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Water Supply as Affected by Micro- and Macro-Watershed Management Decisions on Forest Lands[1]

Abstract

Micro-watershed management decisions pertain to small, unit watersheds and may influence the amount and distribution of water on an annual, seasonal, or single storm basis. In contrast, macro-watershed management decisions pertain to extensive areas that may be the primary source of water for municipalities, industry, and agriculture. Within the structure of a forest environment, the effects of macro-watershed management decisions on water supply are negligible. Little can be gained from managing a large, complex watershed for the specific purpose of increasing water yields or reducing flood flows because forest land topography is heterogeneous, the natural variation of streamflow is large, and the conflict for the variety of goods and services that extensive forest lands can furnish, is so intense. The primary purpose of both micro- and macro-watershed management decisions should not be the control or enhancement of water supplies, but the preservation and amelioration of the basic forest resource—the soil.

Introduction

Water and timber are two of the many products of forest lands. Generations ago, foresters discovered that good management will increase merchantable timber yields. Similarly, watershed researchers found that clearcutting of upland forests results in measurable increases in water yield (Hibbert, 1967), and claimed that appropriate watershed management techniques would increase a forest's yield of water (Rich, 1972). Moreover, watershed administrators postulated that watershed management's primary goal is to increase the land's yield of water and reduce the occurrence of floods (Holscher, 1967).

Although our experiments on small forested watersheds have shown that clearcutting does increase a forest's water yield (particularly during the first year after cutting), the time has come to view these results in a proper perspective—the perspective of the *managed forest* and the water user.

In managing a forest, the administrator establishes a hierarchy of objectives that will include essential and desirable goals. High on this list should be one goal that is very necessary to the perpetual existence of forests and also realistic in its attainment; the goal is soil conservation—maintaining the soil as the medium for both the growth of vegetation and the safe conduct of waters from mountain to valley. On the other hand, in the management of extensive forests, there is another goal that although desirable is not realistic. The thesis of this paper is that, in the great majority of cases, extensive forest lands should not be managed primarily for more water or lower flood peaks because these goals are not realistic and may often conflict with other highly desirable goals.

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The terms, micro- and macro-watershed, relate the size of a watershed to the ground area of a rainstorm event—the cell. Austin and Houze (1972) found that the areal extent of rainstorm cells in New England averaged less than 10 km^2 (less than 4 square miles). For our purposes, we have arbitrarily set the areal limit between micro- and macro-watersheds at 5 square miles.

Small Watersheds and Large Forests

It takes many small watersheds (such as those used in watershed management experiments) to make up a forested area of significant size. For example, the frequently cited Coweeta water-yield experiments were generally conducted on watersheds approximately 0.1 square miles in area, yet a forested area that is a significant water producer normally covers scores, hundreds, or even thousands of square miles, and the ultimate water user may live far beyond the forest's borders.

The fact that cutting the timber growing on one small watershed will increase the water yield of *that* watershed may be immaterial to the water user who depends on the flow from a much larger area. Thus, the implication is clear: managing upland forests for effective increases in water yields means managing the entire forest for water—not a single minor unit; it also means relying principally on clearcutting, because that is the harvesting technique that produces the greatest increases.

We manage forests to increase their benefits to man. If a major goal is more water, then we should demonstrate that the additional amounts that can be obtained are so worthwhile that they override the other objectives of management. On the other hand, if the potential increase is insignificant from a practical point of view, then we should re-evaluate our goals. To assess the value of managing extensive upland forests for more water, we should consider at least two facets of the problem: the relation of possible water increases to the normal expectations; and the limitations imposed by the required management technique.

Streamflow Variability

A universal characteristic of streamflow is its large variability. This fact is shown in Tables 1 and 2 that list data for randomly selected, nonregulated rivers in, respectively, a wide area (20 different states) and a more limited area (the Snake River Basin in Idaho). In these tables variability is expressed by the coefficient of variation (the standard deviation as a percent of the mean). In Table 1, the range of the coefficient is 15 to 96 percent for annual flow, and 23 to 95 percent for peak flow. In Table 2, the maximum listed values are 36 percent for annual flow and 53 percent for peak flow. Data in both tables reveal a high inverse correlation between coefficient of variation and annual yield (statistically significant at the 0.999 percent level of probability after logarithmic transformation).

The significance of this variability is twofold. First, the yearly natural variation is large and may be considerably greater than the average potential change in streamflow regimen that can be achieved by forest management. Second, coordinating timber cutting plans with future weather conditions to attain maximum streamflow benefits is a systems problem that cannot be solved with the data available now or in the foreseeable future. Experimental evidence suggests that increases in streamflow are directly related to quantity of precipitation (Hewlett and Helvey, 1970; Hibbert, 1967; Nakano, 1967). Hibbert (1967) stated the matter succinctly: "Exceptional climatic conditions must prevail if large increases are to be obtained." But forest cutting plans are long-term projections; the forest manager formulates his plans many years before the timber is cut, and we cannot expect him to coordinate his plans with undetermined weather conditions that may exist at a future date on a specific area.

TABLE 1. Variability of 20 widely dispersed, nonregulated rivers in the United States. (Base=15 years)

		Annual flow		Momentary maximum flow			
State	River No.	Average	CV[1]	Average	CV	Area	Source of data[2]
		(inch)	(%)	(csm)	(%)	(sq. mi.)	
Arizona	3935	0.2	96.2	4.21	75.2	886	1733, 1926
Utah	410	6.0	45.1	3.95	60.7	113	1734, 1927
Michigan	1680	7.0	40.3	17.25	48.2	82.9	1727, 1912
Minnesota	1305	7.4	20.5	5.75	47.0	187	1728, 1913
Missouri	9000	8.1	71.5	31.5	58.0	225	1730, 1919
Texas	240	9.4	85.8	30.2	94.8	111	1732, 1922
Indiana	3240	10.6	44.4	12.6	27.6	266	1725, 1909
Colorado	3045	10.9	25.2	4.5	31.4	762	1733, 1925
California	4015	11.0	64.4	13.4	93.7	739	1735, 1931
Virginia	6725	11.8	30.7	11.2	65.5	393	1722, 1903
Wyoming	2970	12.0	24.6	11.1	33.6	85	1729, 1916
Georgia	2065	15.7	32.0	29.3	60.4	134	1724, 1905
Kentucky	2525	15.7	32.0	28.1	38.2	621	1725, 1908
Vermont	1390	18.4	25.3	16.0	39.5	98.4	1721, 1901
Pennsylvania	5430	20.8	28.6	43.9	55.5	272	1722, 1903
Mississippi	4330	22.3	31.3	39.6	63.7	335	1724, 1906
New Hampshire	780	23.2	31.3	20.4	46.9	85.8	1721, 1901
Idaho	3130	24.8	20.2	16.5	23.1	213	1737, 1934
Oregon	2030	46.3	22.1	50.1	62.6	43.3	1738, 1935
Washington	565	127.0	15.0	128.0	37.6	58.1	1736, 1932

[1] CV = coefficient of variation = standard deviation as percent of mean.
[2] USGS Water Supply Paper.

TABLE 2. Variability[1] of randomly selected, nonregulated rivers in the Snake River Basin.

	Annual flow		Maximum instantaneous peak			
River No.	Average	CV[2]	Average	CV	Area	Length of record
	(csm)	(%)	(csm)	(%)	(sq. mi.)	(years)
1965	0.44	31.8	3.43	53.35	5.75	10
1625	0.59	31.1	4.85	30.72	89	7
3175	0.60	35.6	7.62	38.06	19.1	5
1865	0.76	35.2	5.68	41.37	131	6
1200	0.91	27.9	7.57	35.27	114	10
320	0.94	27.7	6.47	32.30	77.1	7
305	1.21	14.9	7.99	29.16	59.2	7
3155	1.24	26.6	14.79	43.00	15.8	9
1870	1.42	32.4	11.70	42.90	55.3	6
120	1.58	17.7	11.98	13.86	378	10
1850	1.65	19.4	9.94	23.84	830	10
115	1.65	24.8	16.98	18.26	160	10
3105	1.82	18.1	13.34	20.84	92	10
3090	1.85	20.5	14.06	30.30	180	10
3085	1.92	19.3	14.34	24.20	138	10
3295	2.76	12.3	21.87	31.05	29.6	10
3405	2.92	14.4	16.72	19.74	996	10

[1] Based on data in USGS WSP 1737.
[2] CV = coefficient of variation = standard deviation as percent of mean.

Forest Management and Annual Water Yield

Let us consider the effects of a clearcutting operation on annual water yields. Although forested areas should be managed for many products, let us assume that a 100 square mile forest is to be managed primarily for more water over a 100-year rotation, with 1 square mile being clearcut each year. Assume further that (1) all parts of the forest are equally productive of water; (2) the cutting operation will result in an exceptional 50 percent increase in streamflow during the first year after cutting; (3) the potential increase will diminish at a uniform rate until no longer apparent after 30 years.

A unit of land that prior to cutting yielded one unit of water annually will now, over the 100-year rotation, yield the sum of:

(a) $(1.5 + 1.0)/2.0$ units of water annually for 30 years; plus

(b) 1.0 unit of water annually for the subsequent 70 years. The average annual yield will be 1.075 units of water.

In its pristine condition, the 100 square mile forest yielded 100 units of water annually; after one rotation it will yield 107.5 units. We must now evaluate the significance of this potential 7.5 percent increase.

Experimental evidence suggests that this increase will not be obtained during years of drought (Lull and Reinhart, 1967). On the other hand, during wet years, the 7.5 percent increase may well be of little value. That leaves the normal years. Before rendering judgment, we should recall that managing forest lands for significantly greater water supplies implies a continuing series of clearcuts; thus, the forest manager has no leeway to consider other forms of timber management (e.g., selection, shelterwood, etc.) that may be more suitable to the forest stand or the terrain; moreover, he may be helpless to change plans to meet emergencies such as fire or disease or insect epidemics.

It appears to me that, in the vast majority of cases, managing a forest for more water may be likened to the actions of a man who lights brief candles to warm a chilly room.

Forest Management and Peak Flow

Suppose the forest manager's objective is to diminish a river's peak flow, thereby reducing flood damages. Two distinct cases should be considered: rainstorms and snowmelt floods.

We have conflicting evidence that clearcutting even a small watershed will substantially increase peak flow from rainstorms. Moreover, if we consider the following two elements: (1) clearcutting does not change the time to peak (Bethlahmy, 1972); and (2) the ground area of cells of high-intensity rainfall is probably less than 10 km^2 (Austin and Houze, 1972); then we may conclude that little can be gained from managing a large forest area for the specific purpose of reducing rainstorm flood peaks.

Snowmelt floods were studied in the Wagon Wheel Gap experiment (Bates and Henry, 1928), performed on two small watersheds, each less than 0.4 square mile. The experiment demonstrated that clearcutting and burning increased the snowmelt flood peak and advanced its date of occurrence. However, the essential question proposed is: "Can the manager of a forest (in contrast to one small subwatershed) advance, delay, or diminish the snowmelt flood peak of the main drainage for that forest area?"

The answer to the question rests on two facts:

1. Normal variation in the date of occurrence of the snowmelt flood is large. For example, at Boulder Creek, Idaho (37 years of data; USGS, WSP 1687, 1736, 1933) the standard deviation of the snowmelt flood date is 22 days. Moreover, experimental evidence indicates that the normal variation in the date of peak flow is considerably larger than the results expected from forest cover manipulation. At Wagon Wheel Gap (Bates and Henry, 1928) clearcutting and burning a 200-acre watershed advanced the peak flow date 3 days and increased the peak flow rate 11 cfs. In contrast, consider the long-term data (Table 3) for the nearby San Juan River and its West Fork tributary. The relative magnitude of the flood data is revealing. A 200-acre clearcut would affect negligibly the crest of the main stream.

TABLE 3. Flood data[1] for Wagon Wheel Gap "B" watershed and the nearby San Juan River and its West Fork tributary.

River	Area Sq.mi.	Day of peak		Peak flow rate (cfs)	
		Average	SD[2]	Average	SD[2]
Wagon Wheel Gap "B"	0.31	140	8	22	15
9-3405	41.2	152	14	778	269
9-3415	87.9	154	15	1380	557
9-3425	298.0	150	19	2816	1372

[1] Source of data: Bates and Henry, 1928; USGS WSP 1683.
[2] Standard deviation.

2. The flood peak on the main stem of a river results from the synchronized convergence of flows from a multitude of subdrainages. To manipulate the peak flow on the main stem would require not only detailed information on flows from each of the subdrainages, but also a good estimate of the possible results of vegetative manipulation. It is not difficult to perceive that the systems management problem for a single forest may be far more complex than the problem associated with managing any of the country's water or power projects. Moreover, it is not inconceivable that management decisions based on a highly probable dearth of hydrologic data and erroneous assumptions could result in higher rather than lower peak flows. But the most important consequence of the forest management program formulated to solve the systems problem is the strong commitment of the forest manager to a long-range clearcutting program that cannot be adjusted to meet the needs of other possible forest management objectives.

The futility of managing a forest for an effective reduction of snowmelt floods may be illustrated by a California drainage where Pacific frontal storms cause floods that are several times larger than snowmelt floods. On the Kaweah River (near Three Forks, California) the two largest recorded rain-caused flows are 80,700 and 52,700 cfs, whereas the two largest snowmelt peaks are only 15,300 and 12,200 cfs (USGS, WSP 1686); the ratio of rainstorm to snowmelt peaks is greater than 4:1 and is considerably greater than the potential effect of forest cutting methods on snowmelt peaks. This example is not unique. Farther inland, the largest floods may in some places be generated by rain-on-snow events. Boulder Creek (northern Idaho near the

Montana border) may again serve as an example; its snowmelt peak normally occurs about May 6 (USGS, WSP 1687, 1736, 1933), but the two largest recorded floods (37 years) occurred in October and December.

Effects of Large-Scale, Unplanned Events

Fire. The 1967 Sundance Fire in northern Idaho (Anderson, 1968) gives a clue regarding the hydrologic effects of large-scale fires. The fire raged over 50,000 acres, principally in the Pack River drainage. Streamflow data (USGS, WSP 1736 and Surface Water Records of Idaho, 1961-1970) were available for three contiguous watersheds: the unburned Priest River drainage (611 square miles); the 50 percent burned Pack River drainage (124 square miles); and the 10 percent burned Deep Creek drainage (133 square miles). Twelve years of data were available for an analysis of covariance: 9 pre-fire and 3 post-fire. The analyses (Table 4) detected no significant change in annual flow, peak flow, or minimum flow during any of the three post-fire years.

TABLE 4. Variance ratios (F) of analyses of covariance to detect changes in streamflow following the 1967 Sundance Fire in Idaho. None of the listed F values is significant at the 5 percent level of probability.

	Pack[1] vs. Priest		Pack vs. Deep		Deep vs. Priest	
Flow	a[2]	b[3]	a	b	a	b
Annual	0.78	4.69	2.95	0.56	0.06	0.66
Peak	2.06	0.14	0.35	0.25	1.27	0.16
Minimum	1.74	0.22	0.10	3.69	1.88	1.57

[1] Percentage of drainage burned: Pack—46%; Priest—0%; Deep—10%.
[2] Test for change in regression coefficient. $F_{05} = 5.32$; $F_{10} = 3.46$.
[3] Test for change in adjusted mean. $F_{05} = 5.12$; $F_{10} = 3.36$.

These results contrast markedly with those reported for small watersheds. Helvey (1972) reported that one year after an uncontrolled fire severely burned three small watersheds (about 2 square miles), substantial increases were noted in annual, seasonal, and peak flows.

Insect Epidemics. In the years following 1941, a catastrophic insect epidemic destroyed many of the trees in national forests near the Continental Divide in Colorado (Wygant and Nelson, 1949). L. D. Love (1955) compared flows of the White (762 square miles) and Elk (206 square miles) rivers, and concluded that death of the dominant forest cover in the White River drainage resulted in a substantial increase (2.28 inches) in streamflow. At the time, Messrs. Bue, Wilson, and Peck (1955) took issue with Love's conclusion. Since then, additional data have become available (USGS, WSP 1313, 1733, 1925) and the analysis of covariance (Table 5) substantiates Love's conclusion that a substantial change did indeed occur in the hydrology of the White River drainage. The new analysis includes the Yampa River drainage that is contiguous to the White and was affected at a later date by the northward migrating insects.

Large-scale, catastrophic events such as uncontrolled insect epidemics are not management tools. Nevertheless, results of the Colorado epidemic indicate that a macro-watershed management decision to alter completely the dominant vegetation (e.g., forest to grass) would significantly affect the water response of the macro-watershed.

To preclude misinterpretation, we should distinguish between forest lands man-

TABLE 5. Results of analyses of covariance to detect changes in streamflow during and after the Engelmann spruce beetle epidemic in Colorado.[1] Base period is 1911-40; Elk drainage is control watershed.

Period	White River drainage Annual increase	White River drainage Level of significance	Yampa River drainage Annual increase	Yampa River drainage Level of significance
	(inch)	(%)	(inch)	(%)
1941-65	1.25	1	0.93	5
1941-45	0.79	<10	0.03	<10
1946-50	1.16	10	0.72	<10
1951-55	1.63	5	1.03	10
1956-60	1.80	1	2.11	0.1
1960-65	0.87	<10	0.77	10

[1] Beetle epidemic started (1941) in the White River drainage and progressed north and east into the Yampa drainage. Damage in the Elk drainage (north of the Yampa) was minor.

aged as forests, and those that will be clearcut and then put to some other use. The arguments presented in this paper apply only to the nonconverted forests.

The Goal of Watershed Management—Soil Conservation

Just as windbreaks protect a farmhouse but do not alter the gross climate of the farm, and city parks lend grace and beauty to a city but affect neither its climate nor its water supply, so watershed management has attainable goals, and others that are not realistic.

We know that land managers can alter the water regime of a small unit of land; the literature is replete with examples. We also recognize that in some cases (e.g., municipal watersheds) the land manager, although not willing to create a "tin roof," is nevertheless primarily concerned with quantity and quality of water. But in most cases, it is evident that the manager of upland forests should not be concerned with water supply *per se*. What is the attainable goal of the upland watershed manager? It is soil conservation: maintaining the soil as a medium for the growth of vegetation, and improving its capacity to conduct water safely from mountain to valley. The ultimate goal of the watershed manager is to perpetuate a healthy watershed.

The watershed manager is the steward and guardian of man's principal resource—the soil. His job is to protect the soil so that future generations may reap the benefits that only a stable soil can offer. The job is by no means a passive activity; it demands an alert manager who actively participates in all land-use planning activities, and who by constant vigilance forestalls potential land damage.

Our past land-use mistakes and blunders are recorded on the land, but this record can be rewritten by the watershed manager. His job includes the arduous task of restoring sick watersheds to their former health, so that they may once again function as an integral part of a healthy environment.

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