Water Yield Opportunities on National Forest Lands in the Pacific Southwest Region[1]

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Abstract: National Forest lands in California produce 47 percent of the State's runoff, but occupy only 20 percent of the total land area. Using results from the ongoing planning process in each National Forest, it is estimated that the maximum possible water yield increase is 1.4 billion m^3 (1.1 million acre-ft.). Under the preferred alternatives, total water yield would increase by slightly more than 1 percent (437 million m^3 or 354,000 acre-ft.). Uncertainties in estimating and obtaining this projected increase may pose difficulties in formulating and executing any water yield policy.

Water has historically been the subject of statutes governing Forest Service management. The Organic Act of 1897, for example, made the first reference to water as a resource on National Forest lands when it cited "...securing conditions of favorable flow..." as one of the principal reasons for establishing National Forests. Water is also cited as one of the "multiple" resources in the landmark Multiple Use Sustained Yield Act of 1960. This Act requires the USDA Forest Service to manage all resources (timber, wildlife, range, etc.) in a harmonious and coordinated manner without detriment to any of them. Water quality and water quantity are both the subject of numerous legislative mandates.

The quantity of water yield from National Forest lands is primarily a function of precipitation and evapotranspiration. Vegetative manipulation activities, such as timber harvesting and/or prescribed burning of brush, will generally decrease evapotranspiration and thereby increase runoff. As a result, many of the normal Forest Service management activities can be expected to increase water yield. As the vegetation grows back to its original size and density, water yields return to their former levels. Similarly, conversion of brush or low-production timber areas to grass will usually increase total runoff. On the other hand, these same management practices constitute a potential threat to water quality, which might manifest itself as increases in turbidity, sediment loads, and stream temperatures, or as a reduction in fish habitat. In practice, Forest Service emphasis has been to minimize the adverse effects of management activities on water quality and aquatic life. Water yield from National Forest lands is typically regarded as a byproduct of other Forest management activities, and influencing water yield has not been a specific objective of management actions.

In some parts of the State, particularly along the North Coast, the supply of water exceeds demand, and management efforts to increase water yield would be superfluous. On the other hand, water supply is a central concern of most Californians, and continuing population growth suggests that the concern will become increasingly acute. It is, therefore, appropriate to assess water yield augmentation opportunities on National Forest System lands, and determine if managing for water yield is indeed a partial solution to predicted future shortages.

The importance of National Forest lands to the water resource in California is evident in several ways. First, over 77,300 km^2 (19 million acres) of land, or nearly 20 percent of California, are managed by the Forest Service, U.S. Department of Agriculture. (The 18 National Forests in California constitute Region 5, the Pacific Southwest Region, of the National Forest System.) Second, Forest lands are located in more mesic areas, so the National Forests yield a disproportionately higher percentage of the State's runoff than would be expected by area alone. Similarly, the high evapotranspiration on National Forest lands suggests that they may have the highest potential for increasing water yields. Finally, the spatial distribution of the National Forests suggests that the results of a water yield program would have relevance to the State as a whole.

Though considerable research has been done on water yield augmentation, relatively little of this has been done in California. The applicability of research study methods to National Forest lands is uncertain as the vegetative treatments typically were either more severe or more widespread than most Forest Service management. Consequently, research findings have not been extrapolated to

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actual land management scenarios in order to provide a comprehensive picture of the Region's opportunities to influence water yield. In the absence of such information, it has been impossible to formulate a Region wide policy on water yield management. The planning process established in response to the 1976 National Forest Management Act (NFMA) provided an excellent opportunity to make the first preliminary estimates of current and potential water yields under different management scenarios. Since all 18 National Forests have completed a draft plan, it is now possible to prepare an overall perspective on water yield opportunities in Region 5.

WATER YIELD ASSESSMENT PROCESS

In 1979, water yield was identified by the public as an issue to be addressed in the Region wide resource management plan ("Regional Guide"). Broad alternative water yield management options were assessed and water yield management guidance given to the 18 National Forests. Subsequent Forest planning direction issued in 1982 included more specific water yield assessment requirements. The context of all this planning effort was NFMA, which required each Forest and the Region to develop comprehensive, long-range land and resource management plans. The mechanism employed to facilitate much of this planning was an extensive linear program (FORPLAN). It was used to quantitatively analyze resource outputs--given certain assumptions and constraints--over a time scale of five decades. With regard to water yield, each Forest was required to estimate water yield under current management, maximum potential yield, minimum yield, and the water yield associated with each of the alternative management scenarios presented in the Forest planning process.

These estimates of current and potential water yield did not take into account ongoing weather modification efforts, as the research results on cloud seeding were found to be inconclusive. Snowpack manipulation was not included in the water yield analysis either, as it was believed to influence runoff timing more than runoff quantity. Forest planning projections of changes in water yield were limited to assessing changes resulting from vegetation manipulation and resulting changes in evapotranspiration.

Some Forests projected water yields by incorporating tables of water yield coefficients within the FORPLAN model. Changes in water yield were then compiled internally as the model made land use allocations and applied various vegetative treatments. Other Forests conducted their water yield analysis outside of the FORPLAN model by applying water yield coefficients to related outputs produced by FORPLAN (e.g., acres of wildfire, miles of road construction, acres of prescribed fire, or acres of timber harvest).

It is important to note here that the methodology used to determine water yield varied from Forest to Forest because of differences in climatological, physical, and biological conditions, and data availability. Some Forests developed water yield coefficients for forested catchments based on research results such as Harr in 1976 and Harr and others in 1979. For more xeric or brush-covered sites, results from Hibbert in 1979 and Burgy and others in 1975 were utilized. Other Forests used similar procedures but made adjustments to account for local conditions not considered in the original studies. In some cases, changes in water yield were simulated by running hydro-meteorologic and vegetation data through computer models such as WET (Williams and Daddow 1982) and HYSED (Silvey and Rosgen 1981). This lack of analytical consistency severely limits the comparability of results from individual Forests, but it is not as critical to the following Region wide summary of potential water yield opportunities. The analysis accomplished by each Forest was as rigorous and accurate as possible for this first cycle of NFMA planning. Despite the methodological differences, the data prepared by the individual Forests provides the best means to assess water yield opportunities from National Forest lands in California. The following sections present the combined results of the water yield assessment for all 18 National Forests, and place these in the context of current management.

Current Water Yield from National Forest Lands

So that all water yield projections may be viewed on an equal basis, current water yield was calculated as the average annual runoff obtained by extrapolating current management practices and policies into the future. The combined water yield values from the Forest's "no action" NFMA alternatives were used to establish the current yield for the Region. In practical terms there is little difference between this projected average yield and actual present yield. Using the "no action" alternative, the 77,300 km^2 of National Forest lands in California are estimated to yield 41 billion m^3 (33.4 million acre-ft.) per year, or 47 percent of the State's total average runoff of 87.6 billion m^3 (71 million acre-ft.) (California Water Atlas 1979). This is an average of approximately 53 cm of water per year over all the National Forest lands in California.

Even though the National Forests are in the more mesic sites, there is still considerable variation in the average annual water yield. Among the 18 National Forests in California, the Cleveland National Forest, headquartered in San Diego, is at the low end, yielding an average of 7.0 cm (2.8 in.) of water over its 1700 km^2 (420,054 acres). At the other extreme is the Six Rivers National Forest, centered in Eureka, which produces an annual average of 165 cm (65 in.) of water over its 3875 km^2 (957,590 acres).

For the purposes of this paper it is useful to divide the National Forests in California into three basic groups--Northern, Sierran, and Southern. These have some basic hydrologic consistency, and they allow general trends to be presented without the overwhelming detail of all 18 Forests. Although water yield should be analyzed by river basin rather than management units, many of the Forests span several basins. Furthermore, the aggregated nature of the water yield values, which were derived from Forest-wide management treatment and vegetation unit allocations as opposed to treatment per watershed, does not render the values readily separable into yields per drainage basin.

The six Forests in the Northern group are the Klamath, Lassen, Mendocino, Modoc, Shasta-Trinity and Six Rivers. These Forests represent 31,181 km^2 (7.70 million acres) or 40 percent of the Region's land base, but provide 60 percent of the annual water yield from National Forest land (79 cm or 31 in. per unit area).

The seven Sierran units include six National Forests--Plumas, Tahoe, Eldorado, Stanislaus, Sierra, and Inyo--and the Lake Tahoe Basin Management Unit. These Forests include 36 percent of the land base (27,560 km^2 or 6.81 million acres) and yield an average of 52 cm (20 in.) of water, or 34 percent of the annual total yield.

The five Forests in the southern group are the Sequoia, Los Padres, San Bernardino, Angeles, and Cleveland. While these Forests incorporate 18,590 km^2 (4.59 million acres) or 24 percent of the land base, they produce an average annual water yield of only 13 cm (5 in.), or 6 percent of the total yield.

It should immediately be recognized that these current National Forest water yield figures are not "natural" or "pristine" yields. Much of the original forest and brush vegetation has been disturbed and manipulated by man. To the extent that the predisturbance vegetation has been replaced by a vegetation type which utilizes less water, or is being harvested on a regular basis, water yields already have increased. On the other hand, fire suppression has allowed tree and shrub species to invade former grasslands and thereby decrease water yield. Since it is unlikely that there will ever be a return to predisturbance vegetative conditions, our baseline is current yield from National Forest System land. Any assessment of potential increases or decreases in runoff must be compared to current management.

Maximum Water Yield Potential

To determine the upper bound for water yield, the Forests were directed to formulate and analyze a Maximum Water Yield alternative. This alternative was defined to be physically and technically feasible, but not necessarily operationally possible. In other words, the Maximum Water Yield alternative was not limited by Forest Service policy, budget considerations, spatial feasibility, or program and staffing requirements. The analysis constraints applied were only those representing management requirements beyond the Forest Service's authority to change (e.g., statutes and regulations rather than internal policy and direction) and the minimum constraints necessary to protect the productivity of the land.

The primary treatments applied within the alternative to maximize water yield were the conversion of brush and low-site timber lands to grass, regular and reoccuring burning or other brush treatments, and intensive timber harvest at minimum rotation ages. These management prescriptions were applied to (a) all of the land base that was capable of sustaining the treatments without impairing the productivity of the land, (b) all land that was administratively available to the Forest (i.e., not withdrawn or under a special designation that would preclude treatment), and (c) all land that was suitable for water yield treatment application (not barren, rock, or water). Whereas this Maximum Water Yield alternative is believed to approximate the upper limit of theoretical water yield potential, it does not pretend to represent optimal multiple-use management.

Frequently the Maximum Water Yield analysis was synonymous with the maximum timber production and maximum range production analyses that were conducted as part of the overall planning effort. Commonly the management prescriptions and treatment schedules associated with maximizing timber and range production are the same activities and schedules which maximize water yield.

A compilation of the Maximum Water Yield analysis indicates that the maximum average annual yield that could be produced from National Forest lands in California is 42.5 billion m^3 (34.5 million acre-ft.). This represents an increase over current yield of 1.4 billion m^3 (1.12 million acre-ft.) per year, or a 3 percent increase. While this appears to be a substantial increase in volume terms, it represents considerably less than 1 percent of the total runoff in California and an areal increase of only 1.8 cm (0.7 in.) of runoff from National Forest System lands.

In contrast to the current distribution of runoff from National Forest lands, this theoretical increase of 1.4 billion m^3 would be distributed as follows:

1. 19 percent or 266 million m^3 (215,500 acre-ft.) from the six Northern Forests; this represents an areal increase of 0.9 cm.
2. 67 percent or 926 million m^3 (751,000 acre-ft.) from the seven Sierran Forests--this is 3.4 cm (1.3 in.) per year on an areal basis.
3. 14 percent or 187 million m^3 (151,400 acre-ft.) from the five Southern Forests, which is 1.0 cm (0.4 in.) per unit area per year.

This analysis indicates that under the assumptions and constraints described above, the greatest potential to increase water yields is in the Sierran Forests. The Northern group of Forests, although they generally have higher average precipitation and presumably a higher average evapotranspiration, have less potential to increase water yields. This is presumably related to analysis constraints imposed on timber harvest and type conversion and because much of the water yield increase potential has already been realized as a result of past and present management activities. For the 18 National Forests in California, the highest potential increases were estimated to be 5.8 cm (2.3 in.) and 5.4 cm (2.1 in.) per year on the Tahoe and Stanislaus National Forests, respectively. The lowest potential increases were on the Modoc National Forest in northeastern California (0.06 cm or 0.02 in.), and the Inyo National Forest (0.07 cm or 0.03 in.) on the east side of the Sierra Nevada.

The Probable Regional Opportunity

A more realistic view of potential water yield increases from National Forest lands in California can be made by comparing total water yields from the composite of the Forest "preferred" alternatives against current yields. The preferred alternative represents the Forests' land allocations and resource management practices which best respond to public issues, management concerns, and resource capabilities. In preparing this preferred alternative, constraints were added to proxy resolution of issues and to assure that the final plan was physically, technically, and operationally feasible. Since the preferred alternatives represent the most likely scenario of future management, they offer the best estimate of future changes in water yield from the National Forests in California.

Total water yield from National Forest lands under the preferred alternative is estimated at 41.6 billion m^3 (33.7 million acre-ft.) per year. This represents an increase of 0.4 billion m^3 (354,000 acre-ft.) or 1 percent above current annual yield. On an areal basis this is approximately 0.6 cm for the entire Region. The respective water yield contributions of the Northern, Sierran and Southern portions of the Region yield more closely resemble distributions typical of the maximum water yield alternative than those represented by current yield conditions. The distribution of this projected increase is as follows:

1. 25 percent (111 million m^3 or 89,600 acre-ft.) of the increased runoff would come from the six Northern Forests; this represents an areal increase of 0.4 cm per year.
2. 55 percent (242 million m^3 or 196,000 acre-ft.) of the increase would come from the seven Sierran Forests; on an areal basis this increase is 0.9 cm per year.
3. 20 percent (85 million m^3 or 68,500 acre-ft.) of the increase in water yield would be derived from the five Southern Forests; this is about 0.5 cm per unit area, or about half the yield increase for the Sierran Forests, but slightly more than could be expected from the Northern Forests.

These projected increases in water yield again differ considerably from current yield, but the proportions are roughly comparable to the estimates obtained under the Maximum Water Yield analysis. Hence the Sierran Forests appear to offer the greatest likelihood for increasing water yields. The projected value of 0.9 cm per year is relatively close to the 0.6 cm estimate by Kattelmann and others, (1983) for the Sierra Nevada Mountains. As in the Maximum Water Yield analysis the largest increase--2.4 cm--is expected to come from the Tahoe National Forest. At the opposite extreme, the Lassen National Forest projects a small decrease in water yield under the preferred alternative.

The important role that management constraints play in influencing the planning analysis output becomes clear when comparing the Maximum Water Yield outputs to those of the preferred alternative. For the Maximum Water Yield analysis only minimal constraints were imposed. For the preferred alternative, additional constraints were imposed by the Forests to assure implementability, resource protection, and responsiveness to public concerns. As a result, the water yields under the preferred alternative are only approximately 42 percent of the maximum yield potential in the Northern group of Forests, 26 percent of maximum potential in the Sierran group, and 45 percent in the Southern group. The reduction in potential water yield for the Sierran group of Forests is greater for several reasons. More constraints were applied to assure implementability and to protect amenity values (riparian ecosystems, old-growth habitat, and visual quality). Reductions were also made in the land base because of special designations (such as research areas, natural landmarks, and other special interest areas) and economic requirements were imposed that precluded vegetative treatments where they were not cost effective. (Much of the upper elevation and east-side lands are believed to fall into this category.)

Future Options and Opportunities

While the projections made under the preferred alternative represent the most realistic estimate for increasing water yield from National Forest lands in California. A variety of other considerations must be taken into account before a water yield policy and management program can be developed.

First, the predicted increases in water yield are estimates and by no means assured. In general, when vegetation density is reduced, or when deep-rooted species are replaced with shallow-rooted species, the amount of water transpired and intercepted by vegetation is less (Bosch and Hewlett 1982). Providing there is rainfall in excess of soil moisture storage and potential evapotranspiration for at least part of the year, runoff should increase. Experience in the Southwest suggests that if mean annual precipitation is not at least 40-45 cm (16-18 in.), there is no increase in water yield (Hibbert 1983). Similarly, in areas with thin soils the potential for augmenting water yield may be negligible, as any type of vegetation can fully exploit the available soil water. In areas with heavy fog drip, the reduced evapotranspiration after forest harvest may not compensate for the reduced fog drip, and water yield can decline (Harr 1980). For areas outside the coastal fog belt and the high elevation zones, higher annual precipitation usually results in higher rates of evapotranspiration, and thereby higher water yield increases from timber harvest or type conversion. Similarly, water yield increases are likely to be greater on high biomass production sites than on poor sites.

Estimating potential increases in water yield is further complicated by factors such as the intensity and spatial distribution of the treatments. A selection harvest does not increase water yield as much as a clearcut, and cut patches high on a slope will, in all likelihood, have a smaller hydrologic effect than patches cut near a stream channel (Anderson and others, 1976). Paired watershed experiments have also indicated that forest cover must be reduced by at least 20 percent before a statistically significant water yield increase can be observed (Bosch and Hewlett 1982). While many of the other site factors might be expected to average out over the large scale of the present analysis, little consideration was taken of the spatial characteristics of the management plans, and actual water yields could be significantly less if the treatments are spatially dispersed.

Another difficulty in managing for water yield is that we can, given enough information, reasonably predict an increase in water yields from National Forest lands in California, but we lack the ability to verify it. The research results which provided the coefficients for the estimated increases in water yield were conducted on small research watersheds where streamflow can be measured to within a few percentage points. In contrast, the accuracy in measuring streamflow on most gauged watersheds is typically 5 to 10 percent. This implies that even with implementation of the Maximum Yield alternative on the highest-yielding National Forest (Tahoe), increased water yields may be just barely measurable. That is, since none of the preferred alternatives will produce yields that even approach those of the maximum yield alternative, it is not reasonable to expect that we would be able to physically measure the projected increases.

Thus the formulation of a Region wide water yield policy will depend to a large extent on whether an increase in water yield that may not be measurable is worth program emphasis and the establishment of management objectives. Will water users accept a theoretical increase in water yield as a basis for National Forest land management? How will the uncertainty in the water yield estimates be dealt with?

These are hardly academic questions when one considers that the average value assigned to water during the Region 5 planning analysis was $66 per acre-foot. On this basis, the total value of water from National Forest lands in California is approximately $2 billion per year. If we accept the Minimum Level Management alternative as a surrogate for pristine conditions, current Forest Service management in Region 5 is already producing an additional 330 million m^3 (268,000 acre-ft.) of water worth almost $18 million. Implementing the preferred alternative on all Forests is projected to increase water yield by an additional 437 billion m^3 (354,000 acre-ft.), which implies an increased resource value of over $23 million. Because the Forest Service does not sell water or obtain royalties for its use, these figures do not represent hard dollars returned to the taxpayer through the treasury. They do, however, provide some insight into the value of the resource and how this value might influence management decisions.

Again it must be emphasized that these economic values are derived from Regional water yield estimates and an average water value. In fact, as discussed in other papers in these proceedings, the value of water is both spatially and temporally dependent. If there is no storage structure, additional water at the time of peak runoff may have little value, whereas increased yield during the summer or fall may be useful for both hydroelectric and consumptive uses. The yield figures are also predicated on average years, but in drought years the actual water yield will be less, and in wet years water yield is likely to increase. Thus water yield management may need to vary within the Region, or even within a single Forest.

Just as there are economic benefits, however, there are also costs that must be considered. For example, if vegetation conversions are made specifically to increase water yield, the cost of the initial treatment and subsequent maintenance treatments must be considered. If harvest rotation ages are reduced to increase water yield, optimum saleable timber volume may be foregone. Management practices compatible with water yield increases may also incur other than economic costs. A reduction in vegetative diversity, in terms of both age classes and species composition, may adversely affect wildlife and visual quality. Again, those management practices that are most likely to increase water yields are generally those which have the potential to adversely affect water quality. The message for the manager, then, is to pursue water yield programs with guarded optimism.

In conclusion, the data presented indicate that the potential water yield increase from National Forest land is at best a short-term answer with only limited influence on California's water supply challenges. All opportunities for water management must be considered and carefully weighed. Conservation, recycling, and groundwater management can all play a role in helping to meet the supply-demand challenge. While economic considerations can help guide the development of a comprehensive, State-wide, multiple-agency water management program, ultimately the program will be a question of relative values, and hence fall into the social and political arena for evolution.

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