Reprinted from JOURNAL OF FORESTRY, April 1951

The Relation of Forests to Our Water Supply[1]

A. R. Croft and Marvin D. Hoover
Foresters, Intermountain Forest and Range Experiment Station, Ogden, Utah, and Southeastern Forest Experiment Station, Asheville, N. C., respectively, Forest Service, U. S. Department of Agriculture.

THE FORESTRY PROFESSION must assume responsibility for water management of forest lands as well as for timber management. From the beginning, public support for conservation in this country was largely based on a concern for perpetuating timber and safeguarding water supply. However, foresters during the past 50 years have devoted most of their effort to producing timber; water yield has been given only slight consideration.

There are several reasons for this neglect of the water resource. First, the forester finds it easy to appreciate the value of timber because it is a crop harvested where he works, whereas, water is put to use a long way from the woods. Even more significant, the forester cannot easily show a cash benefit for anything done in the interest of water. Water appears to be a gift of the gods—free, unchangeable, inexhaustible. In his desire to get a return from other products he tends to pay scant attention to water production or the damage that may be done to a water user who is perhaps 200 miles downstream.

Then too, in forestry education, the way in which forestry practices influence quality and quantity of water has not been given adequate consideration.

But times have changed. Public concern and increasing demand for water is demonstrating to foresters that water from the lands they manage may have values equal to or greater than the timber.

To begin with, we know that a forest is more than just trees. Between the tree tops and their root tips is a complicated association of plants, animals, soil, climate, water, and physiography. These components through geologic ages have been integrated into a complex, or whole, that constitutes the forest.

The trees of the forest, by checking air movement, increasing humidity, and altering temperature and light, create a climate different from the over-all climate above them. This forest-made climate is an important factor in the existence and perpetuation of the forest complex.

Water is an intimate part of this complex. Indeed, water entering the forest as rain or snow, being intercepted by trees, penetrating the litter, duff, and soil, oozing from seeps and springs to form streams, is so closely associated with every part of the forest that it may be considered part of the forest complex itself. Streams under pristine conditions are adjusted to this complicated environment.

The forester can alter the quantity, quality, and timing of runoff by his management of vegetation and soils of the forest. This has been demonstrated both by observation and controlled experiments, a few examples of which will be presented in this paper. Before going into this subject, however, it will be helpful to consider briefly how forests function in water yield.

How Forests Function in Water Yield

A watershed may be considered a basin that receives intermittent precipitation and converts part of it to more or less sustained stream flow. In this process every square foot of land receives and disposes of water.

Water that enters the forest as precipitation is first stored. It is stored as snow, on leaves and branches of trees, in depressions on the soil surface, in the litter and duff, in the soil mantle as capillary water, and temporarily as free water in the cracks and pores of the litter, duff, and soil, and in fissures of the underlying rock.

The soil and geologic mantle is by far the greatest reservoir for water storage. This storage takes several forms. First, each foot of soil holds from 0.4 to 1 inch of water so tightly that it cannot be removed by plants or gravity. This unavailable water corresponds to the dead storage below the outlet of a water reservoir and ordinarily represents the minimum moisture content of the soil.

The soil also retains 2 or 3 inches of capillary water against the force of gravity but not against the pull of plants. It is this water, mainly, that plants use in growth. Maximum capillary storage is referred to as field moisture capacity.

The water stored temporarily in the cavities of the litter and duff and in the large pore spaces within the soil is called detention storage. It varies from 0.1 to 3 inches per foot depending on the amount and character of the litter and duff, and the depth and texture of the soil. This temporary storage is very important for it furnishes an emergency storage capacity for water in addition to that held in capillary form by the soil mantle. It is important when permeability of the soil is low because it prolongs the period of percolation. Except for this detention storage much water, at times, would flow quickly overland to stream channels rather than pass through the mantle as seepage flow. Direct overland runoff produces high and flashy stream flow, erodes the soil, and loads streams with sediment. It is destructive and undesirable. Water that penetrates the surface percolates more slowly through the soil to streams and gives less flashy and more sustained flow. Seepage flow is the normal manner of water yield from forested lands.

Undisturbed forest soils provide highly favorable conditions for seepage flow. At the surface are the organic layers grading gradually from the undecayed fallen leaves to a mixture of decomposed organic matter with mineral soil that pro-

[1] Presented at the annual meeting, Society of American Foresters, Washington, D. C., December 16, 1950.

tects the soil surface against rain drop impact and creates ideal conditions for infiltration of water. Roots ramify throughout the organic horizons and penetrate below to considerable depths. As these roots die and decay they form pipe lines that carry water quickly to lower depths and also contribute to the porosity of the soil.

Water from precipitation that is stored in the forest is disposed of in different ways: some is lost by evaporation from the foliage, litter, and from snow; some may flow overland to streams but under undisturbed conditions the amount is extremely small, if any; and finally, large quantities are removed by evaporation and transpiration. Any precipitation not disposed of by these processes passes through the soil mantle as free or gravitational water to streams or to ground water storage. No free water can pass through the soil mantle to generate stream flow, however, unless the soil is at field moisture capacity. Stream flow and ground water are then residuals of the precipitation, being that part not consumed by the forest.

Thus foresters, in having charge of key water yielding areas are in effect managing huge detention reservoirs. Considered strictly from the water yield point of view the objective is to get maximum amounts of water into the reservoir and, on the other hand, draw out as little as possible. This permits the maximum amount of the precipitation to percolate through the soil as seepage flow to streams.

How Forest Practices Affect Water Yield

The amount of water which enters and leaves the soil reservoir will be influenced by the way the forest is managed. From experiments in various parts of the country we are obtaining information that suggests the magnitude of changes in stream flow that may be achieved by management. Although these results do not apply directly to watersheds which differ in climate, soils, and geology from the test areas, the principles involved are rather universally applicable.

Total Water Yield

The factors that determine total water yield are expressed by the simple formula: water yield equals total precipitation minus (interception + evapo-transpiration ± storage). Let us consider briefly how each of these factors may be influenced by forestry practices.

Interception losses. — Water losses due to interception by forest stands range from 10 to 40 percent of the annual precipitation (*6*). It must not be assumed that elimination of interception results in equivalent increases in stream flow. Actually, most rains are so small they wet the soil only a few inches and the water is soon lost by evaporation or transpiration. These minor rains, therefore, have practically no immediate effect on water yield. Sometimes, however, even though rains are not large enough to raise the soil moisture to field capacity so that water can pass through to streams, they do tend to raise the moisture content of the soil. By so doing they decrease the seasonal soil moisture deficit so that less water from subsequent rains or snow is required to raise the soil moisture to field capacity. Thus reduction of summer rainfall interception by removal of timber may help increase water yield.

Experimental results indicate that where winter snowfall furnishes most of the runoff, it is possible to increase water yields by opening the stand to permit more snow to reach the ground. For example, in lodgepole pine at the Fraser Experimental Forest in Colorado, 26 percent more precipitation reached the ground as snow when all trees larger than 10 inches d.b.h. were cut (*8*). This saving increased water available for stream flow about 31 percent. In the same study it was found that light cuts and thinnings in young stands also decreased interception losses. It therefore appears that any cutting in similar areas can be expected to have some effect upon water yield. These results were obtained on sample plots and have not yet been tested on a watershed basis. Further research is needed to furnish the information necessary for practical use.

In certain humid regions, interception occurs at times when the soil is at field capacity. Under such conditions high interception is desirable because it reduces water available to streams and reduces peak discharges.

Evapo-transpiration. — Evapotranspiration as used in this paper refers to water lost from the forest floor by evaporation and water withdrawn by plants from the soil and geologic mantle and from ground water. These losses depend on many factors. Chief among these are climate, leaf area, extent and depth of roots, available water which is largely a function of soil depth, and proximity of roots to the water table.

Evaporation is less effective than transpiration as a medium of water loss because it decreases in rate with mantle depth. It is effective mainly in the upper 2 feet of soil. Transpiration, on the other hand, removes water from the entire root zone at a rather uniform rate regardless of depth. For example, in the Wasatch Mountains of Utah the moisture deficit created by evaporation in soil without plants during the growing season averaged about 4 inches while that of an aspen forest at the same site created a deficit three times as great (*3*). Evaporation was largely from the upper 2 feet of soil, but even at this depth about 1 inch of water per foot of soil was still available to plants at the end of the growing season.

Means of reducing the amount of water transpired by forest vegetation have been studied in the southern Appalachians and in the Wasatch Mountains of Utah. In the latter study, it was found that an aspen stand in a 0.1-acre plot during the growing season used all available water to a depth of 6 feet. On another plot where aspen was cut, but herbaceous vegetation left, only the available water in the upper 4 feet was removed. The moisture deficit in the fall was 12 inches under aspen as compared to 8 inches where aspen had been cut. Because moisture deficits must be replaced before water can flow through the soil, the difference of 4 inches represents the possible gain in stream flow which could be obtained by replacing aspen by shallow-rooted herbaceous species. In evaluating these results for watershed application, it is important to consider soil depth. If the soil had been less than 4 feet deep both types of vegetation would have used all available water. In general, management can expect to decrease transpiration draft most effectively where soils are deep.

At the Coweeta Experimental Forest in western North Carolina, on two 40-acre watersheds which had an oak-hickory forest, stream flow was measured for 5 years and then the trees were cut (*5*). To prevent soil disturbance, no logging was done, the trees were left where they fell, and slash was scattered. The first year after cutting, stream flow was increased 17 area inches or 65 percent with the largest increases occurring during summer and fall months. On one watershed, regrowth has been kept to a minimum by annual mowings and the streamflow increase has been maintained. Because of the protection given to the soil, flood peaks have not been increased and flow is still from seepage and ground water. On the second watershed where natural regrowth has occurred, the flow 8 years later is still 20 percent greater than before treatment. Water yields were increased because, with the reduction in transpiration, summer rainfall was frequently sufficient to raise the soil to field capacity so that free water could pass through the soil to recharge the water tables which feed the stream.

There can be little doubt that water yield from forests can be materially increased or decreased as changes in forest cover alter water losses from interception and evapo-transpiration.

Distribution of Water Yield

Ordinarily stream flow is highest in spring and lowest in the summer. An increase in water yield in the summer when demand is high, is of great economic value in both semiarid and humid regions.

Reduction in evapo-transpiration from ground water along streams may also increase yield at times of low flow. At the Coweeta Experimental Forest, for example, cutting all trees less than 15 feet above the stream, increased stream flow 20 percent during the late summer months although only 12 percent of the watershed was cut (*4*). The treatment was most effective during periods of no rainfall. In the Wasatch Mountains of Utah, trees and other riparian vegetation consumed about one-third of the late summer stream flow from a 6,300-acre watershed (*2*). It is believed that about one-half of water lost could be saved by removing trees that have their roots in the ground water along the main stream channels.

Increase in water yield in late summer may have great value. For example, a study of the 5,000-square mile Merrimack River basin, about 70 percent forested, suggests that low water flows could be increased about 7 percent by improved forestry practices designed to increase seepage flow by reducing water losses from evaporation, transpiration, and quick surface runoff. If this could be done hydro-electric power companies estimate the value of the increased flows for power production to be $250,000 annually. In addition, the increased flow in summer would help relieve stream pollution.

Frost may have an important effect on distribution of water flow by causing water to flow overland quickly to streams rather than percolate through the soil and geologic mantle to streams. This was investigated in the Pocono Mountains of Pennsylvania on two adjacent watersheds—one 90, the other 40 percent forested. The 90 percent forested watershed produced the lowest peak discharges 21 out of 32 times. It also produced the highest summertime stream flows 20 out of 21 times. The more uniform stream flow on the densely forested area was closely associated with frozen soil. For example, during a rainstorm that followed a short freezing period, overland flow to streams was observed from nonforested pastured areas with frozen soil but not from forested lands where soils were not frozen. Where overland flow occurred small streams were highly turbid.

A recent study in California shows how forest cover may affect seasonal distribution of water by checking quick overland flow to streams, thus promoting seepage flow (*7*). A normal woodland-chaparral forest infiltrated the total precipitation of 60 inches, about 43 inches of which percolated through the root zone mantle and therefore became available for recharge of stream flow or ground water. On an adjacent area denuded of its cover, only 24 inches percolated through the root zone and an equal amount left the area as overland flow. The following year when precipitation was only 25 inches, 8 inches percolated through the soil of the forest and none ran off the surface. About 7 inches percolated through the soil of the cut-over stand and 3.2 inches ran off the surface. Thus in both years more water became available to streams and ground water from the forested land because loss of water from the study area by overland flow was prevented.

In some parts of the country flood control may be an important objective of management. Any water that can be stored in the forest during times of high precipitation will lower flood peaks. For example, consider conditions on the Truckee River watershed in Nevada and California which produced devastating flood discharges on November 20 and 21, 1950. Rainfall in September, October, and November was about three times normal. In its present condition the watershed could neither store nor slow the release of sufficient rainfall to prevent a record peak discharge that caused several million dollars damage to roads, water supply facilities, and business property in and around Reno in only a few hours. Nor could the pristine forest have prevented this flood. There can be little doubt, however, that preservation of only a reasonable part of the pristine forest, that is, some of the trees, litter, duff, and top soil that has been destroyed in the past 80 years by uncontrolled fire, and destructive logging and grazing, would have provided sufficient additional water storage capacity on forested lands to have reduced considerably the high peak discharge that did much of the damage.

An example of how increasing the water storage capacity in the soil may reduce floods is provided by Bromfield's Malabar Farm in southern Ohio (*1*). Bromfield says, "When we first took over the fields at Malabar as much as 80 percent or more of the water that fell during a sudden cloudburst or even a long, heavy rain ran off the farm within 24 hours." He attributed this largely to removal of virgin deep-rooted hardwood forests that once occupied the deep glacial soils followed by "130 years of farming only 8 or 9 inches deep," that produced a plow pan almost impervious to water.

Using deep tillage tools and commercial fertilizers, deep-rooted alfalfa, brome grass and ladino clover have been established on these lands. "Today," writes Bromfield, "we keep over 95 percent of the rainfall where it falls to sink into the ground to feed our streams." He calls this "farming 3 to 20 feet down." It is entirely conceivable that this striking change in the hydrology of the land has been brought about by the deep-rooted plants that do two important things in flood control. First, deep root systems promote infiltration of water into the soil during periods of high rainfall. Secondly, they pump large quantities of water out of the soil by transpiration thus creating a like storage capacity in the soil for potential floodwater. The surface vegetation slows water movement giving it time to percolate into the soil. Furthermore, each time field capacity is reached by penetration of rainfall into the soil, water may pass on through to ground water and streams. These deep-rooted farm crops are doubtless controlling water on the land as forests did before they were cut.

That the seasonal distribution of water can be materially altered by forestry practices is apparent from available data. It cannot be emphasized too much, however, that accelerated soil erosion and resulting sedimentation must be prevented and therefore removal of trees from stream channels and slopes must be carefully appraised from this point of view.

Water Quality

As used here, water quality refers to the extent to which water is free of polluting elements that render it unfit for domestic and industrial uses or of sediment that may be deposited downstream. A cutting may cause little change in the composition and density of the stand but the roads for taking out the timber may have far reaching effects. Large quantities of dirt may be dumped directly into the streams, unstable cuts and fills made, and large areas of impervious surface created. Only a comparatively small area of such disturbance is sufficient to muddy runoff water. For example, during the Columbia River flood of 1948, it was observed that the runoff from logging roads and trails on a logging chance one square mile in area changed the North Fork of the Clearwater River from a slightly turbid, to a dirty muddy stream.

On the Coweeta Experimental Forest, a 200-acre watershed was logged by practices commonly used in the Southern Appalachians. Eventually 2.3 miles of truck road were bulldozed into the watershed to finish the logging job. Turbidity of the water from the logged area averaged 93 parts per million as compared with 4 p.p.m. for the stream on an adjacent undisturbed area. During storms, the water turbidity on the logged area reached a maximum of 7,000 p.p.m. as compared with 80 p.p.m. for the check area. Repeated measurements of road cross sections showed a loss of soil from the road of 1 cubic yard per lineal yard—a total of 6,850 cubic yards. From these figures, it is easy to see why this one logging job was sufficient to muddy the water from the 4,000-acre watershed to which it is only a minor tributary. Flash runoff from the roads has also caused higher flood peaks. Although the logged area is still forest covered and will produce another crop of timber, its water quality and sediment production are more typical of poorly farmed steep land than of forest.

Even the most careful logging operations greatly disturbed the soil. For example, under actual logging operations on a national forest in the Northern Rocky Mountains where the road and trail layout was carefully designed, the minimum area occupied by roads was about 8 percent for jammer and 10 percent for "cat" logging. Fortunately, there is little mystery about the principles of erosion control on logging roads and there are examples of good jobs. Generally, however, the possible damage to downstream water users has not been realized. A number of common sense improvements will go a long way towards lessening the destructiveness of logging operations.

In the Northern Rocky Mountains it is believed this can be accomplished by adherence to the following practices: Keep road grades below 25 percent, with 10 percent the objective on erosive soils; outslope or drain all truck and "cat" roads; exclude roads from stream bottoms; log lightly in a streamside strip 200 to 400 feet wide along permanent streams; skid logs to roads outside streamside strips with horses or winch; keep slash out of streams; dam all skid trails at frequent intervals to prevent development of gullies.

The fact that logging is largely an engineering problem may explain why only minor attention has been given to its hydrologic effects by the forestry profession. Nevertheless, since it constitutes such an important part of the practice of forestry, foresters rather than engineers have been and will continue to be blamed for destructive logging whether they are responsible directly or not.

Plans for prevention of pollution and sedimentation should be an essential part of every logging operation, the cost of which should be a legitimate charge against the logging operation. At the present time large amounts of valuable timber are located on municipal watersheds. In many instances timber removed on a carefully designed basis would materially increase water yield. Surely American ingenuity can find ways of logging these valuable forests without damage to the quality of the water they yield.

From these experiments and observations—and others—we know that the quantity and quality of water from forested lands can be changed by forestry practices. True, we don't know all the answers. Neither do we know everything about silviculture but we attempt to use what we do know while gaining additional knowledge from research and practice.

Similarly we should begin to put to work our present knowledge of the relation of forest land management to water supply while we are gaining further knowledge by research and observation.

The first 50 years of professional forestry in the United States lies behind us. The profession can be proud of its accomplishments during this period in the science of growth and harvesting of the timber crop but it has only just awakened to its responsibility for that other great forest resource—*water*. Actually some foresters ignore this multi-billion dollar forest resource.

The future is crowding us with its challenging problems in resource management. None of these is more important than the problem of sustaining a usable water supply. On forested lands timber production is so closely allied with the regulated yield of pure, clean, sediment-free water that the forestry profession must assume responsibility for water management as well as for timber management in order to discharge its obligation to society.

To do this three things are necessary: (1) The forestry profession must clearly recognize and assume responsibility for water management from forested lands. (2) The job of managing the water supply from forested lands must be integrated with forest management. (3) Forestry schools must give sufficient instruction in the hydrology of forested lands to prepare foresters to assume responsibility for water management as part of their jobs as forest managers.

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