UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

AN INVESTIGATION OF BASIN EFFECTS ON FLOOD DISCHARGES IN NORTH DAKOTA

By Orlo A. Crosby

Open-File Report 74-346

Prepared in cooperation with the

North Dakota State Highway Department

The opinions, findings, and conclusions expressed in this publication are those of the author and not necessarily those of the North Dakota State Highway Department or the Federal Highway Administration.

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ABSTRACT

An investigation of the relationship of peak discharge to causative storm variables and drainage-basin characteristics was made to provide guidelines for future analyses of frequency and magnitudes of floods from small drainage areas. The procedure used was (1) to estimate peak discharges on the 11 study basins from multiple-regression models developed from the storm variables and (2) to relate the peak discharges to the basin characteristics through regression or correlation with particular attention given to the effect of basin shape.

The average standard error of estimate for the peak discharges ranged from 65 to 119 percent when only the four storm variables common to most basins were used.

INTRODUCTION

The high cost involved and the long period of time required to collect adequate data to define the magnitude and frequency of floods from small drainage areas have led to various methods of estimating discharges. At the present time (1974) mathematical models that relate peak discharges of a given frequency to climatic and drainage-basin variables are widely used.

At the time the present study was begun (1965), the index-flood method was being used by the U.S. Geological Survey for regional frequency analysis. This consisted of defining ratios of floods of given frequencies to an index flood (the mean annual flood) and developing relations between physical characteristics of drainage basins and the index flood. The first such analysis for North and South Dakota (McCabe and Crosby, 1959) used only drainage area and regionalization to define the annual flood. Two subsequent reports (Patterson, 1966; Patterson and Gamble, 1968) used storage in lakes and mean elevation, respectively, as well as drainage area and regionalization to define the mean annual flood. However, lake storage and mean elevation were not found significant in North Dakota.

Multiple-regression methods relating discharge for a given frequency to climatic and drainage-basin variables have been adopted as a regionalizing tool since this study was effected. This study will contribute to the understanding of the basic hydrologic effects of the variables used.

In accordance with U.S. Geological Survey policy, a dual system of English and metric units is used in this report. The following factors may be used to convert the English units published herein to metric units.

Multiply English units	By	To obtain metric units
inches (in)	25.4	millimetres (mm)
feet (ft)	.3048	metres (m)
miles (mi)	1.609	kilometres (km)
square inches (in^2)	.000645	square metres (m^2)
square miles (mi^2)	2.590	square kilometres (km^2)
cubic feet per second (ft^3/s)	.02832	cubic metres per second (m^3/s)
cubic feet per second per square mile [(ft^3/s)/mi^2]	.010935	cubic metres per second per square kilometre [(m^3/s)/km^2]
feet per mile (ft/mi)	.1894	metres per kilometre
miles per square mile (mi/mi^2)	.6212	kilometres per square kilometre (km/km^2)

The constants used in the empirical relations developed in this report can be used only with the English units.

Purpose and Scope

This study supplements a cooperative project between the U.S. Geological Survey and the North Dakota State Highway Department investigating magnitude and frequency of floods from small drainage basins. The present study was designed to provide more complete flow and storm data than are collected under the cooperative highway project--under which only peak-flow data are collected. Particular attention was to be given to basin shape. For this reason, 11 basins were selected that had reasonably similar topographic and cultural characteristics but pronounced variations in the ratio of length to width. A representation of the State's climatic and geographic conditions was also desired; therefore, groups of basins were selected in three different areas of the State.

The objective was to define the discharge hydrograph for each flood event at each site, and to relate flood magnitudes to the measurable storm variables and the basin characteristics. No attempt was made to obtain data for analysis during the winter months as it was not within the scope of this study to determine the effects of frozen ground or variations in snowmelt rates on flood magnitudes.

Acknowledgments

The U.S. Geological Survey collected the data and prepared this report in cooperation with the North Dakota State Highway Department.

DESCRIPTION OF STUDY AREAS

North Dakota is located in two provinces of the Interior Plains. Fenneman (1931, 1938) defines the boundary between these provinces: the Great Plains lie to the west and the Central Lowland to the east. The boundary between the provinces (fig. 1) crosses North Dakota along the base of the eastern

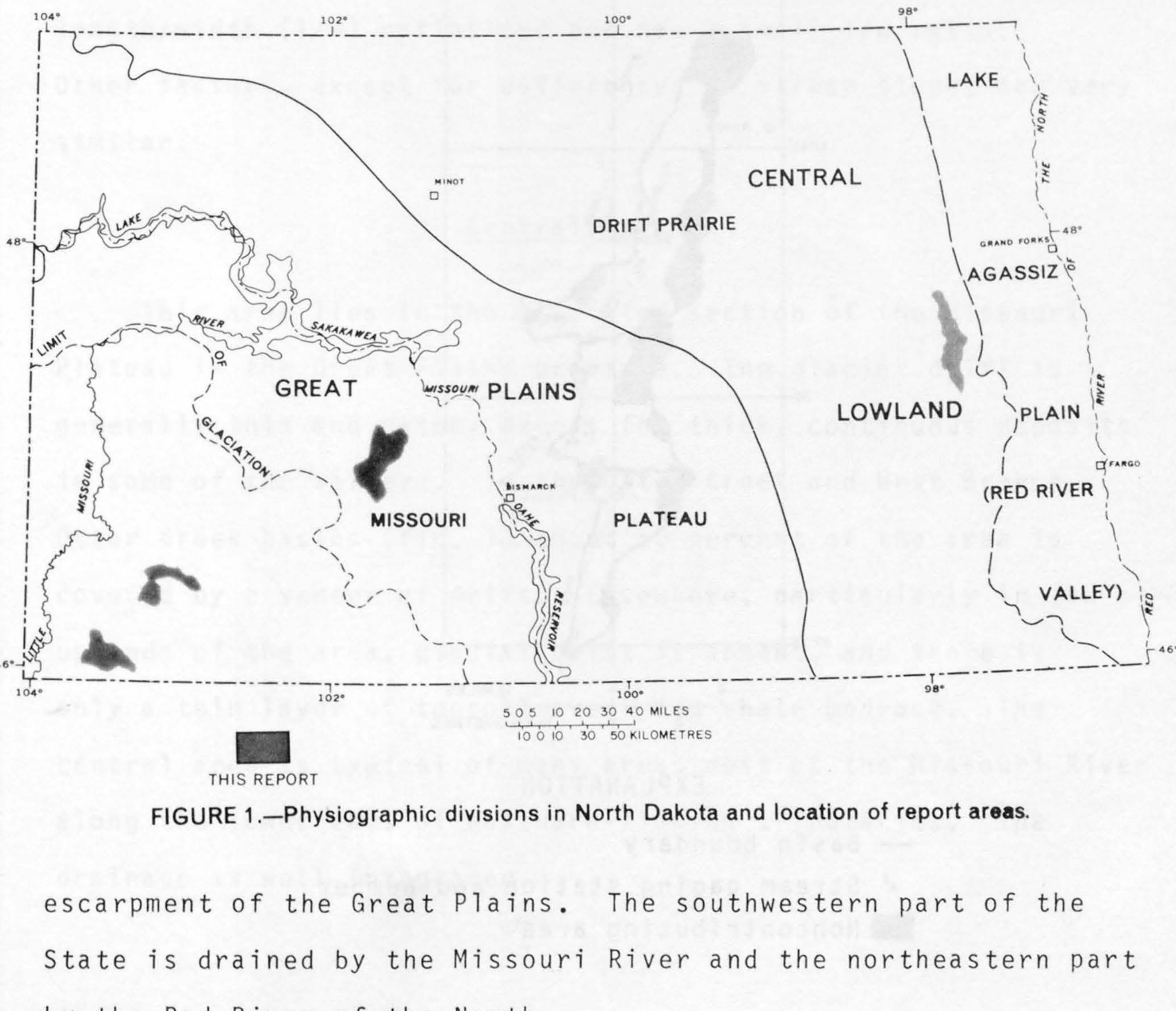
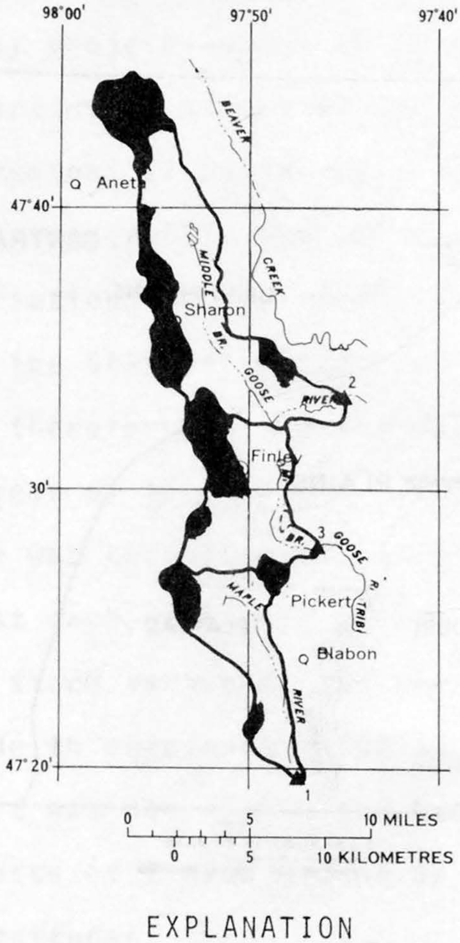


FIGURE 1.—Physiographic divisions in North Dakota and location of report areas.

escarpment of the Great Plains. The southwestern part of the State is drained by the Missouri River and the northeastern part by the Red River of the North.

Eastern Area

The eastern area lies in the Central Lowland province and is typical of much of the glaciated part of the State. The area is covered by glacial drift and underlain by shale. The drainage is poorly defined (fig. 2). Many areas do not



EXPLANATION

— Basin boundary

▲2 Stream gaging station and number

■ Noncontributing area

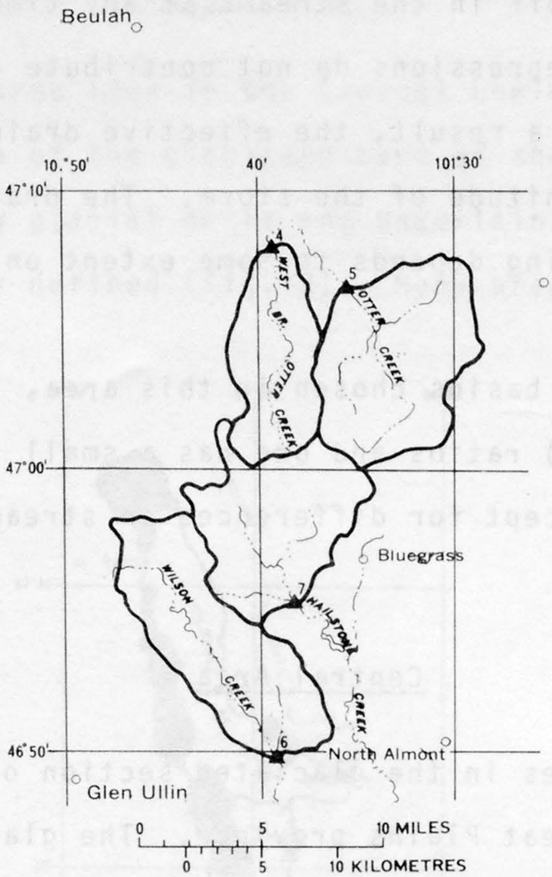
Figure 2.--Study area located in eastern North Dakota.

contribute to runoff in the streams at any time and many interspersed smaller depressions do not contribute except during major floods. As a result, the effective drainage area can vary with the magnitude of the storm. The drainage area delineated as contributing depends to some extent on the judgment of the author.

Of the three basins chosen in this area, two have large length/width (l/w) ratios and one has a small l/w ratio. Other factors, except for differences in stream slope, are very similar.

Central Area

This area lies in the glaciated section of the Missouri Plateau in the Great Plains province. The glacial drift is generally thin and patchy except for thick, continuous deposits in some of the valleys. In the Otter Creek and West Branch Otter Creek basins (fig. 3) about 50 percent of the area is covered by a veneer of drift. Elsewhere, particularly in the uplands of the area, glacial drift is absent, and there is only a thin layer of topsoil overlying shale bedrock. The central area is typical of many areas west of the Missouri River along the lower ends of eastward-flowing tributaries. The drainage is well integrated.



EXPLANATION

— Basin boundary

▲4 Stream gaging station and number

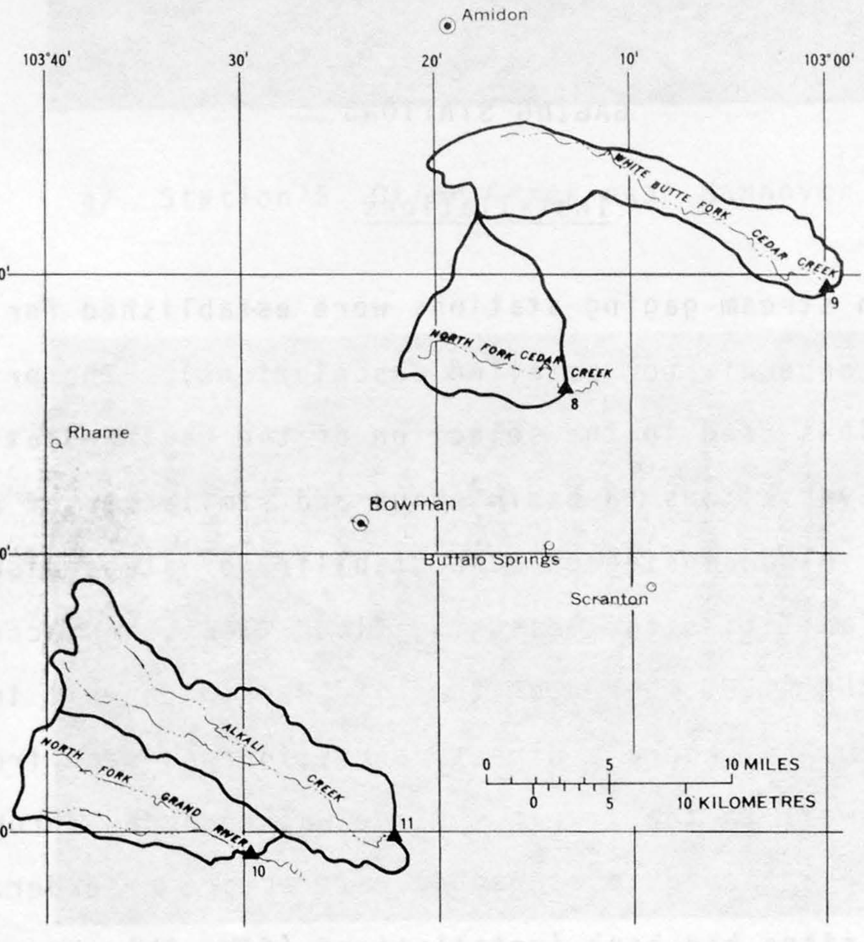
Figure 3.--Study area located in central North Dakota.

Two of the study streams in this area flow north and two flow to the southeast. There is a stream having a large l/w ratio and a stream having a small l/w ratio flowing in each direction. The northward-flowing streams have denser stream patterns, greater stream slopes, and higher soil infiltration indices than the southeastward-flowing streams.

Western Area

This area lies in the unglaciated section of the Missouri Plateau. Most of the area has a thin cover of topsoil underlain by several feet of sand, then shale. There are scattered buttes throughout the area.

The study basins in this area are not all contiguous (fig. 4). About 14 miles (23 km) separates the pairs of



EXPLANATION

—— Basin boundary

▲8 Stream gaging station and number

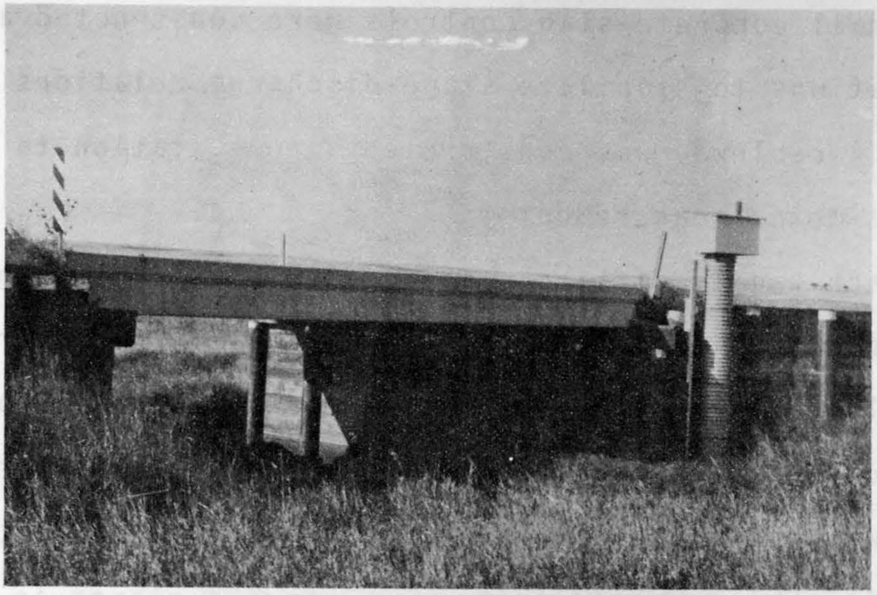
Figure 4.--Study area located in western North Dakota.

stations, but they have very similar characteristics except for l/w ratios and stream slopes. The headwaters of White Butte Fork Cedar Creek and Middle Fork Cedar Creek lie in a high (3,500 feet; 1,070 m) butte area, which rapidly drops off to surrounding plains. Alkali Creek and North Fork Grand River tributary head in shallow troughs on the plain above the Little Missouri drainage. The drainage is well integrated with very little natural surface storage in the basins.

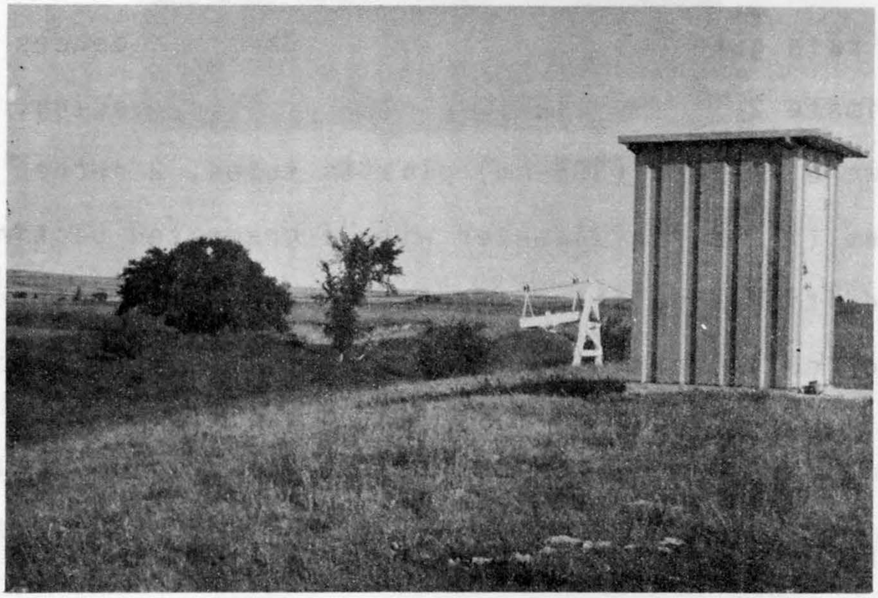
GAGING STATIONS

Installations

Eleven stream-gaging stations were established for the study (see appendix for detailed descriptions). The prime considerations used in the selection of the gaging-station sites were variations in basin shape and similarity of drainage area size. Also considered were stability of stage-discharge relation, facilities for measuring flood flows, and accessibility to the site. Seven of the sites had wing-wall installations (fig. 5a) where a direct connection was made from a stilling well to the stream. Stage was recorded through a float device attached to a graphic water-stage recorder. The other four sites had bank installations (fig. 5b) where stage was recorded on a graphic water-stage recorder by a gas-purge pressure reflected through a servo-manometer assembly.



a/ Station 5 Otter Creek near Hannover



b/ Station 4 West Branch Otter Creek near Beulah

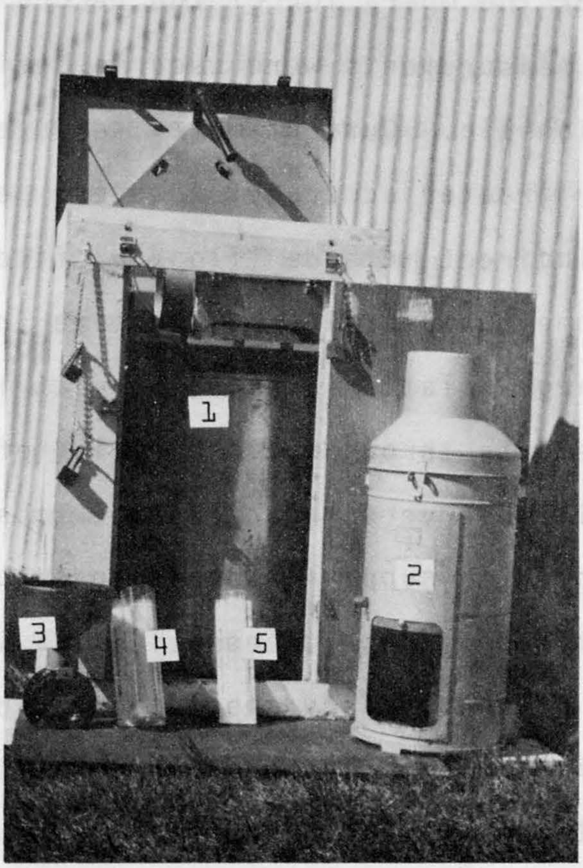
Figure 5.--Typical gaging station installations

Small concrete-slab controls were constructed at two of the stations to stabilize stage-discharge relations at low flow. A cableway was constructed at one station to obtain current-meter measurements.

Each gaging station was equipped with a tipping bucket rain gage with the standard 8-inch (203-mm) receiver. The rainfall was recorded on the same chart as the stream stage to synchronize the two records. Several other types of rain gages were installed in each of the study areas (fig. 6). Two specially built recording rain gages were placed in each area when the study was started. These gages had a catchment area of 690 square inches (0.45 m^2) with the rainfall measured by a float device attached to a graphic recorder. Observer-read manual rain gages were installed at farm residences on an approximate 2- to 3-mile (3- to 5-km) grid spacing. These gages were 12-inch (305-mm) plastic tubes, 2 inches (51 mm) or 3 inches (76 mm) in diameter with a graduated backing. In 1968, five additional weighing-type rain gages with 8-inch (203-mm) diameter collectors were installed in the three areas.

Data Collection

The stations were operated from spring breakup to freezeup in the fall and were visited once a month (more often in the first few years and during runoff events) to service the



1. Float-type recording gage
2. Weighing-type recording gage
3. Tipping-bucket recording gage
4. Manually-read 3-inch (76.2-millimetre) diameter gage
5. Manually-read 2-inch (50.8-millimetre) diameter gage

Figure 6.--Various rain gages used in the study

instruments and to measure streamflow. Rain catchments were measured to check the operation of the recording rain gages.

Streamflow measurements were used to define the stage-discharge relationship. Current-meter measurements were preferred for their greater accuracy; however, peak flows had to be computed by indirect methods (flood profiles and channel geometry) for some floods. There were some instabilities in the stage-discharge relations, especially at low flows, necessitating measurements throughout the period of data collection.

The rainfall observers reported their observations monthly. They were requested to supply information on precipitation, total amounts, times of onset, cessation, maximum intensity, and if hail was present. They also reported other pertinent conditions, such as wind. The most common data received were total precipitation and time of onset.

SELECTION OF RECORDS FOR ANALYSIS

Streamflow Records

Discharge hydrographs were computed for all significant floods. The level at which a flood was considered significant varied with antecedent flow conditions. Minimum flood magnitudes of about 15 to 20 ft^3/s (0.42 to 0.57 m^3/s) were considered when antecedent flow conditions were near zero. Higher flood magnitudes were required at other times. Floods during the early spring were not used if it was believed they were affected by snowmelt, ice backwater, or frozen ground, as these conditions could not be evaluated using the parameters being monitored.

The discharge hydrographs were analyzed to give the following flood characteristics in cubic feet per second:

1. Antecedent discharge.
2. Instantaneous peak discharge.
3. 1-hour peak volume.
4. 2-hour peak volume.
5. 6-hour peak volume.
6. 12-hour peak volume.
7. 24-hour peak volume.

In some instances, owing to faulty record, not all characteristics could be determined, but antecedent discharge and instantaneous peak discharge were usually defined. In defining the relationships between the flood characteristics and the independent variables it made little difference whether the instantaneous peak discharge or the 6-hour peak volume was used.

Precipitation Records

Precipitation records from the National Oceanic and Atmospheric Administration (1965-72) recording rain gages were used to augment the records collected during this study.

The precipitation records were analyzed for each chosen runoff period. The total precipitation values and the times of storm onset were plotted on a base map for each area. Isohyets were drawn through points of equal total precipitation and a storm direction determined from the onset time of precipitation.

STORM VARIABLES

The storm variables chosen for investigation are as follows:

Total precipitation (Rt) is the mean total precipitation, in inches, on the drainage basin as determined from averaging values from a 1-mile (1.6-km) spaced grid on the isohyetal map of the storm.

Duration of rainstorm (Dr) is the time of duration, in hours, of the storm, determined from the recording rain-gage records.

Maximum precipitation intensity (Ri) is the maximum rainfall, in inches, in any 1 hour during the storm, determined from the recording rain-gage records.

Antecedent precipitation index (Ra) is the antecedent rainfall, in inches, as expressed by the formula:

$$Ra = P_1 + 0.7P_2 + 0.5P_3 + 0.3P_4 + 0.2P_5 = 0.15P_6 + 0.1P_7$$

where P_1 is the rainfall (in inches) during the first 24-hour period preceding the storm being considered, P_2 is the rainfall in the second 24-hour period preceding, and so on.

Antecedent discharge (Da) is the discharge, in cubic feet per second, in the stream at the gaging station at the onset of the storm.

Storm aspect (As) is 1.00 plus the cosine of the angle the streamflow direction makes with the storm direction (plus if with the storm direction, and minus if against the storm direction); thus varying from 2.00 to 0.00.

Month of storm (Sd) is a dimensionless number assigned to months in an attempt to indicate vegetation demand, i.e.

10	June	Greatest demand
9	July	
8	August	
7	May	
6	September	
5	April	
4	October	Least demand

Time to maximum intensity (Dm) is the time, in hours, from the onset of rainfall to and including the hour during which the maximum rainfall intensity was recorded. It is computed from recording rain-gage records.

Rainfall distribution (Rd) is the ratio of the average total rainfall on the upper half of the basin to the average total rainfall on the lower half of the basin.

BASIN CHARACTERISTICS

Almost any basin characteristic brought to mind could have an influence on the magnitude of the peak discharge. It would be impractical to try to determine the effects of one without consideration of the others. The following characteristics were analyzed in an attempt to determine their influence on the magnitude of the peak discharge.

Drainage area (A) is the contributing area above the gaging station, in square miles, as computed from hydrographic divides drawn on U.S. Geological Survey quadrangle maps or North Dakota State Highway Department general highway maps.

Slope (S) is the main-channel slope, in feet per mile, determined from elevations between points at 10 percent and 85 percent of the distance along the channel from the gaging station to the divide. This index was described and used by Benson (1962, 1964).

Length (L) is the main-channel length, in miles, from the gaging station to the basin divide, as measured by dividers on the best available map, in increments of 0.2-mile (0.32-km) or less.

Storage (St) is the area of lakes and ponds, expressed as a percentage of the drainage area, determined from available maps and (or) field inspection.

Soils infiltration index (Si) is an index to soil infiltration capacity, expressed in inches, determined from a map prepared from information supplied by the U.S. Soil Conservation Service.

Elevation (E) is the mean basin elevation, in feet above mean sea level, measured on U.S. Geological Survey topographic maps or 1:250,000 U.S. Army Map Service maps by laying a grid over the map, determining the elevation at each grid intersection, and averaging the determined elevations. The grid spacing was selected to give at least 25 intersections within each basin.

Shape (Sh) is a ratio of length to average width of a basin, obtained by dividing the main-stream length squared by the drainage area.

Stream density (D) is the total length, in miles, of defined stream channels as taken from the presently available maps, divided by the drainage area in square miles.

Upper basin slope (Sb) is the average slope of the upper basin, in feet per mile, obtained by measuring the slope from the divide to the first defined stream course at 9 points equidistant around the basin perimeter.

Gage slope (Sg) is the slope, in feet per mile, of the main stream at the gage.

Cultivation (C) is the area cultivated, expressed as a percentage of the drainage area, as determined from aerial photographs or field inspection.

ANALYTICAL METHODS

Statistical multiple-regression analysis techniques are used in this study to relate peak-flow magnitudes to storm variables. The regressions provide a defined mathematical relationship at each of the gaging-station sites.

Experience indicates an apparent linear relationship between streamflow discharge and climatological and basin characteristics if the logarithms of each are used. The mathematical equation is defined in the regression analysis in the form:

$$\log Q = \log a + b_1 \log X_1 + b_2 \log X_2 \; . \; . \; . \; . \; . \; +b_n \log X_n$$

in which Q is the discharge magnitude for a given storm, X_1 to X_n represent storm or basin characteristics, a represents the regression constant, and b_1 to b_n represent regression coefficients. The equation can be expressed in an equivalent form as:

$$Q = aX_1^{b_1} X_2^{b_2} \; . \; . \; . \; . \; . \; . \; X_n^{b_n}$$

The equations define the relationship between flood magnitude as the dependent variable and the various storm and basin characteristics as the independent variables. The analysis provides a measure of error (the standard error of estimate) for each defined relation and a measure of the usefulness of each independent variable in the relation.

The equation with the greatest number of significant independent variables would ordinarily be used for prediction barring other considerations. However, if a variable was found significant but had only a slight effect on the standard error, it might have been omitted. If a variable was not significant at the chosen level of significance at one site but was significant at other sites, it might have been included for consistency with the other equations.

After the relations between storm characteristics and peak magnitudes were developed, an attempt was made to explain the basin-to-basin variations in peak magnitude by use of basin characteristics. Synthetic peaks were developed for a given set of storm characteristics for each of the basins. The equations yield the peak discharge in the units cubic feet per second. The peak magnitudes were considered in the units cubic feet per second per square mile to minimize the effects of drainage area size. Graphic plots or regressions were made of the peaks against the basin characteristics. Both single characteristic effects and multiple characteristic effects were investigated. The use of multiple-regression techniques for more than two independent variables on this phase of the study was precluded by an inadequate number of stations.

RESULTS

Table 1 is a simple correlation matrix of the independent storm variables. This correlation is based on the combined data for all the basins. One of the requirements in multiple-regression analysis is that the independent variables cannot be

TABLE 1.--Simple correlation matrix of independent variables

	Rt	Dr	Ri	Ra	Da	As	Sd	Dm	Rd
Rt	1.00	0.38	0.45	-0.16	-0.24	0.03	0.03	0.21	-0.15
Dr		1.00	- .19	.01	- .07	.09	.02	.56	.03
Ri			1.00	.03	- .26	.04	.20	- .14	- .04
Ra				1.00	.15	.12	.38	.17	.14
Da					1.00	.04	- .10	.07	.12
As						1.00	- .05	- .04	.31
Sd							1.00	.14	.02
Dm								1.00	.03
Rd									1.00

Rt - total precipitation.
Dr - duration of rainstorm.
Ri - maximum precipitation intensity.
Ra - antecedent precipitation index.
Da - antecedent discharge.
As - storm aspect.
Sd - month of storm.
Dm - time to maximum intensity.
Rd - rainfall distribution

highly related among themselves. A high degree of correlation can lead to unstable values for regression coefficients and to difficulty in interpreting the effectiveness of the independent variables included in the equation. In table 1 a value of 1.00 indicates perfect correlation; a value of 0.00 indicates complete independence, and a value of -1.00 indicates perfect inverse correlation. Values from 0.70 to 1.00 and -1.00 to -0.70 are suspect, and one of the variables should probably be deleted in a regression equation. The variables shown in table 1 appear to be highly independent. This independence is also true when the three general areas are considered individually.

The correlation matrix in table 2 shows the degree of correlation between the instantaneous peak discharge and the independent variables for each basin. There is generally a fairly high degree of correlation between the peak discharge and total precipitation and between peak discharge and precipitation intensity. It should be noted, however, that table 1 shows a fair degree of correlation between these two independent variables. There are other scattered instances of fair correlation throughout table 2.

TABLE 2.--Simple correlation matrix between instantaneous peak discharges and independent variables

Peak discharge	Storm variables								
	Rt	Dr	Ri	Ra	Da	As	Sd	Dm	Rd
Q_{I_1}	0.37	-0.09	0.13	0.77	0.30	0.30	0.10	0.22	0.26
Q_{I_2}	.59	- .30	.20	.14	- .02	.17	.14	- .28	- .49
Q_{I_3}	.25	- .24	.62	.26	.31	.38	.10	- .28	.66
Q_{I_4}	.92	.13	.58	.12	.10	--	.31	.14	- .40
Q_{I_5}	.88	.12	.70	- .04	- .45	.21	.40	.24	.43
Q_{I_6}	.77	.02	.75	- .14	- .23	.02	.01	.15	- .41
Q_{I_7}	.77	.04	.55	.04	- .01	.07	.18	.32	.20
Q_{I_8}	.72	- .07	.53	- .41	.11	- .11	.07	.04	.43
Q_{I_9}	.50	- .12	.51	- .27	- .03	.31	.00	- .03	.15
$Q_{I_{10}}$	.50	- .13	.31	.18	.03	- .11	.46	.48	.38
$Q_{I_{11}}$	.37	- .27	.19	.19	.39	- .12	- .09	.26	- .07

Q_{I_n} - peak discharge at station n.

Rt - total precipitation.

Dr - duration of rainstorm.

Ri - maximum precipitation intensity.

Ra - antecedent precipitation index.

Da - antecedent discharge.

As - storm aspect.

Sd - month of storm.

Dm - time to maximum intensity.

Rd - rainfall distribution.

The correlations in tables 1 and 2 are useful in selecting the most significant combination of variables in the regression analysis.

The individual basin response (peak discharge) to a given set of storm variables had to be determined before the variations due to basin characteristics could be evaluated. Table 3 shows the results of a regression analysis for each station with peak discharge a function of all the measured climatic variables. Regression coefficients are shown for all variables that had at least a 95 percent probability of being effective in the relation.

The one variable always significant was, understandably, total precipitation. The other most commonly significant variables were duration of rainstorm (seven equations), rainfall distribution (five equations), and antecedent discharge (four equations).

Antecedent precipitation was not found significant in any of the equations. This was probably due to the time scatter of thunderstorms in the State, with the consequent generally dry antecedent conditions.

The month during which the storm occurred was found significant in only one equation. When it was deleted from that equation, it changed the other coefficients only slightly, but made a promounced change in the regression constant. The regression constant after this variable was deleted was more consistent with those in the other equations.

TABLE 3.--Regression equations for peak discharge using all significant variables and computed discharge

$$\text{Model is } Q_I = aRt^{b_1}Dr^{b_2}Ri^{b_3}Ra^{b_4}Da^{b_5}As^{b_6}Sd^{b_7}Dm^{b_8}Rd^{b_9}$$

Peak discharge	Regression coefficients for independent variables									Regression constant (a)	Standard error of estimate (percent)	$Q_{I/A}$ [(ft³/s)/mi²] [(m³/s)/km²]
	b_1	b_2	b_3	b_4	b_5	b_6	b_7	b_8	b_9			
Q_{I_1}	3.01	-0.68			0.26	0.41	2.23		0.38	1.50	35	10.6 (.116)
Q_{I_2}	2.86	- .94				.82				297	106	3.4 (.037)
Q_{I_3}	1.29		.67		.28				4.07	29.5	61	5.3 (.058)
Q_{I_4}	3.02									26.4	102	4.1 (.045)
Q_{I_5}	3.25	- .71								272	67	5.0 (.055)
Q_{I_6}	2.38	- .65								301	128	4.4 (.048)
Q_{I_7}	2.60	-1.96	.51		.54			1.09	-2.17	1900	38	8.6 (.094)
Q_{I_8}	1.67								1.50	59.4	73	4.6 (.050)
Q_{I_9}	1.06									86.9	119	3.3 (.036)
$Q_{I_{10}}$	1.68	- .57						.59		123	76	4.0 (.044)
$Q_{I_{11}}$	1.85	- .55			.38			.36	1.01	227	52	5.7 (.062)

The last column in table 3 gives the resultant peak discharge in cubic feet per second per square mile (cubic metres per second per square kilometre) for each basin from a hypothetical storm with the following parameters:

Total precipitation (Rt)	1.6 in (40.6 mm)
Duration of rainstorm (Dr)	12 h
Maximum precipitation intensity (Ri)	1.0 in/h (25.4 mm/h)
Antecedent precipitation index (Ra)	0.4 in/h (10.2 mm/h)
Antecedent discharge (Da)	2.0 ft^3/s (0.057 m^3/s)
Storm aspect (As)	1.0
Month of storm (Sd)	9.0
Time to maximum intensity (Dm)	4.0 h
Rainfall distribution (Rd)	1.1

The above storm parameters are very rough averages of the storm parameters experienced. Any major deviation from the actual experience causes extreme variations in the basin response. This is especially true for those variables found significant in only one or two basins.

Table 4 shows the results of regression equations for each station, with peak discharge a function of those significant variables of the four variables common to the most equations. Several extremely high peak discharges have been excluded from the base data in an attempt to make the data for the stations more comparable. The standard errors of estimate are not

TABLE 4.--Regression equations for peak discharge using selected variables and computed discharge

Model is $Q_I = aRt^{b_1}Dr^{b_2}Da^{b_3}Rd^{b_4}$

Peak discharge	Regression coefficients for independent variables				Regression constant (a)	Standard error of estimate (percent)	$Q_{I/A}$ [(ft³/s)/mi²] [(m³/s)/km²]
	b_1	b_2	b_3	b_4			
Q_{I_1}	3.04	-0.65	0.26	0.41	122	70	7.3 (.080)
Q_{I_2}	2.86	- .06	.16	-1.39	13.5	70	1.3 (.014)
Q_{I_3}	2.96	- .78	.36	4.36	36.5	68	2.2 (.024)
Q_{I_4}	2.92	- .32	.02	.27	44.9	108	3.1 (.034)
Q_{I_5}	2.87	- .66	- .16	.18	236	70	3.7 (.040)
Q_{I_6}	1.95	- .48	.10	.30	208	119	4.2 (.046)
Q_{I_7}	2.98	-1.54	.64	-2.28	1656	86	4.4 (.048)
Q_{I_8}	1.99	- .32	.10	1.08	126	65	5.2 (.057)
Q_{I_9}	1.42	- .33	.06	.81	111	117	2.5 (.027)
$Q_{I_{10}}$	2.26	- .48	.16	1.32	134	78	4.0 (.044)
$Q_{I_{11}}$	2.00	- .39	.41	.78	244	65	5.9 (.065)

changed appreciably from the equations shown in table 3 except for stations 1 and 7 which appear to be outliers when all the variables are used. The last column in the table is the peak discharge from the previously mentioned hypothetical storm. The peak discharges from table 4 are used in evaluating the effects of the basin characteristics.

The only basin characteristics found to have a possible effect on peak discharge are shape, length, slope, and cultivation. Figure 7 is a logarithmic plot showing the computed peak discharge as a function of basin shape. The standard error for each peak discharge is shown. Figure 8 is a logarithmic plot showing the computed peak discharge as a function of stream length.

A plot of the residuals from the regression equation in figure 7 against the other basin parameters indicates a possible improvement in the definition of the peak discharge by incorporating main-channel slope or percentage of cultivation.

A multiple regression using shape factor and slope results in the equation:

$$Q_{I_c} = 16.6\ Sh^{-0.32}\ S^{-0.33}$$

The standard error of this equation is 0.200 log units or 48 percent. Thus a small reduction is obtained by incorporating slope, but there appears to be an anomally in that the peak discharge decreases with increasing slope. This anomally

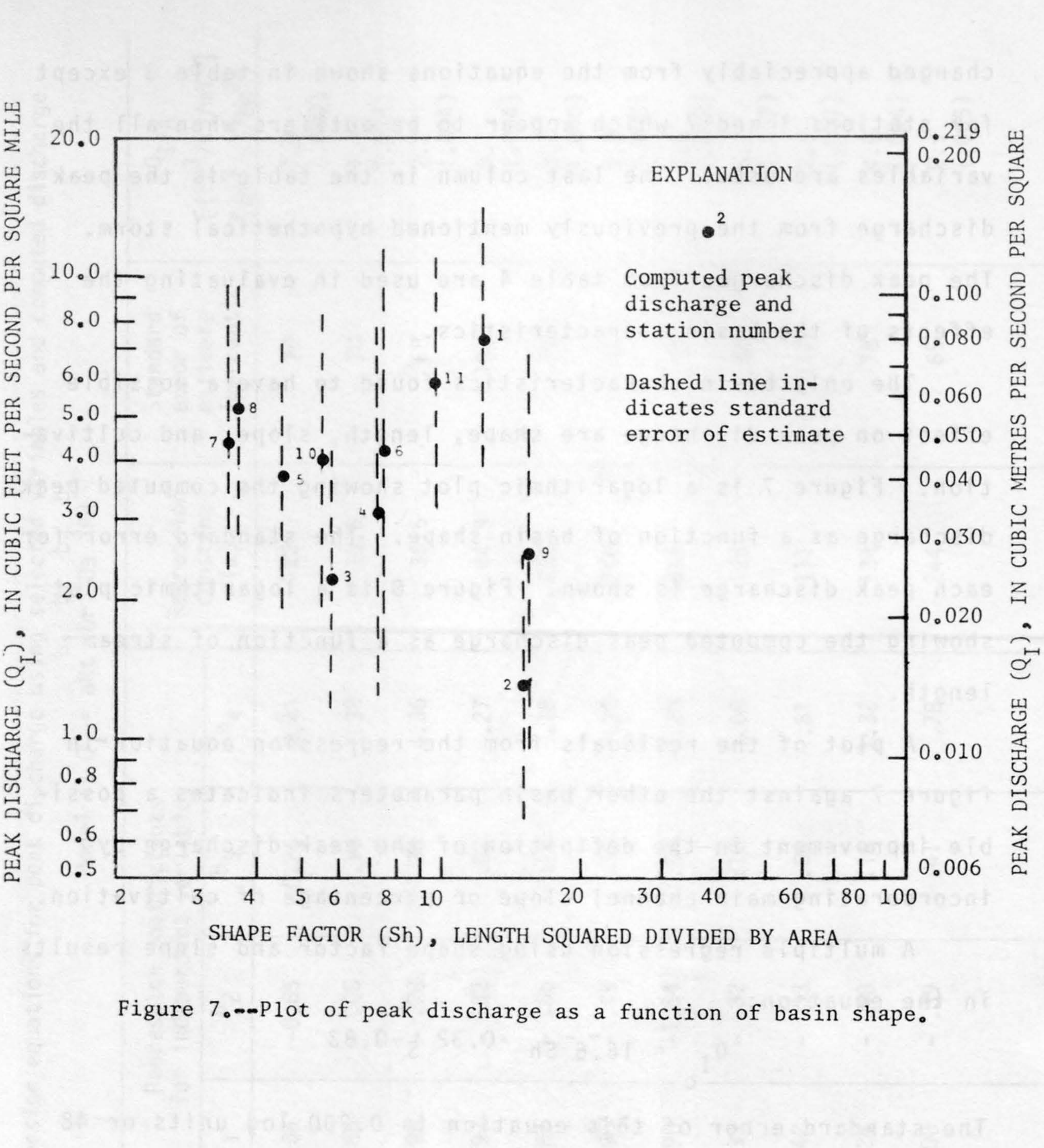


Figure 7.--Plot of peak discharge as a function of basin shape.

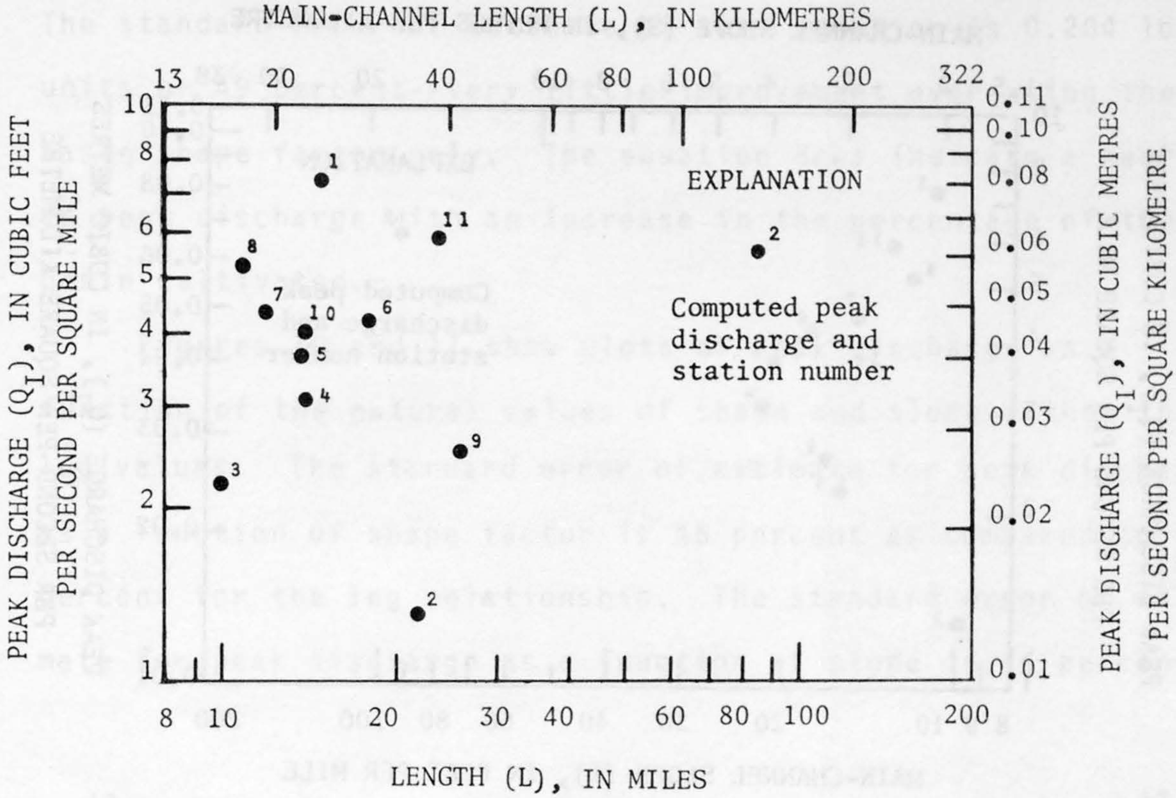


Figure 8.--Plot of peak discharge as a function of stream length.

recurs throughout the data analysis and occurs because of the terms hidden in the variables. As fall increases A increases and Q/A decreases. L has no effect.

Figure 9 is a logarithmic plot showing peak discharge as a function of slope. The standard error of estimate here is 0.224 log units or 54 percent. The regression equation does,

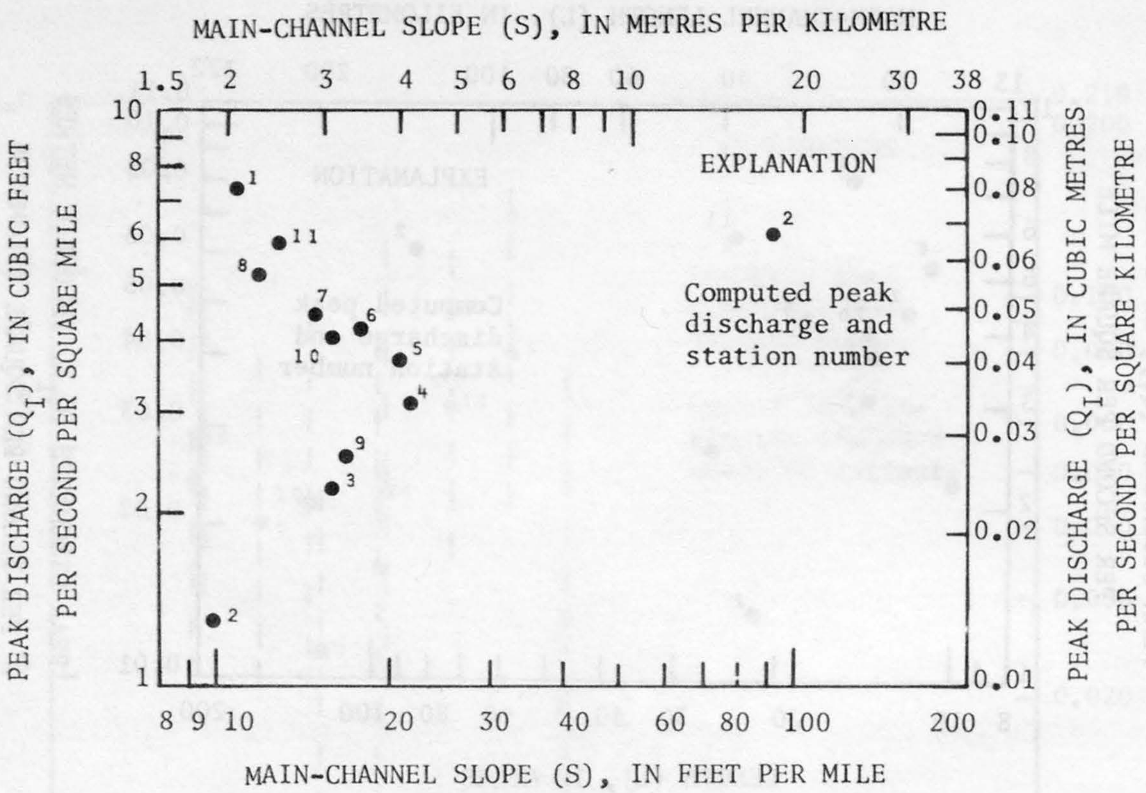


Figure 9.--Plot of peak discharge as a function of main-channel slope.

however, indicate only a very small change in peak discharge for marked changes in slope -- 3.7 $(ft^3/s)/mi^2$ at 10 ft/mi [0.040 $(m^3/s)/km^2$ at 1.9 m/km] to 3.5 $(ft^3/s)/mi^2$ at 20 ft/mi [0.038 $m^3/s)/km^2$ at 3.8 m/km].

A multiple regression with peak discharge a function of basin shape and cultivation results in the equation:

$$Q_{I_C} = 167\ Sh^{-0.24}\ C^{-0.80}$$

The standard error of estimate of this equation is 0.204 log units or 49 percent--very little improvement over using the basin shape factor only. The equation does indicate a decrease in peak discharge with an increase in the percentage of the basin cultivated.

Figures 10 and 11 show plots of peak discharge as a function of the natural values of shape and slope rather than log values. The standard error of estimate for peak discharge as a function of shape factor is 45 percent as compared to 51 percent for the log relationship. The standard error of estimate for peak discharge as a function of slope is 44 percent

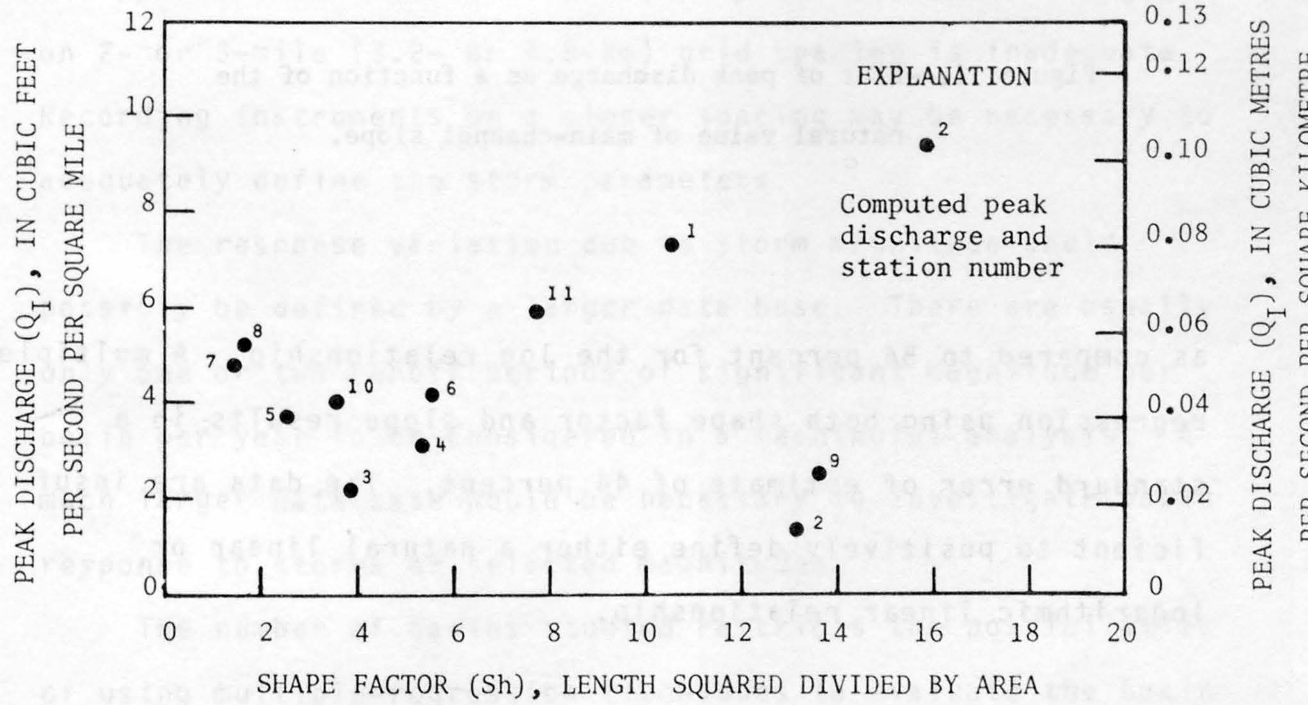


Figure 10.--Plot of peak discharge as a function of the natural value of basin shape.

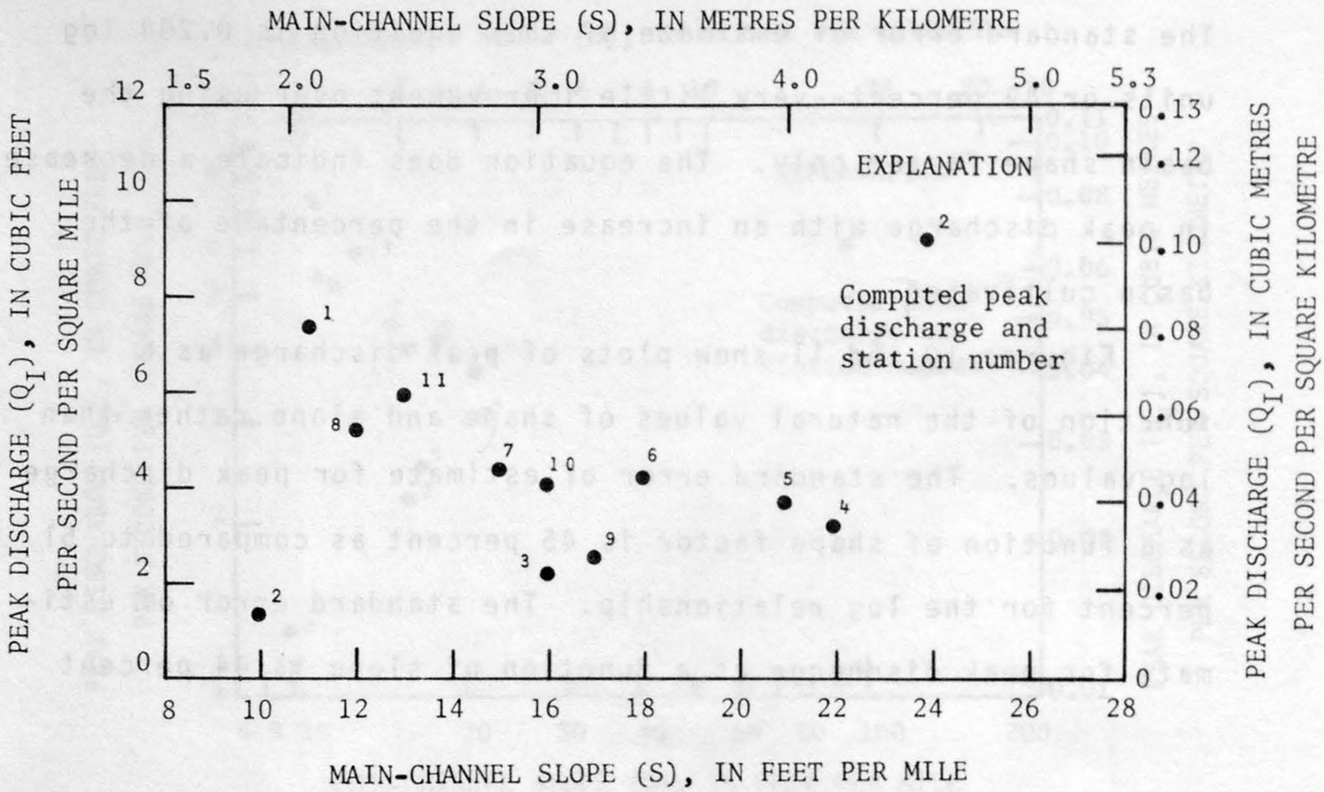


Figure 11.--Plot of peak discharge as a function of the natural value of main-channel slope.

as compared to 54 percent for the log relationship. A multiple regression using both shape factor and slope results in a standard error of estimate of 44 percent. The data are insufficient to positively define either a natural linear or logarithmic linear relationship.

CONCLUSIONS

The results of the regressions with peak discharge as a function of the storm variables are not conclusive. Other than total precipitation, the influencing variables are very inconsistent among the basins. The standard errors of estimate are high (65 to 119 percent). The large standard errors may be due to an oversimplification of the storm parameters as well as a varying influence on the peak discharge with storm magnitude.

The oversimplification of the storm parameters can be overcome only by more highly sophisticated instrumentation. It appears that the areal variability is such that rain gages on 2- or 3-mile (3.2- or 4.8-km) grid spacing is inadequate. Recording instruments on a closer spacing may be necessary to adequately define the storm parameters.

The response variation due to storm magnitude could possibly be defined by a larger data base. There are usually only one or two runoff periods of significant magnitude per basin per year to be considered in a meaningful analysis. A much larger data base would be necessary to investigate basin response to storms of selected magnitudes.

The number of basins studied restricts the possibilities of using multiple-regression techniques to evaluate the basin characteristics. Regressions with more than two independent basin variables are impractical.

Simple linear regressions with discharge as a function of each of the basin characteristics, residual plots, and simple correlations indicate that shape, length, slope, and cultivation may be the parameters having the most effect on peak discharge. A study of the shape factor alone indicates a marked decrease in peak discharge with changes from a circular-type to a long, narrow-type basin. The effect of the shape factor on peak discharge does not change much with the inclusion of the main-channel slope or percentage of cultivation.

The data are insufficient to define a relationship between peak discharge and the various basin characteristics. A quantification of the effects of the basin characteristics cannot be made.

The regression-type frequency interpretation, wherein the basin characteristics are used when found significant, is probably the best present-day solution for frequency and magnitude of floods. Effort should be directed to collection of sufficient data to define the frequency curves, storm characteristics, and basin characteristics of typical basins.

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APPENDIX

1. MAPLE RIVER NEAR HOPE, N. DAK.

LOCATION.--Lat 47°19'30", long 97°47'25", in NW¼NW¼ sec. 4, T. 144 N., R. 56 W., Steele County, 100 ft (30.5 m) downstream from box culvert on State Highway 38, 3 mi (4.8 km) west of Hope.

GAGE.--Water-stage recorder with tipping-bucket rain gage attachment. Datum of gage is 1,296.62 ft (395.2 m) above sea level.

STAGE-DISCHARGE RELATION.--Defined by current-meter measurements to 467 ft^3/s (13.2 m^3/s) and extended to 734 ft^3/s (20.8 m^3/s).

TOPOGRAPHIC CHARACTERISTICS.--Drainage area, 17.4 mi^2 (45.1 km^2); length of main stream, 14.8 mi (23.8 km); slope of main stream, 11 ft/mi (2.1 m/km); upper basin slope, 75 ft/mi (14.2 m/km); gage-vicinity stream slope, 23 ft/mi (4.4 m/km); stream density, 2.0 mi/mi^2 (1.2 km/km^2); basin elevation, 1,350 ft (411 m); percentage of surface storage, 1 pct; percentage cultivated, 83 pct; soil index, 3.2; length/width basin, 12.6.

REMARKS.--Topographic characteristics from 7½-minute topographic maps. This station operated throughout the year as a hydrologic network station.

2. MIDDLE BRANCH GOOSE RIVER NEAR FINLEY, N. DAK.

LOCATION. Lat 47°33'25", long 97°45'00", in SE¼SE¼ sec. 11, T. 147 N., R. 56 W., Steele County, on left downstream wingwall of bridge on county highway, 4.5 mi (7.2 km) northeast of Finley.

GAGE.--Water-stage recorder with tipping-bucket rain gage attachment. Altitude of gage is 1,265 ft (386 m) above mean sea level (from topographic map).

STAGE-DISCHARGE RELATION.--Defined by current-meter measurement to 458 ft^3/s (13.0 m^3/s) and extended to 1,250 ft^3/s (35.4 m^3/s).

TOPOGRAPHIC CHARACTERISTICS.--Drainage area, 33.1 mi^2 (85.7 km^2); length of main stream, 22.4 mi (36 km); slope of main stream, 10 ft/mi (1.9 m/km); upper basin slope, 47 ft/mi (8.9 m/km); gage-vicinity stream slope, 14 ft/mi (2.7 m/km); stream density, 1.2 mi/mi^2 (0.7 km/km^2); basin elevation, 1,400 ft (427 m); percentage of surface storage, 0.2 pct; percentage cultivated, 96 pct; soil index, 2.9; length/width basin, 15.2.

REMARKS.--Topographic characteristics from 7½-minute topographic maps.

3. MIDDLE BRANCH GOOSE RIVER TRIBUTARY NEAR FINLEY, N. DAK.

LOCATION.--Lat 47°28'05", long 97°46'20", in NW¼NW¼ sec. 14, T. 146 N., R. 56 W., Steele County, on downstream left wingwall of bridge on county highway 4.5 mi (7.2 km) southeast of Finley.

GAGE.--Water-stage recorder with tipping-bucket rain gage attachment. Altitude of gage is 1,385 ft (422 m) above mean sea level (from topographic map).

STAGE-DISCHARGE RELATION.--Defined by current-meter measurement to 352 ft^3/s (10.0 m^3/s) and extended to 3,200 ft^3/s (90.6 m^3/s) on the basis of an indirect measurement of flow over the road.

TOPOGRAPHIC CHARACTERISTICS.--Drainage area, 18.2 mi^2 (47.1 km^2); length of main stream, 10.4 mi (16.7 km); slope of main stream, 16 ft/mi (3.0 m/km); upper basin slope, 105 ft/mi (19.9 m/km); gage-vicinity stream slope, 7 ft/mi (1.3 m/km); stream density, 1.4 mi/mi^2 (0.9 km/km^2); basin elevation, 1,400 ft (427 m); percentage of surface storage, 0.8 pct; percentage cultivated, 89 pct; soil index, 3.2; length/width basin, 5.9.

REMARKS.--Topographic characteristics from 7½-minute topographic maps.

4. WEST BRANCH OTTER CREEK NEAR BEULAH, N. DAK.

LOCATION.--Lat 47°08'05", long 101°39'35", on east line of sec. 11, T. 142 N., R. 87 W., Oliver County, on right bank 10 mi (16 km) southeast of Beulah.

GAGE.--Water-stage recorder with tipping-bucket rain gage attachment. Altitude of the gage is 1,975 ft (602 m) above mean sea level (from topographic map).

STAGE-DISCHARGE RELATION.--Defined by current-meter measurement to 169 ft^3/s (4.8 m^3/s) and extended on the basis of indirect measurements at 3,000 ft^3/s (85.0 m^3/s) and 23,700 ft^3/s (671 m^3/s).

TOPOGRAPHIC CHARACTERISTICS.--Drainage area, 26.5 mi^2 (68.6 km^2); length of main stream, 14.0 mi (22.5 km); slope of main stream, 22 ft/mi (4.2 m/km); upper basin slope, 98 ft/mi (18.6 m/km); gage-vicinity stream slope, 2 ft/mi (.4 m/km); stream density, 3.4 mi/mi^2 (2.1 km/km^2); basin elevation, 2,150 ft (655 m); percentage of surface storage, 0.1 pct; percentage cultivated, 73 pct; soil index, 3.7; length/width basin, 7.4.

REMARKS.--Barometric levels used to determine basin characteristics. This station operated as a hydrologic network station.

5. OTTER CREEK NEAR HANNOVER, N. DAK.

LOCATION.--Lat 47°06'40", long 101°35'55", in NE¼NE¼ sec. 20, T. 142 N., R. 86 W., Oliver County, on downstream left wingwall of county highway bridge, 8 mi (13 km) west of Hannover.

GAGE.--Water-stage recorder with tipping-bucket rain gage attachment. Altitude of gage is 1,985 ft (605 m) above mean sea level (by barometer).

STAGE-DISCHARGE RELATION.--Stage-discharge relation defined by current-meter measurements to 246 ft^3/s (7.0 m^3/s) and extended on the basis of indirect measurements at 971 ft^3/s (27.5 m^3/s) and 45,300 ft^3/s (1,283 m^3/s).

TOPOGRAPHIC CHARACTERISTICS.--Drainage area, 42.9 mi^2 (111.1 km^2); length of main stream, 13.8 mi (22.2 km); slope of main stream, 21 ft/mi (4.0 m/km); upper basin slope, 117 ft/mi (22.2 m/km); gage-vicinity stream slope, 7 ft/mi (1.3 m/km); stream density, 2.9 mi/mi^2 (1.8 km/km^2); basin elevation, 2,150 ft (655 m); percentage of surface storage, 0.1 pct; percentage cultivated, 61 pct; soil index, 4.3; length/width basin, 4.6.

REMARKS.--Barometric levels used to determine basin characteristics.

6. WILSON CREEK NEAR GLEN ULLIN, N. DAK.

LOCATION.--Lat 46°49'53", long 101°39'23", in NW¼NW¼ sec. 27, T. 139 N., R. 87 W., Morton County, on right bank 1,000 ft (305 m) below county highway bridge, 8 mi (13 km) east of Glen Ullin.

GAGE.--Water-stage recorder with tipping-bucket rain gage attachment. Altitude of the gage is 1,995 ft (608 m) above mean sea level (from topographic map).

STAGE-DISCHARGE RELATION.--Stage-discharge relation defined by current-meter measurement to 864 ft^3/s (24.5 m^3/s) and extended on the basis of an indirect measurement at 20,800 ft^3/s (589 m^3/s).

TOPOGRAPHIC CHARACTERISTICS.--Drainage area, 41.4 mi^2 (107.2 km^2); length of main stream, 17.7 mi (28.5 km); slope of main stream, 18 ft/mi (3.4 m/km); upper basin slope, 95 ft/mi (18.0 m/km); gage-vicinity stream slope, 16 ft/mi (3.0 m/km); stream density, 2.2 mi/mi^2 (1.4 km/km^2); basin elevation, 2,150 ft (655 m); percentage of surface storage, 0.1 pct; percentage cultivated, 59 pct; soil index, 2.4; length/width basin, 7.6.

REMARKS.--Barometric levels and 7½-minute topographic maps used to determine basin characteristics.

7. HAILSTONE CREEK NEAR BLUEGRASS, N. DAK.

LOCATION.--Lat 46°55'25", long 101°38'15", in NW¼SW¼SW¼ sec. 23, T. 140 N., R. 87 W., Morton County, on right downstream wingwall of county highway bridge 3 mi (4.8 km) southwest of Bluegrass.

GAGE.--Water-stage recorder with tipping-bucket rain gage attachment. Altitude of gage is 2,115 ft (645 m) above mean sea level (from topographic map).

STAGE-DISCHARGE RELATION.--Stage-discharge relation defined by current-meter measurement to 80 ft^3/s (2.3 m^3/s) and extended on basis of an indirect measurement at 12,000 ft^3/s (340 m^3/s).

TOPOGRAPHIC CHARACTERISTICS.--Drainage area, 38.7 mi^2 (100.2 km^2); length of main stream, 11.7 mi (18.8 km); slope of main stream, 14 ft/mi (2.7 m/km); upper basin slope, 81 ft/mi (15.3 m/km); gage-vicinity stream slope, 12 ft/mi 2.3 m/km); stream density, 2.1 mi/mi^2 (1.3 km/km^2); basin elevation, 2,150 ft (655 m); percentage of surface storage, 1.0 pct; percentage cultivated, 76 pct; soil index, 2.6; length/width basin, 3.5.

REMARKS.--Barometric levels and 7½-minute topographic maps used to determine basin characteristics.

8. MIDDLE FORK CEDAR CREEK NEAR BUFFALO SPRINGS, N. DAK.

LOCATION.--Lat 46°15'55", long 103°13'30", in SW¼SW¼ sec. 8, T. 132 N., R. 100 W., Bowman County, on downstream right corner of bridge on county road, 6.3 mi (10 km) north of Buffalo Springs.

GAGE.--Water-stage recorder with tipping-bucket rain gage. Altitude of gage is 2,823 ft (860 m) above mean sea level (by barometer).

STAGE-DISCHARGE RELATION.--Stage-discharge relation defined by current-meter measurement to 136 ft^3/s ($3.9\ m^3/s$) and extended on basis of an indirect measurement at 2,050 ft^3/s ($58.1\ m^3/s$).

TOPOGRAPHIC CHARACTERISTICS.--Drainage area, 32.9 mi^2 ($85.2\ km^2$); length of main stream, 11.0 mi (17.7 km); slope of main stream, 12 ft/mi (2.3 m/km); upper basin slope, 70 ft/mi (13.3 m/km); gage-vicinity stream slope, 7 ft/mi (1.3 m/km); stream density, 2.1 mi/mi^2 ($1.3\ km/km^2$); basin elevation, 3,000 ft (914 m); percentage of surface storage, 0.1 pct; percentage cultivated, 69 pct; soil index, 3.3; length/width basin, 3.7.

REMARKS.--Barometric levels used to determine topographic characteristics.

9. WHITE BUTTE FORK CEDAR CREEK NEAR SCRANTON, N. DAK.

LOCATION.--Lat 46°19'20", long 102°59'45", in NW¼ sec. 21, T. 133 N., R. 98 W., Slope County, on left bank 1,200 ft (366 m) downstream from bridge on county highway, 13 mi (21 km) northeast of Scranton.

GAGE.--Water-stage recorder with tipping-bucket rain gage attachment. Altitude of gage is 2,696 ft (822 m) above mean sea level (by barometer).

STAGE-DISCHARGE RELATION.--Defined by current-meter measurement to 591 ft^3/s (16.7 m^3/s) and extended to 645 ft^3/s (18.3 m^3/s).

TOPOGRAPHIC CHARACTERISTICS.--Drainage area, 42.8 mi^2 (110.9 km^2); length of mainstream, 26 mi (42 km); slope of main stream, 17 ft/mi (3.2 m/km); upper basin slope, 100 ft/mi (18.9 m/km); gage-vicinity stream slope, 7 ft/mi (1.3 m/km); stream density, 2.2 mi/mi^2 (1.4 km/km^2); basin elevation, 2,900 ft (884 m); percentage of surface storage, 0.1 pct; percentage cultivated, 59 pct; soil index, 3.1; length/width basin, 15.7.

REMARKS.--Barometric levels used to determine topographic characteristics.

10. NORTH FORK GRAND RIVER TRIBUTARY NEAR BOWMAN, N. DAK.

LOCATION.--Lat 45°59'20", long 103°28'55', on north line sec. 19, T. 129 N., R. 102 W., Bowman County, on downstream wingwall of county highway bridge 14 mi (22.5 km) south of Bowman.

GAGE.--Water-stage recorder with tipping-bucket rain gage attachment. Altitude of gage is 2,857 ft (871 m) above mean sea level (by barometer).

STAGE-DISCHARGE RELATION.--Stage-discharge relation defined by current-meter measurement to 458 ft^3/s (13.0 m^3/s) and extended to 621 ft^3/s (17.6 m^3/s).

TOPOGRAPHIC CHARACTERISTICS.--Drainage area, 36.7 mi^2 (95.1 km^2); length of mainstream, 14.3 mi (23 km); slope of main stream, 16 ft/mi (3.0 m/km); upper basin slope, 103 ft/mi (19.5 m/km); gage-vicinity stream slope, 7 ft/mi (1.3 m/km); stream density, 2.6 mi/mi^2 (1.6 km/km^2); basin elevation, 3,000 ft (914 m); percentage of surface storage, 0.1 pct, percentage cultivated, 43 pct; soil index, 2.5; length/width basin, 5.6.

REMARKS.--Barometric levels used to determine topographic characteristics.

11. ALKALI CREEK NEAR BOWMAN, N. DAK.

LOCATION.--Lat 46°00'00", long 103°22'05", on west line sec. 18, T. 129 N., R. 101 W., Bowman County, on right bank on downstream side of county highway bridge, 12 mi (19 km) south of Bowman.

GAGE.--Water-stage recorder with tipping-bucket rain gage attachment. Altitude of gage is 2,794 ft (852 m) above mean sea level (by barometer).

STAGE-DISCHARGE RELATION.--Stage discharge relation defined by current-meter measurement to 128 ft^3/s (3.6 m^3/s) and extended to 628 ft^3/s (17.8 m^3/s).

TOPOGRAPHIC CHARACTERISTICS.--Drainage area, 58.1 mi^2 (150.5 km^2); length of main stream, 23.8 mi (38.3 km); slope of main stream, 13 ft/mi (2.5 m/km); upper basin slope, 90 ft/mi (17.0 m/km); gage-vicinity stream slope, 6 ft/mi (1.1 m/km) stream density, 2.8 mi/mi^2 (1.7 km/km^2); basin elevation, 2,950 ft (899 m); percentage of surface storage, 0.1 pct; percentage cultivated, 46 pct; soil index, 2.1; length/width basin, 9.8.

REMARKS.--Barometric levels used to determine topographic characteristics.

AN INVESTIGATION OF BASIN EFFECTS ON FLOOD DISCHARGES IN NORTH DAKOTA By Orlo A. Crosby