four experimental watersheds located in the vicinity of Guelph, Ontario were instrumented commencing in 1952. The location is at 80° 15' west longitude and 43°32' north latitude in the general physiographic region classified by Chapman and Putnam (1951) as the Guelph Drumlin Field. The topography is typical of about 1100 square miles of Ontario. The land consists of drumlins or groups of drumlins fringed by gravel terraces. The drumlins are separated by swampy valleys in which flow the tributaries of the Grand River. The elevation is from 1100 to 1400 feet above mean sea level. The experimental watersheds are within the drainage area of the Speed River which in turn is a tributary of the Grand.

The glacial till is stoney with some surface boulders. Two main soil types dominate the area--the Guelph and Burford loams described by Hoffman et al (1963). Both are well drained with profiles at least two feet deep. They have characteristics of the Grey-Brown Podzolic Great Soil Group.

The region is dominantly a dairy farming area, with hay, wheat, corn and pasture being the most commonly produced crops.

Climate

The climate is humid-continental, characterized by moderate winters, warm summers, and sufficient rainfall for successful crop production. The mean annual temperature is 44°F, with a mean January temperature of 20°F and a mean July temperature of 68°F. The mean annual precipitation at Guelph is approximately 33 inches with a slightly lower mean monthly precipitation during the winter than during the summer months. The November-March precipitation is almost equally divided between rainfall and snow.

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Watersheds

The watersheds are each approximately 20 acres in size with a median slope of about five per cent. The cultural treatments and watershed characteristics of W1 and W3 are shown in Table 1. For this paper only these two watersheds will be discussed.

Runoff measurements have been made with a 3-foot Type-H, rate measuring flume on each watershed (Figure 1).

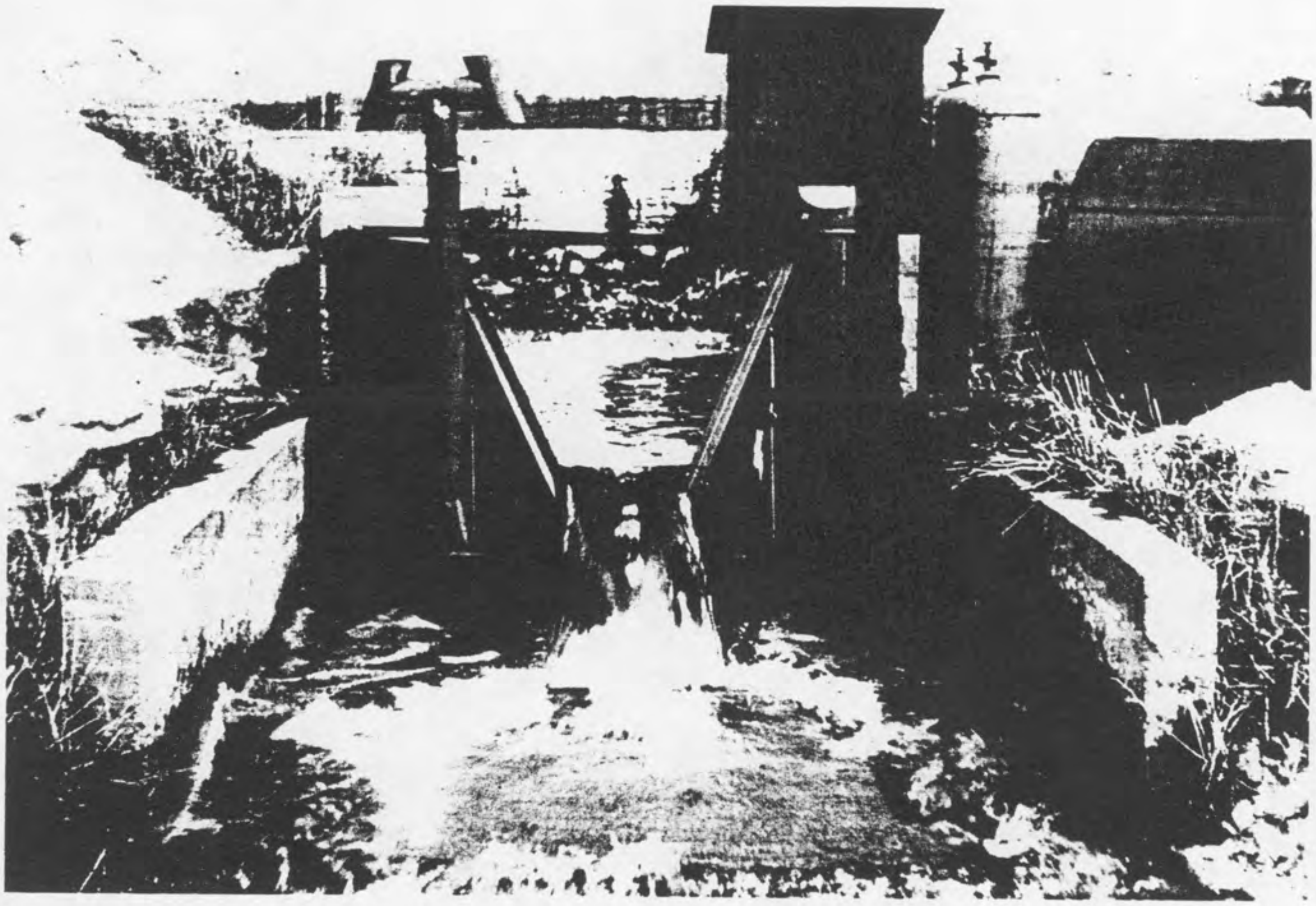

Figure 1.--Type H Rate Measuring Flume Used on Experimental Watersheds

The design of the flume is described by Harrold and Krimgold (1943). Water stage recorders with a 1:1 stage scale and a time scale of one inch equals 2.5 hours were used until 1958 when the stage recorders were changed to 1:2.4 for stage and one inch equals 5/6 hours for the time scale.

Precipitation measurements have been made with the U.S.W.B. 8-inch Standard Gauge and the Bendix Friez Weighing Recording Gauge. Only occasional snow course observations have been made because of the relatively low accumulative snow depth at any one time.

TABLE 1 - WATERSHED TREATMENTS

		W1		W3	
Area:		19.64 acres		20.81 acres	
Soil :		Guelph loam (95%) Donnybrook sandy loam Brisbane loam		Donnybrook sandy loam (95%) Brisbane loam	
Slopes:	Median	5.5%		4.8%	
:	90% range	1.9 to 9.0 %		1.0 to 9.4 %	
Year*		Winter	Summer	Winter	Summer
1952-53		Corn Stubble	Small Grain	Hay Sod	Hay Sod
1953-54		Hay Sod	Hay Sod	Hay Sod	Hay Sod
1954-55		Hay Sod	Hay Sod	Plowed	Corn
1955-56		Hay Sod	Hay Sod	Corn Stubble	Small Grain
1956-57		Plowed	Corn	Hay Sod	Hay Sod
1957-58		Corn Stubble	Small Grain	Hay Sod	Hay Sod
1958-59		Hay Sod	Hay Sod	Hay Sod	Hay Sod
1959-60		Hay Sod	Hay Sod	Plowed	Corn
1960-61		Hay Sod	Hay Sod	Corn Stubble	Small Grain
1961-62		Hay Sod	Hay Sod	Hay Sod	Hay Sod
1962-63		Hay Sod	Hay Sod	Hay Sod	Hay Sod
1963-64		Hay Sod		Hay Sod	

* Year - Oct. 1 - Sept. 30.

RESULTS AND DISCUSSION

Seasonal Runoff Distribution

The annual winter season (November - March) runoff totals are presented in Table 2 and Figure 2. The quantities in brackets are for the complete water year. It will be noted that for the past eight years surface runoff has been observed only during the winter months. The average monthly distribution of winter runoff over the twelve years is approximately as follows:

November	0%
December	1%
January	7%
February	26%
March	66%

Effect of Cover Condition

The differing cover conditions on W1 and W3 have permitted an evaluation of the effect of soil surface condition and vegetative cover on the winter runoff regime on these watersheds. The years 1958-59, 1961-62, 1962-63 and 1963-64 were the only years when both watersheds were in hay sod over the winter months. Although the calibration period is very short, the following relationship is suggested as a first assumption:

$$Qw3 = 0.70\ Qwl - 0.08 \text{ inches.}$$

On the basis of this equation estimates of the probable total winter discharge with sod cover on W1 and W3, were made for the years when the surface was actually ploughed, or in stubble.

These computed values when compared with actual values provided a measure of the influence of cultural treatment on the winter runoff. The results are presented in Table 3.

TABLE 3.--EFFECT OF WATERSHED TREATMENT ON WINTER RUNOFF

Winter	Watershed Treatment	Runoff (inches) Observed	Sod Estimate	Increase
1956-57	W1-Plowed	0.00	0.64	+0.64
1957-58	W1-Corn Stubble	0.00	0.78	+0.78
1954-55	W3-Plowed	0.74	1.91	+1.17
1955-56	W3-Corn Stubble	0.92	1.30	+0.38
1959-60	W3-Plowed	0.10	1.41	+1.31
1960-61	W3-Corn Stubble	0.13	0.57	+0.44

Figure 2. Winter water balance on Watershed W-1

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Winter and Spring Run-off Regime on an Experimental Watershed

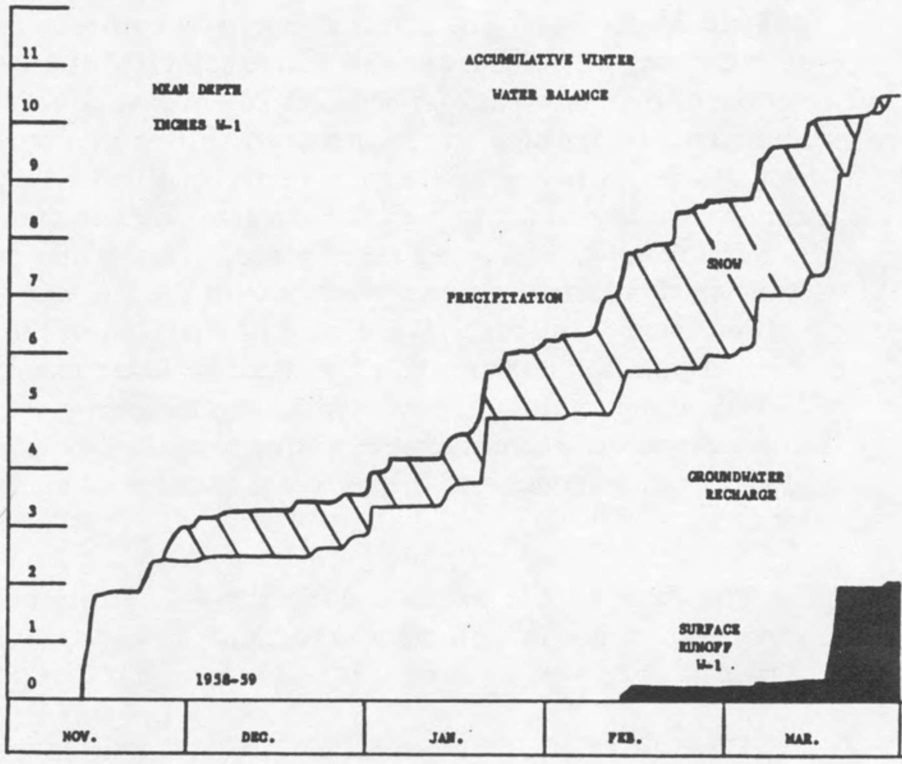

Figure 2.--Winter water balance on Watershed W-1

TABLE 2

WINTER RUNOFF FOR NOVEMBER TO MARCH ON RESEARCH WATERSHEDS (INCHES)

Year	W1	W3
1952-53	1.63 (2.44)	N.R.
1953-54	1.96 (1.96)	N.R.
1954-55	2.86 (2.86)	0.72 (0.81)
1955-56	1.97 (2.11)	0.91 (1.46)
1956-57	T	0.37 (0.37)
1957-58	0.00	0.47 (0.47)
1958-59	2.28 (2.28)	1.52 (1.52)
1959-60	2.05 (2.13)	0.10 (0.10)
1960-61	0.93 (0.93)	0.13 (0.13)
1961-62	0.77 (0.77)	0.27 (0.27)
1962-63	0.44 (0.44)	0.34 (0.34)
1963-64	0.20 (0.20)	0.08 (0.08)

In each of the six years of comparisons, greater winter water yields were realized from sod covered watershed conditions than from either ploughed or corn stubble conditions. The effect is noted on both watersheds, although the magnitude is different. The cause of the increased yield from sod is probably due to the nature of the snow pack on sod covered areas. The snow is supported by leaves and stems of grasses and legumes, resulting in a porous low density snow pack immediately adjacent to the soil surface. The soil surface is insulated against radiant energy and it is not until the later stages of snowmelt that melting of moisture in the upper soil layer takes place. On the other hand on a ploughed surface the snow settles intimately into contact with the soil and is trapped in the depressions between furrow slices. The dark soil surfaces of the furrow ridge are often visible a few days after a snowfall. The dark surfaces absorb radiant energy readily so that moisture melts. Heat is conducted to nearby snow and underlying soil, so that this type of surface ismore receptive to melt water. This coupled with the depressional storage results in decreased quantities of surface runoff from this type of surface.

The corn stubble surface is intermediate in its effect however. Depression storage is of low magnitude and vegetation density is low. The reduction in surface runoff by corn stubble over sod is not so marked as caused by ploughing.

The effects of cover conditions are indicated in the hydrographs of runoff for January 1, 1955, where rainfall and snowmelt were concurrent (Figure 3).

Figure 3.

Hydrographs of Discharge from Winter Rainfall on Experimental Watersheds

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Winter and Spring Runoff Regime on an Experimental Watershed

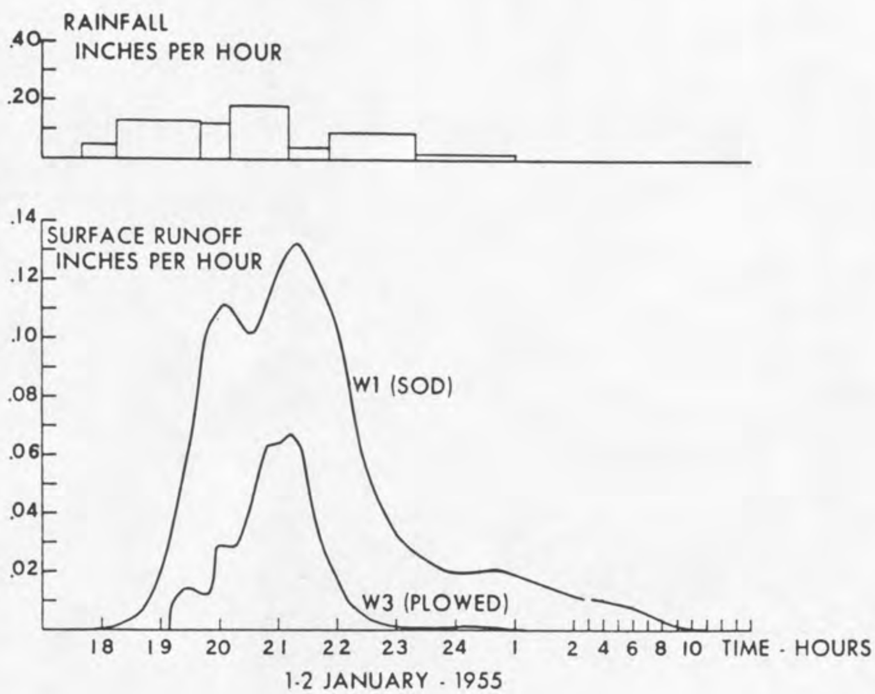

Figure 3.--Hydrographs of Discharge from Winter Rainfall on Experimental Watersheds

Runoff Intensities and Infiltration Rates

The distribution of daily runoff intensities is indicated below. About 73 per cent of the daily runoff intensities are 0.100 inches per day or less.

Runoff Intensities on Watershed W-1
Adjusted to Sod Conditions 1953-1962 inclusive

Inches per day	Occurrences
0 to 0.010	46
0.011 to 0.100	55
0.101 to 0.200	19
0.201 to 0.300	6
0.301 to 0.400	3
0.401 to 0.500	5
0.501 to 0.600	1
0.601 to 0.700	1
0.701 to 0.800	1
0.801 to 0.900	1
0.901 to 1.000	0
Over 1.001	1

The degree-day factor for snowmelt runoff was computed for various events. Concurrent rainfall limited the number of events which could be checked in this manner. The range in degree-day factor was from about 0.015 inches to 0.040 inches per degree of the daily maximum temperature above 32°F. For the most part the factor was about 0.020 until March 15th and increased to about 0.04 inches after this date.

Infiltration rates were determined on a daily basis under the assumption of a degree-day factor of 0.020 inches. The values ranged from 0.08 to 0.16 inches per day for sod during the initial runoff period of the winter season. The passage of a frontal storm during the melt followed by a rapid lowering of temperatures with the incursion of polar air is a common occurrence. The result of this has been to lower initial infiltration rates for the next melt and runoff period to 0.02 inches per day or less. However, three or more consecutive days of 40°F temperatures or higher in March usually resulted in recovery of infiltration rates to 0.20 or 0.30 inches per day or higher. This of course is still very much lower than the rates prevailing during the summer months.

Moisture Deficit and Runoff

The soil moisture deficit at the beginning of the winter (Oct. 31) has been shown to be a significant factor in the total yield of the Speed River during the winter months. By using a moisture budgeting system explained in another paper by the author (Ayers, 1965), the moisture deficit in the soil at Oct. 31 was computed for the years 1953 to 1963 inclusive. The moisture budget was based on precipitation on the experimental watershed through the winter months. The curvilinear relationship between winter precipitation less moisture deficit for November - March and Speed River discharge for November to April is indicated in Figure 4.

Figure 4.

Precipitation-
Discharge Relationship
for Speed River

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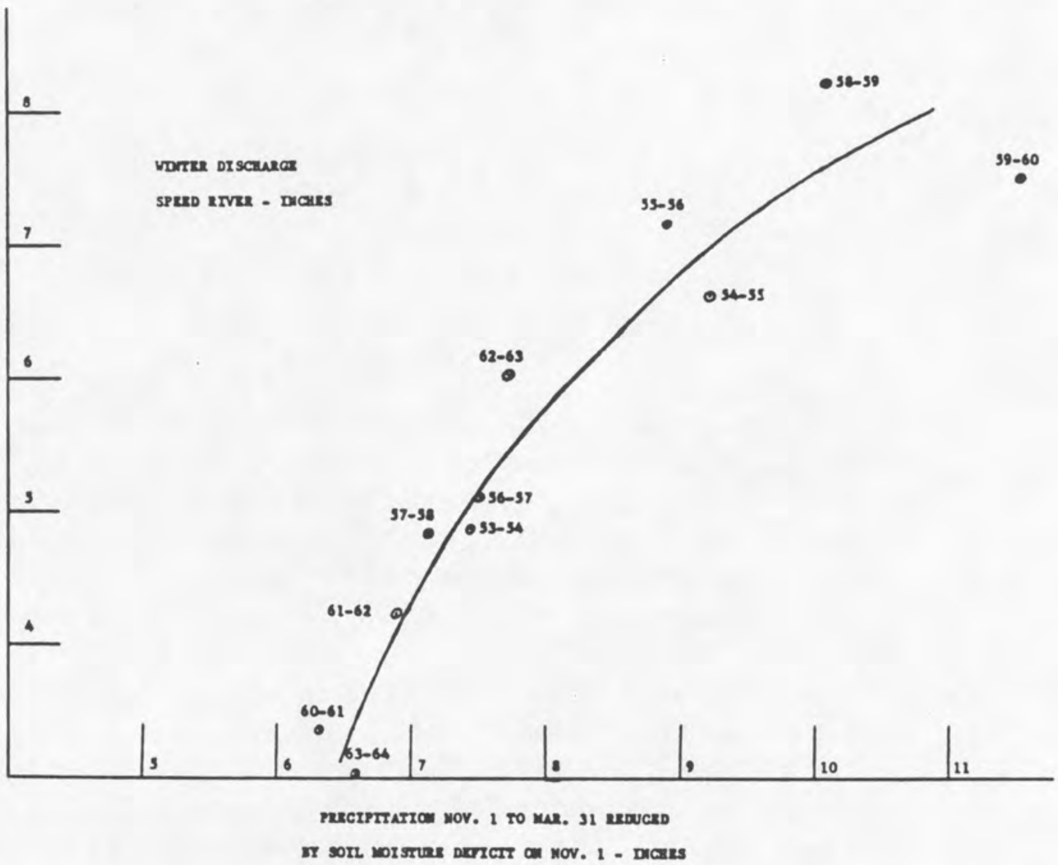

Figure 4. -- Precipitation-Discharge Relationship for Speed River

The use of this relation permits the determination of deep groundwater recharge available for summer flow following snowmelt. By adjustment of Speed River discharges for observed surface runoff values on the experimental watersheds a basis is provided for estimates of March - April flow from shallow or surficial saturated storage elements to the main stream. It is believed that most of the spring runoff in streams in this region comes from drainage of the saturated soil zone prior to the time the frost has completely left the ground. Time does not permit a full discussion on this process, although investigations are proceeding in an effort to develop this idea further.

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