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RUNOFF FROM SMALL PEATLAND WATERSHEDS

ROGER R. BAY*

Abstract: Runoff was measured on four forested bog watersheds in northern Minnesota for 5 years. The experimental basins ranged in size from 24 to 130 acres and included both organic and mineral soils. Annual runoff was not evenly distributed. Spring runoff, from the beginning of flow in late March to the 1st of June, accounted for 66% of total annual water yield. Summer and fall runoff was normally very low and ceased on most of the bogs during each summer. Annual peak rates of discharge were low and recessions were long, indicating the bogs were effective as storage areas for short-term runoff. However, they were not effective as long-term storage areas or regulators of streamflow.

Wet peatlands contribute to important river systems in many parts of the world, yet few studies have reported on the runoff characteristics of individual peat bogs. Research on the hydrology of peatlands has been conducted in Europe, the British Isles, and Russia, but this has generally been concerned with ditched, farmed, or otherwise disturbed bog areas. A few studies of organic soils, bog water tables, and other aspects of bog hydrology have been made in the United States, but no detailed runoff experiments have been reported on natural peatland watersheds in the northern forest region of this country. During the past 5 years, however, data have been collected on the hydroclimate, bog water table fluctuations, deep groundwater levels, and runoff from several forested bog watersheds in north-central Minnesota. Water storage properties and runoff characteristics from four of the study bog watersheds are discussed here.

Study watersheds

The experimental bog watersheds are located in north-central Minnesota (ca. 47° 32′ N, 93° 28′ W). Each catchment is composed of two distinct components – the bog and the surrounding upland area contributing to it (Fig. 1). Instrumentation began in 1960, and comparable runoff records from all bogs began with the 1962 flow year.

* Principal Hydrologist, Northern Conifers Laboratory, Grand Rapids, Minn. (field office of the North Central Forest Experiment Station, Forest Service, U.S. Department of Agriculture, maintained in cooperation with the University of Minnesota).

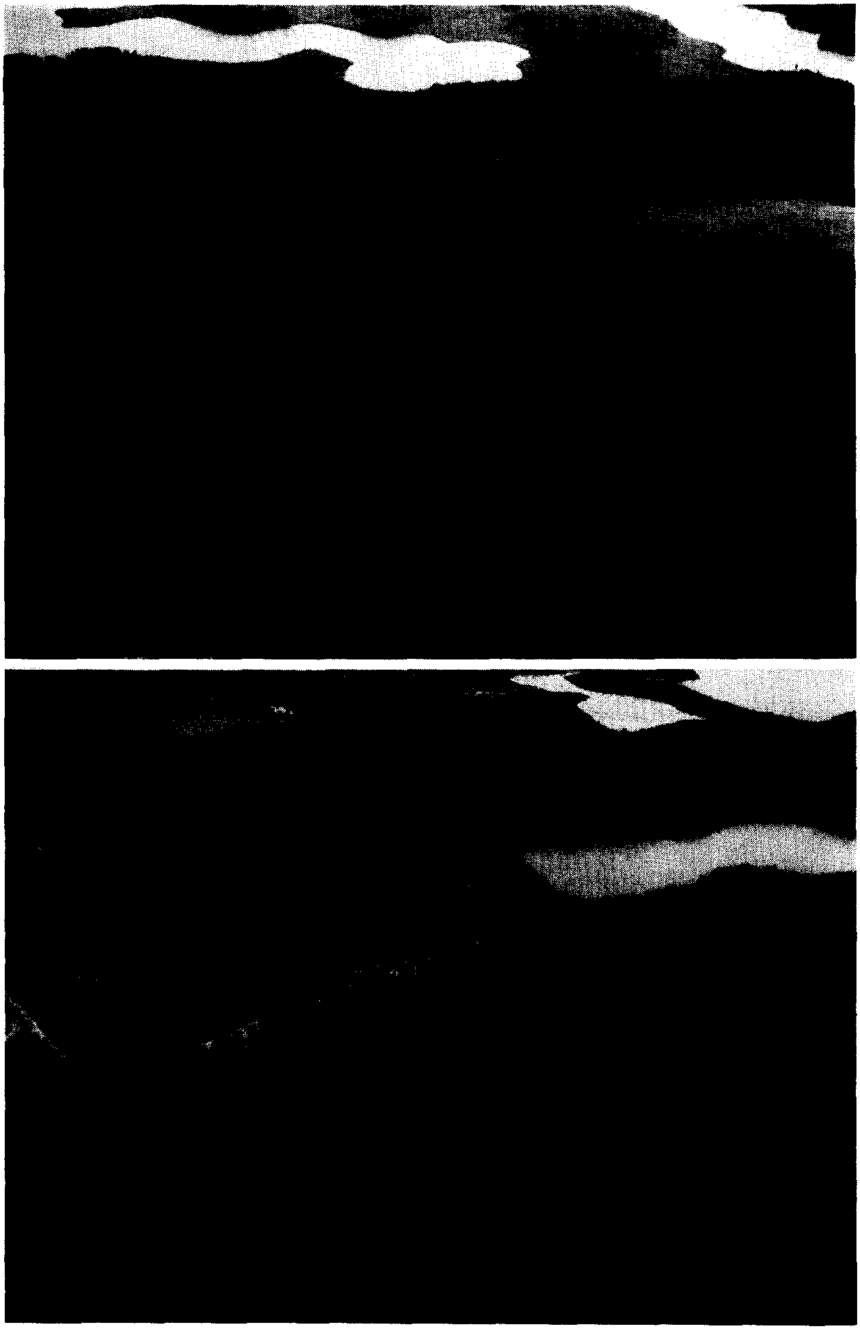

Fig. 1. Aerial views of two bog watersheds – S-1, top, and S-2, bottom. The approximate watershed boundary is shown as a dashed line. The forested bogs are in the center of each watershed.

All of the watersheds have gageable outlet streams and one has two outlets at which streamflow is measured. Precipitation is the only source of incoming water. They are typical undisturbed, forested watersheds and as elemental as hydrologic systems can be.

Each watershed contains a peat bog 8 to 20 acres in area. Total watershed areas, including both bogs and uplands, range from 24 to approximately 130 acres. Indistinct divides on two watersheds made it difficult to determine exact contributing areas. Consequently, only data from the two watersheds that could be the most accurately delineated have been used in hydrologic analyses involving area inches of runoff.

The bogs were apparently formed in ice-block depressions that gradually filled with peat materials. A typical peat profile has aquatic peat at the bottom, compacted and decomposed sedge and woody peats throughout most of the deposit, and undecomposed sphagnum at the surface. Medium-textured mineral soils surrounding the bogs developed on a clay-till parent material which effectively isolates the bogs from the deep groundwater aquifer. Deep bore holes in the upland areas have confirmed that the study bogs are perched above the regional groundwater system.

Woody vegetation in the bogs consists of nearly pure stands of low- to medium-quality black spruce (*Picea mariana* (Mill.) B.S.P.). Several species of heath shrubs (Ericaceae) are abundant in all the bogs. The bog surface is covered with sphagnum and other mosses and mosslike plants. The upland, mineral soils support mature stands of quaking aspen (*Populus tremuloides* Michx.).

All of the watersheds are instrumented in a similar manner. Precipitation is measured with standard and recording rain gage networks, and snow is accounted for with permanently established snow courses in the bogs and uplands. Recording and nonrecording bog wells monitor shallow water table fluctuations within the peat deposit. In recent years, upland soil moisture has been measured with a neutron probe. Runoff from the bogs has been measured with H-flumes or V-notch weirs. These were constructed on natural stream courses downstream from the bog outlets to eliminate ponding in the bogs and unnatural hydrographs.

A more detailed description of the experimental watersheds and the instrumentation for collecting hydroclimatic, hydrogeologic, and surface water data is given in a recent paper[1]).

Annual and seasonal water yields

There is no runoff during the winter on the study watersheds. Flow normally extends from late March or early April (when snowmelt begins) to late November or early December when the small streams freeze solid. Because of this, runoff data have generally been analyzed on a flow-year basis – from the beginning of flow in spring to the approximate end of flow in early winter. When it was necessary to deal with data on a water-year basis, a water-year from December 1 to November 30 was chosen because precipitation after December 1 is normally in the form of snow and stored on the ground until spring. Runoff before December 1 is usually caused by fall rains on the bogs.

During the 5 years of the study, annual precipitation on the watersheds averaged just over 31 inches and annual runoff slightly over 7 inches. Average monthly precipitation-runoff relationships indicate that flow is generally low during late summer and early fall even though precipitation is high (Fig. 2). April and May are normally the high runoff months while low

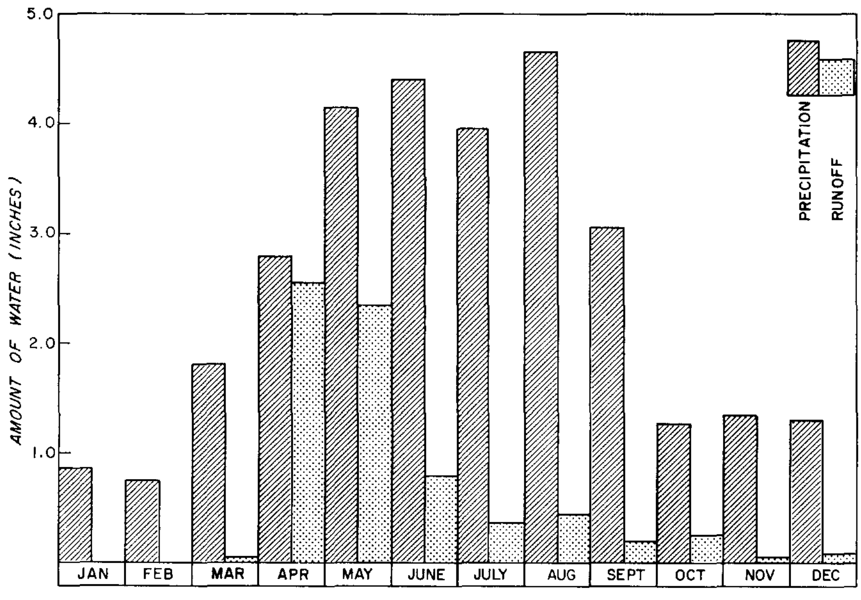

Fig. 2. Average monthly precipitation and runoff for bog watershed S-4, an 86 acre watershed containing 20 acres of peatland. Similar patterns of precipitation and runoff were measured on the other study watersheds.

runoff occurs during summer and fall. High runoff during April is primarily due to snowmelt. These values indicate that water yields are not high and generally fall within the expected yields from larger basins in northern Minnesota.

The daily distribution of flow is shown by the annual hydrograph for a

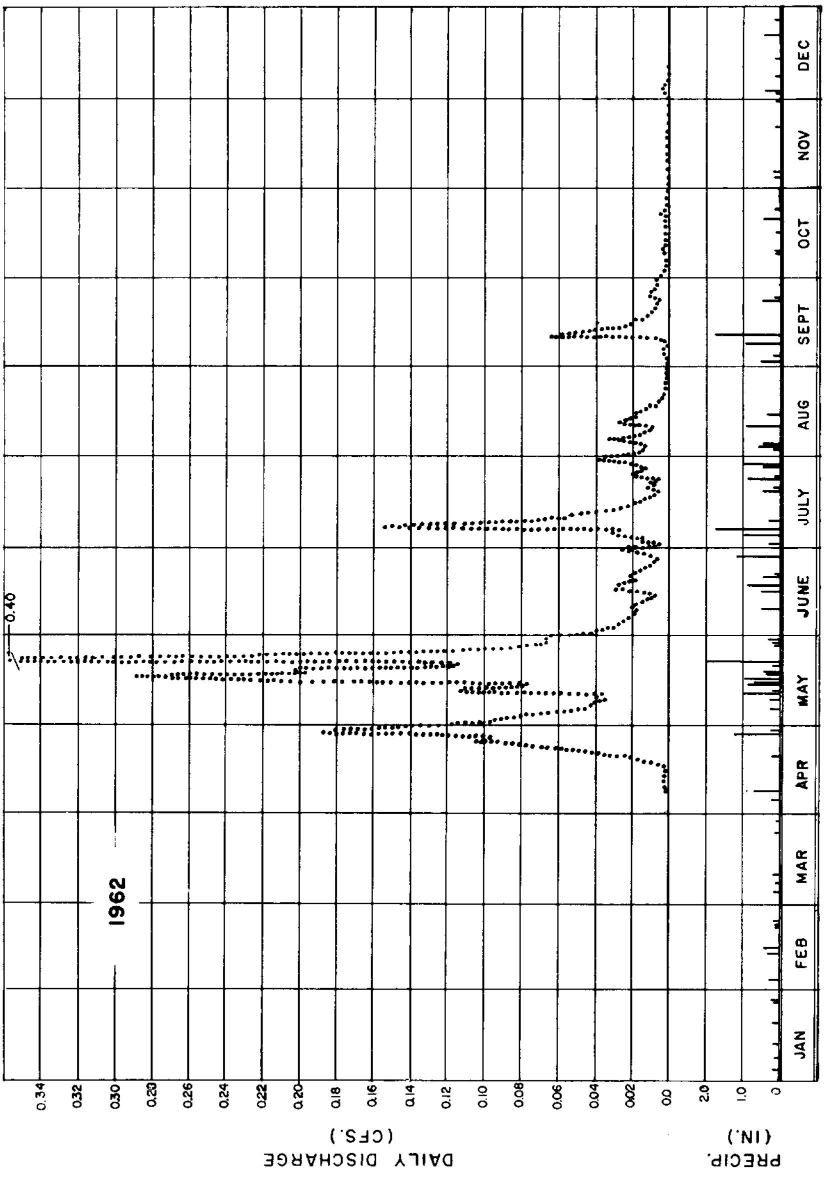

Fig. 3. Hydrograph of mean daily discharge from bog watershed S-2, a 24 acre watershed containing 8 acres of peatland, 1962.

fairly typical runoff year, 1962 (Fig. 3). Although average precipitation during June, July, and August was about 13 inches, total summer runoff was low. Only excessive summer rains caused appreciable rises in discharge. The other watersheds and other years showed somewhat similar runoff patterns.

To further study the distribution of annual runoff, the flow year has been divided into three periods (Table 1): spring, from the beginning of flow to June 1; summer, June 1 to September 1; fall, September 1 to the end of flow in early winter. Each period is important in terms of climatic changes, vegetational development, and water yield.

TABLE 1

Annual water yield by seasons
(In per cent)

Watershed and season	Year					5-year mean
	1962	1963	1964	1965	1966	
S-1						
Spring	70	43	53	43	70	60
Summer	25	56	23	20	26	27
Fall	5	1	24	35	4	13
S-2						
Spring	68	45	52	48	67	57
Summer	26	49	22	18	30	27
Fall	6	5	25	32	3	14
S-4						
Spring	84	40	69	55	81	69
Summer	15	58	22	15	18	22
Fall	1	1	9	26	1	8
S-5						
Spring	84	34	68	50	81	68
Summer	15	65	23	18	17	23
Fall	1	1	9	30	2	9

The greatest percentage of annual water yield occurs in spring due to snowmelt, high water tables in the bogs, and low evapotranspiration. Normally, 20% to 25% of the annual precipitation is snow which accumulates over winter and melts in late March and early April. Usually, 4 to 6 inches of water are available in the spring snowpack for soil moisture recharge and runoff. Water tables in the bogs are fully recharged and stand near the bog surface in spring. Little storage space is available and most of the precipitation that falls in April and May runs off. Evapotranspiration demands are also low during this period because leaf development on deciduous trees and herbaceous vegetation does not begin until late May.

In all but one of the study years, all watersheds yielded a major portion of annual runoff in spring. And even in 1963, 63% to 71% of the total annual runoff came before June 15. Thus, low spring water yields in 1963 are somewhat misleading.

Water yields during the summer period are usually low even though average monthly precipitation is highest. Solar energy is high and most of the summer rainfall is lost through evaporation and transpiration. Normal summer rains recharge bog water tables from time to time, but high evapotranspiration draft soon lowers the water tables again, making more storage space available. Heavy rainfall is required to produce any great amount of runoff.

Low flow in the fall is a direct result of normally low fall precipitation. The amount of fall rain needed to recharge upland soils and bog water tables depends on summer moisture conditions; thus, a wet or dry summer will influence early fall runoff. The higher runoff shown during the falls of 1964 and 1965 is due to exceptionally heavy rains in September of those years.

The long-term runoff characteristics of larger river basins in northern Minnesota containing extensive peatland exhibit similar seasonal variations [2]).

Low flow characteristics

Because popular opinion holds that slow release of water from peatland sustains streamflow over long periods, the low-flow characteristics of streams draining the experimental bogs were studied. Runoff actually ceased on most of the watersheds at some time during each year. On one watershed runoff was continuous during 2 different years, but both years had some days of negligible flow at the weir. Flow generally ceased in late summer when evapotranspiration potential was high and normal or subnormal rainfall could not meet the high evaporative demands. The greatest number of no-flow days occurred in August and the second greatest number in July. In addition, there were many days of extremely low runoff in the fall. Although evapotranspiration is not high during the fall, rainfall is generally light and runoff from the experimental bogs was barely sustained.

Low-flow characteristics of streams can also be shown graphically (Fig. 4). The flow-duration curves presented here are from the smallest (S-2) and largest (S-5) bog watersheds and show the general trend of discharge frequency. They are based on short-term records and are useful primarily for showing the low and high flows on individual streams. Steep slopes throughout the range of discharge – and particularly at the upper and lower

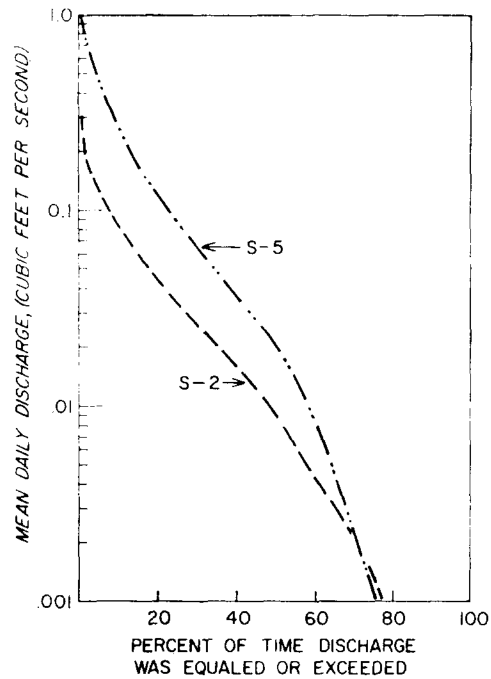

Fig. 4. Flow-duration curves for two bog watersheds based on data for 1962 through 1966, April 1 to December 1 flow period.

ends – indicate a negligible amount of perennial storage in the drainage basins. Groundwater is not a component of flow from these perched bogs, and it is apparent that water yield from the peat deposit itself is minimal at times. Most of the water yield from these bogs occurs during wet periods, and perennial storage is not available to sustain flow during dry periods.

Storm flow characteristics

The previous data indicate that annual and seasonal bog runoff is not well regulated, but analyses of individual storm hydrographs show that the bogs apparently delay short-term or storm runoff. Although runoff normally reacts fairly quickly to rainfall (providing flow has not ceased beforehand), recessions are drawn out and storm peaks are relatively low.

Lag times were computed for 19 storms occurring over a 5-year period on S-2 (a 24-acre watershed, 33% in peatland) and 7 storms occurring over a similar period on S-5 (an approximately 130-acre watershed, 12% in peatland). Storm rainfall, measured in recording and standard rain gages in each watershed, varied from 0.75 to nearly 5 inches and durations ranged from a few hours to 27 h. Lag times were computed from the centroid of gross rainfall to the time of hydrograph peak (Fig. 5). Gross rainfall was used rather than effective rainfall because storm runoff normally started very soon after the beginning of rainfall (Fig. 5).

Seventy-seven percent of the storms examined had lag times ranging from 1 to $3\frac{1}{2}$ h. The longest lag time was approximately 9 h. These figures are considerably smaller than lag times reported for a drainage basin containing a thick mat of *Sphagnum* moss in Alaska[3]). However, in these small undisturbed bogs, water tables were generally within 1 foot of the average surface

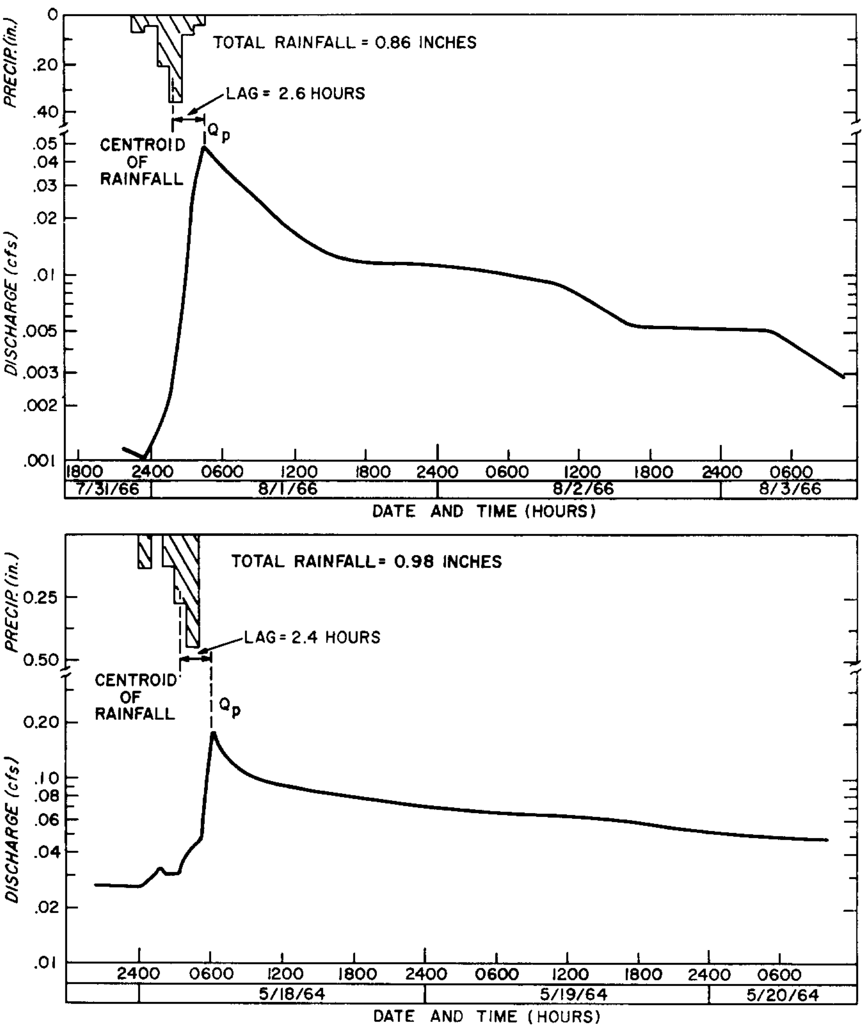

Fig. 5. Hydrographs and accompanying hyetographs for two storms on bog watershed S-2.

where hydraulic conductivities of the moss horizons are generally high[4]). Small additions to the bog water system appeared at the outlet fairly soon. The bogs are thus serving as the channel system for the watershed and the delivery of water to the outlet is influenced by the position of the water table in the peat profile, the hydraulic conductivity of the peat material, and the slope of the system. Of course, individual storm characteristics also influence lag times.

The recession curves for a number of simple hydrographs for bog S-2 were also compared. All storms exhibited long, drawn out recessions similar to the hydrographs in Fig. 5. The steeper slope of the upper portion of the recession segment is probably due to direct surface runoff in the immediate vicinity of the stream gage and the nearby bog outlet. The remainder of the recession limb plots as a relatively straight line on semilogarithmic paper similar to a groundwater recession curve, except for storms occurring in the summer growing season. From mid-May to early September, evapotranspiration in the bogs uses water which would normally contribute to streamflow, causing an accelerated rate of recession. This diurnal loss of water is particularly evident in the recession segment of the 8/1/66 storm in Fig. 5. Such high evapotranspiration losses rapidly deplete water stored in the bogs and runoff ceases if rainfall input is low.

Dormant season storms do not exhibit such pronounced daily fluctuations (storm of 5/18/64, Fig. 5). Low storm discharges during this time are particularly drawn out because evapotranspiration does not withdraw water from storage in the peatland. Such long recessions at low discharge rates are probably due to the nearly level bog topography and to the slow release of water from deeper peat horizons as water tables recede. Storm flow from the other gaged bogs exhibited long recessions similar to those illustrated in Fig. 5.

Low peak rates of runoff are another indication of the influence of these small bogs on storm runoff. Annual peaks were generally low, ranging from a few cubic feet per second per square mile to 35 csm, depending upon precipitation characteristics and antecedent conditions. These csm values were computed using total watershed area because most of the peaks occurred during wet periods when the entire drainage basin was probably contributing to flow. Low peaks may be due to large detention storage in the bogs in proportion to total drainage area and relatively high retention in the undisturbed, forested uplands.

Most annual runoff peaks were due to major rainstorms occurring in spring or early summer when bog water tables were already high because of snowmelt or previous rain. Annual peaks due to snowmelt alone occurred in 2 years when record snowpacks accumulated. The only annual peaks occurring late in the year were the result of heavy rains and wet antecedent conditions.

Peak flows are related to a number of climatic and physiographic factors, including storage capacity of the watershed. In bog watersheds, storage capacity depends greatly on the position of the water table in the peat profile. Storm runoff can thus be ralated directly to water table position (Fig. 6). Greatest runoff occurs when water tables are high because there is

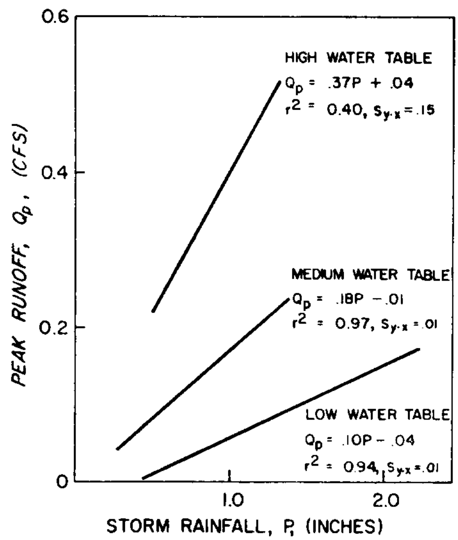

Fig. 6. Relation of peak flow (Q_p) to storm rainfall (P) and water table position, bog S-2. High water table conditions existed when water tables were fluctuating above the average moss surface and within the hummock and hollow micro-topography. Low water table values were computed when water tables were greater than 6 inches below the average low hollow elevation.

little storage capacity in the peat and water moves directly to the bog outlet. Surface peats also tend to have high hydraulic conductivities and drain quickly while deeper peats are generally more decomposed and retain more water[4]). During high water tables, runoff is probably controlled more by the flat topography of the bogs than by the physical properties of the peat materials.

Unfortunately, runoff from these peatland watersheds has not been separated into direct storm runoff and base flow components because there is a serious question as to what constitutes base flow. Since streamflow ceases on these small watersheds during summer rainless periods, there is really no sustained base flow. An attempt is now being made to devise a suitable method of consistently separating possible quick flow and delayed flow components for more detailed analysis of storm flow characteristics.

Conclusions

In general, the small bog watersheds in this study were not effective as long-term storage areas and regulators of streamflow. Runoff was not well regulated, and perennial storage from these perched bogs was not available to sustain flow during midsummer dry periods. However, low peak flows and long-drawn out recessions suggest that the small bogs do store short-term or storm runoff, particularly after summer drying periods when bog water tables are low.

The bogs discussed here represent only one type of hydrogeologic situation. They are independent of the underground water system and runoff from the bogs is not influenced by discharge from a general underground system. However, other types of bogs are receiving recharge from local groundwater systems[5]), and the discharge characteristics of such bogs would depend upon storage changes in the groundwater basin. This influence of local hydrogeologic conditions on bog runoff was recognized by Chebotarev in the U.S.S.R.[6]).

Larger, more complex peatlands may influence water yield differently, but some of the general relations between water table levels and runoff, and the seasonal distribution of flow, should also hold true on many of these areas. Various organic soils and peatland types within any one bog would complicate the total hydrologic situation. However, the uneven distribution of annual runoff and the lack of sustained flow during dry periods has also been observed on other peatland areas[7]).

Bogs and swamps have sometimes been considered as regulators of streamflow, storing snowmelt and rain waters during wet periods and then slowly releasing water to sustain runoff. The runoff characteristics of the bogs in this study indicate that at least some types of peatlands do not provide long-term storage of water nor do they make any substantial contribution to streamflow during dry periods. The next step in this particular study will utilize the controlled watershed approach to test the influence of land management practices, such as forest harvesting procedures or water control systems, on the total hydrologic regime and particularly low flows.

References

1) R. R. Bay, Techniques of hydrologic research in forested peatlands, U.S.A. XIV Cong., Int. Union Forest. Res. Organ. **1**, Sect. 11 (1967) 400–415

2) T. C. Winter, R. W. Maclay, and G. M. Pike, Water resources of the Roseau River watershed, northwestern Minnesota. Hydrol. Invest. Atlas HA-241, Dept. Interior, U.S. Geol. Survey (1967)
3) S. L. Dingman, Characteristics of summer runoff from a small watershed in central Alaska. Water Resources Res. **2** (1966) 751–754
4) D. H. Boelter, Hydraulic conductivity of peats. Soil Sci. **100** (1965) 227–231
5) R. R. Bay, Factors influencing soil-moisture relationships in undrained, forested bogs. *In:* International Symposium on Forest Hydrology (Pergamon Press, Oxford, 1966) 335–343
6) N. P. Chebotarev, Theory of stream runoff (Moscow Univ., Russian transl. TT 65-50027, 1962)
7) H. Vidal, Vergleichende Wasserhaushalts- und Klimabeobachtungen auf unkultivierten und kultivierten Hochmooren in Südbayern. Mitteilungen für Landkulture, Moor- und Torfwirtschaft **8** (1960) 50–107