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Analysis of Winter Low-Flow Rates in New Hampshire Streams

Rae Ann Melloh

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U.S. Army Corps
of Engineers
Cold Regions Research &
Engineering Laboratory

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Prepared for
OFFICE OF THE CHIEF OF ENGINEERS

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PREFACE

This report was written by Rae Ann Melloh, Research Physical Scientist, Geological Sciences Branch, Research Division, U.S. Army Cold Regions Research and Engineering Laboratory. Funding for this investigation was provided through Civil Works Project *Water Resources of Cold Regions*, Work Unit 32547, *Winter Effects on Flow Frequency*, and DA Project 4A762784AT42, Work Unit SS/025, *Field Water Supply on the Winter Battlefield*.

The author thanks Timothy Pangburn and Richard Haugen of CRREL for technically reviewing the manuscript, Eleanor Huke and Edward Perkins for providing the illustrations, and Mark Hardenberg for the editorial review.

CONVERSION FACTORS: U.S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

These conversion factors include all the significant digits given in the conversion tables in the ASTM *Metric Practice Guide* (E 380), which has been approved for use by the Department of Defense. Converted values should be rounded to have the same precision as the original (see E 380).

Multiply	*By*	*To obtain*
foot	0.3048	meter
$mile^2$ (U.S. Survey)	2589998.0	$meter^2$
$foot^2$/second	0.02831685	$meter^2$/second

Analysis of Winter Low-Flow Rates in New Hampshire Streams

RAE ANN MELLOH

INTRODUCTION

A better understanding of winter low flows is needed to assess a diverse range of winter stream conditions, including winter water quality and aquatic habitat, flow rates during periods of ice formation and cover, and winter water supplies. The timing and magnitude of low flows vary regionally in response to basin climate and geology. This report investigates the regionalization of low flows in the White Mountain and Upland physiographic sections of New Hampshire. This preliminary effort establishes a data set that will be used in the development of improved analytical methods for estimating flows that occur in the winter. The primary objectives of this report are to determine whether or not winter season low flows vary significantly between the physiographic sections and to provide possible explanations for this. The magnitude of basin-to-basin variation in winter low-flow rates within the two physiographic sections is compared with average regional variation. The correlation between mean basin elevation and discharge per square mile is assessed as an indicator of the effect of elevation-related climate gradients on stream flows. Summer low flows are also developed for use as a comparison set.

BACKGROUND

Establishing a relationship between drainage basin characteristics (climate and geology) and low-flow magnitudes provides a method of identifying the more significant factors controlling low flows for a given region. It is reasonable to assume that in regions where climate is fairly uniform and geologic variations are pronounced, geology will dominate low-flow variation. On the other hand, climate variations will dominate in regions of fairly uniform geology.

Winter low-flow events take place during prolonged cold and dry periods. The rate of stream flow recession following a rainfall or snow-melt event is influenced by geomorphic factors, including average distance of the watercourse from the drainage area divide and watercourse storage characteristics; however, during periods of no surface runoff, the rate of recession reflects the transmissivity and storage characteristics of the along-stream and groundwater aquifers. The effect of climate on low flows in cold regions is largely related to precipitation and temperature, or more precisely, availability of rainfall and snow melt during the winter low-flow period. Temperature and precipitation vary with elevation and latitude in New England, and to a lesser extent with proximity to water bodies, local land forms, forest cover and land use (Lee 1969, Hendrick and DeAngelais 1976). Other regional climate effects may include increased surface runoff attributable to frozen ground and the loss of flow volume into overflow icings.

Basin description

The New Hampshire landscape may be divided into two primary physiographic sections, the Upland in the southern half of the state and the White Mountains in the north—there is also a small seacoast section in the southeast. The Upland is a dissected plateau-like landscape sloping southeastward from about 1400 ft above sea level near the White Mountains to 400–500 ft at the seaboard edge. The surface of the Upland is hilly, with local relief between hilltops and valleys generally ranging from several hundred to in excess of 1000 ft at larger monadnocks. The Upland is formed on metamorphosed sedimentary and volcanic rocks, and intruded igneous masses. Glacial till deposits are thin or absent and as a result bedrock is close to, or at, the surface. The White Mountains, formed on granitic masses, rise above the Upland to maximum altitudes over 6000 ft. The White Mountain section does not contrast sharply with the Upland section, but rather is a loosely defined northern area encompassing numerous mountains that stand conspicuously above the Upland (Thornbury 1965).

The nature of aquifers that supply base flow during periods without rainfall or snow melt appear to be relatively consistent across the White Mountain and Upland sections. Unconsolidated gravel and sand beds, where present along watercourses, have both high storage and transmissivity characteristics. Glacial tills, consisting of poorly sorted clay, sand, gravel and boulders, are generally thin and relatively impervious, and provide a limited source of groundwater (Sinnott 1982). Springs at bedrock interfaces and fractures in the non-porous bedrock also provide base flow during periods of no rainfall.

Climate

The higher elevations and more northern latitudes of the White Mountains create a distinguishable difference in climate between the two physiographic sections. Hendrick and DeAngelais (1976) did one of the more comprehensive studies of water input (approximated as rainfall plus snow melt) with elevation and latitude in the region by developing a model of snow pack accumulation and water input for the November through May period. The model was developed using 12 years of data from the Sleepers River watershed near Danville, Vermont, extended to the elevation and latitude range of the entire New England region (except Maine) using NWS weather station data. Hendrick and DeAngelais (1976) demonstrated that climatic and individual seasonal patterns of snow accumulation, melt and water input in New England are largely determined by the distribution of elevation and latitude. Winter season climate functions developed for the model show precipitation and temperature decreasing with increasing latitude, temperature decreasing with increasing elevation, and precipitation increasing with increasing elevation. Water input computed by the model decreased with both latitude and elevation during winter.

Previous studies have shown that many characteristics of stream flows in New Hampshire, including those of low-flow duration, average flow, variability of annual and daily flows, and flood flows, are significantly related to mean basin elevation (Dingman 1981). These elevation effects are largely attributed to changes in climate with elevation that result in gradients in evapotranspiration, precipitation, snow depth, snow water equivalent and other factors. The effect of climate change with elevation on water input and runoff for wet and dry periods in the Sleepers River watershed of Vermont has been described by DeAngelais et al. (1984), though for spring, summer and fall seasons only.

Previous low-flow investigations

Dingman (1978), in a flow-duration curve analysis of daily flows in New Hampshire streams, reported that the unit area flow rate (ft^3/s per mi^2) exceeded 95% of the time was significantly correlated with mean basin elevation. Results of the analysis suggested two populations: for mean basin elevations below 1500 ft there was no correlation and for mean basin elevations above 1500 ft there was strong positive correlation. Dingman further reported that extensive trials of relating geomorphic parameters (drainage density, slope and relief) to New Hampshire stream flows had proven fruitless. Winter and summer periods were not separated in the analysis.

A regional study evaluated the stream-flow network in central New England as it existed in 1970 (Johnson 1970). The study combined stream flows from 135 streams in Massachusetts, New Hampshire, Rhode Island and Vermont and related stream-flow characteristics to basin and climatic characteristics using multiple regression techniques. Drainage basin characteristics evaluated were drainage area, main-channel length, main channel slope, mean basin elevation, forest cover, mean annual precipitation, area of lakes and ponds, mean maximum annual 24-hour rainfall, minimum January temperature, seasonal snowfall and a soil infiltration index. Of 37 stream-flow characteristics evaluated, three pertained to low flow; those were mean annual 7-day low flows at 2-, 10- and 20-year reoccurrence intervals. The relevance of the results of the regression analyses to this study is limited by the generality of Johnson's study, which did not separate winter and summer low flows and thus did not attempt to explain winter low-flow variability in New Hampshire streams in terms of hydroclimatic variables. It is of interest to note that basin characteristics found to have significance in determining the annual period low flows were climate variables that are known to vary appreciably between the White Mountain and Upland sections. The regression variables found to be of significance for estimating mean annual 7-day events were, in order of importance, drainage area, seasonal snowfall, mean annual precipitation, elevation and average minimum January temperature. Mean annual 7-day low-flow events, however, occur predominantly in summer.

In summary, previous low-flow studies have not separated winter and summer periods and, thus, are not uniquely representative of either summer or winter conditions. The important parameters identified, with exception of drainage area, were either climate variables or elevation. The latter is apparently a useful surrogate for a group of climate variables that change with elevation. In addition, the important parameters identified in previous studies suggest a climate-related regionalization of low-flow characteristics distinguishing the White Mountain and Upland physiographic sections. Geologic–geomorphic factors have not been reported as important stream-flow variables in New Hampshire, though methods of identifying geologic controls are widely known and have been used successfully elsewhere.

LOW-FLOW ANALYSES

The approach suggested by previous work is that regional climate variation may be of some utility in explaining the magnitudes of winter low-flow events in New Hampshire; however, the significance of climate factors may depend on regional gradation in water input magnitudes. Previous studies indicate that elevation- and, to some degree, latitude-driven gradients in water input during winter exist, though magnitudes are relatively low compared to those of spring and fall (Hendrick and DeAngelais 1976). It is also apparent from previous studies that a climatic approach might be greatly simplified using elevation as a surrogate for the climate factors themselves, which are substantially interrelated. Such an approach might provide a method of establishing regional equations of low-flow event magnitudes, using a minimum of variables. Geologic variables such as those indicated by flow recession rates and geomorphic measurements, though of influence, will not be assessed here.

Data set and limitations

The flow records used in this analysis included those of gauges on unregulated streams as well as a few gauges where there has been diurnal regulation by mills or dams, though with no appreciable effect on recorded daily average flows (Johnson 1970, USGS 1980–84). Streams included in the present analysis have drainage area sizes in the 50- to 230-mi^2 range. The gauging station locations are as shown on Figure 1, and a list of the station names, years of record, drainage area size and mean basin elevation are provided in Table 1. Mean basin elevations were adopted from previous studies (Langbein 1947, Johnson 1970, Dingman 1978) and were determined by either area–elevation curves, grid sample techniques or, in a few instances, approximated using a relationship developed between maximum, minimum and mean basin elevation for New Hampshire streams (Dingman 1978). The stream-flow records represent a range of elevations and drainage area sizes within each physiographic section.

Average minimum 3-, 7-, 14- and 30-day events for winter and summer seasons and the annual period were derived from the daily flow records. August and January 3-day events were also developed, specifically to exclude the effects of fall and spring transition periods in some of the flow comparisons. Though assessment of winter low flows is of primary interest in this study, annual and summer season low flows were also developed for comparison. The winter period was taken as 1 December through 30 April, though low-flow events rarely occur beyond March. The summer period was 1 May through 30 November, and the annual period

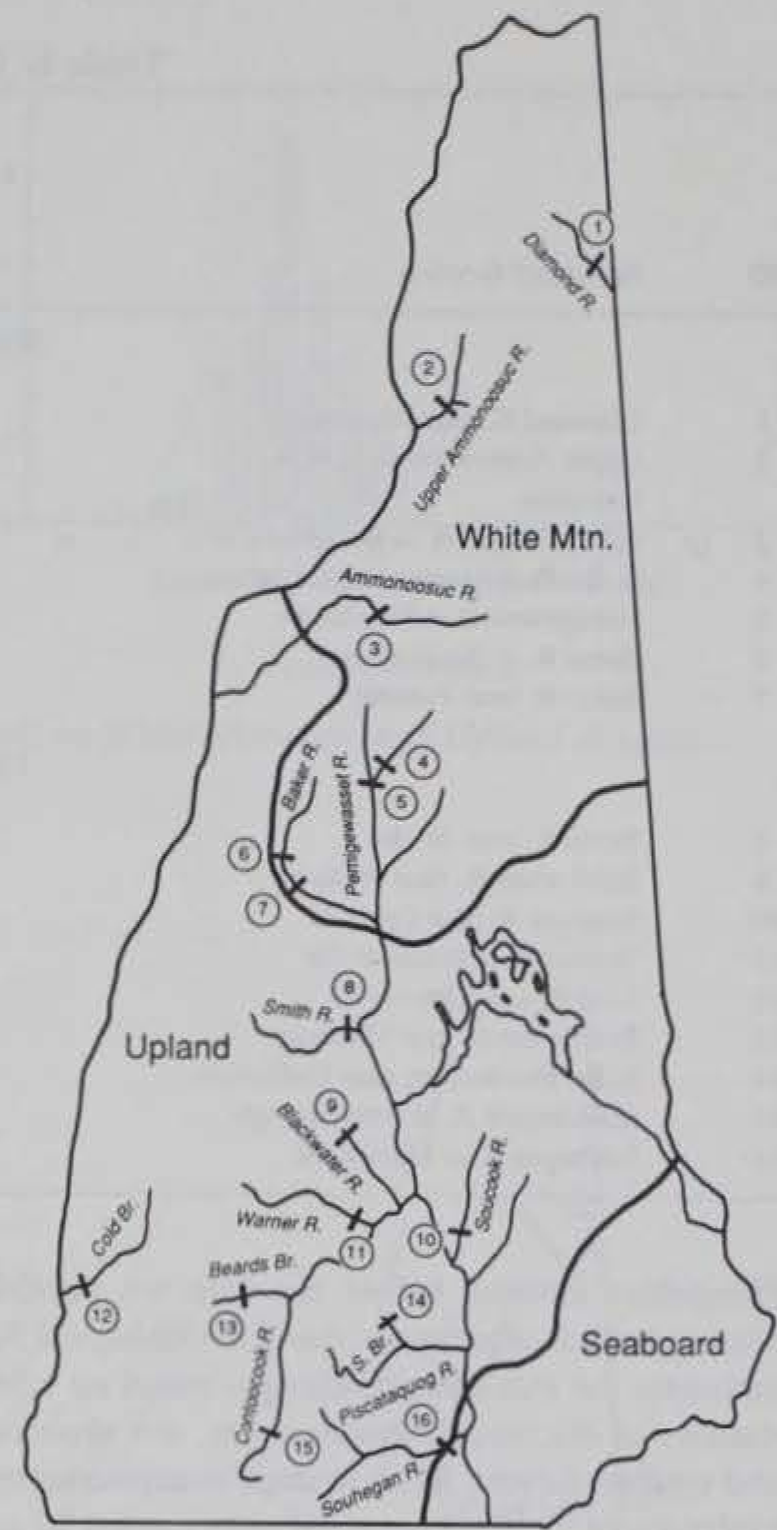


Figure 1. Locations of streams, gauging stations and physiographic sections.

included all calendar dates. The 1942 to 1978 period (37 years) was chosen for the analysis because the period was well represented by stream-flow records. Average low-flow event magnitudes for stations with shorter records were adjusted to the 1942 to 1978 period by estimating missing years of record through correlations with stations having longer records.

Stream-flow records, unfortunately, are inherently inaccurate in winter because ice in the channel invalidates the normal, ice-free discharge relationship. In addition, the amount of ice in the channel varies over time in response to periodic thaw and refreezing, making the stage–discharge relationship with ice in the channel a variable one. A great deal of time and effort is put into correcting daily low-flow records on New

Table 1. Gauging station records.

ID	*Name and location*	*Drainage area (mi^2)*	*Elevation above sea level (ft)*	*Years of record*	*USGS ID*
	White Mountain streams				
1	Diamond R. near Wentworth	153	2030	1941–1987	1052500
2	Upper Ammonoosuc R. near Groveton	232	1970	1940–1985	1130000
3	Ammonoosuc R. at Bethlehem Jct.	88	2510	1939–1985	1137500
4	E. Br. Pemigewasset near Lincoln	104	2800	1929–1953	1074500
5	Pemigewasset at Woodstock	193	2490	1940–1977	1075000
6	Baker R. at Wentworth	59	1740	1941–1952	1075500
7	Baker R. near Rumney	143	1580	1929–1977	1076000
	Upland section streams				
8	Smith R. near Bristol	86	1260	1918–1985	1078000
9	Blackwater R. near Webster	129	1100	1918–1985	1087000
10	Soucook R. near Concord	77	680	1952–1984	1089000
11	Warner R. near Davisville	146	970	1940–1978	1086000
12	Cold R. near Drewsville	83	960	1940–1978	1155000
13	Beards Brook near Hillsboro	55	1140	1946–1970	1084500
14	S. Br. Piscataquog near Goffstown	104	780	1940–1978	1091000
15	Contoocook R. at Peterborough	68	1170	1945–1977	1082000
16	Souhegan R. at Merrimack	171	810	1909–1976	1094000

Hampshire streams before the data are published.* During periods of ice cover, the U.S. Geological Survey estimates the true daily discharges based on a limited number of discharge measurements, site observations and weather factors. Rises in stage unexplained by precipitation or thaw are assumed to be caused by anchor or sheet ice in the channel and reported flows are adjusted accordingly. Accuracies of the winter season flow records used in this analysis are given an overall fair rating by the USGS, indicating that the recorded values are expected to be within 15% of true flow rates. Despite inherent inaccuracies, the data are the best available for evaluating regional variations in low-flow quantities.

*Personal communication with K. McKenna, U.S. Geological Survey, Concord, N.H., 1989.

Annual runoff hydrographs

The contrast in annual hydrologic cycles of White Mountain and Upland watersheds is reflected in annual runoff hydrographs of streams of the two sections. Plots of average daily flows from 1939 to 1977, smoothed over 7-day periods, depict unique characteristic hydrographs for the two regions (Fig. 2). The two example hydrograph plots are of streams of comparable drainage

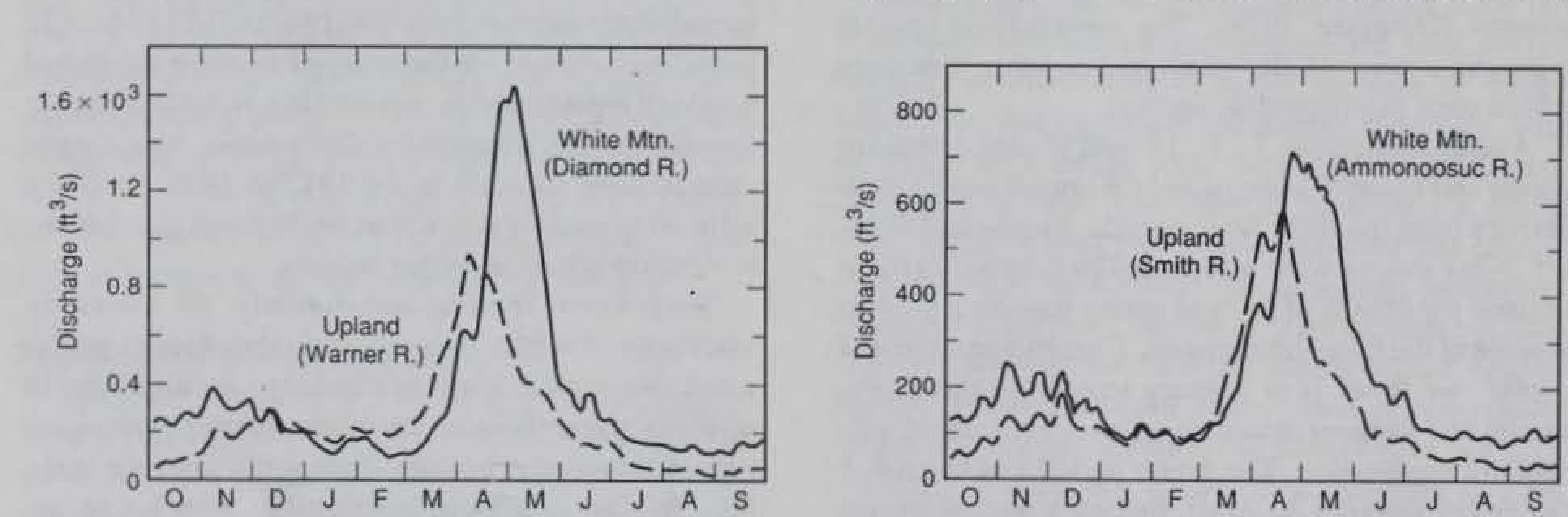
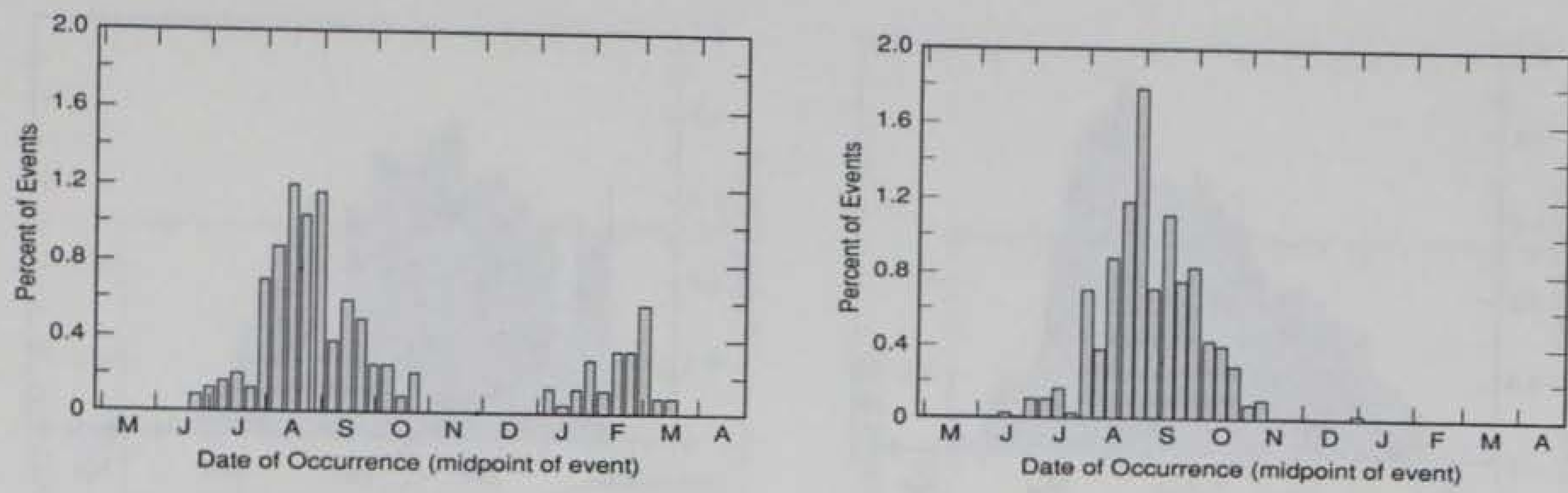


Figure 2. Annual runoff hydrographs comparing White Mountain streams (Diamond R. near Wentworth and Ammonoosuc R. at Bethlehem Junction) with Upland streams (Warner R. near Davisville and Smith R. near Bristol).



a. White Mountain streams.

b. Upland streams.

Figure 3. Date distribution of annual 14-day low-flow events on White Mountain and Upland streams.

area size: the Ammonoosuc (88 mi^2) and Diamond rivers (153 mi^2) in the White Mountains and the Smith (86 mi^2) and Warner rivers (146 mi^2) of the Upland. The hydrographs show higher runoff volumes in White Mountain streams through all seasons except winter. The higher runoff rates throughout most of the year in the White Mountains are most simply explained by higher water input at the higher elevations. Though the White Mountain streams show a more pronounced winter low-flow period than Upland streams, comparison of winter stream flows in the two regions shows similar flow rates. Summer flow magnitudes differ more by region than do winter flows; summer flows are greater in the White Mountains than in the Upland for a given drainage area size.

Annual and seasonal distribution of low-flow events

The dates of minimum annual and winter low-flow events vary geographically. This is apparent from time distributions of midpoint dates of 14-day low-flow events (Fig. 3) summed for all the years of record of all gauges included in the analyses. Streams in the Upland section almost never experience annual events in winter—there was only one occurrence in 384 events. The White Mountain streams, in contrast, all experience annual low-flow events during winter, though summer occurrences continue to dominate. Of the 242 annual events, 21% happened during winter on White Mountain streams. The percentage of annual events occurring during winter for each of the stream-flow stations, when plotted on a map of New Hampshire (Fig. 4), shows strong differentiation between the regions.

The dates of low-flow events chosen only from the winter records show a different temporal distribution in the White Mountains than in the Upland (Fig. 5). In the White Mountains, there is a gradual increase in the

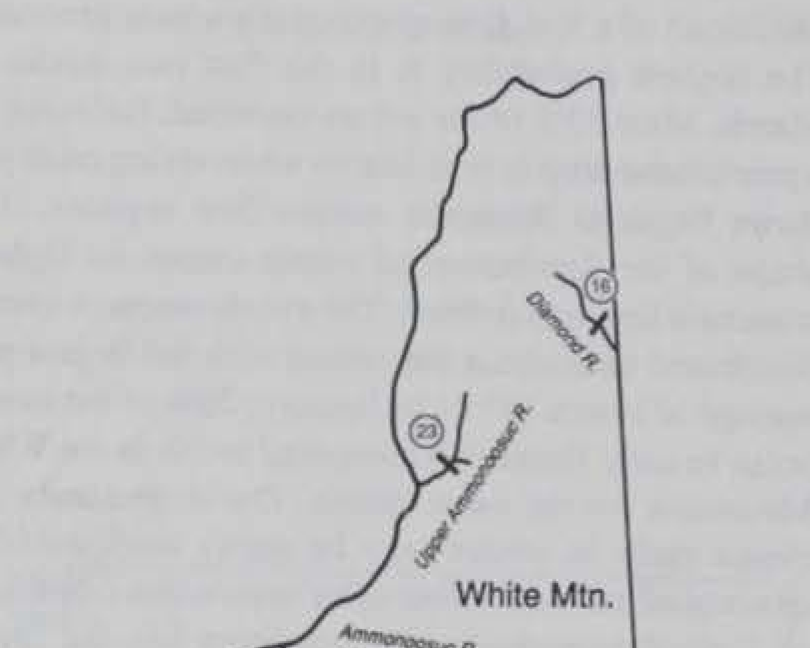
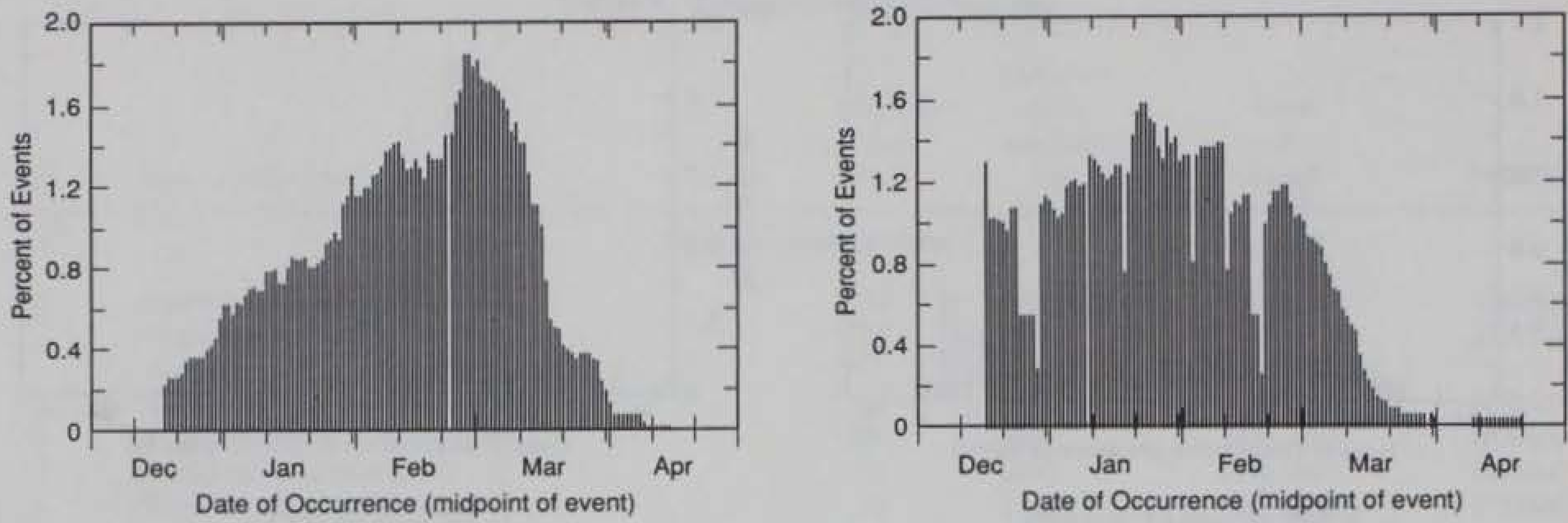


Figure 4. Regional distribution of the percentage of annual 14-day events occurring in winter.



a. White Mountain streams. *b. Upland streams.*

Figure 5. Smoothed date distribution of winter 14-day low-flow events on White Mountain and Upland streams.

likelihood of a low-flow event as the winter proceeds. The highest probability is in the first two weeks of March, when 32% of the events occurred, followed by a precipitous drop in mid-March when spring rains and thaws begin to dominate stream-flow regimes. The shape of the distribution of winter events on Upland streams is less well defined. The events are more evenly distributed throughout the season with the largest percentage of events (35%) in January; 26% of the events occur in early December compared to 5% in the White Mountains for the same month. The large number of events early in winter may be partly attributable to incomplete recovery from drier antecedent conditions on Upland watersheds. The transition into the spring runoff period happens a bit earlier in the Upland, where only 11% of the winter low-flow events occurred in March.

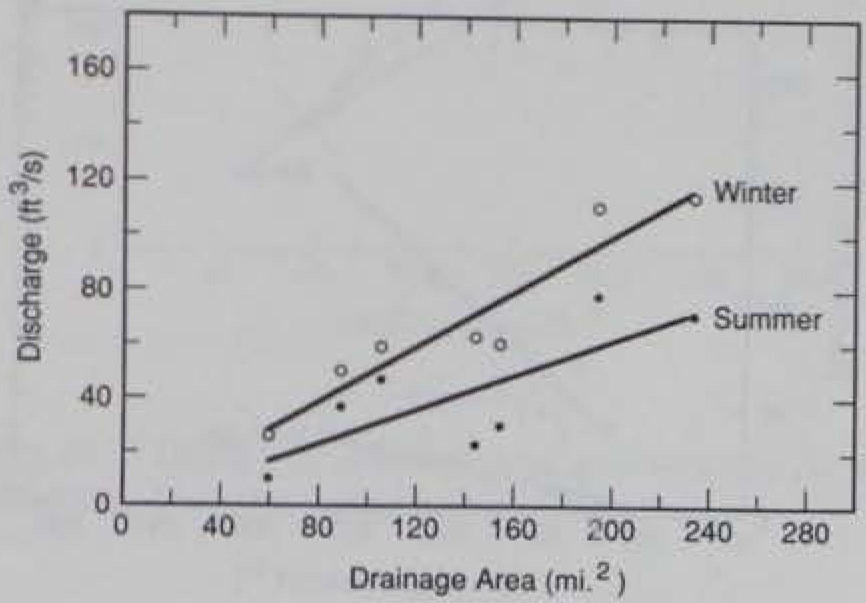
Low-flow variation with drainage area

Drainage area size is a catchment parameter that is readily available and usually quite useful in estimating stream-flow rates. Total stream length or stream density are also used to explain basin to basin differences in flow rates; however, these parameters are not as easily obtained. Stream length is likely to be highly correlated with drainage area size anyway, especially in areas of fairly consistent geology. In cold regions, where weather is sufficiently severe that lower order streams may freeze to the bed and become disconnected from the groundwater system, "unfrozen stream length" has been suggested as a more appropriate parameter (Gerard 1981). The extent to which streams freeze to the bed in New Hampshire is not known; however, in limited field inspections during late winter, it appears unlikely that this is an important parameter.

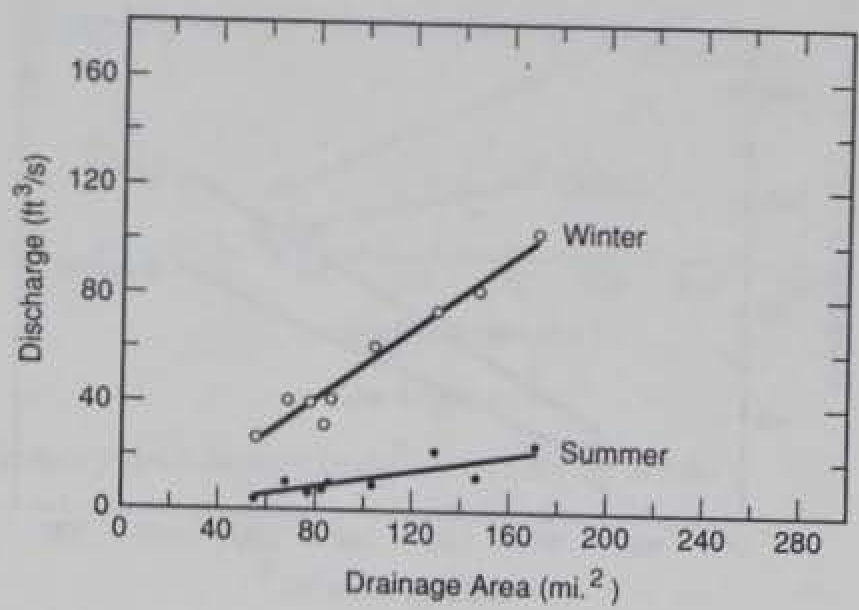
Simple linear regressions of low-flow event magnitudes and drainage area size for White Mountain and Upland streams, in both winter and summer seasons, were computed. Regression lines plotted on Figure 6 compare 3-, 7-, 14- and 30-day summer and winter seasonal events. Three-day events selected from the months of January and August only were also computed. Results for 3-day January and August events on White Mountain and Upland streams are compared on Figure 7. The proportion of variance explained (r^2) and associated significance, regression line slopes and intercepts, computed 100-mi^2 discharges, and standard error of flow estimates are shown on Table 2 for each event.

The average magnitudes of winter low-flow events in both White Mountain and Upland streams are highly correlated with drainage area size, resulting in coefficients of determination (r^2) of 0.89 or better. In contrast, summer season low flows are less well correlated with drainage area size, resulting in coefficients of determination in the 0.6 to 0.7 range. The arrangement of data points about the regression lines is consistent across all event durations, suggesting no apparent change in controlling factors for longer versus shorter events. Increased variance of flows with increased drainage area was not apparent in the data sets; thus, data transformations were not applied.

The computed regression lines for winter events are nearly coincident for the Upland and White Mountain sections. A close look at the computed values, however, shows consistently higher flows in the Upland, though the magnitude of the difference is small (Table 2). Computed 100-mi^2 discharges for 3- to 30-day events, for example, range from 49 to 64 ft^3/s in the White Mountains compared to 54 to 79 ft^3/s in the Upland. Significant variance and overlap in the data sets occur, as can be seen in the scatter plots (Fig. 6 and 7), making it difficult to judge whether or not the two are signifi-

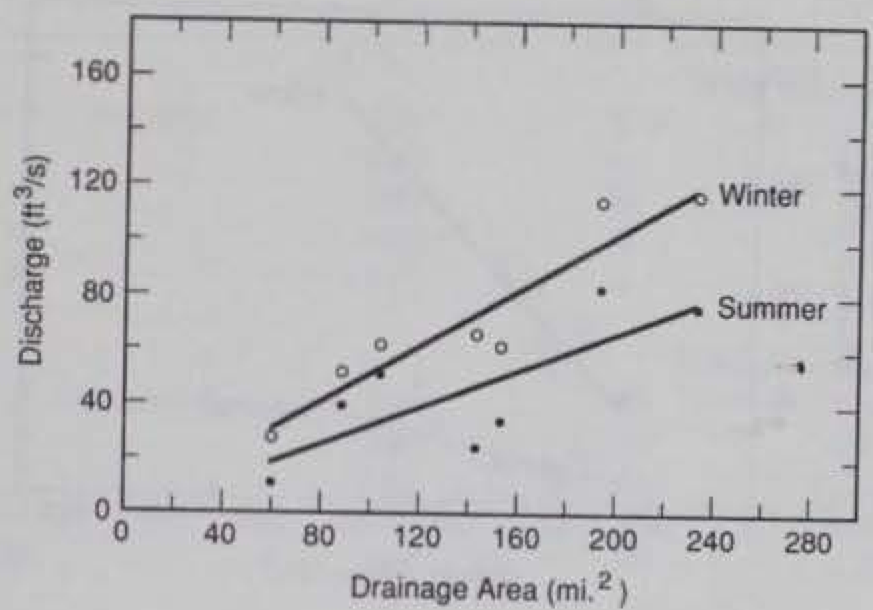


1. White Mountain streams.

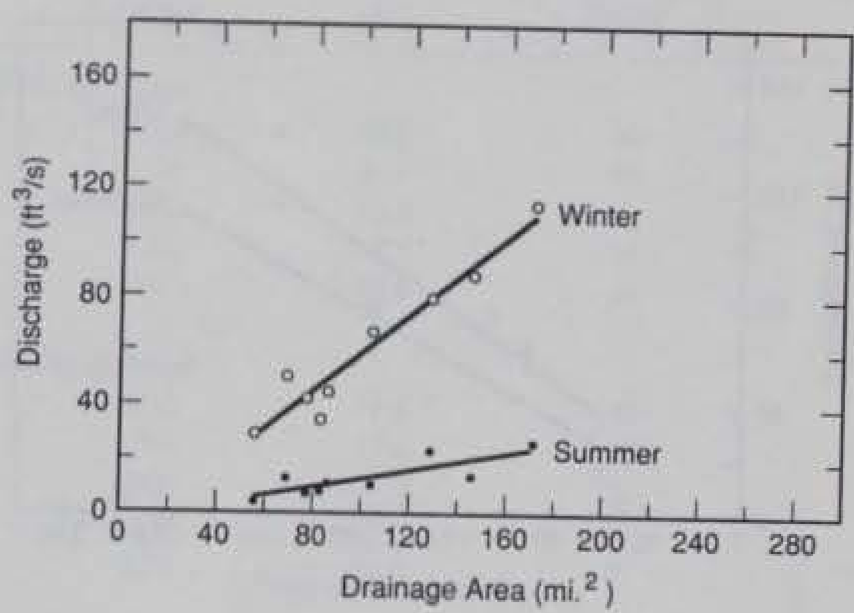


2. Upland streams.

a. 3-day events.



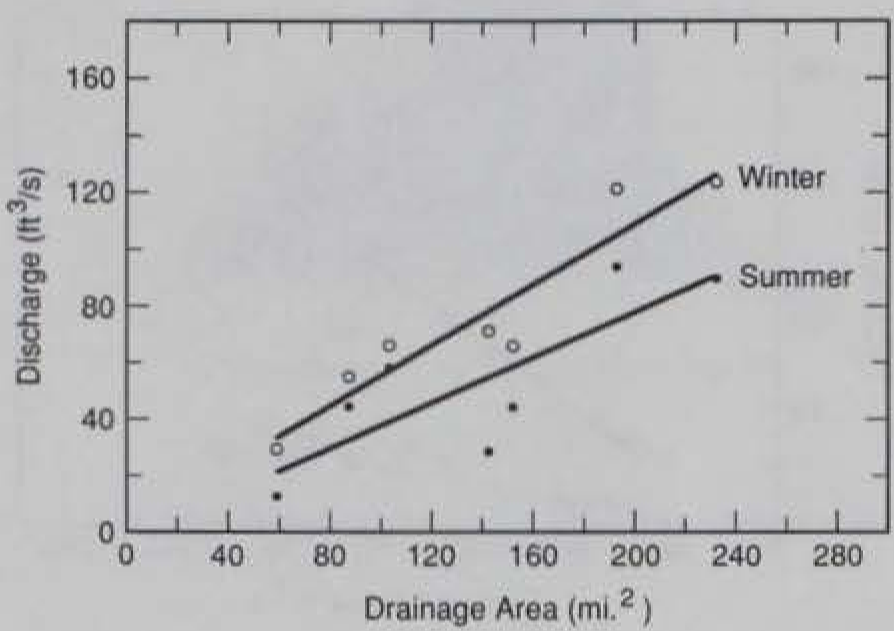
1. White Mountain streams.



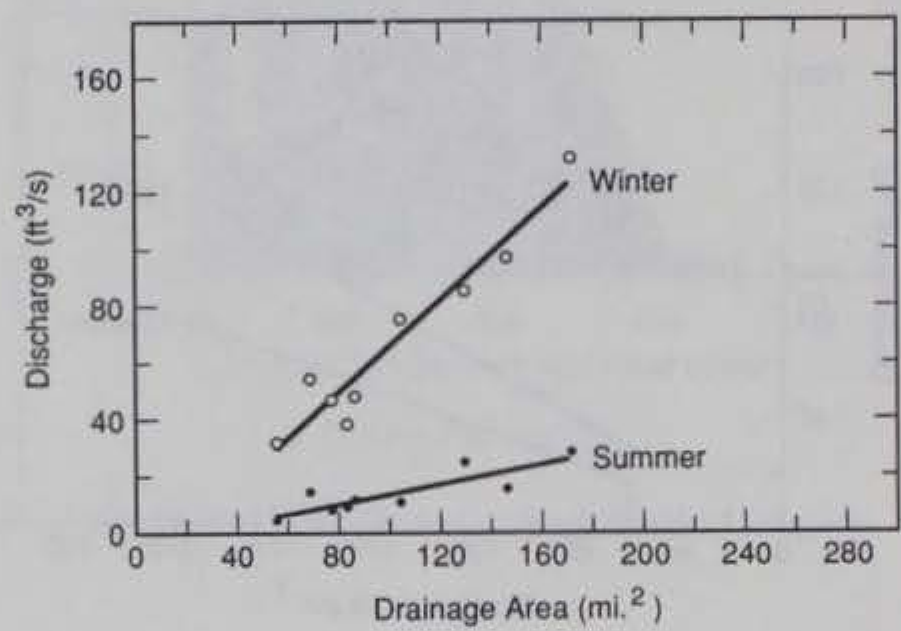
2. Upland streams.

b. 7-day events.

Figure 6. Discharge drainage area relationships for seasonal low-flow events on White Mountain and Upland section streams.

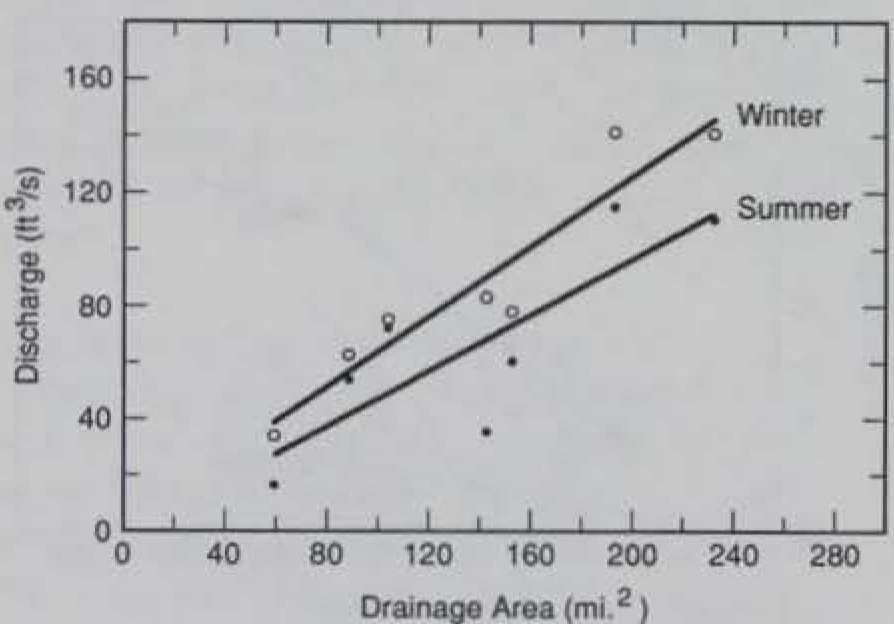


1. White Mountain streams.

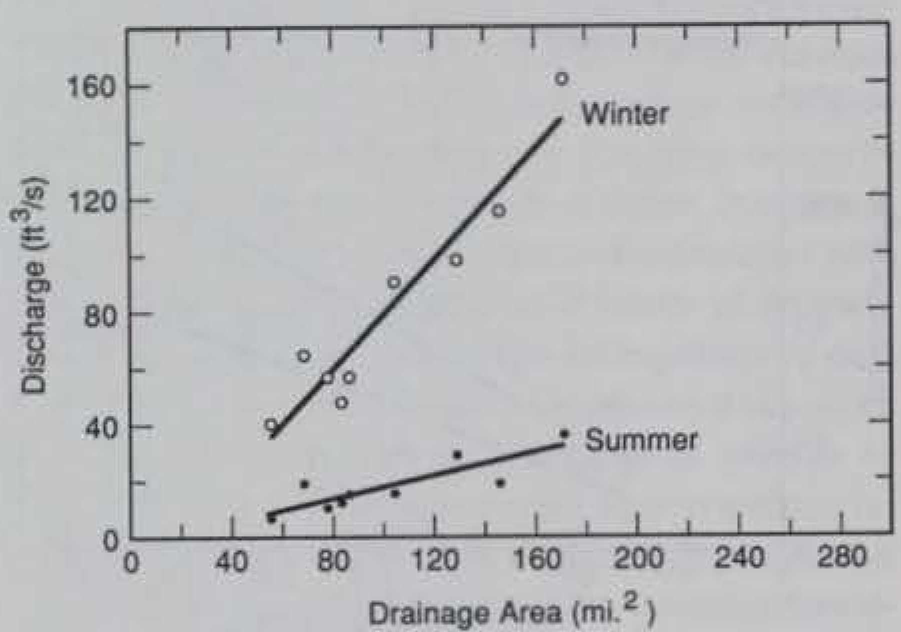


2. Upland streams.

c. 14-day events.



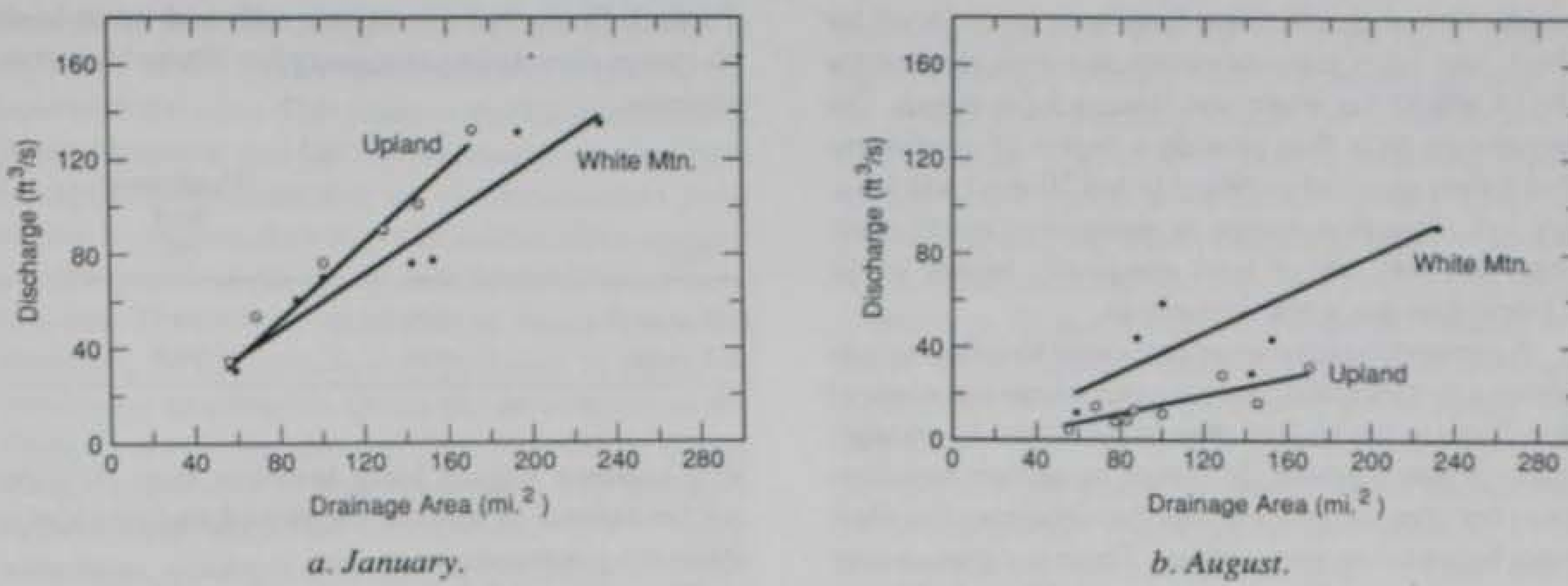
1. White Mountain streams.



2. Upland streams.

d. 30-day events.

Figure 6. (cont'd) Discharge drainage area relationships for seasonal low-flow events on White Mountain and Upland section streams.



a. January.

b. August.

Figure 7. Discharge drainage area relationships for 3-day January and August low-flow events on White Mountain and Upland section streams.

cantly different for a given event. Small-sample *t*-tests were thus employed to help assess, with a defined level of confidence, whether the regression lines for the two sections are coincident. Comparisons of White Mountain and Upland regression lines were made by evaluating hypotheses of both equivalent slopes and equivalent intercepts, at the 95% confidence level. The hypothesis of equal intercepts was not rejected for any of the events; however, the hypothesis of equal slopes was accepted for some events and rejected for others. The

Table 2. Discharge and drainage area correlation summary.

Days		r^2	Significance level (%)	Coefficient	Constant	Standard Error of Y	ft^3/s at 100 mi^2
				White Mountain streams in winter			
3	(Jan only)	0.92	99.9	0.6002	-0.21	12.0	60
3		0.90	99	0.5042	-1.20	11.4	49
7		0.89	99	0.5138	0.41	12.0	52
14		0.89	99	0.5379	1.22	12.5	55
30		0.90	99	0.6236	1.49	13.9	64
				White Mountain streams in summer			
3	(Aug only)	0.66	95	0.4139	-4.12	19.5	37
3		0.60	95	0.3150	-1.87	17.0	30
7		0.62	95	0.3435	-2.02	17.7	32
14		0.66	95	0.4004	-2.89	19.2	37
30		0.68	95	0.4986	-2.85	22.7	47
				Upland streams in winter			
3	(Jan only)	0.95	99.9	0.8204	-13.71	7.9	68
3		0.96	99.9	0.6515	-11.27	5.8	54
7		0.93	99.9	0.7069	-11.29	7.8	59
14		0.93	99.9	0.8085	-14.70	9.3	66
30		0.92	99.9	0.9663	-17.35	11.8	79
				Upland streams in summer			
3	(Aug only)	0.71	99	0.1937	-4.43	5.2	15
3		0.74	99	0.1533	-4.00	3.8	11
7		0.71	99	0.1588	-3.33	4.2	13
14		0.71	99	0.1700	-2.87	4.6	14
30		0.71	99	0.1995	-2.03	5.3	18

results were that coincident lines were not rejected for the 3- and 7-day seasonal events, but were rejected for the 14-and 30-day winter and January 3-day events. The hypotheses tests thus provide a degree of confidence that longer seasonal events (14- and 30-day) and January 3-day low-flow events, as represented by the available data sets, are at least marginally higher in the Upland than the White Mountains.

A comparison of summer and winter low-flow events shows a greater difference between winter and summer low flows in the Upland than in the White Mountains. There is also a greater difference in summer low-flow rates between the two sections than in winter low-flow rates between the two sections. These summer–winter comparisons may have been suspected from looking at the annual runoff hydrographs shown previously. Summer low flows in the White Mountains are considerably less well explained by drainage area size alone than are winter flows; the higher variance of summer low flows is quite noticeable on Figures 6 and 7. As will be discussed below, elevation is an important additional parameter for estimation of summer low flows in the White Mountains, but not for winter low flows.

Variation with elevation of low-flow discharge per square mile

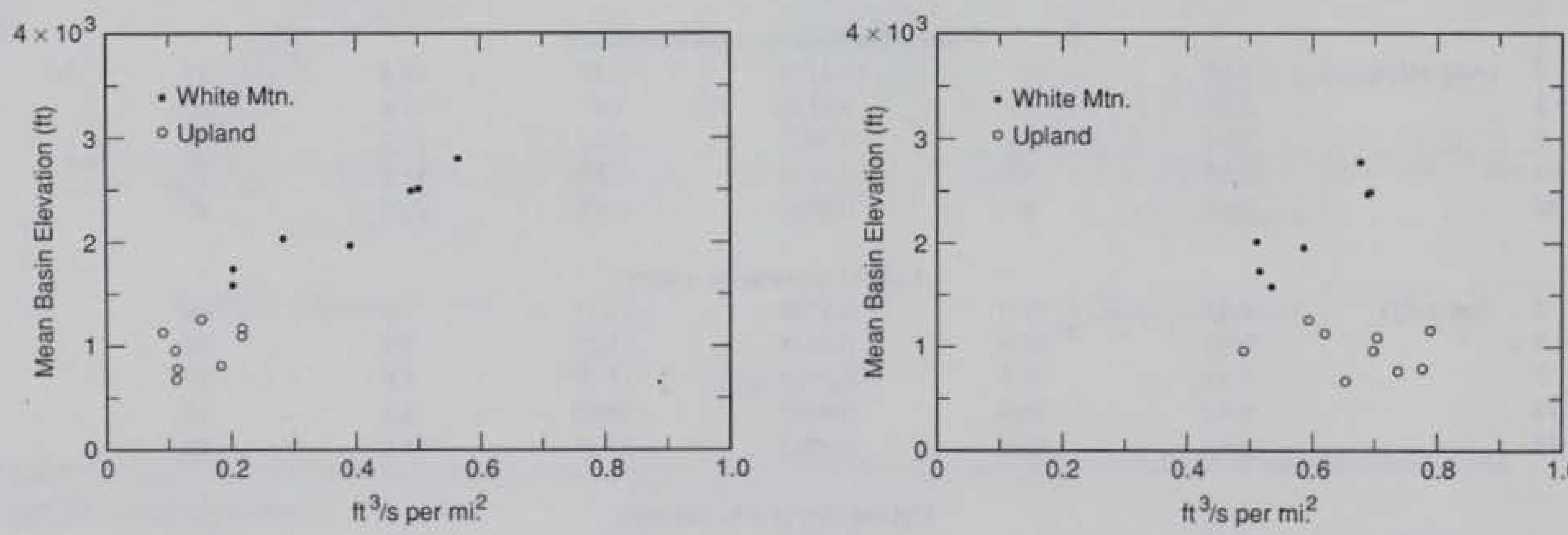
The correlation between low-flow discharge per unit area (ft^3/s per mi^2) and mean basin elevation was assessed for the January 3-day events. The elevation parameter is intended as a surrogate for elevation related climate variables. In particular, water input is thought to decrease with elevation and latitude during winter and may thus influence flow rates regionally. The relationship between August 3-day low-flow rates (ft^3/s per mi^2) and elevation was also developed, and provides an interesting comparison.

Table 3. Discharge per square mile and mean basin elevation correlation summary for White Mountain streams.

Days	r^2	*Significance level (%)*
3 (Jan)	0.78	99
3 (Aug)	0.92	99.9

The relationship between mean basin elevation and discharge per unit area varied from winter to summer. In the White Mountain section, where the mean basin elevations ranged from 1580 to 2800 ft above sea level, there was strong positive correlation for summer low flows ($r^2 = 0.92$) and a weaker positive correlation for winter low flows ($r^2 = 0.78$). In the Upland, where mean basin elevation varied less (680 to 1260 ft above sea level), there was no apparent correlation between elevation and low flows during either January ($r^2 = 0.02$) or August ($r^2 = 0.08$). There was no significant correlation between mean basin elevation and drainage area size in the White Mountain ($r^2 = 0.004$) or Upland ($r^2 = 0.10$) sections, thus ruling out a potential source of spurious correlation. A summary of the correlation results is provided in Table 3 for the White Mountain section only.

Scatter plots of winter and summer unit area flow rates (Fig. 8) make an interesting comparison. The August Upland data are seen to cluster in a narrow range



a. August. *b. January.*

Figure 8. Discharge per square mile versus mean basin elevation for 3-day January and August events on White Mountain and Upland Section streams.

that falls in line with a slightly curvilinear extension of the White Mountain low flows, which are highly correlated with elevation. This suggests that the magnitude of White Mountain and Upland summer flows may both be significantly controlled by elevation-related parameters. In contrast, the winter Upland data show no comparable graphical continuity with winter White Mountain data. The positive correlation of winter flows with elevation, though statistically significant, is much less convincing graphically. Given the assumption of decreased water input with elevation and latitude during winter, a decrease in flow magnitude with elevation seemed more likely for winter events in the White Mountains, making it difficult to explain a positive correlation between elevation and winter low flows. The relatively low water input magnitude and thus a weaker gradient with elevation in winter may permit the dominance of other factors, including geomorphic characteristics.

CONCLUSION

The geographic variation in magnitude and date of low-flow events in New Hampshire was assessed based on available stream flow data for 1942 through 1978. Though there is some geographic difference in the temporal distribution of winter low-flow events, there are only marginal differences between White Mountain and Upland winter low-flow magnitudes. A preliminary overview of annual runoff hydrographs for New Hampshire streams shows typically higher runoff in the White Mountains compared to the Upland for all seasons of the year except winter. A detailed analysis of flow data suggests that winter low-flow events in the White Mountains are about the same or slightly more severe than those in the Upland. The critical periods for low-flow events vary somewhat geographically—annual low-flow events are rare in winter on Upland streams, but are frequent during winter on White Mountain streams. When looking only at events that occur during the winter, the likelihood of a low-flow event increases as winter proceeds in the White Mountains, but is more evenly distributed throughout the winter in the Upland.

The relationships established between low flows, drainage area and mean basin elevation allow some inferences to be made about the factors controlling low flows in New Hampshire. Average winter low-flow magnitudes for streams in both the White Mountain and Upland sections are highly correlated with drainage area size alone. The high correlations suggest a somewhat consistent effect of both geology and winter climate within the sections. The departure of data points from the regression line, on the other hand, reflects basin to basin differences in climate or geology, or both (as well as potential error in the flow measurements). Consideration of additional factors, including along-stream aquifers, lakes along the water course, extent of ground freezing and aufeis development, may provide at least qualitative explanations for these basin to basin differences. As previously mentioned, differences between White Mountain and Upland predicted flows are small and, for the lower duration seasonal events, not statistically different at a 95% confidence level. In general, basin-to-basin differences within the sections are of comparable magnitude to differences in mean flows predicted between sections (Fig. 7). From this it is inferred that local differences in geology and winter climate for a particular watershed are as important in determining winter flow rates as regional geology or climate gradation.

Mean basin elevation was of little additional help in explaining winter flow rates within either the White Mountain or Upland sections, though elevation was quite important in explaining summer low-flow variation in the White Mountains. The importance of elevation in explaining summer low flows in the White Mountains is presumably related to climate gradients, especially increased water input with elevation. In winter, a positive correlation between discharge per unit area (ft^3/s per mi^2) and elevation in the White Mountains is opposite to the premise of decreased water input with elevation during that season. On the other hand, a lower winter runoff rate in January in White Mountain streams compared to Upland streams agrees with the premise of a regional decrease in water input with latitude and elevation. A better understanding of the magnitude and gradient of winter water input in New Hampshire is needed to allow full understanding of climate effects on regional winter low-flow rates.

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The timing and magnitude of winter low flows vary regionally in response to basin climate and geology. This report investigates the regionalization of low flows in the White Mountain and Upland physiographic sections of New Hampshire to establish a data set that will be used in improved analytical methods for estimating winter flows. For the summer and winter low flow periods, 3-, 7-, 14- and 30-day duration low flow events are estimated for various sizes of drainage areas (50 to 230 mi^2). The likelihood of a low-flow event increases as winter proceeds in the White Mountains, but is more evenly distributed throughout the winter in the Upland. White Mountain streams have higher runoff volumes through all seasons, except winter. The average magnitudes of winter low-flow events in both physiographic sections are highly correlated with drainage area size. Mean basin elevation was of little additional help in explaining winter low-flow events within either physiographic section, though it was important in explaining summer low-flow variation in the White Mountains.

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