PROGRESS REPORT ON HYDROLOGIC INVESTIGATIONS OF SMALL DRAINAGE AREAS IN NEW HAMPSHIRE-- PRELIMINARY RELATIONS FOR ESTIMATING PEAK DISCHARGES ON RURAL, UNREGULATED STREAMS

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16. Abstracts

The magnitude and frequency of floods on rural, unregulated streams in New Hampshire with drainage areas between 0.27 and 622 square miles may be estimated from drainage area, main-channel slope, and a precipitation intensity index. Based on multiple-regression analyses of data from 59 gaged sites in New Hampshire and adjacent areas of bordering states, peak discharges for recurrence intervals of 2, 5, 10, 25, 50, and 100 years can be estimated by the following equations:

$$P_2 = 1.34A^{1.06}S^{0.37}I^{1.24},$$

$$P_5 = 1.00A^{1.06}S^{0.44}I^{1.69},$$

$$P_{10} = 0.84A^{1.06}S^{0.46}I^{1.98},$$

$$P_{25} = 0.70A^{1.05}S^{0.52}I^{2.29},$$

$$P_{50} = 0.62A^{1.05}S^{0.54}I^{2.50},$$

$$P_{100} = 0.55A^{1.05}S^{0.56}I^{2.72},$$

where

P_t is the peak discharge, in cubic feet per second, for the specified recurrence interval t, in years,
A is the drainage area, in square miles,
S is the main-channel slope, in feet per mile, and
I is the maximum 24-hour precipitation having a recurrence interval of 2 years, expressed in inches.

The estimating relations can be applied to streams where flows are not significantly affected by regulation, diversion, or urbanization; where usable manmade storage does not exceed 4.5 million cubic feet per square mile; or where the basin characteristics are within a specified range. The average standard error of the estimate ranged from 35 percent for the 2-year flood to 58 percent for the 100-year flood.

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CONTENTS

ILLUSTRATIONS

TABLES

FACTORS FOR CONVERTING U.S. CUSTOMARY UNITS TO

INTERNATIONAL SYSTEM (SI) UNITS

The following factors may be used to convert the U.S. customary units published herein to the International System of Units (SI):

U.S. customary units	Multiply by	To obtain SI units
inches (in)	25.4	millimeters (mm)
feet (ft)	.305	meters (m)
miles (mi)	1.61	kilometers (km)
feet per mile (ft/mi)	.189	meters per kilometer (m/km)
square miles (mi^2)	2.59	square kilometers (km^2)
cubic feet per second (ft^3/s)	.02832	cubic meters per second (m^3/s)
cubic feet per square mile (ft^3/mi^2)	.0109	cubic meters per square kilometer (m^3/km^2)

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By Denis R. LeBlanc

ABSTRACT

The magnitude and frequency of floods on rural, unregulated streams in New Hampshire with drainage areas betwen 0.27 and 622 square miles may be estimated from drainage area, main-channel slope, and a precipitation intensity index. Based on multiple-regression analyses of data from 59 gaged sites in New Hampshire and adjacent areas of bordering states, peak discharges for recurrence intervals of 2, 5, 10, 25, 50, and 100 years can be estimated by the following equations:

$$P_2 = 1.34A^{1.06}S^{0.37}I^{1.24},$$

$$P_5 = 1.00A^{1.06}S^{0.44}I^{1.69},$$

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P_t is the peak discharge, in cubic feet per second, for the specified recurrence interval t, in years,
A is the drainage area, in square miles,
S is the main-channel slope, in feet per mile, and
I is the maximum 24-hour precipitation having a recurrence interval of 2 years, expressed in inches.

The estimating relations can be applied to streams where flows are not significantly affected by regulation, diversion, or urbanization; where usable manmade storage does not exceed 4.5 million cubic feet per square mile; or where the basin characteristics are within a specified range. The average standard error of the estimate ranged from 35 percent for the 2-year flood to 58 percent for the 100-year flood.

INTRODUCTION

This progress report presents the preliminary results of an investigation designed to obtain hydrologic data on small watersheds in New Hampshire and to analyze and present those data for use in the hydraulic design of highway drainage structures.

These preliminary results are presented in the form of a technique for estimating floods on ungaged, virtually natural streams in New Hampshire. The technique consists of a set of equations that relate floods experienced at continuous-record and crest-stage partial-record gaging stations to readily determined topographic and climatic characteristics. Because the data base for flood peaks is relatively small, particularly that of the crest-stage stations, the interim estimating relations presented will be further refined in the final report for this investigation.

Floods are described in terms of magnitude and frequency. Flood magnitude is expressed as a volume rate of flow, in cubic feet per second (ft^3/s). Flood frequency is expressed in terms of recurrence interval, which is the average interval of time, in years, within which the given flood magnitude will be exceeded once. This investigation is being conducted in cooperation with the New Hampshire Department of Public Works and Highways, the New Hampshire Water Resources Board, and the Federal Highway Administration.

Benson (1962) applied flood frequency analysis to relate flood magnitude to drainage basin characteristics for unregulated streams in New England. The relations Benson obtained were based on sparse data for drainage areas of less than 25 square miles and are poorly defined below 10 square miles. As a result of programs begun since Benson did his analysis, more flood-magnitude data are now available for small basins in New Hampshire, and the flood-frequency distribution on large streams has been refined. Following the techniques outlined by Benson (1962), this preliminary investigation used the additional data for small basins and the wealth of flood data for larger streams to refine the estimating relations, so they could be used for smaller drainage basins in New Hampshire.

ESTIMATING TECHNIQUES

For ungaged sites on rural, unregulated streams, peak discharges P_2, P_5, P_{10}, P_{25}, P_{50}, and P_{100}, for recurrence intervals of 2, 5, 10, 25, 50, and 100 years, respectively, can be estimated by the following equations:

	Average standard error of the estimate (percent)
$P_2 = 1.34A^{1.06}S^{0.37}I^{1.24}$	35
$P_5 = 1.00A^{1.06}S^{0.44}I^{1.69}$	40
$P_{10} = 0.84A^{1.06}S^{0.46}I^{1.98}$	44
$P_{25} = 0.70A^{1.05}S^{0.52}I^{2.29}$	50
$P_{50} = 0.62A^{1.05}S^{0.54}I^{2.50}$	54
$P_{100} = 0.55A^{1.05}S^{0.56}I^{2.72}$	58

where

P_t is the peak discharge, in cubic feet per second, for the specified recurrence interval t, in years,
A is the drainage area, in square miles,
S is the main-channel slope, in feet per mile, and
I is the maximum 24-hour precipitation having a recurrence interval of 2 years, expressed in inches.

These basin characteristics are determined in the section "Computation of Independent Variables."

ACCURACY AND LIMITATIONS

The accuracy of the estimating relations can be measured by comparing the peak discharges computed using these relations with the peak discharges obtained from the flood-frequency analyses of gaging station records. This comparison is shown graphically in figure 1, where peak discharges determined from the flood-frequency curves for the 50-year recurrence interval are plotted against those computed with estimating relations. The standard error of the estimate is also a measure of how well the computed flood peaks compare with the observed flood peaks. In general, approximately two out of the three sites had experienced flood peaks within one standard error of the estimated flood peaks, and approximately 19 out of 20 sites had experienced flood peaks within two standard errors of the estimated flood peaks. The average standard error of the estimate for each estimating relation is given in the previous section, "Estimating Techniques."

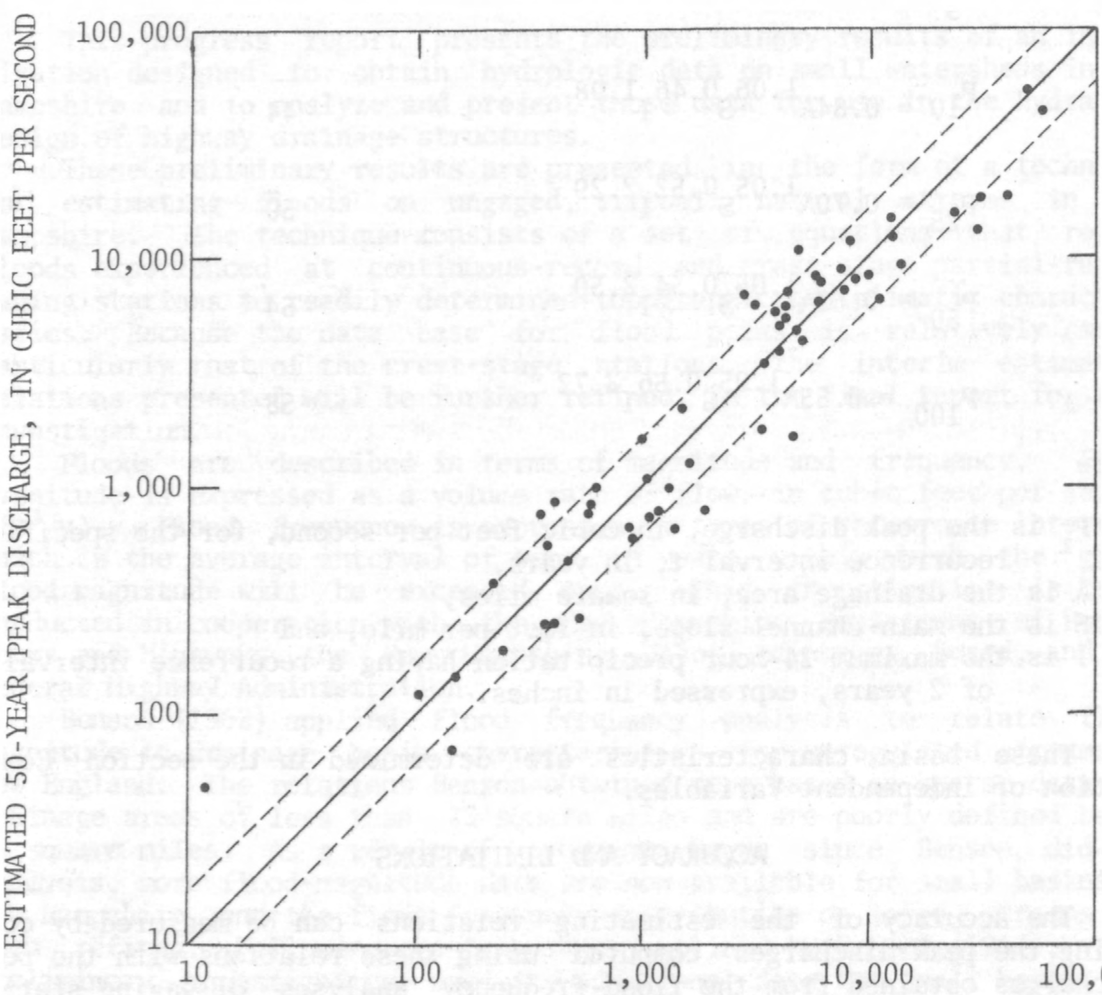

Figure 1.--Observed and estimated 50-year peak discharges for the 59 sites used in this analysis

These relations do not apply to streams where flood flows are significantly affected by regulation, diversions, or urbanization and where usable manmade storage is over 4.5 million cubic feet per square mile. The relations should be used only if the basin characteristics of the stream are in the range of the basin characteristics upon which the relations are based. The maximum and minimum values of each basin characteristic are:

Basin characteristic	Maximum	Minimum
Drainage area (mi^2)	622	0.27
Main-channel slope (ft/mi)	589	6.23
Precipitation intensity index (in)	3.8	2.3

COMPUTATION OF INDEPENDENT VARIABLES

In applying these relations, the drainage area, the main-channel slope, and the precipitation intensity should be determined by the following methods or methods of equivalent accuracy:

(1) Drainage area: Outline the drainage area on a topographic map along the divide indicated by the contour lines, starting at the point on the stream for which the drainage area is desired. The map should meet National Map Accuracy Standards and be of a scale of 1:62,500 or larger. Planimeter the outlined drainage area to obtain the area, in square miles, to one hundredth of a square mile below 10 square miles, and to three significant figures above.

(2) Main-channel slope: Outline the main channel on the map of the basin. Upstream from each stream junction, choose the main channel as the branch which drains the largest area. Continue the main channel to the divide beyond the end of the stream line shown on the map by drawing flow lines indicated by contours. Measure the total length of the main channel to one-tenth of a mile, locate the points 85 and 10 percent of the total length above the point of interest on the stream, and determine the altitude of these points. The main-channel slope is the difference in altitude, in feet, divided by the length, in miles, between the two points.

(3) Precipitation intensity index: Locate the basin of interest on figure 2-4 of U.S. Weather Bureau Technical Paper 29 (1959). By interpolation, determine the maximum 24-hour precipitation, having a recurrence interval of 2 years, to the nearest one-tenth of an inch. This value should be an estimated average for the entire drainage area above the point of interest on the stream.

ANALYTICAL TECHNIQUES

Fifty-nine stations in New Hampshire and in adjacent areas of bordering states (fig. 2) were used in this analysis. Flood-peak data for the large and small streams were both used in this analysis, because the longer period of record for many large streams provided additional data for use in defining the estimating relations for the rarer flood peaks. Basin and flood charateristics for each of these sites are given in table 1.

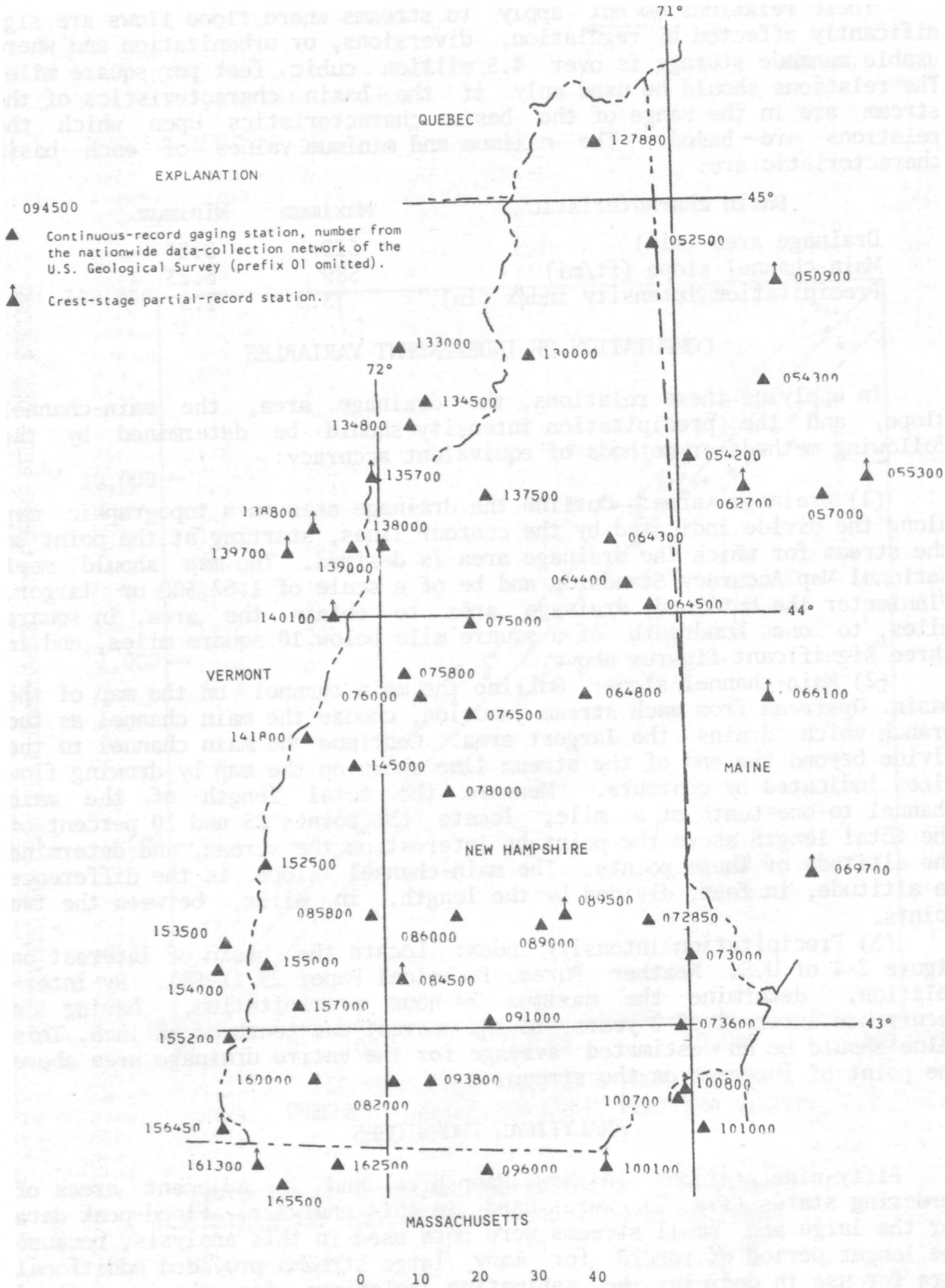

Figure 2.--Stations used in this analysis

Table 1.--Selected basin parameters and flood characteristics for gaging stations used in this analysis

Station number	Drainage area (mi^2)	Main-channel slope (ft/mi)	Maximum 24-hour precipitation at 2-year recurrence interval (inches)	Peak discharge from station frequency curve, in cubic feet per second, for indicated recurrence interval: 2-year	5-year	10-year	25-year	50-year	100-year
01050900	3.41	90.00	2.5	96	168	230	326	412	512
01052500	153.00	41.04	2.4	4512	5898	6834	8040	8958	9893
01054200	69.50	104.62	3.3	5238	10146	14714	22322	29549	38322
01054300	131.00	53.77	2.8	3516	4890	5883	7233	8310	9449
01055300	10.50	58.00	2.8	178	244	292	357	410	465
01057000	76.20	51.92	3.0	2150	3195	3971	5046	5916	6847
01062700	5.35	117.00	3.0	215	398	562	830	1079	1377
01064300	10.90	555.00	3.8	1126	2698	4418	7689	11174	15808
01064400	4.68	481.00	3.3	386	872	1384	2327	3306	4582
01064500	386.00	50.99	3.3	14814	23566	30428	40358	48704	57890
01064800	5.41	437.00	3.1	417	1030	1723	3080	4564	6581
01066100	4.62	212.00	3.2	154	261	353	496	624	774
01069700	10.70	25.00	3.2	242	435	610	897	1166	1490
01072850	8.87	74.67	3.0	205	407	604	948	1290	1720
01073000	12.10	21.50	2.9	271	422	540	714	861	1025
01073600	4.97	20.50	3.0	143	229	303	417	520	639
01075000	193.00	80.70	2.6	10720	17862	23840	32988	41073	50347
01075800	2.94	589.00	2.6	174	385	604	1000	1406	1929
01076000	143.00	107.10	2.6	5256	9224	12684	18155	23132	28972
01076500	622.00	42.00	2.6	20469	30070	37274	47368	55628	64540
01078000	85.80	22.60	2.7	1718	2577	3254	4243	5083	6017
01082000	68.10	33.90	3.2	1141	1654	2045	2604	3069	3577
01084500	55.40	78.30	3.0	1163	1627	1971	2449	2837	3254
01085800	5.75	456.00	3.0	219	388	537	779	1002	1267
01086000	146.00	31.80	2.9	2126	2911	3478	4247	4860	5509
01089000	76.80	33.20	2.8	1141	1814	2368	3208	3945	4786
01089500	157.00	16.35	2.8	2186	3492	4596	6303	7832	9606
01091000	104.00	30.60	3.0	1917	2926	3715	4855	5816	6875
01093800	3.60	230.00	3.1	131	189	234	299	353	413
01096000	62.80	43.55	3.0	1275	1914	2428	3194	3856	4603
01100100	4.32	50.00	3.0	133	159	178	201	219	237
01100700	4.93	18.40	3.0	79	139	194	284	371	477
01100800	0.77	64.80	3.0	49	73	92	119	143	170
01101000	21.60	6.23	3.2	198	294	370	484	582	693
01127880	6.36	285.00	2.4	270	367	434	523	591	662
01130000	232.00	28.60	2.3	4813	7223	9077	11728	13937	16354
01133000	53.80	60.50	2.4	1295	1875	2304	2900	3382	3899
01134500	75.20	78.40	2.4	2037	2705	3167	3772	4240	4723
01134800	8.05	135.00	2.5	437	765	1044	1479	1867	2316
01135700	0.76	456.00	2.5	28	46	61	84	104	126
01137500	87.60	72.00	3.2	4149	6330	8022	10453	12488	14723
01138000	395.00	28.70	2.4	10744	16312	20610	26768	31908	37539
01138800	4.26	183.00	2.5	92	171	243	359	466	594
01139000	98.40	89.80	2.3	1573	2328	2897	3697	4353	5063
01139700	1.09	475.00	2.5	37	76	114	178	240	316
01140100	0.27	583.00	2.5	5	7	8	10	12	13
01141800	4.60	175.00	2.7	163	303	430	636	829	1060
01145000	80.50	50.20	2.7	1468	2216	2786	3593	4260	4986
01152500	269.00	27.40	2.6	4680	6778	8355	10570	12388	14354
01153500	103.00	56.50	2.7	3597	5273	6558	8392	9918	11588
01154000	72.20	87.40	2.9	2420	3702	4714	6192	7448	8844
01155000	82.70	49.00	2.7	1867	2866	3663	4839	5846	6974
01155200	10.00	267.00	3.0	273	514	738	1112	1470	1907
01156450	1.12	122.00	3.0	45	70	90	121	147	177
01157000	71.10	38.50	2.7	1544	2336	2959	3866	4635	5489
01160000	36.00	100.00	2.7	909	1570	2164	3133	4040	5132
01161300	2.33	330.00	3.0	98	161	216	300	377	465
01162500	19.40	27.20	3.0	351	612	847	1231	1591	2024
01165500	12.30	48.10	3.0	252	431	586	830	1053	1314

The flood-peak frequency curve for each station was determined using the latest guidelines issued by the U.S. Water Resources Council (1976). The length of record at 6 sites was 10 years or less, and that at 24 sites was between 11 and 25 years. A log-Pearson Type III distribution was fitted to the observed annual peaks using a weighted skew coefficient. Tests for low outliers were done, but none was detected. The flood-frequency curves were further refined where historical flood information was available. The 2-, 5-, 10-, 25-, 50-, and 100-year flood peaks were determined from the final flood-frequency curves developed for each station.

Previous studies (Benson, 1962) had determined that the logarithms of the flood peaks are linearly related to the logarithms of the basin and climatic characteristics. Initially, 11 drainage basin and climatic characteristics were selected for use in the analysis. These characteristics were: drainage-basin area, main-channel length, main-channel slope, area of lakes and ponds in the drainage basin, forested area in the drainage basin, mean elevation of the drainage basin, mean annual precipitation, precipitation intensity for 24 hours at a 2-year recurrence interval, mean minimum January temperature, mean annual snowfall, and a soils index representing the potential maximum infiltration during an annual flood under average soil-moisture conditions. Values for these characteristics can be obtained from readily available maps and reports. For each recurrence interval, the relation between peak discharge (the dependent variable) and the set of basin characteristics (the independent variables) was determined by step-forward and step-backward linear, multiple-regression techniques. Basin characteristics were eliminated from the analysis as they were tested by the regressions if they were highly related to another independent variable or resulted in little or no improvement when included in the estimating relations.

DISCUSSION

The user of these relations should be aware of the limitations of absolute reliance on relations derived from the mathematical manipulation of a data set. The estimating relations should be considered preliminary because of the limitations described below and should be used cautiously, particularly when estimating the rarer flood peaks. Upon completion of the project, a larger data base will be available and will be used to further develop and improve the estimating relations and the understanding of the nature of the relationship between basin characteristics and the magnitude and frequency of floods.

Several factors will be considered in more detail:

(1) The length of record at sites on small drainage basins is generally shorter than at the stations on large streams. To improve the estimating relations for flood peaks on small streams, especially for the rarer flood peaks, these relations will be refined when additional flood-peak data for small gaged streams become available.

(2) In the multiple-regression techniques used in this analysis, it is assumed that the drainage basin and climatic characteristics used in the analyses are independent. However, there are varying degrees of interdependence among these characteristics which may mask the true relation between flood peaks and the characteristics.

(3) The possibility of developing different estimating relations for different regions of the State, or for different recurrence intervals, will be examined. At a particular site, flood magnitude of different recurrence intervals may be controlled by different interactions between the basin and climatic characteristics. Also, the magnitude of flood flows in one region may be controlled by different interactions between the basin and climatic characteristics than those in another region. Examination of the areal distribution of the ratio between the observed and the estimated flood peaks suggest that there is a regional pattern, with flood magnitude overestimated in some areas and underestimated in other areas. For the present analysis, there were insufficient data to evaluate areal bias adequately.

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