GROUND SNOW DISTRIBUTION and SPRING RUNOFF
in a
PARTIALLY URBANIZED BASIN

by

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Urbanization, which may be defined as the process of change in land occupancy and use resulting from conversion of rural lands to suburban, industrial and urban communities, causes severe changes in the hydrologic characteristics of a drainage basin. Construction destroys the protective vegetative cover, exposes the soil, and some parts of the surface are rendered impermeable, thus altering the hydrologic regimen of the watershed. Although each change may be insignificant in itself, the aggregate effects of all urban land development drastically alters the drainage pattern. Leopold (1968) states that of all land use changes affecting the hydrology of an area, urbanization is by far the most forceful and the two principal factors governing flow regimen are: 1) percentage of area made impervious; and 2) the rate at which water is transmitted across the land to stream channels.

The impact of urbanization on virtually all phases of the hydrologic cycle is well researched and documented in the literature. Extensive reading has revealed, however, a lack of studies undertaken of snow distribution in urban environments. Snow, a significant element of the hydrological system, is subject to tremendous variations in space and time as a result of the parent storm characteristics, energy exchanges and especially wind transport. The generation of snowmelt and sequential streamflow from the snowpack that accumulates in winter, forms one of the most important phases of the northern hydrologic cycle and it is during this phase that the vagaries of the effects of urbanization upon the hydrologic regimen become most apparent.

The objective of this paper is twofold in that it will first examine the effect of urban development upon snowpack distribution and secondly, upon subsequent snowmelt runoff within the study area of Kawartha Heights, Peterborough, Ontario. This study is one segment of a continuing examination of the study area, undertaken by Trent University, and is intended to accumulate information and to facilitate an understanding of the basin's response to winter and spring events.

The Kawartha Heights study area (Figure 1) is located on the western city limits of Peterborough, Ontario and is the headwaters of a minor system draining into the Otonabee River immediately downstream of the city. The study area has a total area of 0.67 square miles and can be divided into the following three subareas: a rural basin, a construction zone and an urban basin of 0.44 square miles, 0.047 square miles and 0.22 square miles respectively. The variation in elevation within the study area is such that the response to a hydrologic event can be monitored during or shortly after its occurrence. For snow study purposes, the three discrete areas were monitored seperately, whereas the construction and urban

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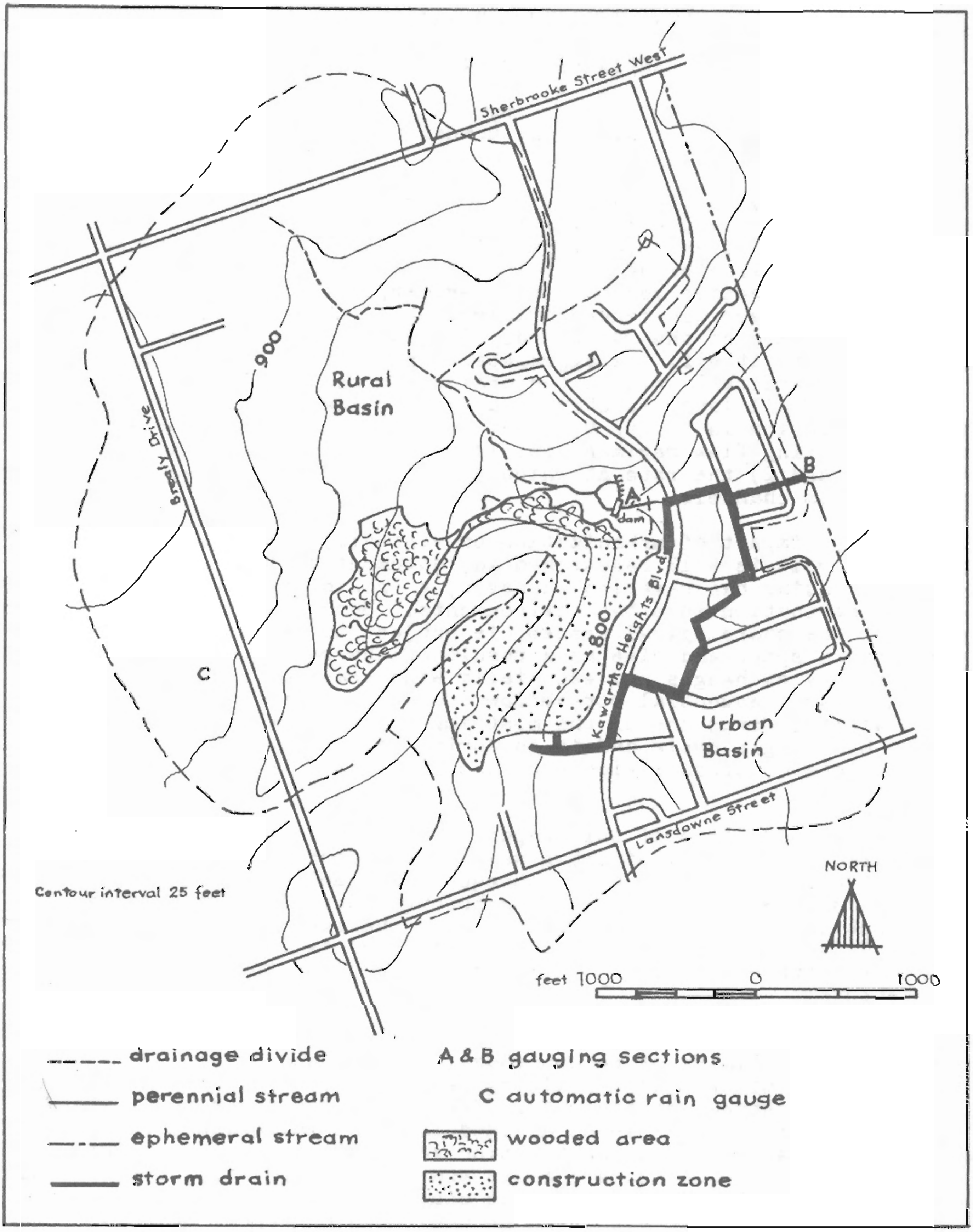


FIGURE 1 Kawartha Heights study area

areas were monitored jointly for the snowmelt runoff study.

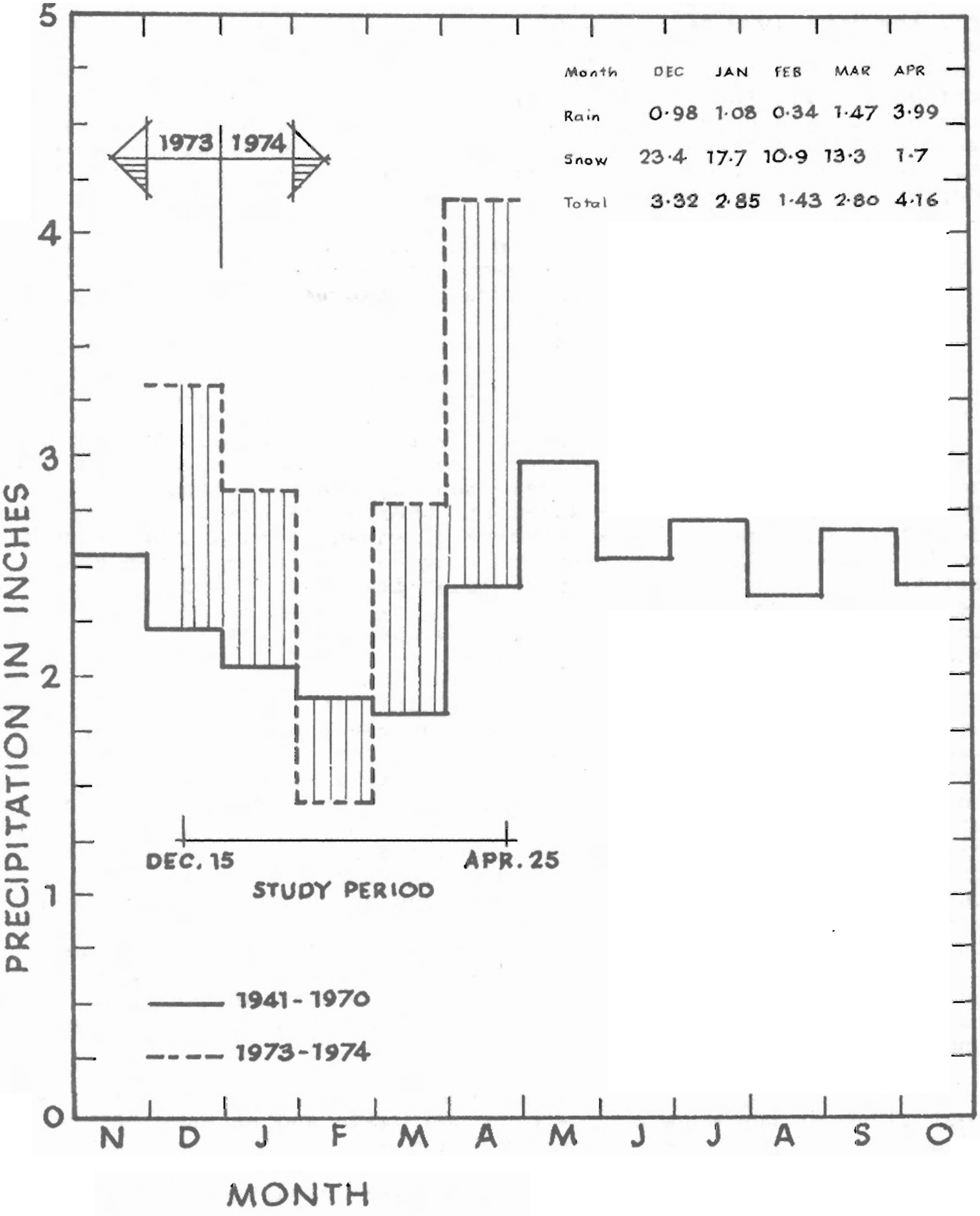
The average annual precipitation for the Peterborough area for the 1941-1970 period is 28.81 inches with a slight summer maximum and some 20 to 30 percent of the annual total occurring as snowfall. The average annual snowfall for the area for the 1941-1970 period is 60.2 inches. The study area is in that area of Canada where the normal winter precipitation includes both snow and rain and where Arctic air dominates in winter but the incursion of warm air, which may occur at anytime, gives rise to winter thaws and the resultant depletion of the snowcover.

Measurements within the catchment area included three end-of-winter snow samples to determine the water equivalent of the snowcover contained within the rural, construction and urban sectors. This was followed by a monitoring of the snowmelt runoff at gauging station 'A' for the rural basin and at station 'B' for the combined construction and urban sectors (Figure 1). The period of measurement ran from December 15, 1973 to April 25, 1974 and as Figure 2 indicates, the level of precipitation received was not particularly representative of the norm for the Peterborough area. The months of December, January, March and Spril received 49%, 39%, 49% and 72% more, respectively, than the mean monthly precipitation received for the 1941-1970 period of measurement, whereas February received 72% less than the mean. The monitoring of snowmelt runoff was terminated on April 25, 1974 when the controlling weir of a small reservoir maintained by the city of Peterborough immediately above the urban sector was installed. Since both gauging stations were located below this impoundment, the streamflow from the natural sector could not be monitored after this date.

Discharge gauging stations, utilizing automatic, float-type stage recorders, providing a continuous record of water level on a weekly basis, were established at the points of outflow of the main channel from both the rural and urban basins to monitor the snowmelt runoff. A Gurley current meter was used to determine the velocity of flow and the product of velocity and cross-sectional area yielded discharge values. Plotting stage and discharge for the two sections of channel resulted in discharge rating curves. Having established the rating curves, the stage records could then be employed to give a continuous record of discharge for both rural and urban sectors. In each case the rural input was subtracted from the urban runoff to develop a hydrograph for the urban basin alone. An automatic, tipping-bucket recording gauge was installed at the head of the rural basin which provided a continuous record of rainfall during snowmelt runoff period.

The objective of the snow study was to determine the water equivalent of the snowcover within the basin and as such the parameters of depth and density were largely ignored. The three discrete subsections of the basin required three distinctly different approaches to the problem of snowcover measurement.

The sampling technique used in the rural area consisted of 8 sampling transects (compass headings) with 20 sample points along each transect (distance between points was governed by length of transect) yielded 160 samples for the end-of-winter sample and gave



Month	DEC	JAN	FEB	MAR	APR
Rain	0·98	1·08	0·34	1·47	3·99
Snow	23·4	17·7	10·9	13·3	1·7
Total	3·32	2·85	1·43	2·80	4·16

FIGURE 2 Mean monthly precipitation at Peterborough, 1941-1970 and monthly receipts of precipitation during the period of study

an excellent areal distribution.

The construction zone required a stratified random sampling technique. The area was divided into 5 strata and a numbered grid was superimposed over the area with the original contour lines forming the top and bottom of each section. Fifteen points were sampled in the end-of-winter sample with 4 in the 790'-820' elevation, 4 in the 820'-850', 4 in the 850'-880', 2 in the 880'-890' and 1 in the 890' elevation. Five of the points were pre-selected control points and the remaining 10 points were selected using a random number table.

The lots within the urban sector were numbered and all lots were selected randomly for sampling using the random number table. Each lot selected for sampling had a randomly determined point (paced) sampled in the back and front yard. Sixty-eight of the 273 lots were sampled in the end-of-winter sample of which 10 were control lots.

The end-of-winter sampling was undertaken on March 2, 1974 and the data are summarized in Table 1.

Utilizing the mean water equivalent, the total water equivalent, in cubic feet, of snowcover for the three areas was determined to be 2.78×10^6 for the rural section, 0.21×10^6 for the construction zone and 0.35×10^6 for the urban portion. It was further determined that at the 95 percent level of probability the interval 2.52×10^6 to 3.05×10^6 for the rural, 0.10×10^6 to 0.32×10^6 for the construction and 0.26×10^6 to 0.45×10^6 cubic feet for the urban sectors contained the true means of the populations.

As a means of determining if urbanization had any effect on the snowcover within the basin, a null hypothesis was formulated which stated that there was no significant difference in mean water equivalent between any of the three areas and an analysis of variance was undertaken to prove or refute this hypothesis. In this case the variation within an area was compared with the variation between the areas using the Snedecor's 'F' test. The pertinent data of these tests are arrayed in Table 2.

The author had assumed the urban and construction areas would be similar and that there would be a dissimilarity with the rural area. This proved not to be the case. Table 2 depicts the results of comparing the water equivalent of the construction zone to that of type A (open fields) of the rural zone and it is clearly indicated that the similarity between the two areas was even greater (as the observed F approaches 1.0) when the influence of the treed area was removed. Approximately 83% of the natural area is open pasture land which is fenced off into regular sections thus keeping man's activities out and the snow in the area relatively undisturbed. This one characteristic, the degree of disturbance, was undoubtedly the factor that contributed the greatest to the observed differences.

The construction and urban areas were more similar than the urban and rural areas. If the construction area had been at a more advanced stage of development and use the differences in the two areas (urban and construction) might not have been so marked.

TABLE 1 End-of-winter survey of basin snowcover

Rural snowcover			
Statistic	Depth	Water Equivalent	Density
Number of samples (n)	160	160	160
Mean ($\bar{x}$)	6.83	2.72	0.35
Range (max. - min.)	16.40	6.40	0.86
Sample deviation (s)	3.60	1.69	0.18
Confidence interval (0.95 level)	6.27 to 7.39	2.46 to 2.98	0.32 to 0.38

Construction snowcover			
Statistic	Depth	Water Equivalent	Density
Number of samples (n)	15	15	15
Mean ($\bar{x}$)	6.23	1.91	0.20
Range (max. - min.)	14.40	5.45	0.40
Sample deviation (s)	5.41	1.80	0.15
Confidence interval (0.95 level)	3.23 to 9.23	0.91 to 2.91	0.12 to 0.28

Urban snowcover			
Statistic	Depth	Water Equivalent	Density
Number of samples	136	136	136
Mean ($\bar{x}$)	2.29	0.68	0.13
Range (max. - min.)	17.60	6.90	0.73
Sample deviation (s)	3.12	1.09	0.18
Confidence interval (0.95 level)	1.76 to 2.82	0.50 to 0.86	0.10 to 0.16

TABLE 2 Snedecor's variance ratio test comparing basin areas

Natural vs construction			
Source of variance (a)	Sum of squares (b)	Degress of freedom (c)	Variance* estimate
Between sample Within sample	9.76 491.28	1 173	9.76 2.84
$F = \frac{\text{greater variance estimate}}{\text{lesser variance estimate}} = 3.44$			
F (0.95) table value = 3.84 to 3.92		Accept	

Natural vs urban			
Source of variance (a)	Sum of squares (b)	Degrees of freedom (c)	Variance* estimate
Between sample Within sample	316.13 602.44	1 294	316.13 2.05
$F = \frac{\text{greater variance estimate}}{\text{lesser variance estimate}} = 154.21$			
F (0.95) table value = 3.84 to 3.92		Reject	

Construction vs urban			
Source of variance (a)	Sum of squares (b)	Degrees of freedom (c)	Variance* estimate
Between sample Within sample	20.46 204.46	1 149	20.46 1.37
$F = \frac{\text{greater variance estimate}}{\text{lesser variance estimate}} = 14.93$			
F (0.95) table value = 3.84 to 3.92		Reject	

Natural (open field) vs construction			
Source of variance (a)	Sum of squares (b)	Degrees of freedom (c)	Variance* estimate
Between sample Within sample	5.01 402.11	1 146	5.01 2.75
$F = \frac{\text{greater variance estimate}}{\text{lesser variance stimate}} = 1.82$			
F (0.95) table value = 3.84 to 3.92		Accept	

* Variance estimate = b/c

From the data arrayed in Table 1 it can be calculated that the rural area contained 39.4×10^6 gals/square mile, the construction area contained 27.8×10^6 gals/square mile and the urban contained 9.9×10^6 gals/square mile. This indicates that the end-of-winter water equivalent of the rural and construction areas were four and three times that of the urban area, respectively. These differences are even more apparent when it is noted that the urban sector has approximately five times the area of the construction zone and the volume of water per unit area for the construction zone was three times that of theurban area. The rural area had less than twice the area of the urban sector yet the volume of water per unit area of the rural snowcover is four times that of the urban area. On the other hand, however, the rural area has more than nine times the area of the construction zone yet the volume of water per unit area of the rural snowcover is less than one-and-a-half times that of the construction area. This would appear to indicate that the construction phase of urbanization provides the greatest potential for spring flooding as a result of the deposition of snowcover in the numerous man-made depressions on the construction site.

An important phase of the hydrologic cycle is the generation of snowmelt runoff which has three components: 1) the water input to the basin from snowmelt; 2) the water input to the basin from rain-on-snow; and 3) the transformation of the basin input to streamflow. A review of the pertinent literature revelas that total direct runoff, peak instantaneous discharge, and lag time are considered to be three characteristics which may adequately indicate the nature of the hydrologic response of the modified urban hydrologic system. These three parameters combine to describe the shape, time distribution, and the magnitude of the discharge and will be briefly considered in the following discussion.

Eleven hydrographs were used (5 resulting from snowmelt and 6 resulting from rain-on-snow) to measure the total direct runoff to be derived from these two conditions for the rural and urban catchments. Several variables, deemed to be possible measures of the prevailing moisture conditions or the volume of snowcover, were introduced in a multiple regression analysis. The derived equations and correlation matrices indicated that variables which estimate the wetness of the basin will be good indicators of the hydrologic response.

The total direct runoff per unit area for the rural and urban areas was compared for the snowmelt and rain-on-snow conditions. It was found that the mean total runoff for the urban basin was 5.2 times greater than the rural for snowmelt and 8.7 times greater for the rain-on-snow situation.

It is quite apparent that the results of this study indicate a far greater increase in total direct runoff as a result of urbanization than is found in either the literature or in a previous study of the same area done by Hart (1974) concerning response to storms. Evidently the alteration of the urban snowcover, resulting from moving, contamination and the melting from more heat absorbant surfaces produced greater volumes of runoff than occurred within the rural setting. The slower removal of the flow-retarding rural snowcover combined with the very wet conditions of the urban area after the snowmelt, thus enhancing the urban runoff, was an additional factor in the disproportionate increase in total direct runoff.

As with the total direct runoff, the variables which would serve as indicators of the basin's hydrologic response appeared to be those which would estimate the wetness or 'preparedness' of the basin. Hart (1974) determined that maximum rainfall intensity, total rainfall preceding the peak, and an antecedent precipitation index combined to explain 76.7 percent of the variation and found that for 10 storms, the urban peak was 2.84 times that of the rural basin. A comparison of peak discharges per unit area for the two situations, snowmelt and rain-on-snow, indicated that the urban peak discharge exceeded the rural, on the average, by a factor of 3.58 and 7.84 respectively. The peaks of magnitude greater than those which would be predicted from the literature or from the previous study conducted in the area must be attributed to the perpetual wetted state which accompanies spring snowmelt and allows more surface runoff to be channeled directly into streamflow, particularly in the urban portion of the basin.

The variable, lag time, could only be applied to the rain-on-snow situations. The elapsed time between the centre of the mass of precipitation and the centre of the mass of the associated hydrograph (determined visually) was the definition of lag time used in this study. The step-wise regression analysis revealed the measures of basin wetness to be the indicating variables of basin lag time response.

Hart (1974) determined that the lag time in the rual basin was 3.50 hours and only 1.52 hours in the urban basin. This study revealed lag times of 4.6 hours for the rural basin and 4.0 hours for the urban basin. The marked similarity in lag times between the two sectors is not only at odds with the literature and Hart's findings but appears to be contrary to what would be expected given the observed results of total direct runoff and instantaneous peak discharge found in this study. Based on arguments put forward to substantiate the findings for direct runoff and peak discharge, the urban lag time should be less than the rual by a wider margin than calculated in this study. This may be a direct result of the method used to determine lag time.

The observed effects of suburban development on the distribution of snowcover and the subsequent spring snowmelt runoff attest to the extent to which human presence may alter the hydrologic regimen of a river basin. Urbanization of a catchment causes surficial alterations resulting in substantial changes in basin hydrology and the related problems must be examined as they are presently disregarded or poorly understood.

This study produced results which indicate total direct runoff from 2 to 3 times greater and instantaneous peak discharge up to 2.5 times greater than that which would have been generalized from either the literature of Hart's previous study of this area. Lag time however was concluded to be less reduced than the results of other researchers would indicate. This study indicates the magnitude of error which could result in extrapolating from rainstorm research to snowmelt situations and that there is insufficient research and information available to fully understand or explain the snowmelt runoff phase of the hydrologic cycle.