

INTERRELATIONSHIPS BETWEEN THE PEAK INSTANTANEOUS AND AVERAGE DAILY DISCHARGES OF SMALL PRAIRIE STREAMS

by

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INTRODUCTION

Discharge records published by such agencies as the Water Resources Branch of the Department of Northern Affairs are usually in the form of average daily discharges. Such records are of little value for studying the peak instantaneous flows, particularly on small watersheds. The obvious method of obtaining the peak instantaneous flows on a watershed is by review of the recorded stage hydrographs. Generally, however, these records are not readily available. Further, the task of analysis is extremely time consuming if a long period of record is involved. An alternative method to the above which is much more expedient, is to utilize the average daily discharges by applying a conversion factor to these flows to derive the peak instantaneous discharges.

CURRENT PROCEDURES

Two approaches are reported in the literature for resolving the relation between the peak instantaneous discharge with another flow parameter and/or a geomorphic property of the watershed. Fuller (3) in 1914 studied the relationship between the peak instantaneous discharges and the average 24-hr flows of floods on large basins located in the Eastern United States. He developed a relationship between these variables of the form,

$$\frac{Q_{\max} - Q}{Q} = 2A^{-0.30} \dots\dots\dots 1$$

where $Q_{\max}$ = maximum recorded instantaneous discharge (cfs),

Q = largest average rate of flow over a 24 consecutive hour period which was recorded during the same period of years as $Q_{\max}$ (the two discharges did not necessarily occur during the same flood), and

A = drainage basin area in sq. miles.

In establishing the "excess ratio", $(Q_{\max} - Q)/Q$, of equation 1, Fuller rationalized that for all floods, $Q_{\max}$ would be greater than Q . In addition, it was postulated that the "excess

ratio" would decrease with an increase in drainage basin size. For larger watersheds, the rate of runoff is generally high for at least 24 hrs because the runoff producing storm is of considerable duration whereas on small basins a cloudburst may cause a flood which will give runoff over a few hours resulting in a large $Q_{\max}$ and only a moderate Q .

Langbein (5) employed a different approach to solve the problem by using only flow records. He established a relationship between the peak instantaneous discharge and maximum daily discharge in terms of (a) the ratio of the daily discharge of the pre-

ceding day to the discharge of the maximum day, and (b) the ratio of the daily discharge of the succeeding day to that of the maximum day. A plot of these ratios as presented by Langbein is given in figure 1.

INVESTIGATIONS

Because of the success and general acceptance of the methods given by Fuller and Langbein in resolving the complex interrelationship between the peak instantaneous flows and the average daily flows for the streams they studied, it was assumed similar methods could be successfully employed to establish the properties for Prairie Streams. To accomplish this objective, discharge hydrographs were collected from 22 small watersheds, which varied in size from 12 - 1000 square miles, located within the central region of Canada. All watersheds selected were equipped with automatic water level recorders which had been in operation at least five years. In total, about 260 hydrographs, including both rainfall and snowmelt runoff events were studied.

Details of the watersheds as to their station description, location and size are given in table 1 and figure 2 respectively. As shown on the figure, the watersheds are widely separated geographically, and hence they represent a wide range in physiographic conditions.

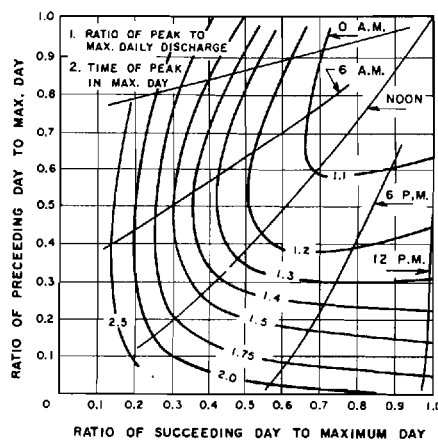


Figure 1. Discharge at and the time of crest, in relation to daily mean discharges (redrawn from Langbein)

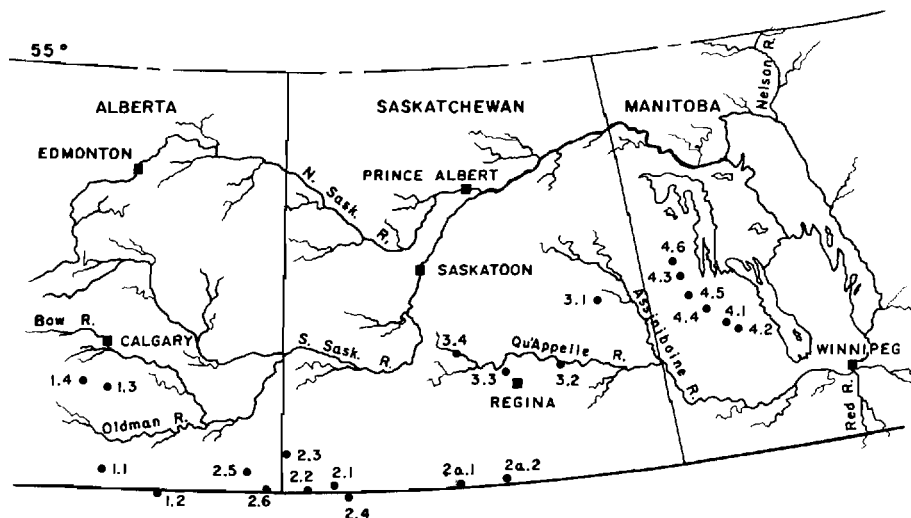


Figure 2. Location of Hydrometric Stations.

In an attempt to minimize the effect of regional influences in the investigations, the watersheds were separated to the regional groups listed in table 1.

consistent flow parameter than the excess ratio. Within regional groups, there was a definite trend for the peak ratio to decrease with drainage basin size.

TABLE 1. DESCRIPTION OF HYDROMETRIC STATIONS

Group	Code	Name	Location	WRB No.	Area a/ A _g A _e	
					A _g	A _e
Foothills	1.1	North Branch Drywood R.	near Twin Butte, Alta.	SAD ₁₆	12	12
	1.2	North Fork Milk R.	above U.S. St.	11AA _{0:3}	62	62
	1.3	Stinson Ck.	near Pekisko,	5BL ₇	96	96
	1.4	Highwood R.	near Diebel's	5BL ₁₉	300	300
Cypress Hills	2.1	Lyons Coulee	at International boundary	11AB ₇₅	66	47
	2.2	Woodpile Coulee	near International boundary	11AB _{0:1}	68	51
	2.3	Battle Ck.	at Ranger Station, Sask.	11AB ₈₁	78	64
	2.4	East Fork Battle Ck.	near International boundary	11AB _{0:3}	111	82
	2.5	Manyberries Ck.	at Brodin's Farm	5AF ₁₀	127	120
	2.6	Sage Ck.	at Q Ranch near Wildhorse, Alta.	11AA ₂₆	174	149
Wood Mountains	2a.1	Horse Ck.	near International boundary	11AE _{0:3}	74	71
	2a.2	East Branch Poplar R.	at International boundary	11AE ₃	534	190
Central	3.1	Little Boggy Ck.	at Cote, Sask.	5MD ₆	60	15 ^b
	3.2	Indianhead Ck.	near Indian Head, Sask.	5JL ₂	203	45
	3.3	Boggy Ck.	above Junction Qu'Appelle R.	5JF ₆	175	56
	3.4	Qu'Appelle R.	above Buffalo Pound L.	5JG ₄	932	222
Manitoba Escarpment	4.1	Scott Ck.	near Laurier, Man.	5LJ ₂₆	26	15 ^b
	4.2	McKinnon Ck.	near McCreary, Man.	5LJ ₂₇	30	17 ^b
	4.3	Garland R.	near Garland, Man.	5LG ₂	30	22 ^b
	4.4	Edwards Ck.	near Dauphin, Man.	5LJ ₂₀	67	38 ^b
	4.5	Mink R.	near Ethelbert, Man.	5LJ ₁₉	82	47
	4.6	Pine R.	near Pine River, Man.	5LG ₁	84	48 ^b

a/A_g is the gross drainage area in square miles and A_e the effective area in square miles.

b/Indicates an estimated effective area.

Peak Ratio - Area Relationships

In the initial phases of the study, plottings were made using an excess ratio ($q_p - q_2$)/ q_2 * (patterned after the works of Fuller) and a peak ratio, q_p/q_2 , against gross drainage area. Gross drainage area as used herein is the total area of the watershed enclosed within the topographic divide. In these plottings, it was found that the peak ratio was a much more stable and

Prairie hydrologists have long recognized the error of using the gross drainage area in rational flood flow formulae when applied to Prairie streams characterized by large amounts of depressional storage. Under these conditions, the area of the watershed which contributes to flow during any given runoff event varies with the magnitude of the flood as different channels and depressions become connected to the main stream system.

Stichling and Blackwell (6) and Durrant and Blackwell (1) found that for these streams use of the "effective area" of a basin produced more successful relationships with flow discharges than use of the gross area. Effective area, as defined by Stichling and Blackwell (6) is, "the gross area of the basin less the areas which do not contribute to the mean annual flood". That portion of the gross area which is excluded includes marshes and sloughs with no connecting channel to the stream and areas upstream from "on-stream" lakes which have the capacity to detain runoff waters until the peak flow has been observed.

Plots were made between the peak ratios of all storms and effective areas for watersheds in groups 2, 3 and 4. In this analysis, the values for the effective areas were taken from the works of Durrant and Blackwell (1). For watersheds which were used but not listed in the reference, the values were determined by applying a regional coefficient, the average ratio of the effective area to gross area for watersheds in the region, to the gross area of the watershed in question. For watersheds listed in the Foothills group, the effective areas had not been determined, hence, the gross areas were used. It is believed that for watersheds in this group the differences between the two areas would be small because of the high degree of drainage development and pronounced relief in the region.

A typical array of peak ratio values and effective areas is shown by those watersheds in the Cypress Hills and Wood Mountain region (see figure 3).

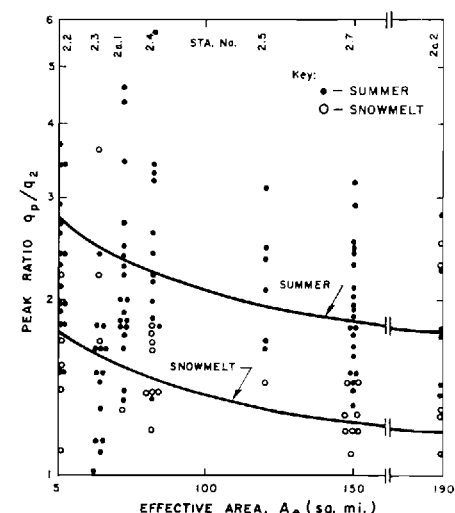


Figure 3. Peak ratio arrays—Group 2.

Perhaps, the most striking feature of the arrays was the large scatter of the

*Note, in the excess ratio and peak ratio, the peak instantaneous discharge, q_p , and the average daily flow for the same day of occurrence of the peak, q_2 are those for individual storm events.

data which represents a wide range in values for the peak ratio with different storms. In addition, several other features were exhibited by the plots.

(a) For watersheds within a selected regional grouping there was a trend for the peak ratio to decrease as the size of the basin increased. This characteristic is to be expected as large watersheds have high base flows. In addition, the hydrograph from large watersheds have long time bases so that q_p is more nearly equal to q_2 , and the ratio closer to unity.

(b) For watersheds within a given regional grouping, the peak ratios from rainfall and snowmelt events were different. In general, it was found that for the watersheds in the Foothills group, the peak ratios of snowmelt events tended to be higher than those from rainfall. Conversely, an opposite trend was apparent in the arrays for watersheds in the Cypress Hills and Wood Mountain group (figure 3) and

those in the Central Plains. Unfortunately, there were not sufficient data available either on watersheds within the same regional grouping or for watersheds in different physiographic regions to permit a complete study of this phenomena.

Average peak ratios of summer storm events and effective area

As a further reduction to the data, the average values of the peak ratios of summer storm events were determined and plotted with effective area as shown in figure 4. As indicated on this figure, the average peak ratios from watersheds within a given physiographic region can be related to effective area in equational form as,

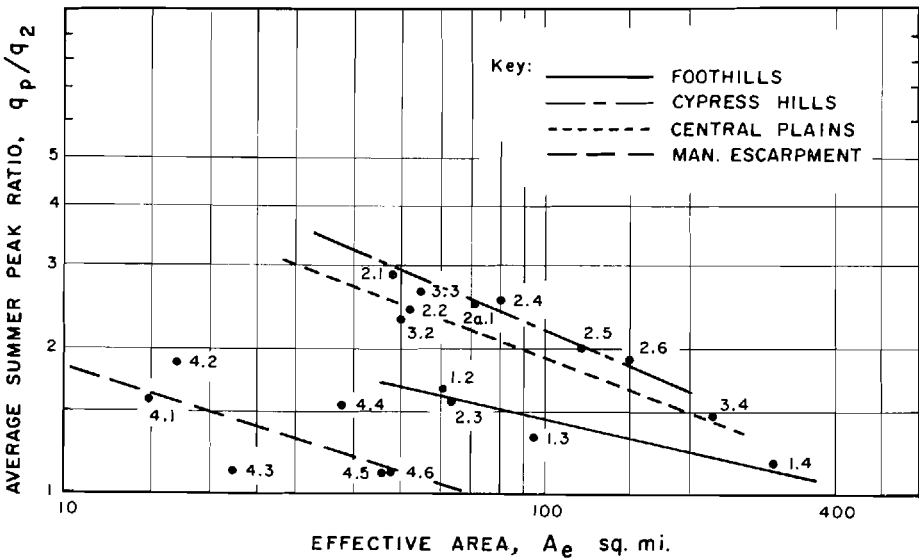


Figure 4. Regional trends in peak ratio—Area relation.

$$q_p/q_2 = CA_e^{-n}$$

where A_e = effective arc miles, and C, n = coefficient exponent.

Values of the coefficient, C , exponent, n , for the different groups are tabulated in table

TABLE II. PEAK RATIO—EFFECTIVE AREA RELATIONSHIPS OF WATERSHEDS IN DIFFERENT REGIONAL GROUPS

Group	q_p/q_2	Exponent, n	Range of Validity
1	q_p/q_2	$A_e^{-0.22}$	60 - 300 mi ²
2 and 2a	q_p/q_2	$A_e^{-0.46}$	50 - 200 mi ²
3	q_p/q_2	$A_e^{-0.36}$	45 - 225 mi ²
4	$q_p/q_2 = 1$	$A_e^{-0.30}$	15 - 50 mi ²

Discussion

The coefficient, C , of equation 2 can be considered as an index of the flashiness of the streams. As shown in table 2, those watersheds which fall in

Cypress Hills and Wood Mountain (Groups 2 and 2a) are very flashy in comparison with the others. Streams of this region are of the intermittent type carrying little or no base flow during the summer months. In addition, the area is covered by relatively-sparse, vegetal cover, the soil mantle is thin and the relief very pronounced. In the region, runoff-producing storms during the summer months are primarily short, intense, thunderstorms. The combination of physiographic and climatic elements of the region tend to produce hydrographs with a short period of rise and rapid recession. In contrast, watersheds in the Foothills although on steep topography do not tend to be nearly as flashy. This can be attributed to the fact that, (a) most of the basins

are situated in the lee of the Rockies and do not receive intense cloudbursts but are affected primarily by long-duration cyclonic-type storms, and (b) the watersheds are densely forested thus the streams are of the permanent type with high base flows. On watersheds in the Central Plains, because of their poor relief and drainage develop-

ment, storage masks the flashiness caused by the intense storms and attenuates the peak flows.

To indicate the interrelationship between the width of the hydrograph and the peak ratios, the average ratio, q_p/q_2 for each watershed was plotted against the average time in hours during which the stage was above 75 percent of the peak stage as measured above base flow, T_{75} , (see figure 5). As

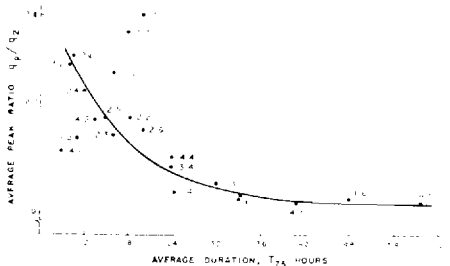


Figure 5. Average peak ratio and the average duration.

shown in the figure, there is a distinct trend for q_p/q_2 to decrease as the width of the hydrograph increases. Further, when T_{75} is greater than approximately 24 hrs the ratio tends toward a limit of unity.

The exponent of area, n , in equation 2, is an index of the relative importance of area as opposed to other factors in contributing to the peak ratio. The streams in Groups 2 and 2a and 3 have the largest exponents being -0.46 and -0.36 respectively whereas the exponents of the equation for Groups 1 and 4 are smaller. Gray (4) has shown that although area is only one of the many factors of the geomorphic regime that establishes hydrograph shape, it is often predominant inasmuch as within a given physiographic region it reflects many other watershed factors (lengths and slopes of streams) which affect the time distribution of surface runoff.

From the preceding discussions it should not be construed that large values of the peak ratio connote large discharges. Generally, the opposite is true since large discharges tend to be more sustained which cause lower values of q_p/q_2 . Yet, the discharge per unit area will be lower on larger basins than on smaller areas.

Langbein's Approach

In accordance with the approach suggested by Langbein (5) a graph was constructed using the following flow data; (a) the average daily flow for the day preceding the peak rate, q_1 , (b) the average daily flow on the day following the peak, q_3 , and (c) the peak instantaneous discharge, q_p and

bear a close resemblance to those of the more amenable streams studied by Langbein (figure 1). In general, because of scarcity and limitations of the original data, it was impossible to locate contours for values of q_p/q_2 greater than 2.5. Other areas of fewest points, and thus least reliability are delineated on the figure. The practical use of figure 6 is as an aid for determining q_p when q_1 , q_2 and q_3 are known.

SUMMARY

Discharge records collected from 22 watersheds located within the central region of Canada were analyzed to establish relationships between the peak instantaneous discharge, q_p , and the average daily discharge, q_2 , for Prairie streams. From analysis of the data it was found that the variation in the average peak ratio, q_p/q_2 , of summer storm events for watersheds within selected regional groupings could be related to the effective size of the drainage basin. Differences in the relationships for watersheds in different physiographic areas could be attributed to such factors as topography, climate and vegetation as they affect the discharge characteristics of streams. In addition, it was found that the peak ratios from rainfall and snowmelt events on watersheds within a given regional grouping were not of the same magnitude and could not be considered from a homogenous population. This necessitates that a separate relationship be established for the different events.

A graph is presented which can be used to estimate the peak instantaneous

discharge for Prairie streams using published average daily flows for; (a) the day preceding the occurrence of the peak rate, (b) the day of occurrence of the peak rate, and (c) the day following the occurrence of the peak rate.

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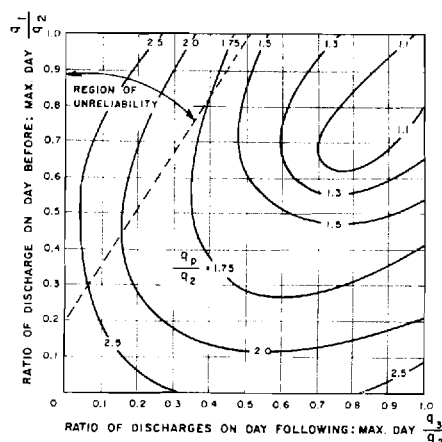


Figure 6. Peak ratio contours in terms of day before, day of, and day following maximum discharge. the average daily flow on the day of occurrence of the peak, q_2 . These data, plotted as dimensionless ratios are shown in figure 6.

The most significant feature of the figure is that it shows that the discharge characteristics of the streams analyzed