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SECTION IV

EFFECTS OF LAND USE ON STREAMFLOW

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How land is used and managed has a very definite effect on streamflow. Vegetal cover and soil are the intervening factors between precipitation and runoff in our streams. The things we do to the vegetal cover and soil as foresters, farmers, conservationists, contractors, highway engineers, recreationists and others affect how much water is intercepted by the vegetal cover, runs off over the surface of the ground, and infiltrates into the soil profile to relieve soil moisture deficits, to recharge the groundwater table, and to runoff laterally into the streams as subsurface flow. These things we do also affect the sediment production from a watershed in the form of sheet, gully, and streambank erosion. The first factors deal with the production of water and the regimen of flow and the second with water quality.

In Northern Alabama we can expect 60 inches of precipitation on the average every year. This precipitation produces an average of 22 inches of runoff annually. The difference in these two values represents water losses of 38 inches. About 6 inches of the 38 inches will be absorbed as interception and 32 inches will be utilized as evapo-transspiration. These figures are determined from average watershed conditions including all types of vegetal cover and soils, and apply to an average annual temperature of 66 degrees.

I shall discuss briefly that portion of the hydrologic cycle dealing with precipitation occurring as a supply of water to the land and eventually part of it becoming runoff in our streams. Interception of the rainfall by trees and grasses is the first factor in the disposition of precipitation. The water, which is held by the vegetal matter temporarily and evaporated back into the atmosphere, usually amounts to about 10 to 20 percent of the precipitation. The amount of interception varies with the type of vegetal cover and with the number of storms and particularly the amount of precipitation which occurs annually in storms of less than say ½ inch.

The water reaching the ground surface is disposed of in several ways. Part is retained on the surface and evaporated back into the atmosphere. Part flows over the ground as overland flow or surface runoff. Part infiltrates into the soil profile. The infiltrated water is used first to satisfy any soil moisture deficit existing in the soil profile with the remaining portion going to either accretion of the groundwater storage or running off laterally as subsurface flow. The water in soil storage between wilting point and field capacity is available for transpiration by plant life and for evaporation from the ground surface. The annual values of evaporation and transpiration are included in the amount of water losses.

I would estimate that on the average about 10 percent of the 22 inches of annual runoff of Northern Alabama would occur as surface runoff, 40 percent as subsurface runoff, and 50 percent as groundwater runoff. These percentages are for an average watershed, and can vary widely due to the kinds of vegetal cover and the types of land management prevailing, the types of soil profile, and the groundwater geology.

The most important elements here are the infiltration characteristics of the soil and cover complex and the capacity of the groundwater storage. The soil is the base for the infiltration rate and the vegetal cover is the modifying factor. The soil factors affecting infiltration are structure, texture, depth, and internal drainage. Soil structure represents the arrangement of soil particles and aggregates into certain patterns. This is closely related to the soil texture and the development of the surface soil horizons. In a light texture soil a large percentage of the pore space is available for soil moisture storage between field capacity and saturation, while in a heavy texture soil the reverse is true. The amount, size, and continuity of the voids in this pore space govern the percolation rate through the soil. An impermeable or restrictive layer in the soil profile limits the percolation to the lower horizons. Similarly the depth of the soil profile may limit the total infiltration possible during the progress of a storm.

The effect of cover and land management modifies the percolation rate of the surface soil horizons and provides protection to the ground against raindrop erosion. A forest cover for instance adds organic matter to the soil in the form of humus. The humus layer provides quick storage almost instantly available to absorb high rainfall bursts and permits the infiltrated water to percolate at slower rate over a longer period of time. In a forest soil the structure is also materially affected by root development and decay and by biologic activities which convert the litter into humus. In our work in rating the hydrologic condition of forest land, we find that there are three items which can be used as indices to indicate the runoff potential. These items are litter depth, humus depth, and humus type. Litter is necessary to protect the soil and humus against raindrop erosion and puddling and sealing. The depth of humus provides the amount of quick storage available. The type of humus reflects the type of land management and degree of disturbance for grazing, fire, clear-cutting, partial cutting, and logging.

In rating the hydrologic condition of agricultural open land and its infiltration characteristics, we work in terms of soil capability classes and the kinds of conservation practices applied on the land. The main objective in developing a farm plan is to design, for instance, the crop rotation so that the soil loss is held to minimum allowable value. Since this farm plan is developed to hold sheet and rill erosion to a minimum, it also follows that the surface runoff is held to a minimum. The best cover for agricultural land in terms of infiltration is permanent meadow and the others in decreasing order are native pasture or range, legumes or rotation meadow, small grains, row crops, and fallow. Contouring and terracing are practices which can be used to hold surface runoff to its least value, just contouring is next best, and straight row, the worst. The type of management such as for grazing and the length of rotation also affect the infiltration rating of crop land. Where the use of the land is such that the soil loss is above the allowable minimum value, it follows that both the sheet erosion and the surface runoff are excessive.

As to whether on a particular watershed the percentage of annual groundwater runoff is 50 or more or less, a lot depends on the capacity of the groundwater table to store water. We find at the Coweeta Hydrologic Laboratory in the North Carolina portion of the Southern Appalachian Area that as much as 6 inches of runoff can be stored in the groundwater table at one time. In the White Mountains Area of New England 2 inches would be a probable maximum value. In the Salt River Watershed of Kentucky along the Ohio River, the value is less than one inch. In each case this maximum groundwater storage value would be a function of the groundwater geology. The regulating effect of the groundwater reservoir depends on the annual amount of infiltrated water and its time distribution and in turn on the annual precipitation.

The operation of the flow from the groundwater table can be compared to that of a surface reservoir with a fixed outlet. The rate of groundwater flow can be considered to be a function of the amount of groundwater storage or the effective head of water. As the outflow from the groundwater table depletes the storage, the rate of flow is gradually decreased, following a die-away type of exponential curve. This groundwater depletion curve and the total storage capacity of the groundwater table varies for each watershed with the geology, type of aquifers, and the general topography. In the case of the surface reservoir when the storage has been used up to the spillway level, the storage above this level is mostly discharged thru the spillway with some increase in flow thru the fixed outlet due to the increased head. In case of the groundwater table the excess above maximum storage may be discharged thru subsurface flow in the soil profile, outflow from perched water tables, and occasionally as overland flow when the level of the groundwater table is above the surface of the ground. Thus the hydraulics of the groundwater table determine what the maximum storage is and its time-distribution of runoff.

In working out any hydrologic problem it is necessary to establish the present soil and cover relations on a watershed. This applies to both flood and water yield problems. We therefore need to know as much as possible about land use hydrology not only to estimate the hydrologic effects of a land treatment program, but also to determine the rainfall-runoff relations under present existing conditions.

The key factor in our land use hydrologic problems is surface runoff. The amount of annual surface runoff was estimated above as 10 percent with a probably range of 1 to 20 percent. Most of this surface runoff is apt to occur in one or several flood-producing storms. In flood volume for a particular storm the surface runoff may represent as much as 50 percent of the total flood runoff. Since surface runoff has the shortest time of travel from any point on the watershed to—say—a bridge on a main stream, surface runoff makes the greatest contribution to the flood peak. It can be approximated that it takes 2 or 3 times as long for subsurface runoff to peak on a watershed as surface runoff and groundwater runoff 5 to 10 times that for surface runoff. In working out a flood problem it is therefore necessary to know as accurately as possible what the amount of surface runoff is. In developing a land treatment program to alleviate flood problems, it is necessary to estimate to what extent the program decreases the volume of surface runoff and its contribution to the flood peak. In water yield problems any water occurring as surface runoff loses an opportunity to satisfy soil moisture deficits and to increase the storage in the groundwater table. In water quality and sediment problems sheet, rill, and gully erosion are directly related to the amount of surface runoff and streambank erosion to the height of the flood peak.

It seems obvious that the infiltration theory should be applied only for the determination of surface runoff. Many people apply this theory, however, to the direct volume of flood runoff which is easily obtained by subtracting the groundwater runoff from the total flood hydrograph as measured. In such cases an average watershed infiltration index rate is derived by trial and error by finding out what rate when applied to the rainfall intensities would reproduce the volume of direct runoff. These index infiltration rates are usually very low and entirely unrelated to actual infiltration rates established for the various soil and cover complexes. In land use hydrology the infiltration theory is followed by using one of the accepted methods for separating the surface runoff from the direct runoff and checking it against the weighted value computed for all the soil and cover complexes in the watershed. In determining the reduction in surface runoff due to a land treatment program, the surface runoff is estimated by taking into account the changes in areal extent and in hydrologic conditions of the soil and cover complexes.

It has been estimated under the flood prevention and small watershed studies of the U. S. Department of Agriculture that a land treatment program would generally produce a 5 to 15 percent reduction in the flood peak discharge. These reductions apply to watersheds in excess of—say—ten square miles and vary with the present hydrologic condition of the watershed and the magnitude of the changes which can be effected within the framework of the economic development of the watershed. These reductions in flood peak discharge are greatest for the small flashy flood peaks and least for the large, long duration ones. While these reductions may seem small, a reduction of 5 percent in peaks may reduce annual flood damages as much as 15 percent and a 15 percent peak reduction may reduce the damages by 40 percent. A large reservoir and structural program seldom reduces the flood peak discharge more than 50 percent and the flood damages more than 90 percent.

When the land has been not used according to its soil capabilities classes, which occurs more frequently and to a larger extent on the smaller watersheds, the flood peaks can be even more greatly reduced. When a steep 23-acre mountain forested watershed was converted to a mountain farm with corn cropland and heavily grazed pastures at the Cowetta Hydrologic Laboratory, the flood peaks were increased from three to four times. The soil losses were increased by mountain farming by over ten times.

Another factor which is contributing to the flood problems of today, and will do so even more in the future, is the extension and development of suburban areas in the countryside. Metropolitan Planning Boards are gradually giving more and more recognition to the flood problem created by the conversion of agriculture and forested land to housing, industrial, and road development. The problem is two-fold: one phase is reduced infiltration into the soil due to both the increased impervious areas of building and roads and to changes in the hydrologic condition of the land remaining exposed to the elements; and the other phase is the reduced time of travel of runoff thru a developed drainage system. In many such suburban areas the frequency and severity of floods have increased greatly. Improvement of the stream carrying capacity and other flood prevention measures could be considered as an associated cost to be included in the total costs for the developing the area.

Land use and management also have another important effect on stream runoff in the case of winter floods. The type and density of vegetal cover affects the amount of snow accumulation on the ground and the rate of snow melt. The type, depth, and duration of concrete frozen ground during the winter season is closely correlated to the factors affecting the rating of the hydrologic or infiltration condition of the soil and cover complexes, being most adverse for cropland without a winter nurse crop cover and most favorable for an excellent forest stand with deep humus development. Frozen ground contributes to the flood problem by increasing the amount of surface runoff and to water yield problems by preventing accretion to the groundwater table.

So far our discussion of land use hydrology has been on basic principles and primarily on the relation of land treatment to flood peaks. I would now like to discuss how land use and management is related to water yield. I have previously indicated how any reduction in surface runoff achieved by improved land management would increase the amount of infiltrated water and to lesser extent the amount in groundwater storage. An increase in groundwater storage would usually increase the evapotranspiration and the usable annual water yield. Since land management does affect the type and density of vegetal cover, it can also be expected to affect the amount of water absorbed by interception and used by plant life in evapotranspiration.

In the beginning I mentioned that the annual water losses, including evapo-transpiration and interception, for a typical watershed in Northern Alabama would equal about 38 inches or the difference between average values of precipitation and runoff of 60 and 22 inches respectively. This is called the water balance equation and the water lossses can be estimated for any watershed where the precipitation and runoff are measured. The water losses have a narrow range of variation and are usually considered constant. Annual precipitation and runoff have a wide variation which often deviate more than 50 percent from the mean.

It is self-evident that any changes effected in evapo-transpiration brought about by land treatment results in changes in annual runoff or water yield. The amount of evapo-transpiration occurring in any given locality is directly related to such metorological elements as wind, humidity, and temperature, and also solar radiation, soil moisture content, and plant factors. Plant factors include stage of growth, season, amount of leaf area, adaptability, and height.

Any manipulation of vegetal cover contemplated to increase water yield by decreasing evapo-transpiration should be done only after an investigation of the climate, soils, and runoff characteristics of the watershed has been made. Most studies of this nature have been made on forest cover. Such studies have been made on unit watersheds at the Coweeta Hydrologic Laboratory where the precipitation averages 75 inches per year, the soils are a deep sandy loam, the cover was in undisturbed forest stands, the surface runoff was negligible, and the annual water losses were 38 inches.

On Coweeta unit watershed 17, all forest vegetation was clearcut and no forest products removed. This resulted in an increase of 15 inches of runoff the first year and a similar decrease in water losses. Each year thereafter except for two World War II years the sprout growth was cut back which resulted in an average increase in water yield of 11 inches over a 15-year period. No surface runoff was observed during the treatment period, and flood peaks were not increased.

On Coweeta unit watershed 13 the treatment was similar to that for watershed 17 except that regrowth was permitted to come back. The increase in annual runoff was the same—15 inches—the first year and averaged less than 8 inches over a 15-year period. No surface runoff was observed during the treatment period, and flood peaks were not increased.

On Coweeta unit watershed 19 a dense understory of laurel and rhododendron, representing about 20 percent of the basal area of the forest cover on the watershed was cut and then permitted to grow back. The increase in annual runoff was 2.8 inches the first year and averaged 2.0 inches over a six-year period.

Other watershed studies being made at Coweeta Hydrologic Laboratory are designed to determine the effects on water yield by cutting the riparian vegetation, by cutting the forest cove type, and by cutting or deadening 50 percent of the forest stand evenly distributed over the watershed. A paired watershed study is now underway at Coweeta to determine what the changes in water yield will be for two watersheds when one is managed primarily for timber production and the other for water production. It must be remembered when manipulating vegetation to increase water yield that surface runoff must be held to a realistic minimum in order not to increase flood and water quality problems.

The basic principles involved in land use hydrology have been presented to illustrate how land use and management may affect runoff. Better land use and management alleviates flood and water quality problems primarily thru reduction in the amount of surface runoff. Manipulation of forest cover increases water yield, particularly during low flow periods, by decreasing the amount of water used by plants for interception and evapo-transpiration.