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RAINFALL INTERCEPTION ON A SMALL FORESTED WATERSHED WITHIN THE KAWARTHA LAKES REGION

by

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ABSTRACT: Interception and precipitation data were collected on a small, mixed forested watershed in the Kawartha Lakes region of east-central Ontario. Measurements were taken from September 13, 1977 to September 12, 1978, in an effort to quantify the effects of vegetation on the disposition of precipitation. Regression equations were developed to describe the atmospheric and surface characteristics influencing interception. From these equations, approximately 12% of gross rainfall is intercepted and returned to the atmosphere. It is hoped that these results will assist in the construction of detailed water budgets for the region and other areas of similar hydrologic behaviour.

RESUME: Des données de précipitation et d'interception ont été recueillies sur un petit bassin versant boisé mixte, dans la région des lacs Kawartha du centre-est de l'Ontario. Des mesures ont été prises du 13 septembre 1977 au 12 septembre 1978 dans le but de quantifier les effets de la végétation sur l'élimination de la précipitation. Des équations de régression ont été développées pour décrire les caractéristiques atmosphériques et superficielles qui influencent l'interception. Selon ces équations, environ douze pour cent de la pluie brute est interceptée et retournée à l'atmosphère. Les auteurs espèrent que ces résultats aideront dans l'établissement de bilans hydriques détaillés, pour la région et pour d'autres endroits dont le comportement hydrologique est similaire.

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INTRODUCTION

The vegetation of a catchment area affects the way in which precipitation is delivered to the basin's soil surface. Plants that intercept precipitation alter its amount, timing and areal distribution, as well as the quality of the water input to the basin as a hydrologic system. Efforts to quantify the amount of water caught and held by vegetation have resulted in interception being one of the most widely and frequently investigated hydrologic processes (Helvey, 1971).

Helvey and Patric (1965b) and Helvey (1971) have reviewed interception research on deciduous and coniferous species in the United States and concluded that the effect of vegetation on the disposition of precipitation is a function of differences in climate and phytomorphological characteristics between specific geographic areas. Summaries of rainfall interception for deciduous and coniferous forest species have shown that losses may range from 10 to 35% of annual precipitation.

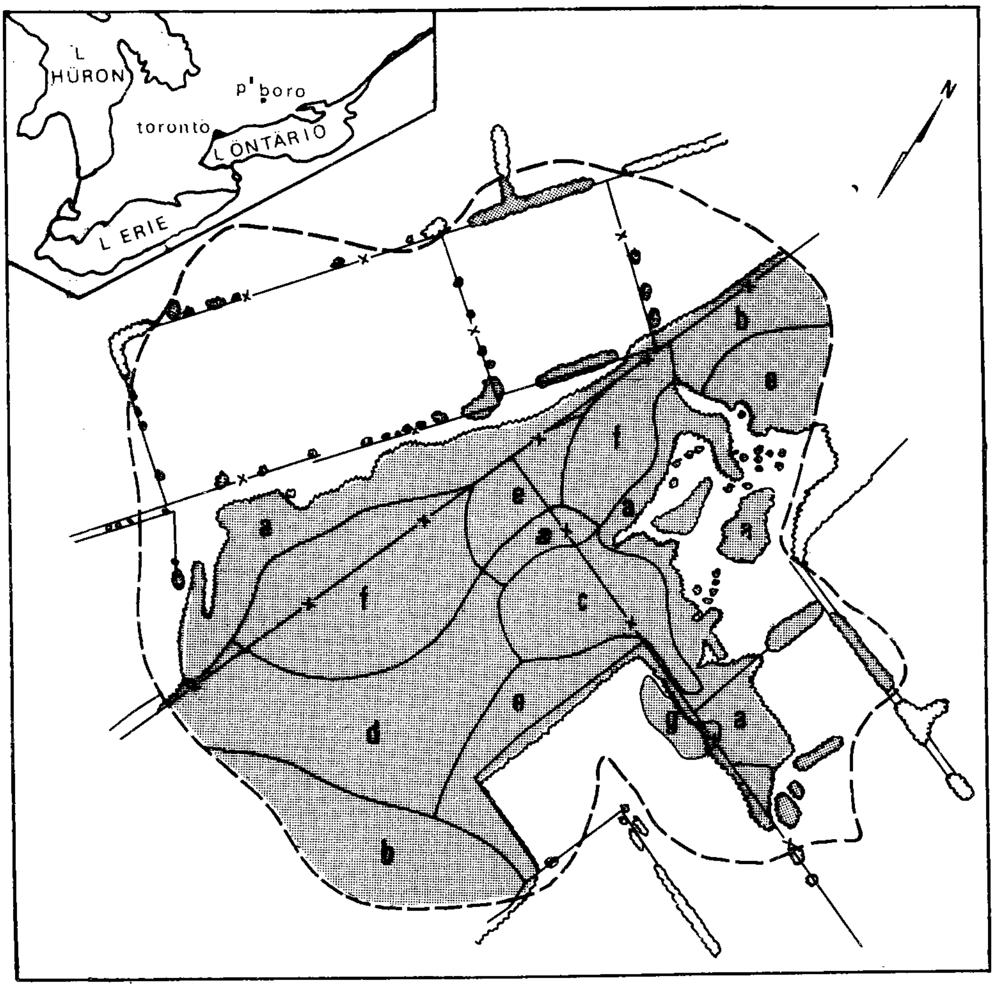
Within the Kawartha Lakes region of east-central Ontario, forest cover plays a major role in controlling the quantity and quality of the region's water resources. In fact, both forest and water resources play a significant role in the overall recreational, industrial and economic functioning of the region (Sneyd, 1976). However, to date, little work has been done in quantifying the effects of vegetation on the quantity, timing and distribution of precipitation in this area (Mathers, 1980).

In order to quantify the disposition of precipitation by vegetation within the Kawartha Lakes region, precipitation, interception, soil moisture and streamflow data were collected on a small forested watershed from September 13, 1977 to September 12, 1978. This paper will describe the regression equations that were developed to estimate basin-wide interception.

DESCRIPTION OF THE BASIN

The study watershed is approximately 47 ha in size and is located about 8 km north-east of Peterborough, Ontario (44°21'00"N , and 78°22'00"W) (see Figure 1). This watershed was selected because it is representative of the watersheds which are headwaters for many of the small streams in the region.

The climate of the area is highly variable, with average annual precipitation amounting to 81.5 cm, of which 28.5 cm is in the form of snow (Atmospheric Environment Service, 1973b). For the most part however, precipitation is evenly distributed throughout the year. The growing season is from May through September, with an average frost-free period of about 140 days



VEGETATION UNITS

UNIT I
- (b) red and sugar maple; beech and white ash nearing maturity.
- (c) pole-sized red, silver and sugar maple.

UNIT II
- (a) white cedar with old growth white pine.

UNIT III
- (d) white cedar, poplar (Spp.), and balsam fir.
- (e) poplar (Spp.), white birch and white cedar.
- (f) white elm, poplar (Spp.), and soft maple (suffocating).
- (g) willow (Spp.), hawthorn (Spp.) and white elm.

FIGURE 1. The location and vegetative composition of the study basin.

(Atmospheric Environment Service, 1973a).

The basin is located in an area of shallow Pleistocene till deposits overlying limestone of the Sherman Falls formation. The main features of the region are drumlins. Maximum relief in the catchment is 18 m, with a range in elevation of between 287 and 305 m.

Soils on the basin are classed as Brown Forest, characterized by loams and clay loams of the Otonabee series. These soils are stony and relatively shallow, with solums averaging 45 cm. The soil profile itself, does not exceed 1.5 m in depth.

The drainage pattern of the basin is characterized by an intermittent stream system. Along the main stream, flow occurs primarily, during the spring snowmelt period and occassionally in the fall, when precipitation is greater than other times of the year. The forested part of the basin is a seasonally inundated wetland, with several runoff-producing zones which shrink and expand in response to seasonal and in-storm inputs of precipitation. Surface soils on up to 60% of the watershed may be saturated under spring snowmelt conditions. The water table in the contributing zones rises and falls, producing several ephemeral, first order streams which supply surface runoff by saturated overland flow during the fall and spring snowmelt periods.

Trees cover approximately 60% of the total basin area. The remainder of the basin consists of open pasture and cultivated fields. Vegetation is characteristic of the Great Lakes-St. Lawrence forest region, with primary species including, eastern white cedar (Thuja occidentalis L.), poplar (Populus Spp.) maple (Scer Spp.) and birch (Betula Spp.). Figure 1 describes the vegetative composition of the basin.

Methods

Rainfall was measured by a network of four rain gauges: three standard and one siphon-type recording gauge.

Interception was determined by measuring throughfall and stemflow, sampling 18 storms, ranging from .2 cm to 5.0 cm in size. Throughfall was measured on 0.01 ha plots on each of the three major vegetation units shown in Figure 1. Four trough-type gauges, similar to those described by Leonard (1963), were located in each plot to catch rain passing through the canopy. Stemflow was measured on two 0.002 ha sub-plots located within each throughfall plot. Rubber collars were attached to a total of 33 trees, covering the range of species and trunk diameters.

Water caught by the throughfall and stemflow gauges was channelled into galvanized holding cans for measurement immediately after each rain event. Volumes were then converted to depths over the projected plot and subplot areas.

Results

Throughfall and stemflow data were subjected to multiple regression and correlation analyses. Independent variables in these analyses included, gross rainfall, mean rainfall intensity, rainfall duration, mean air temperature during the rain event, mean wind speed and wind direction.

Table 1 describes throughfall and stemflow equations for the various vegetation units during the growing and dormant seasons. It also compares these equations to those developed by Helvey and Patric (1965b). For the purposes of this study, the growing season was defined as May 1 to October 31 and, the dormant season from November 1 to April 30.

Gross rainfall was the only independent variable significantly correlated with throughfall. It accounted for between 71 and 94% of the explained variation in equations 1 to 5. During the dormant season, it was also the only independent variable significantly correlated with stemflow, accounting for between 54 and 87% of the explained variation in equations 6, 8 and 10. During the growing season, both duration and gross rainfall were significantly correlated with stemflow. For equations 7, 9 and 11, the combined effects of rainfall duration and gross rainfall accounted for between 78 and 87% of the explained variation in stemflow. Inclusion of rainfall duration in the regression equations, during the growing season, illustrated the effect of increased leaf area on enlarging the storage potential of the foliage during this season.

The regression equations in Table 1 suggest that there are considerable differences in the patterns of throughfall and stemflow, both between vegetation units and between seasons. These differences reflect the spatial and temporal incongruities in throughfall and stemflow due to differences in vegetative characteristics between units. In an attempt to determine whether these differences were significant, analysis of variance was performed on the data. However, no significant differences in the pattern of either throughfall or stemflow were detected at the .05 level. Therefore, the data in Table 1 were pooled, giving the following equations to describe basin-wide throughfall and stemflow:

PLOT	SEASON	REGRESSION	r^2	EQUATION
I	dormant	TfI= .65(Grf) + .109	.94	1
I	growing	*		
II	dormant	TfII = .70(Grf) + .036	.94	2
II	growing	TfII = .79(Grf) + .139	.71	3
III	dormant	TfIII = .83(Grf) - .062	.94	4
III	growing	TfIII = .82(Grf) + .107	.82	5
Helvey& Patric (1965b)	dormant	Tf = .91(Grf) - .015		
	growing	Tf = .90(Grf) - .031		
I	dormant	SfI = .141(Grf) - .006	.71	6
I	growing	SfI = .159(Grf) - .005(Dr) + .068	.78	7
II	dormant	SfII= .070(Grf) + .004	.54	8
II	growing	SfII= .077(Grf) -.002(Dr) - .013	.87	9
III	dormant	SfIII= .019(Grf) + .002	.82	10
III	growing	SfIII= .079(Grf) -.002(Dr) +.010	.81	11
Helvey& Patric (1965b)	dormant	Sf = .062(Grf) - .005		
	growing	Sf = .041(Grf) - .005		

* no variables significant at .05 level
Tf, throughfall, cm
Sf, stemflow, cm
Grf, gross rainfall, cm
Dr, duration of rainfall, hr

Table 1. Regression equations for throughfall and stemflow on vegetation units I, II and III during the dormant and growing seasons.

$$Tf = .77(Grf) + .048, \ r^2 = .87 \tag{12}$$

$$Sf = .109(Grf) - .002(Dr) + .016, \ r^2 = .70 \tag{13}$$

The combination of throughfall and stemflow data produced an equation to describe net rainfall (Nr), over the basin. This equation can be written as follows:

$$Nr = .88(Grf) - .002(Dr) + .064, \ r^2 = .74 \tag{14}$$

By manipulating equation (14), the following equation was derived to describe basin-wide interception:

$$Ir = .12(Grf) + .002(Dr) - .064, \ r^2 = .74 \tag{15}$$

Comparing equation (15) to the equations developed by Helvey and Patric (1965b):

$$Ir = .06(Grf) + .036, \text{ (growing season), and}$$

$$Ir = .02(Grf) + .020, \text{ (dormant season),}$$

it can be seen that equation (15) accounted for a much larger interception loss. The variation between the two sets of equations can be attributed to several factors, including:

1. the relatively high density of immature vegetation on the study basin. There are, on average, approximately 503 stems/ha, which may have presented a greater intercepting surface than Helvey and Patric's equations would indicate. Of particular importance could be the multi-layered nature of the canopy in all vegetation units. A canopy structure of this type could result in a greater interception loss than a single-tiered one;

2. the species composition of the basin. Although the study basin was predominately deciduous, the inclusion of a high percentage of coniferous species may have contributed to a higher interception loss than Helvey and Patric's equations would indicate;

3. the meteorological conditions prevailing over the study area. Many of the studies described by Helvey and Patric, in developing their equations, were conducted in the eastern and south-eastern States. There areas receive larger and more intense inputs of rain than does east-central Ontario and hence, the lesser interception loss;

4. the period of study for this report could have been, meteorologically, unusual. Since interception is a function of storm size and vegetation characteristics, the preponderance of low intensity and long duration storms during the study period, could have resulted in a larger interception loss. Without a longer and more detailed period of study, however, the relative impacts of such conditions are uncertain.

While equation (15) does account for a somewhat larger interception loss than Helvey and Patric's equations, the study results compare quite favourably with other results reported throughout North America. For example, studies by Lawson (1967), DeWalle and Paulsell (1969), Brown and Baker (1970), Johnston (1971), Swank et al., (1972) and Verry (1976) all report interception losses ranging from approximately 9 to 18% of gross annual precipitation. As such, the 12% interception loss reported in this paper is within the limits outlined by these studies.

Discussion

Considering the impacts of equation (15) on the water economy of the study basin, it would appear that vegetation intercepted approximately 12% of gross rainfall, returning about 7.2 cm (of the study total, 68.2) to the atmosphere. While this amount does not appear to be of major hydrologic importance, it must be recognized that interception and the redistribution of precipitation by vegetation can be an important part of the water budget and, could significantly affect water yield. The influence of interception on streamflow has been shown conclusively by Douglass (1967) and Swank (1968) and Bormann and Likens (1979). Within the Kawartha Lakes region, the impact of interception on streamflow could be of particular importance, given the fact that runoff from the study watershed and, many other watersheds within the region, is generated chiefly by saturation overland flow. Within these watersheds, runoff is controlled by contributing (saturated) areas which shrink and expand in response to seasonal and in-storm inputs of precipitation. As a result, the presence (or lack) of vegetation, as well as the type and density of vegetation, could have a pronounced effect on the disposition of precipitation, and hence, the amount, timing and distribution of runoff from these basins.

To date, no detailed, long-term investigation has been undertaken to determine the overall effects of vegetation on the disposition of precipitation. Because vegetation and water are the major features of the Kawartha Lakes region, it is important that a study of this nature be initiated. Until such a study is undertaken, it will be difficult to fully understand how vegetation affects the water economy of this region.

CONCLUSIONS

From the results reported here, it can be seen that interception is highly variable. While the amount of precipitation intercepted by vegetation on the study basin is relatively small, it must be realized that the interception process is an integral part of the complex mechanisms governing the hydrologic cycle in forested watersheds. Not only is interception the first step in a complex chain of events that precedes other geophysical and biological processes, but quantification of this process is a necessary first step in providing information on how vegetation affects the water economy of forested watersheds.

It is believed that the data set presented in this paper will assist in the initial construction of detailed water budgets for the study area and other areas of similar hydrologic behaviour. Compilation of such budgets will not only provide clearer insight into how interception affects water yields within the region, but more importantly, they will facilitate a better understanding and management approach to the land and water resources of the Kawartha Lakes region.

As a cautionary note, it should be pointed out that interception is a function of climatic and vegetational characteristics. As such, extrapolation of experimental results, from one physiographic region to another, could give significantly different results if applied to storm sizes other than those from which the original relations were developed.

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