Soil Moisture Priming, Soil Temperature and Water Available for Snowmelt Runoff[1]

by

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Well over half the annual streamflow of Northeastern United States and much of Canada is derived from melting snow. Predicting annual variations in the amount of water potentially available from this source is required for the most effective use of the resource. Intuitively, the idea is generally accepted that the soil moisture of a site must be completely recharged before rapid snowmelt runoff can occur. And it has long been felt that seasonal water yield forecasting, and snow runoff forecasting for river regulation could be improved by taking into account any deficit in soil moisture at the time of the forecast.

Unfortunately, sound data upon which to evaluate this assumption has been rare, and almost completely unavailable in the east. The U. S. Soil Conservation Service began collecting this information on some of their snow courses in the west in the early 1950's and now have approximately 200 installations where soil moisture is measured. They have found that soil moisture data is of value where forecasts based on other parameters are good (Stockwell, 1966).

Interest in the potential utility of soil moisture information in seasonal water yield forecasting has led the U. S. Geological Survey to purchase equipment and begin installations in the Black River watershed in New York. This new program has prompted the present study--a look at soil moisture and temperature data which is already available (collected as part of a study of factors influencing tree growth) and its interpretation in the light of snow course data and runoff from a nearby Adirondack watershed.

Requisites for a suitable index station

To be useful as a soil moisture index station a site should have a soil similar to those commonly found on the watershed where snowmelt runoff is under study. In addition, the site should be on or near enough to the watershed to receive imputs of precipitation and energy similar to those on the watershed. Where anticipation of the soil conditions on the watershed is of some value, the index station may be at a lower elevation than the mean of the watershed and probably on a southerly or southwesterly facing slope. The vegetation on the site should not be greatly different in structure and density from that covering most of the watershed.

Description of index site and soil parameter measurements

Soil moisture and temperature data were measured at the Charles Lathrop Pack Demonstration Forest about 4 miles north of Warrensburg, New York. The site on which most of the data has been gathered is an essentially level sand terrace formed by glacial fluvial activity. The water-sorted strata of the coarse-textured soil which has developed here vary from gravels through silt but most of the material is a loamy coarse sand to a coarse sand.

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Eight 1/5 acre plots have been established in a Red pine plantation on this site, four on a potassium deficient area and four on an area where potassium is less limiting to tree growth. Four of these plots, two each on the deficient and normal areas, have been irrigated since 1966 with 2 inches of water on the first and fifteenth of each month from June through August. Two inches of water are also added on September 1. This gives the irrigated plots 14 inches more water per season than the unirrigated plots, adding one-quarter to one-third more to their annual precipitation and approximately doubling the growing season precipitation.

Soil moisture was measured on these plots with a P-19 Nuclear-Chicago d/M system. The Ra226-Be source probe was calibrated by the sand-alum technique (Marston 1965 and Van Bavel _et al_. 1961). Sixteen aluminum alloy, 6061-T6, 12 foot access tubes 1.5 inches in diameter were placed in the irrigated area and 8 similar tubes were placed in the non-irrigated area. Moisture measurements were taken at 2 foot depths at odd foot intervals to estimate the water in 12 feet of soil.

Repeated measurements of soil moisture content after water application gives an indication of field capacity. The soil holds approximately 0.8 to 1.2 inches of water per foot of depth when the rate of downward drainage becomes slow. This amount of water depends upon the soil stratification at a particular access tube point.

The soil moisture measurements were made in each access tube at weekly intervals during April through October of each year and approximately twice monthly during the remainder of the time.

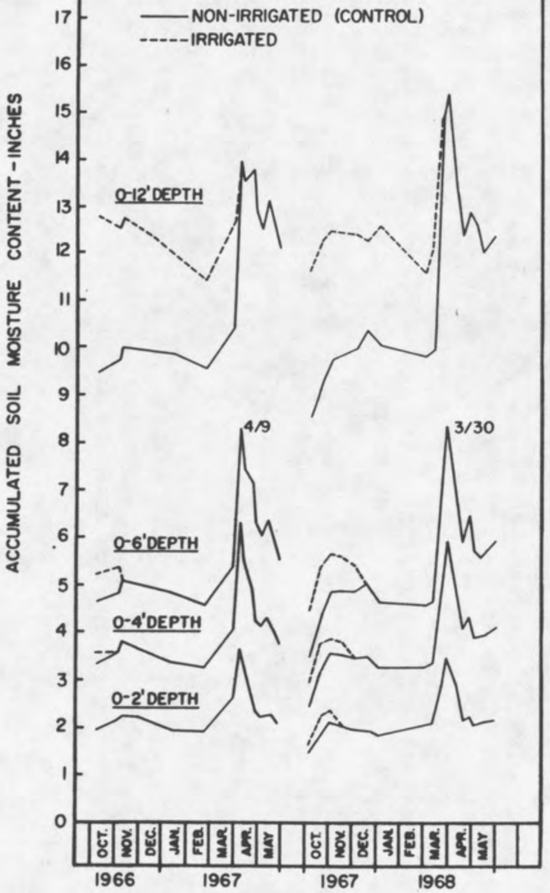
Figure 1 shows a generalized pattern of soil moisture and time for the period of 1 October to 31 May in the water years 1967 and 1968 for this site. This figure is based on mean values of data from 8 access tubes in the nonirrigated area when there is no significant difference between the irrigated and nonirrigated sites. When there was a significant difference the means from the 16 access tubes in the irrigated area are also shown. Moisture values at each date are accumulated by depth. These moisture measurements show a maximum moisture storage occurring shortly after snowmelt. Standard errors of soil moisture content range from a low of approximately .08 inches in the top 2 feet of soil, to a high of about .47 inches of moisture in the top 12 feet of soil at each date. The soil moisture of the irrigated area as a function of time is shown in Figure 1 at various depths for times when these moisture contents were significantly different from the values of nonirrigated areas at the 95 percent level of confidence.

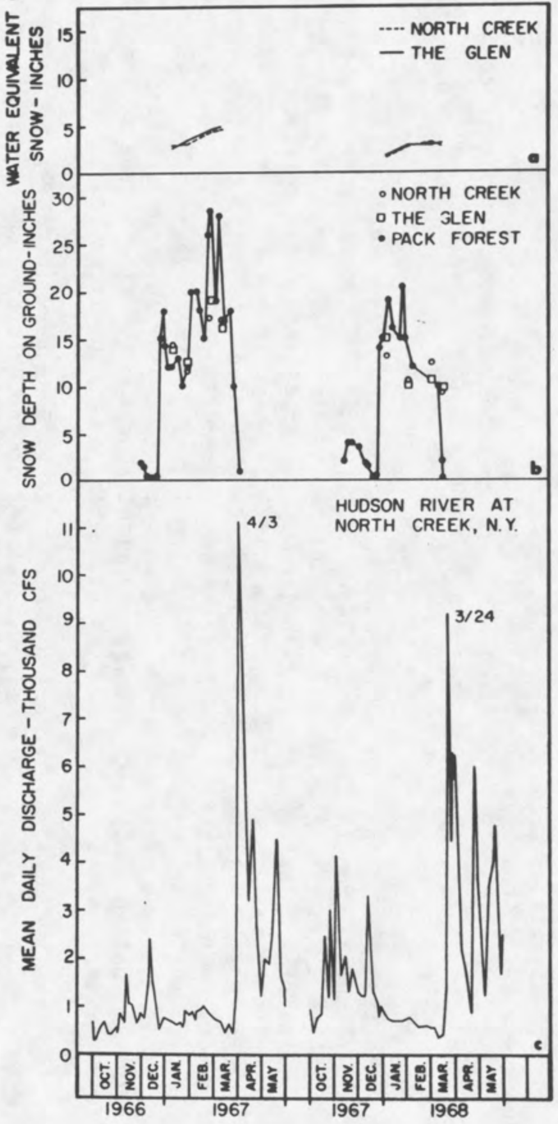
Estimates of the variation in soil temperature on the study area were obtained at 8 randomly located points. Copper-constantan 24-gauge thermocouples were placed at depths of 2, 4, 8, 20, 39, 60, and 120 inches at each location and temperatures were measured with a portable temperature-compensated potentiometer. All thermocouples were plastic spray-coated, tested in an ice bath and installed six months before initial measurements. Measurements of soil temperature were taken at all locations at weekly intervals during April through October and approximately twice monthly during the remainder of the year (Figure 3).

The point values of the soil moisture and temperature data are probably better defined than one is likely to find in a large scale operational sampling scheme.

Snow data

Snow depth on the ground was measured daily at a cooperative weather station on the Forest and is shown in Figure 2b. Snow courses at the Glen and North Creek are measured by the Geological Survey and Niagara Mohawk Power Corporation and published in the Cooperative Snow Survey. Their elevations are 1,040 and 1,150 feet respectively and they are about 200 feet above the Hudson River. They are 2 and 13 miles from the Pack Forest site. The snow accumulation patterns at these sites in 1967 and 1968 are shown in Figure 2a and 2b.





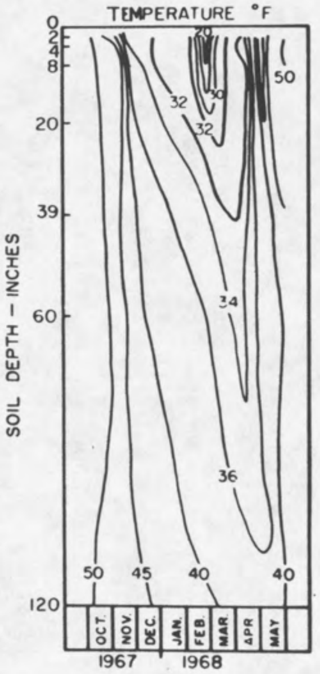


Figure 1. Accumulated total moisture content in 2, 4, 6, and 12 feet of soil on the Pack Forest.

Figure 2. (a) Water equivalent of snowpacks at North Creek and The Glen, N.Y.
(b) Snow depth on the ground at North Creek, The Glen, and Pack Forest.
(c) Mean daily flow of the Hudson River at North Creek, N.Y.

Figure 3. Soil temperature pattern, October 1967 through May 1968.

Streamflow data

The Geological Survey maintains a streamgaging station on the Hudson River at North Creek, and the discharge for the months October through May in water years 1967 and 1968 are shown in Figure 2c. This somewhat schematic illustration contains most of the information and the maximum monthly variation. It represents the flow on the 1st and every fifth of the month and the highest and lowest flows.

Discussion

What can we hope to show with this odd assortment of data? Obviously, from the shortness of the soil moisture record--less than 3 years--we cannot hope to present a rigorous statistical analysis of the relationship between soil moisture and snowmelt runoff. If there is a close or identifiable relationship between soil moisture content and subsequent streamflow we would expect the variation in streamflow to reflect the variation in soil moisture. There are a number of reasons why soil moisture measured at this location should be a good forecast index for snowmelt streamflow of the Hudson River at North Creek. The Pack Forest plots are about 13 miles southeast of the watershed gaging station and almost 200 feet lower in elevation with a nearly level west southwest aspect. Snowmelt and subsequent soil water movement should occur here earlier than on any areas on the watershed. This is, in part, what actually does occur. The snow does disappear before the peak of streamflow is reached in both the years shown here. To show that this is not just an aberration peculiar to the Pack Forest, over both seasons the measured snow depth agrees remarkably well with the mean depth of nearby snow courses at North Creek and the Glen (Figure 2b). An indication of the amount of water in the snowpack at these 2 locations is also shown. It amounts to about 4.5 inches in 1967, and 3.0 inches in 1968.

On the Upper Hudson the snow survey on the 3rd week in March showed 5.16 inches of water in 1967 and 3.76 in 1968. These values are 0.70 and 1.95 inches lower respectively, than the 23 and 24 year long term averages. This fact should make the soil moisture-snowmelt streamflow relationship more clear if it is significant. Soil moisture status may be expected to be more critical when there is less water in the snow pack. Figures 1 and 2 suggest that this is not the case. Soil moisture values at their peaks and during most of the winter do not appear to fluctuate with streamflow. And the seasonal peak of streamflow occurs <u>before</u> the peak of soil moisture. This is the reverse of what we might expect if soil moisture recharge were a limiting factor in snowmelt runoff. There is other evidence that soil moisture recharge or priming is not limiting in the fact that there is no difference between the soil moisture content of the irrigated and unirrigated plots after October 1 at 2 feet; after November 6 at 4 feet; and after November 12 at 6 feet in 1966. In 1967 these dates are November 18, and December 5, and 19, respectively. Soil moisture is about at field capacity all winter at depths up to 6 feet. A significant difference between irrigated and unirrigated plots does persist until snowmelt takes place in the total moisture contents to 12 feet but this is of little importance as far as streamflow is concerned. Although most of the soils of the watershed are of approximately the same texture as the Hinckley soil on the plots, and probably range from a sand to a loamy sand, their average depth is much more restricted. Even where horizon development has not produced an impeding layer, the total depth of unconsolidated material is probably less than 5 feet over most of the Adirondacks.

The soil moisture content on several possible prediction dates--near March 1 or 15--does not show the wide range of values found necessary for an effective predictor variable, based on western experience (Stockwell, 1965). Moisture content in 6 feet of soil on or about March 1, 1967 and 1968 was 4.6 inches; on March 15 in both years it was 5.0 inches.

For the reasons cited, and within the limitations imposed by data available, it does not appear that soil moisture information will be particularly helpful in forecasting streamflow timing or yield from snowmelt in the Adirondacks.

What does all this suggest about the disposition of the snowmelt? Does it enter the stream as surface runoff. This is highly improbable. Evidence of surface runoff is almost entirely lacking over most of the Adirondacks. Where it is a common spring phenomenon on this watershed--in the high peaks around Mount Marcy--it occurs later in the season, and is confined to hiking trails at higher elevations. In addition, there is a clear indication that the melted snow eventually gets into the ground both in the soil moisture content change and the temperature pattern in the soil (Figure 3). The isotherms of temperature indicates warming of the surface and cooling of the deeper soil to the temperature of the percolating meltwater at about the time the soil moisture storage peaks. Probably much of the water from melting snow appears in streams as a result of rapid shallow subsurface flow before complete saturation of the soil mantle occurs.

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