WATER STORAGE LIMITATIONS IN FOREST SOIL PROFILES

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THE literature of forest-streamflow relations indicates a lack of complete agreement as to the manner in which forest soils function in the control of water on the land. Contributing to this lack is the failure to take cognizance of water storage limitation within different soil profiles. An understanding of the natural physical limitations of some forest soils to store water is useful to both foresters and engineers interested in watershed management.

The amount of water that can be stored underground depends upon both the structure and the depth of the soil. Undisturbed forest soils as a rule have a favorable structure for water infiltration, but infiltration at the surface is only one phase of water control. Unless underground storage can absorb the total amount of precipitation of a single storm, it is logical that the excess of water will appear as storm runoff in the stream. When this precipitation excess is considerable then runoff of flood proportions occurs regardless of the use of the land. For this reason excessive storm runoff is occasionally observed from certain forest areas. A clear understanding of these physical processes of hydrology is useful in discussing problems of land use planning for water control.

Because of the demand for agricultural land in many localities all of the deep fertile soil types have been cleared and forests have remained only on the land too shallow and steep for agricultural use. Consequently, the underground storage opportunities for the forested areas now relegated to shallow soils on steep slopes is potentially much less than for the cleared land with naturally deep soils. In some localities it is impossible to compare the water control value of forests with other land use covers because there are no natural forests remaining on the better soil types.

INTERPRETATION OF STORM RUNOFF FROM FOREST LAND

The writer believes that a misleading emphasis is placed on the fact that occasionally flood discharges are recorded from forest areas. The real consideration is not that storm runoff sometimes occurs from forest land, but rather what would be the relatively much greater runoff from the area under any other type of land use than forest.

This point should be kept in mind when discussing the magnitude of the flood discharges that have been recorded from forest areas of steep topography and shallow soils. In his textbook on hydrology, Meyer (4)[3] refers to a flood in May 1901 on Cane Creek in Avery County, N. C. He reports that the drainage area of 22 square miles produced an estimated discharge of 1,341 c.s.m.[4] Precipitation amounted to 8 inches in 24 hours, falling on wet soil. A survey of the drainage area shows it to be almost entirely rough and mountainous, with thin soils and considerable exposed rock. The stream channel has a fall of 150 feet per mile. Agricultural use amounts to only a small percentage of the entire area, principally along the stream. The remainder is in hardwood forest. Considering the physical conditions of the watershed and the amount of rainfall the peak discharge from this area is an indication of the controlling effect of the forest on storm water and is not an example of lack of forest influence on streamflow. The peak discharge reported is unquestionably much less than would have occurred had not the forest cover been present. Natural limitations in water storage within the forest soil profile on the Cane Creek drainage area are largely physiographic but fires and trampling by cattle would reduce the controlling effect of the forest cover, and in this sense land management also becomes a factor. The principal consideration is the natural limitation for water storage in the soil.

RUNOFF FROM EXPERIMENTAL WATERSHEDS

Relatively high storm runoff from uncleared forest land has also been observed on small accurately gaged experimental drainage areas. On the Coweeta Experimental Forest[5] in Macon County, N. C., peak discharges of flood proportions have been recorded from small forested watersheds of 100 acres. The drainages that produce these high peaks all lie at elevations ranging from 3,500 to 5,000 feet, and have steep mountainous slopes with comparatively thin soils. An 8-inch storm with very low intensities on December 27 to 29, 1942, produced a peak of 167 c.s.m. for the high elevations, whereas for drainages of similar size below 3,500 feet and with less steep slopes and deeper soils, the maximum peak recorded was less than 30 c.s.m. The average rainfall intensity for this storm was 0.16 inch per hour, and the maximum intensity recorded for any 15-minute period did not exceed 0.46 inch per hour. Consequently, lack of surface infiltration was not a limiting factor.

Differences in peak discharge are due to the limitations of storage opportunities at higher elevations where the shallow steep soils occur. The soil above 3,500-foot elevation will average less than 2 feet in depth. A large amount of exposed rock is present. Soils at the lower elevations will average 6 feet in depth and there is no exposed rock. Thus there is a

[1]Contribution from the U. S. Dept. of Agriculture, Appalachian Forest Experiment Station, Asheville, N. C.
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[3]Figures in parenthesis refer to "Literature Cited", p. 414.
[4]Cubic feet per second per square mile.
[5]Maintained by U. S. Forest Service, Appalachian Forest Experiment Station.

difference of at least 48 inches in the depth of the soil. By assigning 4% by volume macro-pore space to the additional 48 inches of soil depth at the lower elevations this alone would account for 1.92 area inches (0.04 × 48) additional detention storage. Capillary storage opportunity would account for at least another 20% by volume when soil moisture is about 50% field capacity. This would add 9.60 area inches (20.0 × 48) of retention storage available at dry seasons, or a total of 11.52 inches. Thus, as a general statement, it would be conservative to say that the lower elevation soil profiles when operating below field capacity have from 4 to 8 area inches greater storage opportunity. This difference in storage easily accounts for the difference in storm runoff from drainage areas in the two elevations.

Exceptional peak discharges sometimes estimated as being 2,000 to 7,000 c.s.m. have been reported from forest land in the high rainfall belt of the southern Appalachian mountains. These estimates are based principally on high water marks as indicated by mud lines on trees in ravines or narrow stream channels with steep banks. The writer has visited the location of a number of these high water marks. In all cases there is evidence of debris dams having been formed from litter, brush, and uprooted trees. In some instances local land slides forming temporary dams have contributed to the high water marks. Occasionally mudflows establish high water marks. It is conceivable that occasionally high peak discharge values may occur from small areas in the southern Appalachian Mountains directly from heavy rains falling on wet soil. However the exceptional peaks based on high water marks in forest land are generally greatly exaggerated because of the debris load carried by the storm water.

The fact remains that storm runoff of considerable magnitude does occur on forest land in mountain areas of high rainfall, thin soils, and steep slopes. This runoff is due to a lack of natural underground storage opportunity and is related to physical conditions of the drainage area. When this lack of natural underground storage exists, vegetation becomes all the more important in delaying storm runoff and preventing erosion. If one were to consider the value of vegetation from such land areas, it would be only necessary to visualize the catastrophic results of removing the vegetation and attempting to use the land otherwise. There is ample evidence available that the mountain soils would be completely removed to the bare rock within a few decades and that subsequently even minor storms would produce torrential floods. Proof that this is true is found in the Copper Basin of Tennessee[6] where all vegetation has been completely killed by smelter fumes over an area of 7,000 acres. Here even moderate thunderstorms produce peak discharges ranging from 500 to 1,000 c.s.m. on small drainage areas of 100 acres or less.

What has been said of the differences in water storage opportunities for forest soils in the Southern Appalachians is true to a more limited degree elsewhere in sections of hilly or mountainous topography. The forests remaining on the shallow steep soil exert a significant regulating effect on the manner of storm runoff although the natural underground storage may be inadequate to provide for complete control of storm water.

OLDFIELD FORESTS ON ERODED SOIL PROFILES

Throughout the eastern states there occur extensive areas of oldfield forest. These areas are now considered as being forest land and have been used for comparison with other land use types to show the effect of trees on runoff. Physical processes of water control in these soils have been very definitely altered during the period of exploitation for agriculture. Consequently oldfield forests would be expected to be different from the original forest with regard to water control. Agricultural land is abandoned principally because it has become so badly depleted and eroded as to be unprofitable for crops. In some sections this in itself might indicate that the soil was originally too shallow or too steep to have been cleared for cultivation in the first place. This point has been emphasized by Auten (1) for states in the Ohio Valley. In the Piedmont Plateau and in the southern Appalachian Region it is particularly true that poor land that proves to be unsuitable for agriculture is considered to be potentially good forest land.

An extreme case, but one that is quite commonly met with in the southeastern states, will illustrate ground water storage limitations under oldfield pine stands. Assuming that capillary storage is about the same for both the natural and abandoned soil profiles, the two may then be conveniently compared entirely on the basis of noncapillary storage. Table 1 indicates the underground water storage above field capacity for the first 36 inches of soil in the two profiles. Data are based on 1,000-cc cylinder samples on Hayesville

TABLE 1.—*Comparative detention storage opportunity.*

Natural forest soil uncleared				Subsoil profile at time of pine invasion			
Inches soil depth	Inches represented	Macro-pore space, % by volume	Area inches storage	Inches soil depth	Inches represented	Macro-pore space, % by volume	Area inches storage
—	—	—	—	0–2	2	10	0.20
0–6	6	30	1.80	3–6	4	7	0.28
7–18	12	12	1.44	7–18	12	3	0.36
19–36	18	3	0.54	19–36	18	3	0.54
Total	36	—	3.78		36	—	1.38

[6]The Copper Basin lies in the southeastern county (Polk) of Tennessee: rainfall, 55 inches annually; elevation, 1,500 to 2,000 feet; topography, rolling to hilly. A dense hardwood forest was removed to operate open hearth furnaces for smelting iron and copper sulfide ores. Sulfur dioxide fumes killed the remaining vegetation leaving the soil completely bare. From 1 to 3 feet of soil have been lost through erosion.

fine sandy loam. Macro-pore space was determined by techniques described elsewhere (3).

It is apparent from Table 1 that a 3-inch rain falling after the soil has been wet to field capacity will be temporarily stored in the natural forest soil. The same rain would produce an excess of 1.62 area inches of storm runoff from the eroded profile on the basis of lack of detention storage alone. This is in addition to storm runoff produced by reduced infiltration.

In the old cotton belt of the southeastern states extensive areas that have been eroded deeply into the subsoil are now in oldfield pine forest. Very little change in structure below the first few inches in the soil profile can be observed even after two decades where the trees have invaded compact clay subsoils. Favorable changes in soil structure do take place but a period of from 60 to 80 years or more is required before these soils should again be referred to as forest soils. Increase in the opportunity for underground storage of water accompanies the improvement in soil structure but during the development of the oldfield forest storage conditions are not comparable to that of the virgin forest profile for the locality.

Coile (2) has reported an intensive study of soil changes associated with loblolly pine succession on abandoned agricultural land in the Lower Piedmont Plateau. Working principally with soils of the Georgeville series on the Duke Experimental Forest at Durham, N. C., he concludes that, "Physical characteristics of the soil measured as volume-weight, water-holding capacity, and air-space change but little during succession and are not related in a casual manner to succession." Field percolation rates actually decrease with pine invasion into herbaceous oldfield vegetation which annually adds incorporated organic material through root decay. Little humus is added to the mineral soil through pine litter for the first fifteen years. To what extent these findings apply throughout the more deeply eroded areas with steeper topography in the Upper Piedmont remains to be determined for here herbaceous oldfield vegetation may be very sparse or entirely lacking before pine invasion. The studies by Coile do show that the presence of oldfield pine does not necessarily indicate maximum soil conditions for water control.

The approximate rate at which soil structure can be restored for water control on depleted subsoil areas has yet to be determined for different sections of the country. Further studies in soil hydrology with relation to soil restoration would furnish pertinent data needed as a guide to relative costs and values resulting from local and regional conservation programs.

SUMMARY

This discussion emphasizes the fact that underground water storage in many forest soils is subject to definite physical limitations inherent to shallow or eroded soil profiles.

Because of limited soil depth, upper slopes of the southern Appalachian Mountains above 3,500 feet may have 4 to 8 area inches less total storage opportunity than lower slopes or terrace lands in the same locality.

Eroded soil profiles of the southeastern Piedmont that have been abandoned after many years of clean cultivation may have less than one-third the macropore storage in the first 36 inches than is found in comparable soil tyes that have not been cleared for agriculture. Consequently, the young pine stands that invade badly eroded land do not have the initial water control and groundwater storage found in the uncleared forest.

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