SEASONAL STREAMFLOW ESTIMATION USING SNOW DATA

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ABSTRACT

The melting of the snowpack in spring is the source of more than 50 percent of the annual streamflow over a large part of northeastern United States. Previous attempts at identification of the area over which the snowpack was significant were arbitrary or based on the occurrence of snowmelt floods, which is felt to be of secondary importance. The area over which snow surveys may provide valuable hydrologic information on seasonal streamflow is identified.

INTRODUCTION

In northeastern United States we typically have a pattern of substantial annual precipitation with approximately equal monthly increments. There may even be a slight increase in some of the late summer months' rainfall. The snowpack in many areas is not persistent but comes and goes, often several times during the season. The depth of snow on the ground rarely exceeds 1 meter.

These characteristics are in sharp contrast to those in the West where 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 long term build-up and a late melt period and outflow. Water available for streamflow can be estimated reasonably well from snow survey data.

All this has produced an intuitive view of the situations in which snow has an important effect on streamflow. Basins where the snowpack is deep and persistent and where average temperatures are below freezing for extended periods are the only ones where the snowpack is thought to be sufficiently important to measure regularly. But we have not examined this concept, instead the snowpack zone has been arbitrarily delineated (Lull and Pierce, 1960) and the prospects for effective management minimized (Federer, et al, 1972). Part of the reason for playing down the prospect of snowpack management is due to the focus on individual flood events. But, although snowmelt may contribute to many of the high flow events, the high flow of record is likely to occur in some other season as a result of the watershed system's being overwhelmed by a single unusual precipitation event or combination of events.

Although flood events may be important in some situations we should focus on snowmelt as the source of a seasons's streamflow and the great bulk of our usable water resource.

It is my intent to examine some information on snow which is generally available in the Northeast and to assess the relation between snow and the seasonal streamflow which it may influence.

THE SEASON

But how to describe objectively the season over which snow may be expected to influence runoff? Over much of eastern U.S. the month with the greatest runoff ranges from February to May and is commonly the first month when the mean temperature is above freezing. Because there are usually a number of days with temperatures above freezing in the last month with below freezing temperatures, snowmelt is often well advanced in that month and flows are high. Similarly, the second month with a mean temperature above freezing has a high total runoff influenced by snow due to the lag effect and, commonly, additional snow. The last month of the season influenced by snow is the first month in which precipitation exceeds runoff. Commonly the last 2 criteria are coincident. These criteria were developed on the basis of experience with watersheds in the Adirondacks and are summarized and illustrated in Table 1.

Table 1: CRITERIA FOR DETERMINING SEASON OF SNOWMELT RUNOFF

The snowmelt season includes:

1. the month with greatest total runoff/the first month in the calendar year where $T>32^{o}F(0^{o}C)$,

and

2. the month which precedes 1., above/the last month in winter-spring where $T<32^{o}F(0^{o}C)$.

and

3. the month which follows 1. above.

and

4. the first month where precipitation > runoff.

Example:

East Branch Sacandaga R. at Griffin (NY)

	Feb.	Mar.	Apr.	May	June
Ave. Precip. (in.)	2.90	3.41	3.15	3.44	3.50(4)
Ave. Runoff (in.)	1.78	2.96 (2)	8.01 (1)	3.74 (3)	1.28(4)
Mean Temp. (^{o}F)	15.7	24.9 (2)	37.7 (1)	49.7	59.3

Thus, the snowmelt runoff season includes the months from March to June.

The snowmelt runoff season is considered to be at least 3 months and may be 4 months long. Of course snowmelt probably contributes to streamflow during all the months when it is present--even the coldest (Federer, 1965) but the months so identified account for the major portion of the snow derived runoff and in many cases a major portion of the annual runoff. For three watersheds in the Adirondacks the snowmelt season and other data is shown in Table 2.

But the question being examined here does not refer to Adirondack watersheds, instead those watersheds which are in situations where snow data may be of questionable value are the ones being considered.

WATERSHED SELECTION

Throughout the East there is a widely recognized correlation between elevation and snow accumulation. Therefore the first criterion used in study watershed selection was the physiographic province. The Glaciated Allegheny Plateau, Allegheny Mountains and Ridge and Valley physiographic provinces were selected as the location of the watersheds (Figure 1.). In addition one low elevation, high latitude watershed was sought.

Table 2. SNOWMELT SEASON AND RELATION BETWEEN SEASONAL AND ANNUAL RUNOFF VOLUME. - ADIRONDACK WATERSHEDS

Stream and Gaging Sta.	Drainage Area mi.^{2} (km^2)	Average Ann. R.O. in.(mm.)	Snow Melt Season	Season R.O. in. (mm.)	As % of Ann. R.O.
E. Br. Ausable R. at Au Sable Forks (NY)	198 (513)	23.26 (591)	Mar-June	12.87 (327)	55.3
Hudson R. nr. Newcomb (NY)	192 (497)	27.53 (699)	Mar-June	16.43 (417)	59.7
E.Br. Sacandaga R. at Griffin (NY)	114 (295)	23.62 (600)	Mar-June	16.00 (406)	67.7

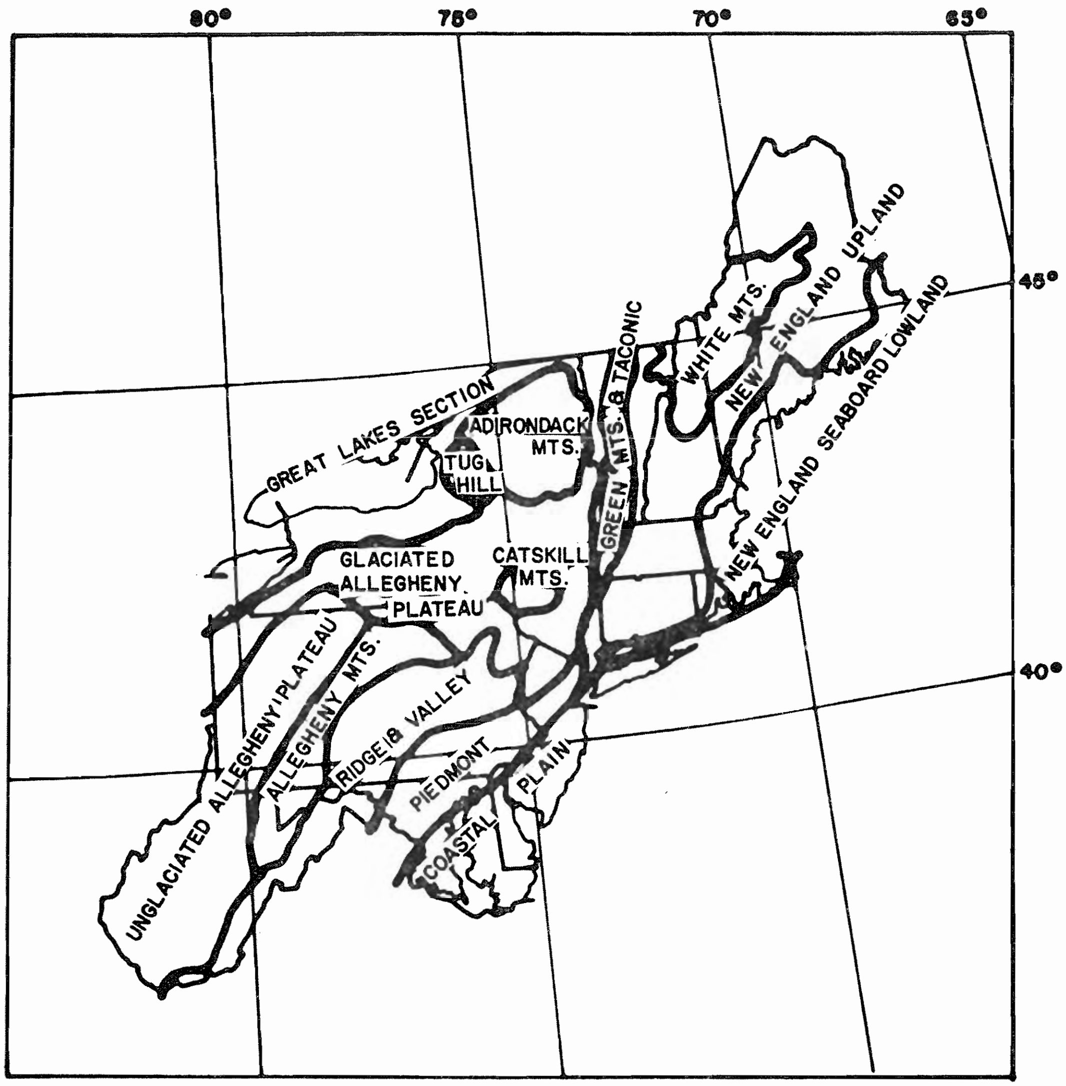

Figure 1. Physiographic regions (Modified, after Fenneman 1938).

Lull and Pierce (1960) arbitrarily defined the snowpack zone as the area which receives more than 60 inches (1524 m.m.) of annual snowfall. They showed this zone to include most of New York with the southern limit including a small section of northwestern Pennsylvania. But a large part of south central and southeastern New York was eliminated. Figure 2. represents a more detailed and up to date map than the one they used.

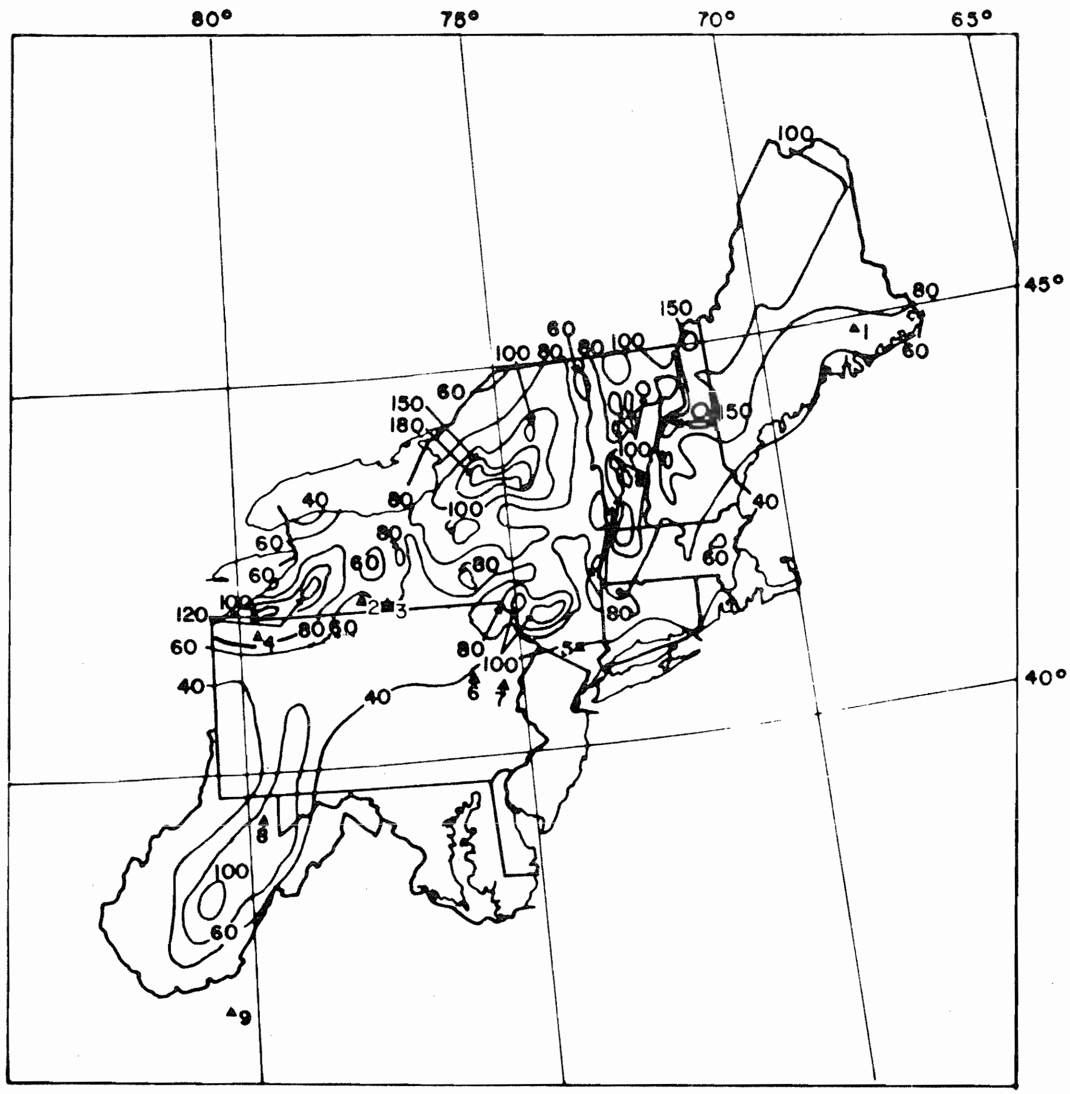

Figure 2. Mean annual total snowfall in inches. (Modified after Baldwin 1968, Lautzenheiser 1968, and Pack 1972.) Numbered triangles refer to the following gaged watersheds: 1. W. Br. Union River Amherst (ME); 2. Canaseraga Cr. at Dansville (NY); 3. Tuscarora Cr. near So. Addison (NY); 4. French Cr. near Carters Corners (PA); 5. Wapinger Cr. near Wappingers Falls (NY); 6. Towanda Cr. near Monroeton (PA); 7. Dilldown Cr. near Long Pond (PA); 8. Big Sandy Cr. near Rockville (W.VA); and 9. Roanoke River near Roanoke (VA).

Watersheds for study were those contributing to upland streams near the 60 inch isohyet. The Union River, a high latitude lowland watershed, and the Roanoke River were also included. The snowmelt season and other data on the selected watersheds are shown in Table 3.

Table 3. SNOWMELT SEASON AND RELATION BETWEEN SEASONAL AND ANNUAL RUNOFF VOLUMES-SELECTED WATERSHEDS.

Stream and Gaging Sta.	Drainage Area - $mi.^2$ (km^2)	Ave. Ann. R.O. in. (mm.)	Snow Melt Season	Season R.O. in. (mm.)	As % of Ann.	Ave. Season Snowfall in (mm)
W. Br. Union R. Amherst (ME)	148 (383)	28.87 (733)	Mar-June	12.93 (328)	44.8	82 (2083)
Canaseraga Cr. at Dansville (NY)	153 (396)	13.46 (342)	Feb-Apr	6.76 (170)	49.8	58 (1473)
Tuscarora Cr. nr. S. Addison (NY)	114 (295)	10.79 (274)	Feb-Apr	6.65 (169)	61.6	60 (1524)
French Cr. nr. Carters Cor. (PA)	208 (539)	27.82 (707)	Feb-Apr	12.82 (326)	46.1	140 (3556)
Wappinger Cr. nr. W. Falls (NY)	181 (469)	19.56 (497)	Feb-Apr	8.68 (220)	44.4	38 (965)
Towanda Cr. nr. Monroeton (PA)	215 (557)	16.79 (426)	Feb-May	10.49 (266)	62.1	45 (1143)
Dilldown Cr. nr. Long Pond (PA)	2.53 (6.55)	30.37 (771)	Mar-May	11.70 (297)	38.5	-
Big Sandy Cr. nr. Rockville (W.VA)	200 (518)	20.40 (518)	Feb-Apr	12.11 (307)	59.4	57 (1448)
Roanoke R. nr. Roanoke (VA)	338 (875)	11.74 (290)	Feb-* Apr	4.73 (120)	40.3	76 (406)

*On the Roanoke River the snowmelt season was assumed to be the maximum flow month and the months preceding and following it. There were no months with mean temperatures below freezing, but snow occurs regularly in April in the area.

All the watersheds are approximately the same size except Dilldown Creek. This watershed is an experimental area on which cooperative research has been carried out between the U.S. Forest Service and the Pennsylvania Department of Forests and Waters in the 1950's and '60's. It is in an area which receives more than 60 inches of annual snowfall, although that fact is not apparent at the scale of the isohyetal map (Figure 2.).

RUNOFF MODEL

The model used to test the utility of snow data on the watersheds' seasonal runoff was a simple linear one in which:

$$RO = S + P_x + P_y + P_z + T_x + T_y + T_z$$

where:

RO = Seasonal runoff in inches
S = Snow on the ground at the beginning of the melt season in inches, water equivalent, (or inches depth, or total inches as precipitation).
P = Precipitation for the months of the snowmelt season, in inches.
T = Mean temperature for the months of the snowmelt season, in °F.

Runoff data was derived from the Water-supply Papers of the U.S. Geological Survey and the Reports 1 through 4 of the Delaware-Lehigh Forest and Water Research Project (Pennsylvania Dept. of Forests and Waters, 1951, 1953, 1955, 1961). These reports also provided snow, precipitation and temperature data.

The snow data used varied and depended upon availability. In Maine and New York it was Snow Cover Survey data collated by the Eastern Snow Conference and published by various agencies. In those states and in all other areas it was (1.) snow depth on the ground, in inches, at the beginning of the melt season, and/or (2.) the total precipitation in the 2 months prior to the snowmelt season. Two estimates of snow available to runoff during the season were used on each watershed, except the Roanoke, as shown in Table 4.

Table 4. FORM OF SNOW DATA AVAILABLE ON SELECTED WATERSHEDS.

Watershed	Snow Survey (in. w.e.)	Snow Depth (in.)	2 mo. Precip. (in.)	Watershed	Snow Survey (in. w.e.)	Snow Depth (in.)	2 mo. Precip. (in.)
W.Br. Union	x.xx	x.		Towanda		x.	x.xx
Canaseraga	x.xx		x.xx	Dilldown		x.	x.xx
Tuscarora	x.xx		x.xx	Big Sandy		x.	x.xx
French		x.	x.xx	Roanoke			x.xx
Wappinger	x.xx		x.xx				

Precipitation, snow depth, and temperature data were taken from the U.S. Weather Service's "Climatological Data".

ANALYSES

Using SAS Institute programs characteristic roots and vectors were extracted by image analysis and factors were obtained by varimax rotation followed by oblique rotation. This identified sets of relationships among the original variables and among the sets of variables and with an intuitive understanding of snow hydrology permitted selection of variables for inclusion in a multiple regression. The 5 percent probability level was used to determine whether a variable was to be retained in the final equation.

The preliminary results of these analyses on the Adirondack watersheds on which the rationale was developed are shown in Table 5.

RESULTS AND DISCUSSION

The positive results of the regression analyses on the selected watersheds is shown in Table 6. On the other watersheds there was no indication of a significant relationship between snow data, however expressed, and seasonal runoff. All the regressions are significant at the 1% level and account for 40.1 to 90.5% of the variation in seasonal runoff (R^2 = 0.401 to 0.905). The regressions show a general agreement with the values arbitrarily selected by Lull and Pierce (1960). The 60 inch (1524 mm) isohyet of average annual snowfall seems to separate areas where the snowpack is and is not important. However, there are areas where the results are incongruous. Near the French Creek watershed the Corry, PA, weather station has received 140 inches (3556 mm) of snow on the average over the 21 years considered, but neither of the snow indexes correlates well with the seasonal streamflow. On the other hand, in a marginal situation--57 inches (1448 mm) average snowfall--both snow depth on February 1 at Rowlesburg, W.VA, and total precipitation for December and January at Brandonville, W.VA, contribute to highly significant regressions on the Big Sandy Creek. Wappinger Creek's snow course, precipitation and temperature records had to be pieced together from at least 2 stations' records in each case; Hibernia and Taghkanic State Park snow courses and Poughkeepsie and Poughkeepsie Airport weather stations. Failure to develop a significant relationship may be as much due to less-than-successful adjustment of the data as to lack of a real correlation.

Tuscarora Creek in south-central New York might be expected to have a significant regression by most standards but it does not. However, the failure to demonstrate significance of the snow course data in predicting seasonal runoff may be due in part to the assumptions in defining the snowmelt runoff season. On the nearby Canaseraga Creek a second season was selected which was the same as the season used on the Adirondack watersheds, March through June. The results are shown in the second Canaseraga equation in Table 6, and indicate that a larger proportion of the longer (March through June) season's runoff is accounted for by the equation than the shorter (February through April) season's runoff (79.6 and 54.1%, respectively).

Table 5. REGRESSIONS AND STATISTICS FOR SEASONAL RUNOFF - ADIRONDACK WATERSHEDS.

E. Br. Ausable R. at Au Sable Forks, (NY)

$$RO(3\text{-}6) = 0.882\ SP(3) + 1.112\ P(3) + 5.316$$

$N = 29 \qquad F = 21.43 \qquad R^2 = 0.622$

Hudson R. nr. Newcomb (NY)

$$RO(3\text{-}6) = 0.924\ SP(3) + 0.932\ P3 + 0.837\ P4 + 1.231\ P5 + 0.525\ P6 - 0.185\ T(4) + 6.274$$

$N = 29 \qquad F = 32.25 \qquad R^2 = 0.898$

E. Br. Sacandaga R. at Griffin (NY)

$$RO(3\text{-}6) = 0.754\ SP(3) + 1.287\ P3 + 0.547\ P4 + 1.061\ P5 + 0.637\ P6 - 0.779$$

$N = 29 \qquad F = 49.26 \qquad R^2 = 0.915$

SP Snowpack water equivalent, inches, on or about first day of indicated month.
P Precipitation, indicated month, inches
T Temperature, indicated month $^{\circ}F$.
(3) March (4) April (5) May (6) June

CONCLUSIONS

Information about the snowpack can contribute significantly to equations predicting a large part of the annual runoff of streams in eastern United States. As a first approximation the area where snowpack data should be collected or where its collection should be continued is the area where more than 60 inches (1524 mm) of snow falls annually on the average and includes all of Maine, New Hampshire, and Vermont, most of New York and higher elevations in Pennsylvania and West Virginia.

The snowmelt runoff season in the Northeast includes 3 or 4 months in which 30 to 60 percent of the annual runoff takes place.

Table 6. REGRESSIONS AND STATISTICS FOR SEASONAL RUNOFF - SELECTED WATERSHEDS.

W. Br. Union R. at Amherst (ME)

RO(3-6) = 0.787 SP(3) + 1.511 P(3) + 1.270 P(4) + 0.773 P(5) - 0.019
N = 21 F = 12.72 R^2 = 0.761

RO(3-6) = 0.931 SD(3) + 1.693 P(3) + 0.638 P(4) + 0.861 P(5) + 3.727
N = 21 F = 10.77 R^2 = 0.729

Canaseraga Cr. at Dansville (NY)

RO(2-4) = 0.224 SP(2) + 1.076 P(2) + 0.494 P(3) + 3.618
N = 23 F = 7.47 R^2 = 0.541

RO(3-6) = 5.988 + 0.661 SP(3) = + 1.061 P(3) + 0.541 P(4) + 0.760 P(5) + 0.336 P6)
N = 23 F = 10.41 R^2 = 0.796

Towanda Cr. nr. Monroeton (PA)

RO(2-5) = 0.625 P(12+1) + 1.361 P(2) + 4.866
N = 21 F = 6.02 R^2 = 0.401

Dilldown Cr. nr. Long Pond (PA)

RO(3-5) = 6.801 P(12+1) - 0.575 T(3) + 23.307
N = 10 F = 17.66 R^2 = 0.835

Big Sandy Cr. nr Rockville (W.VA)

RO(2-4) = 0.050 SD(2) + 1.132 P(2) + 1.035 P(3) + 0.980 P(4) + 0.094
N = 21 F = 38.09 R^2 = 0.905

RO(2-4) = 0.110 P(12+1) + 1.186 P(2) + 1.169 P(3) + 0.846 P(4) - 0.824
N = 26 F = 42.68 R^2 = 0.890

SP Snowpack water equivalent, inches, on or about first day of indicated month.

SD Snow depth on first day of indicated month, inches, clim. data.

P Precipitation, indicated month, inches

T Temperature, indicated month ^{o}F.

(2) February (3) March (4) April (5) May (6) June (12+1) Dec. + Jan.

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