

By

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## INTRODUCTION

There is a great difference in the amount of snowpack research which has been done in eastern and western United States. Based solely on the difference in the mass of information available, one might conclude snow is unimportant in the water resource picture of the Northeast. Such is not the case; however, and our failure to appreciate the importance of the snowpack derives in part from our acceptance of the western model of what makes the snowpack important.

In the mountainous areas of the West snow is obviously the primary source of water. Precipitation other than snow is limited and probably all used for evapotranspiration in situ.

The important water yielding areas of the West have a persistent snowpack -- often of impressive depth. This pack has a regular, long term buildup and a later regular melt period and outflow. Water available for streamflow can be estimated reasonably well from snow survey data, after deducting the amount of water needed to recharge soil moisture.

## EASTERN CONDITIONS

In contrast, in the East we typically have a pattern of substantial annual precipitation with approximately equal monthly increments. There may even be a slight increase in precipitation in some of the late summer months. The seasonal total snow falls are approximately equal to those in the West, even though precipitation measurement is more confined to lowland areas (Figure 1). Maximums in excess of 450 cm. are experienced in the Tug Hill and southwestern Adirondacks of New York State. And 250 cm. occurs frequently throughout northern New England, the Adirondacks, Catskills, and even in the higher elevations of West Virginia. Lull and Pierce (1960) have indicated the 150 cm line in southern New York as the limit of the area in which snow is important.

Important water yielding areas of the East may or may not have a persistent snowpack and the depth on the ground at any time rarely exceeds one meter. But, in contrast to many western situations, snowfall almost always takes place when the soil is at or above field capacity (Eschner, et al., 1969), and its melt makes a steady, significant contribution to streamflow, even in some of the coldest periods and environments (Federer, 1965).

Snowmelt-caused high flows in spring make up the majority of the high frequency events; those with relatively short return periods -- but not necessarily the very infrequent extremely damaging flood flows. Fifty to 100 year floods or the maximum flows of record at a gaging station are caused by individual precipitation events or a combination of events which overwhelm the watershed system and are as likely to come in August or September as in March or April.

## OBJECTIVE

It is my purpose to illustrate some connections between Eastern snow amounts and the runoff which its melt produces.

## THE STUDY WATERSHEDS

To do this we'll take a look at data from 3 New York streams: the East Branch of the Ausable River at AuSable Forks, the Hudson River at Newcomb, and the East Branch of the Sacandaga River near Griffin (Figure 1). These streams all have long gage records,

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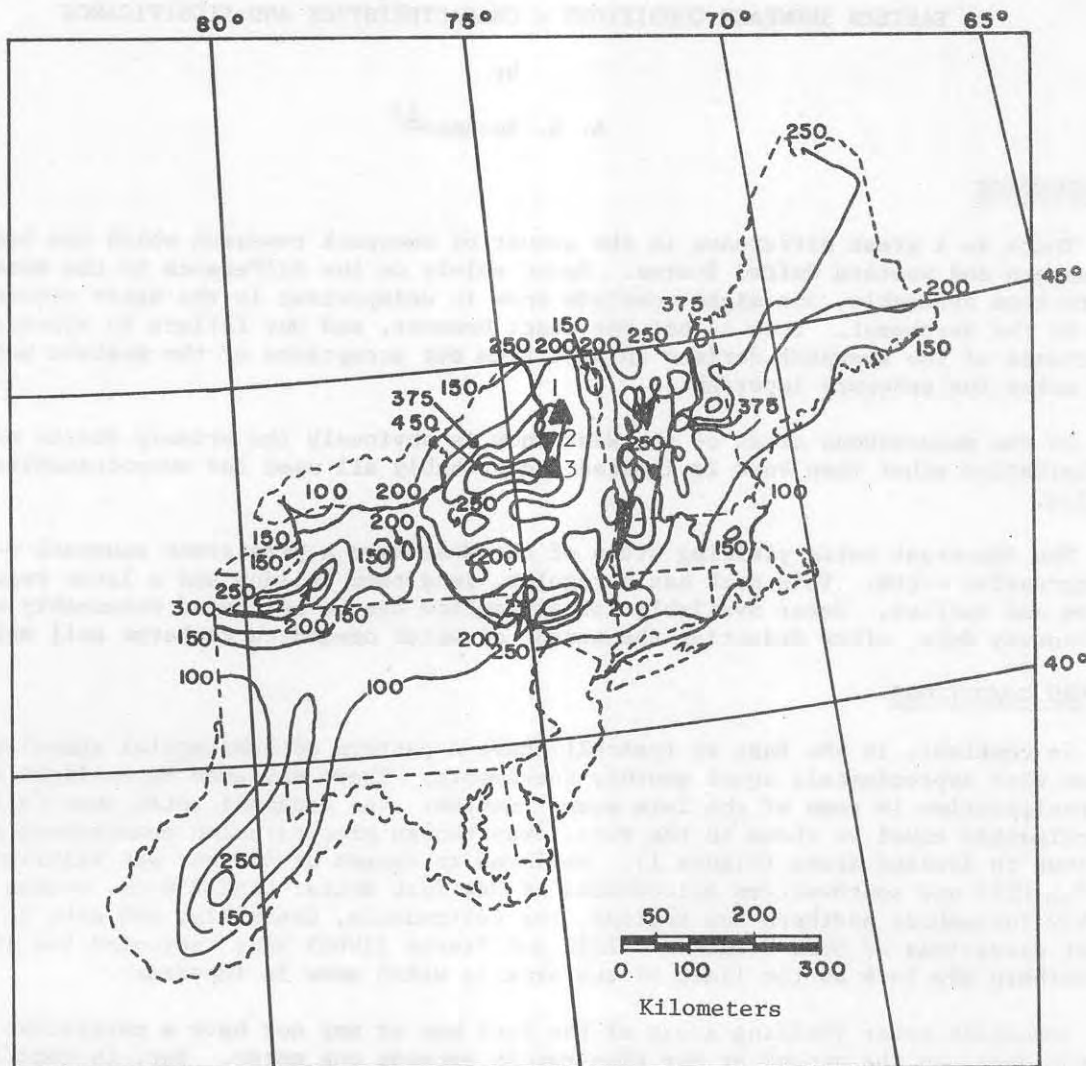


Figure 1. Mean annual snowfall in the Northeast. (Centimeters.) Triangles indicate location of watersheds mentioned in text. 1. East Branch Ausable River at AuSable Forks; 2. Hudson River at Newcomb; and 3. East Branch Sacandaga River at Griffin.

nearby climatologic data, and snowcourses which have been measured at least since 1940.

They are typical of many watersheds in the Northeast with a mean elevation between 550 and 700 meters and an elevation range of 700 to 1500 meters. Annual snowfall is on the order of 150 to 250 centimeters per year. The average first date with a minimum temperature of 0°C is September 10 to 20; the last is May 20. Snow occurs from October to April, and occasionally May. Over the dormant season from October to April snow is commonly present, eventually building to an average maximum pack in mid-March of 48 to 54+ cm. depth and 130 to 160 mm. water equivalent.

The data from these stations were analyzed by multiple regression for several time periods. In addition to the dormant season a period approximating the conventional snow-pack snowmelt period from March to June was selected based on the criteria in Table 1. The inclusion of June in this period may be questioned but snow often lies until late May at higher elevations and continues to contribute to streamflow well into June. A typical annual daily streamflow hydrograph is shown in Figure 2. (This represents 44 years of record and is partially schematic in that maximum and minimum flow dates for each month have been plotted as well as every fifth day.) The flow rate quickly climbs to a high rate after the beginning of recharge in September and only dips in February, the coldest month, when most of the streamflow is derived almost exclusively from ground melt. Recharge of soil moisture and the limited groundwater aquifers is complete by mid-October -- in sharp contrast to the situation on many western watersheds. The April peak of runoff is obvious and high flows in March and May are pronounced. By June evapotranspiration is sufficiently strong so runoff begins to drop below that of any previous month in the water year.

From the previous discussion two approaches may be developed to determine the season when snow is an important part of the hydrologic cycle.

The first is to consider the entire dormant season from October to April. Snow falls throughout this period but it is converted to runoff at a variable rate.

The second method is more conventional and similar to the western idea of when snow is significant. The rationale is illustrated in Table 1.

Table 1. Criteria for determining season of snowmelt runoff.

1. The month with greatest total runoff/  
first month in calendar year where  $\bar{T} > 0^\circ\text{C}$ .
2. The month which precedes 1., above/  
last month in winter-spring where  $\bar{T} < 0^\circ\text{C}$ .
3. The month which follows 1. above.
4. The first month where precipitation > runoff.

Example:

East Branch Sacandaga River Near Griffin (NY)

	<u>Feb.</u>	<u>Mar.</u>	<u>Apr.</u>	<u>May</u>	<u>June</u>
Ave. Precipitation (mm)	74	87	80	87	90
Ave. Runoff (mm)	45	75	203	95	32
Mean Temperature (°C)	-9	-4	3	10	15

In the example, April is the month with the greatest total runoff and also is the first month in the calendar year with a mean temperature greater than 0°C. March fits the second criterion and also experiences considerable snowmelt -- even though its mean temperature is less than 0°C. May delivers more runoff than precipitation received and

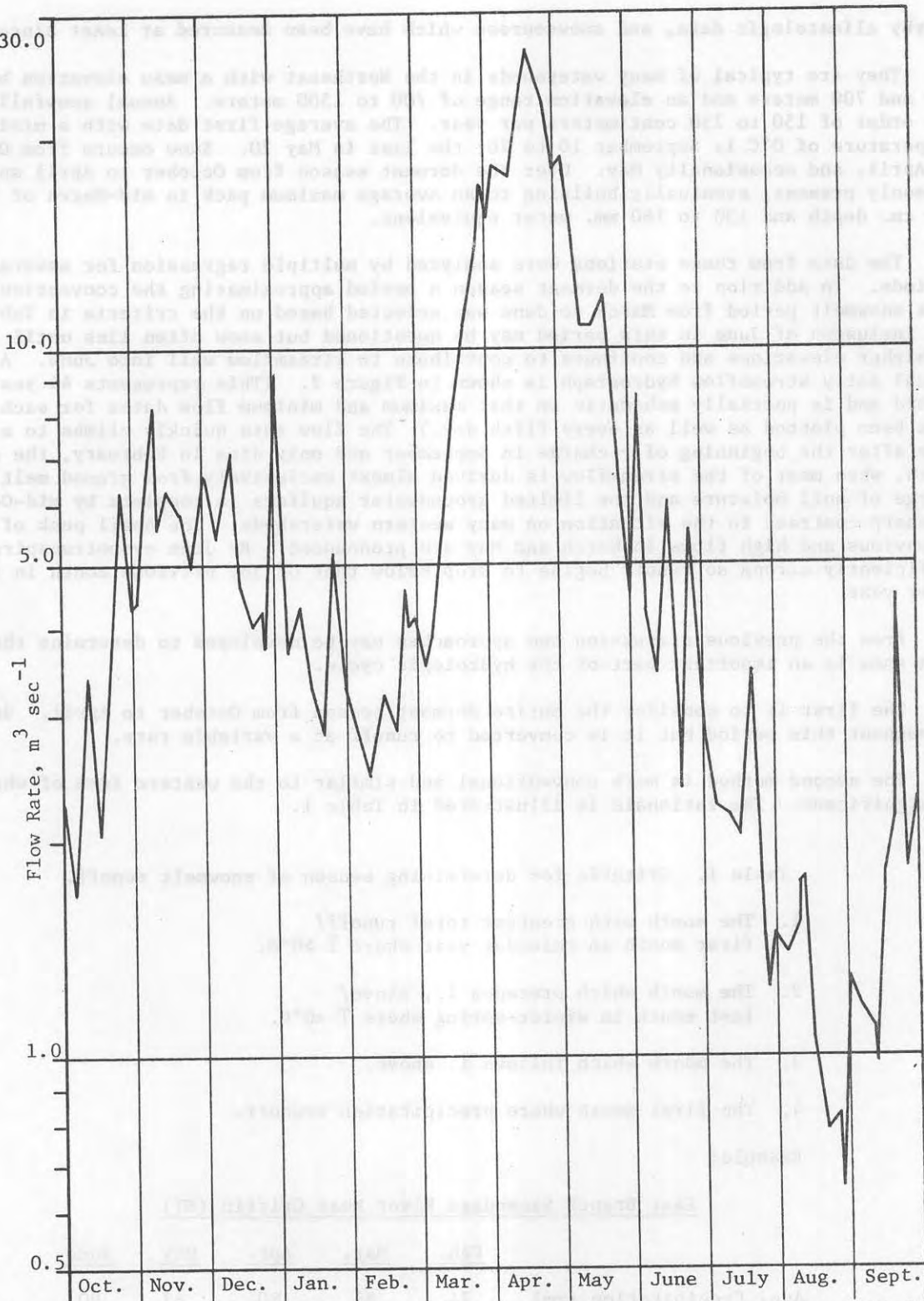


Figure 2. Average mean daily flows, East Branch Sacandaga River, Water Years 1934-77.

June's final flow rate is, on the average, the same as March's beginning rate. Snowpack measurement on or about March 1 and monthly precipitation and temperature data should be useable in estimating the total volume to be expected over the March to June snowmelt runoff season.

Some of the average values of hydrologic data for the watersheds are shown in Table 2. The dormant season runoff is 60 to 73 percent of annual runoff and the 4 month snowmelt season regularly produces 60 percent of the annual runoff. However the snowpack on March 1 does not give a very clear indication of the magnitude of the melt season's runoff. The snow and rain of the months following the snow pack measurement contribute substantially to the season's runoff, but they are obviously not the sole source.

Table 2. Summary of Hydrologic Data.

Stream and Gaging Station	Area (km <sup>2</sup> )	Annual Precipitation (mm)	Annual Runoff (mm)	Dormant Season Precipitation (mm)	Dormant Season Runoff (mm)	Snowmelt Season Precipitation (mm)	Snowmelt Season Runoff (mm)	Average March 1 Snowpack-Water equiv. (mm)	Max. Flow of Record (m <sup>3</sup> sec <sup>-1</sup> )	Date
E.Br. Ausable R. AuSable Forks, NY	513	974	540	507	333	318	332	130	222	9/22/ 38
Hudson River Newcomb, NY	497	1039	712	584	434	348	426	162	192	1/1/ 49
E.Br. Sacandaga R. Griffin, NY	295	1069	659	587	482	359	415	163	224	12/31/ 48

#### ANALYSES

In order to obtain an estimate of the relative importance of various parameters in a particular time period, a simple linear model of the watersheds input, output, and energy exchange was assumed. And the precipitation and temperature of the months of the interval as well as an index of preceding precipitation was compared to the runoff value.

Table 3 shows the parameters found to be significantly correlated with the March to June runoff. For the East Branch of the Sacandaga runoff (RO) for the period March through June can be described by the following equation:

$$RO = .761 S + 1.320 P_3 + .652 P_4 + 1.083 P_5 + .490 P_6 - 26.254$$

The F values for S, P<sub>3</sub>, P<sub>4</sub>, P<sub>5</sub> and P<sub>6</sub> are 55.28, 76.08, 12.64, 56.77 and 16.24 respectively.

The level of significance selected in these and succeeding analyses is 10 percent. That is, there is only a 10 percent chance the F value would be exceeded in a large number of repeats of the same comparison. Most results shown in this table were more significant than this minimum level. In every case the March 1 snowpack water equivalent is one of the variables in the equation and its significance is very high. This date's snowpack is not taken at the time of the maximum pack -- that is usually mid-March -- but it is one which is always taken and thus simplifies analysis. March and April precipitation are largely snow and contribute to the pack. May precipitation has a decreasing proportion of snow, but snow on the ground usually persists at high elevations and shaded aspects. Virtually all of June's precipitation is rain but previously melted snow still makes up a large portion of the runoff. The negative coefficient for April's mean temperature indicates on the Hudson River the colder April is, the higher is the seasonal runoff volume. Using the indicated variables in a multiple regression would result in a very precise prediction of seasonal runoff volumes. Ninety-two percent of the variation in

Table 3. Multiple regression coefficients and regression statistics - snowmelt season runoff.

Stream	Multiple Regression Coefficients						Intercept	R <sup>2</sup>
	S	P <sub>3</sub>	P <sub>4</sub>	P <sub>5</sub>	P <sub>6</sub>	T <sub>4</sub>		
E. Br. Ausable R.	.629	.998	-	.461	.930	-	56.129	.668
F value	8.70	13.65	-	3.73	14.39	-		
Prob. > F	.0059	.0008	-	.0622	.0006	-		
Hudson River	.844	.989	.790	1.319	.592	-11.079	13.002	.916
F value	35.79	38.58	14.96	72.45	15.30	15.72		
Prob. > F	.0001	.0001	.0006	.0001	.0005	.0004		
E. Br. Sacandaga R.	.761	1.320	.652	1.083	.490	-	-26.254	.921
F value	55.28	76.08	12.64	56.77	16.24	-		
Prob. > F	.0001	.0001	.0013	.0001	.0004	-		

S = Snowpack water equivalent - March 1 (mm)

P<sub>3</sub> = March precipitation (mm)

P<sub>4</sub> = April precipitation (mm)

P<sub>5</sub> = May precipitation (mm)

P<sub>6</sub> = June precipitation (mm)

T<sub>4</sub> = Mean temperature April (°C)

the East Branch of the Sacandaga's and the Hudson's snowmelt season runoff is explained; as is 67 percent of the Ausable's variation.

But as pointed out previously, melting snow contributes to streamflow throughout the dormant season, and the precipitation of that period is a highly significant variable (Table 4). The snowpack has an additional effect on the season's runoff of the Ausable River, and higher April temperatures increase runoff on the Hudson and Sacandaga by producing early melt. The quantity of the previous September's rainfall is only important on the Hudson River. The predictions are not as precise for this period as for the previous one -- probably because an undetermined amount of precipitation is carried over to the extended snowmelt season. Still, on the Sacandaga 81 percent of the variation is explained; on the Hudson 64 percent; and on the Ausable 60 percent.

Finally, it is apparent from Table 5 that the water stored in the snowpack has an additional effect on the annual runoff, beyond the linear effect of input as precipitation. And the predictions are more precise than those for the dormant season with R<sup>2</sup> of 64, 80, and 84 percent as opposed to 60, 64, and 81 percent.

All these analyses have been based on an implicit assumption that the relationships among the parameters have remained constant over the period of record. But previous analyses have shown changes with time on all these watersheds as a result of logging, mining, a "hurricane", and the invasion of the beech bark disease (Eschner, 1978). Some of the unexplained variation must be associated with these surface changes but its analysis was not germane to this illustration.

Table 4. Multiple regression coefficients and regression statistics - dormant season runoff.

Stream	Multiple Regression Coefficients					R <sup>2</sup>
	S	P <sub>D</sub>	T <sub>4</sub>	P <sub>9</sub>	Intercept	
E. Br. Ausable R.	.468	.652	-	-	- 58.684	.602
F value	3.27	37.88	-	-		
Prob. > F	.0796	.0001	-	-		
Hudson River	-	.832	14.787	.511	-158.410	.644
F value	-	39.32	6.49	3.50		
Prob. > F	-	.0001	.0157	.0702		
E. Br. Sacandaga R.	-	.998	11.314	-	-140.961	.812
F value	-	121.70	6.10	-		
Prob. > F	-	.0001	.0189	-		

S = Snowpack water equivalent - March 1 (mm)

P<sub>D</sub> = Dormant season (Oct.-Apr.) precipitation (mm)

P<sub>9</sub> = Previous September's precipitation (mm)

T<sub>4</sub> = Mean temperature April (°C)

Table 5. Multiple regression coefficients and regression statistics - annual runoff.

Stream	Multiple Regression Coefficients				R <sup>2</sup>
	S	P <sub>ann</sub>	T <sub>4</sub>	Intercept	
E. Br. Ausable R.	.863	.626	-14.535	-131.246	.644
F value	5.92	31.59	3.67		
Prob. > F	.0206	.0001	.0640		
Hudson River	.928	.809	-	-278.662	.796
F value	7.83	93.47	-		
Prob. > F	.0084	.0001	-		
E. Br. Sacandaga R.	.410	.866	-	-333.322	.841
F value	3.10	140.62	-		
Prob. > F	.876	.0001	-		

S = Snowpack-water equivalent - March 1 (mm)

P<sub>ann</sub> = Annual precipitation (mm)

T<sub>4</sub> = Mean temperature - April (°C)

## SUMMARY

In spite of a substantial annual precipitation uniformly delivered over the year, the seasons when snow is present on the ground or in the process of melting provide the bulk of streamflow for many areas in the East. Although approximately as much precipitation falls in the growing season as in the dormant season, its contribution to streamflow is small, and the snowpack is a significant parameter for predicting even total annual runoff.

Snowmelt-caused high flows in spring make up the majority of the high frequency events; those with relatively short return periods -- but not necessarily the very infrequent extremely damaging flood flows. Fifty to 100 year floods or the maximum flows of record at a gaging station are caused by individual precipitation events or a combination of events which overwhelm the watershed system and are as likely to come in August or September as in March and April.

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