Harvest trees, reap water

By James O. Evans and James H. Patric

Living trees consume large amounts of precipitation, thereby reducing the supply of water available to forest streams. Conversely, the harvest of trees permits more precipitation to become streamflow, resulting in a greater quantity of water to meet human needs.

While this precept has been validated by more than 90 outdoor laboratory studies worldwide, it has not been tested in the United States as an operational land management practice.

Some background

Historical records of early folklore and ancient beliefs reveal that people's concern and fascination with forests and streams date back hundreds to thousands of years. More than 2000 years ago, for example, Vitruvius directed the Romans to explore mountainous regions in hopes of locating underground water. He advised that "the presence of a forest makes it impossible for the sun's rays to reach the water surface," and "snow remains on the ground there much longer because of the dense forests," therefore, there is "no loss of water...due to evaporation."

Twenty centuries later, consistent with that viewpoint, forest cutting commonly was perceived as a threat to water supplies. A post-Civil War report on forestry by Franklin Hough deplored that "our streams diminish as the woodlands are cut away." And since the beginning of the conservation movement at the turn of the century people have attributed major floods to deforestation, believing that forests maximize water supply while preventing floods and soil erosion—beliefs implicit in the Weeks Law of 1911.

Only in recent years has man developed the skills needed to quantify the interrelationships of forests and streams. E. B. Fernow, a pioneer forester, implied a quantitative relationship over a century ago, however, proclaiming that "without forest management no rational water management is possible." Since then, forest scientists have sought to determine how forest management influences streamflow.

This concern led, in 1909, to America's first watershed research, at Wagon Wheel Gap, Colorado (1). Many land managers were surprised by this clear demonstration of increased streamflow after timber cutting, a finding confirmed in subsequent studies worldwide—studies that revealed much about the hydrologic cycle and land use effects on it and that convinced most hydrologists that forest cutting does increase streamflow. Straightforward though that influence is, the conceptual pathway to it has been winding and difficult.

Since the beginning of the conservation movement, foresters have advocated proper land use to ensure abundant, regular streamflow and soil erosion control. Ironically, it was the U.S. Army Corps of Engineers that undertook empirical studies of some eastern rivers to first uncover forest influences on flow in large streams. Results of those studies, conducted from 1910 to 1920, were summarized by Major Hiram M. Chittenden. His three conclusions agreed remarkably with subsequent research:

- Forests have little effect on major floods, but can mitigate freshet flows.
- Prevention of forest regrowth, not cutting of trees per se, can substantially accelerate soil erosion.
- Deforestation can increase streamflow.

Modern studies of the forest influence on water supply began in 1934 at the world-famous Coweeta Hydrologic Laboratory. There, in the mountains of western North Carolina, the Forest Service initiated studies of forests and streamflow that continue to this day. Subsequently, the Forest Service established experimental watersheds in perhaps 20 states, from New Hampshire and Mississippi to California and Washington. A number of universities started similar research.

Water yield research usually features the paired-watershed approach. Adjacent headwater catchments of similar physiography, soils, and vegetation are instrumented. Precipitation and streamflow are sampled and recorded. Some form of cutting or other manipulation of vegetation is applied on the treated watershed. Predicted water yield, based on measured flow from the control (fully vegetated) watershed, is subtracted from measured water yield on the treated watershed. The difference—increased water yield—is accepted as the effect of the treatment on streamflow. Simply put, streamflow is the water remaining from precipitation after deducting all water losses. The paired-watershed approach has produced much of our knowledge about the land phase of the hydrologic cycle on forested uplands and of people's influences on it.

The following version of the familiar...
water balance equation shows why water yield and subsequent streamflow are changed by removal of vegetation: \( P - ET = BO \), where \( P \) is annual precipitation, \( ET \) is annual evaporative loss (evapotranspiration), and \( BO \) is annual streamflow. Annual evaporative loss includes major losses to interception and transpiration as well as lesser losses to evaporation from the land surface and to physiological processes, such as respiration and guttation.

Given precipitation as provided by nature, annual streamflow remains after deducing evapotranspiration. Disregarding the lesser evaporative losses, evapotranspiration is primarily the interception and transpiration losses, both of which are greatly influenced by the stage of vegetative growth. Evapotranspiration may range from 31.5 inches (800 millimeters) per year on fully forested land at southernmost latitudes to a third of that amount in the northerly regions of the United States.

No amount of cutting can eliminate all interception, transpiration, and other evaporative losses. Hence, clearcutting minimizes but does not eliminate evapotranspiration, with the much lower evaporative losses accounting for increased streamflow. Partial forest cutting and natural catastrophes reduce evaporative losses to a lesser extent, yet they still increase streamflow in rough proportion to the reduction in forest canopy. Redevelopment of a complete leafy canopy, requiring surprisingly few years in humid areas, marks the return of evaporative loss to pre-cutting levels; consequent streamflow decreases also to pre-cutting levels. Because conifers have foliage year-round and have at least twice the leaf surface area of hardwoods, interception losses are demonstrably greater from coniferous stands. Also, because of their permanent foliage, the potential for year-around transpiration from coniferous trees exists, although a substantially larger transpiration loss from conifers than from hardwoods has yet to be demonstrated.

Experimental results

A long-term study at Coweeta clearly demonstrated the results of research on cutting the eastern forest and its influence on water supply (3). After a suitable calibration period, all trees on watershed 13 [40 acres (16.1 hectares)] were cut during 1939. Streamflow increased 14.3 inches (362 millimeters), 65 percent more than predicted flow. [A streamflow increase of 14.3 inches from a 40-acre watershed can be envisioned more readily as 1.2 feet (0.362 meter) of water spread across a 173,300-square-foot (16,100-square-meter) field or as 205,813 cubic feet (5,828 cubic meters) of water.] In subsequent years flow gradually declined toward pre-cutting levels as the hardwood forest regrew. A 14.8-inch (375-millimeter) increase occurred when the clearcutting treatment was repeated in 1962. Stormflow was unaffected by either treatment.

In temperate climates of the western United States where rain is the predominant form of precipitation (including Northern California and the Pacific Northwest, but excluding the upper Pacific coastline areas, where canopy interception of fog produces significant amounts of water), forest cutting similarly increases streamflow. But in the colder zones where snow predominates, the annual increases generally are smaller. They may persist longer, however, as exemplified on the Frazier Experimental Forest, located high in the Colorado Rockies. There, from 1954 to 1956, coniferous timber was harvested from 40 percent of the watershed in alternate cut-and-leave strips. Snow, the predominant form of precipitation, blew into the cut strips where water from melting drifts increased streamflow about 40 percent, and an average annual flow increase of 2.9 inches (7.4 centimeters) has been maintained since cutting (5). Snow continues to drift into the cut strips, though they are densely covered with saplings. Increased flow should persist from 35 to about 60 years as trees in the cut strips regrow slowly.

Although the influence of tree harvesting on water yield and streamflow may differ significantly from one climatic area to another, several generalizations can be made concerning the influence of forest cutting on water supplies. A recent review of 92 watershed studies worldwide established that:

- A reduction in commercial forest vegetation increases water yields, although an initial reduction in vegetation of less than 20 percent has not increased water yields detectably.
- Cutting coniferous and hardwood forest stands increases annual water yield about 1.6 and 1 inches (40 and 25 millimeters), respectively, for each 10 percent additional reduction of forest vegetation (above an initial 20 percent reduction in forest vegetation).
- Establishment of forest on sparsely vegetated land reduces water yield.

These generalizations incorporate much variability among watersheds and treatments as well as unavoidable differences in soils, climate, physiography, and vegetation. Only by consulting the original reports can the range of conditions that led to these simple summary statements be appreciated.

Eastern vs. western perspective

Research shows conclusively that water yield can be augmented by watershed management to reduce evapotranspiration. Contrasting climatic and soil conditions in eastern watersheds versus those in the Rocky Mountain Region, however, can produce widely differing water yield responses to vegetation management.

Apparent, revegetation has limited bearing on contrasting duration of flow increases after timber harvest at Coweeta versus Frazier. Natural revegetation was prompt and complete on both watersheds, although the new trees regrew less rapidly at the higher altitudes of Frazier. The predominant form and distribution of precipitation may affect the rate at which streamflow declines to preharvest levels.

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Stream gaging installations, like this one at the Coweeta Hydrologic Laboratory in North Carolina, provide continuous records of the water level in streams draining experimental watersheds.
ences. A uniformly humid climate fosters rapid revegetation of cutover forest land in the East (and in the upper Pacific Coast). In areas of the western United States with low precipitation and high evaportranspiration, increases in water yield from deforestation are lower but may persist longer.

Harvesting timber by clearcutting has caused concern about environmental quality. But contrary to popular belief, properly managed clearcutting does not significantly accelerate erosion rates in the eastern hardwood region or in most coniferous forests. Sediment yields ranged from nothing to 0.9 ton per acre (0.2 metric ton/hectare) per year at Frazier and up to 1.3 tons per acre (0.3 metric ton/hectare) per year at Coweeta. By way of comparison, the Soil Conservation Service places the tolerable soil loss (the erosion rate at which economic production is sustainable) at 0.9 to 3.1 tons per acre (2.7 metric tons/hectare) per year for most forest soils.

Low rates of soil loss have been measured on other clearcut watersheds where logging roads have been prudently located and managed. Logging roads are a key factor in forest soil erosion. As a rule, no form of forest cutting greatly accelerates soil loss, but poor logging roads can and do. The chief exception to this rule occurs on steep forests in humid regions of the Pacific Coast, where mass wastage (landsliding) can become the dominant erosion process.

From here to where?

Tree harvesting has increased streamflow substantially on experimental watersheds throughout the United States. In fact, tree cutting is an option for increasing water yield on the national forests. Clearcutting vast landscapes to increase water yield is improbable, however. Because most of the northern Pacific Coast area and the eastern states enjoy abundant precipitation, cutting to increase water yield in these locations is seldom needed. Also, where many private owners control land in small tracts, tree harvest for significant water yield is not possible. When one owner harvests timber on his tract, trees are regrowing after cutting on another tract. A flow increase in one place is nullified by a reduction elsewhere.

Random cutting thus has little influence on the larger streams that integrate water production from many small tracts. Conceivably, an urgent need for water could result in synchronous cutting to increase streamflow—a measure probably precluded by environmental concern and that under present conditions seems economically unattractive, even impractical. Furthermore, tree cutting to increase water yield is futile during abnormally dry weather. No forest management can wring water from land so dry by evaporation that increased streamflow is not attainable.

Nevertheless, options remain for increasing water yield from tree-covered land. Forested watersheds fully controlled by municipalities can be maintained in grass or low-growing woody plants that use less water than trees. Such vegetation may evaporate less water yet protect the soil from erosion equally as well as trees.

In the western states, combinations of timber and snow management practices can increase water yield. Surprisingly, only in recent years has this option attracted serious attention in the perennially water-short West. Cheyenne, Wyoming, urgently needs more water. Coon Creek, in the Sierra Madre Mountains, is a tributary to Encampment River, Cheyenne’s major water supply. The physiography and vegetation of the Coon Creek watershed resemble those of the Frazier (4), and an improved patch cutting pattern is planned. Stream gages and other equipment have been installed, but not until 1986 will the calibration and roads be complete. Timber harvest will begin soon thereafter. Several more years must pass before the effects of tree cutting on Cheyenne’s water supply can be fully evaluated.

Vegetative treatment can be a valuable option for augmenting water supplies to help meet critical local needs. When that option is exercised, however, the worth of timber, wildlife, amenities, and other resources—herein disregarded—must be dealt with. In the humid East and the upper Pacific Coast areas where abundant precipitation ordinarily provides water sufficient to meet most human needs, large-scale tree cutting to increase regional streamflow is unlikely to be tried. Vegetation and snow management to increase water yield has begun in the intermountain West, however, and future research will find even better ways for producing more water from forests to meet ever-expanding human needs.

REFERENCES CITED