

MUNICIPAL WATERSHED MANAGEMENT

Symposium Proceedings



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University of New Hampshire

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FOREWORD

SINCE THE BEGINNING of time, forests and streamflow have been interrelated. Although this relationship has not always been completely understood, it was accepted about the turn of the century that forests generally exert a beneficial influence on streamflow. This concept was based on the fact that forests provide a protective cover on the soil surface, thereby allowing rainfall to infiltrate into the soil rather than flowing over the surface and eroding the soil. History has provided sufficient evidence that, where man has carelessly removed the forest and has denuded the land, devastation occurred. Fertile top soil was lost by erosion; springs ceased to flow; streams dried up; and damaging floods occurred. In some instances, the total result was the demise of the civilization.

Increasing population and improved technology have placed new values on the forest and water resources, particularly in highly urbanized regions. For instance, in the densely populated Northeast, the primary source of most of the surface water is streamflow from forested watersheds. In this area there are more than 2 million acres of land under the control of municipalities, private water companies, and state and federal agencies for management as either water-source areas or protection lands for municipal water supplies. Continuing urbanization has increased water demands and has necessitated that these watersheds be managed for maximum water production, while at the same time there are mounting public pressures to utilize these areas for recreation.

During the past 30 years, forest-watershed-management research has produced a wealth of information about water-yield augmentation and water-quality protection. The purpose of this Symposium was to bring together some of the research and management information that would be useful to municipal watershed administrators in formulating land-management policies.

Financial support for the Symposium was provided by the Institute for Research on Land and Water Resources and the School of Forest Resources, The Pennsylvania State University; New Hampshire Water Resources Research Center, University of New Hampshire; and The Pinchot Institute for Environmental Forestry Research, Northeastern Forest Experiment Station, Forest Service, U.S. Department of Agriculture. Partial support was also provided by the Office of Water Resources Research, U.S. Department of Interior, as authorized under the Water Resources Research Act of 1964, Public Law 88-379.

The program was conducted in cooperation with the American Water Works Association, the New England Water Works Association, and the Pennsylvania Department of Environmental Resources.

A report on the Symposium held 11-12 September 1973 at The Pennsylvania State University, University Park, Pennsylvania, and 19-20 September 1973 at The University of New Hampshire, Durham, New Hampshire.

MUNICIPAL WATERSHED MANAGEMENT

Symposium Proceedings

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CONTENTS

Session I:

Effects of Management Practices on Water Quality and Quantity

COWEETA HYDROLOGIC LABORATORY, NORTH CAROLINA <i>James E. Douglass and Wayne T. Swank</i>	1
FERNOW EXPERIMENTAL FOREST, WEST VIRGINIA <i>James N. Kochenderfer and Gerald M. Aubertin</i>	14
BALTIMORE, MARYLAND, MUNICIPAL WATERSHEDS <i>Edward S. Corbett and Warren Spencer</i>	25
PENN STATE EXPERIMENTAL WATERSHEDS <i>James A. Lynch, W. E. Sopper, E. S. Corbett and D. W. Aurand</i>	32
NEWARK, NEW JERSEY, MUNICIPAL WATERSHEDS <i>Edward S. Corbett and John M. Heilman</i>	47
HUBBARD BROOK EXPERIMENTAL FOREST, NEW HAMPSHIRE <i>James W. Hornbeck and C. Anthony Federer</i>	58
OTHER HYDROLOGIC RESEARCH IN THE NORTHEAST <i>Arthur R. Eschner and Donald L. Mader</i>	66
THROUGHOUT THE NORTHEAST—AN OVERVIEW <i>Kenneth G. Reinhart</i>	79

Session II:

Programs in Municipal Watershed Management

BALTIMORE MUNICIPAL WATERSHEDS <i>Brent A. Hartley</i>	84
BETHLEHEM MUNICIPAL WATERSHEDS <i>John C. Anspach</i>	98
METROPOLITAN BOSTON'S MUNICIPAL WATERSHEDS <i>Bruce A. Spencer</i>	105
HARTFORD MUNICIPAL WATERSHED <i>Irving A. Hart</i>	111
PROVIDENCE MUNICIPAL WATERSHED <i>Hans T. Bergey</i>	115
PRIVATE MUNICIPAL WATERSHEDS <i>James F. Heagy</i>	124
NATIONAL FOREST WATERSHEDS <i>Gordon Stuart and William M. Alden</i>	129
CONSULTANT'S ROLE IN MUNICIPAL WATERSHED MANAGEMENT <i>Curtis H. Bauer</i>	135

Session III:

Management Considerations

MEETING CURRENT AND FUTURE DRINKING-WATER QUALITY STANDARDS <i>Kenneth E. Shull</i>	142
RECREATION PROBLEMS AND OPPORTUNITIES <i>Herbert E. Echelberger, George H. Moeller, and Raymond E. Leonard</i>	154
SOIL CONSERVATION—A PARAMETER OF QUALITY WATER YIELDS <i>David K. Bowen</i>	162
USE OF HERBICIDES IN TIMBER AND RESERVOIR MANAGEMENT <i>Roy R. Johnson</i>	167
MULTIPLE-USE MANAGEMENT ON MUNICIPAL WATERSHEDS? ONE WAY TO FIND AN ANSWER <i>David P. Worley</i>	170
STATE TECHNICAL ASSISTANCE PROGRAMS <i>Alfred Darrach</i>	181
SUMMARY OF MUNICIPAL WATERSHED-MANAGEMENT SURVEYS IN THE EASTERN UNITED STATES <i>George E. Dissmeyer, Edward S. Corbett, and Wayne T. Swank</i>	185
RESEARCH NEEDS RELATED TO MANAGEMENT OF MUNICIPAL WATERSHEDS <i>Roger R. Bay and J. S. Krammes</i>	193

over 10 inches can occur during any month, but rainfall is less than 2 inches per month only 5 percent of the time. Precipitation varies widely over short distances because topographic features modify wind patterns and rainfall distribution. Also, an orographic effect causes an approximate 13-inch difference in rainfall between low and high elevation watersheds.

The maximum and minimum air temperatures on record are 98 and -15°F . Annual maximums may occur anytime between June and the end of September, and minimums can occur between November and March. The average maximum and minimums are 92° and 1°F , respectively; and the mean annual temperature is 54.7°F . Pan evaporation averages 35 inches and has varied from 31 to 39 inches $\pm$ a standard error of 0.35 inch. Less than 1 inch of pan evaporation is common in December and January; and between May and October, pan evaporation ranges from about 3 to 5 inches per month.

Geology, Physiography, Soils

The laboratory is in the Nantahala range of the Blue Ridge Mountains. Underlying rock is classified as Carolina gneiss from the Precambrian era. Granite gneiss, mica gneiss, and mica schists are all represented and have undergone complex folding.

Topography is steep, and elevations range from 2,220 to 5,223 feet. Average slope of the basin (max.-min. elevation/distance) is 19 percent, but individual watersheds are considerably steeper. Slopes in places exceed 100 percent, and some rock outcrops are found on steep slopes at high elevations.

Soils vary because of differences in parent material, topography, and elevation. At lower elevations, soil horizon development is complete, but immature soils are found on higher, cooler sites.

Soils are highly permeable; infiltration rates frequently exceed 50 inches per hour, and runoff over the soil surface is virtually unknown on undisturbed sites. The regolith is deep; drilling has shown that porous material is sometimes over 70 feet deep and averages perhaps 20 feet deep.

Vegetation

Basin vegetation was originally dominated by American chestnut, oak, and hickory. In 1909, several small logging operations began and continued intermittently until 1918, when the land was acquired and timber rights reserved by the Forest Service. Logging continued until 1923, but no trees smaller than 15 inches diameter on the stump were cut. Cruises made in 1933 showed that basal area at mid and upper elevations often exceeded 150 square feet/acre. Between 1930 and 1945, chestnut was blight-killed, and basal area was reduced on all watersheds.

Currently, about 60 species of hardwoods are indigenous in the basin; and hemlock, pitch pine, and eastern red cedar are the native conifers. The type groups, as described by the Society of American Foresters, are oak-hickory, pitch pine-oak, northern red oak, and yellow-poplar. The abundant understory is composed of hardwood saplings, mountain laurel, rhododendron, blueberry and huckleberry, azalea, and less numerous trees and shrubs. Ground cover consists of grasses, anemones, asters, bedstraw, ferns, trilliums, violets, mayapples, and mosses.

TREATMENT EFFECTS ON WATER YIELD

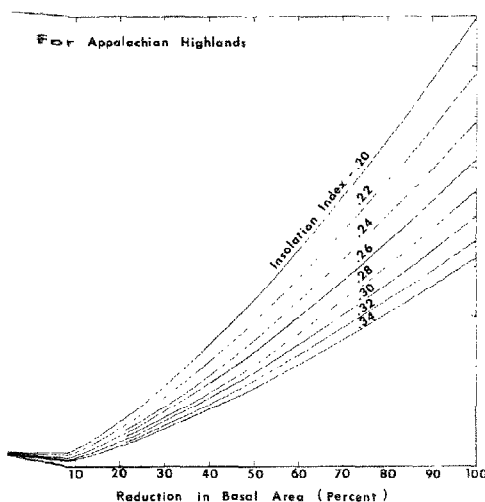
Water yields have been measured at Coweeta after cutting or deadening part or all of the vegetation and after conversion from hardwood to another cover type.

In his survey paper, Hibbert (1966)

cluded that the increase in streamflow after removal of hardwood cover at Coweeta was proportional to the amount of cover removed. He also noted that the streamflow increase was much greater in north- than for south-facing watersheds. Prediction of the increase in flow after cutting or deadening the forest can be improved simply by grouping watersheds by aspect.

To explain the difference in streamflow observed when north- and south-facing watersheds are cut, Swift (1960) studied the theoretical solar energy available for evapotranspiration. He found little difference in incoming extraterrestrial radiation during the growing season but considerably more radiation in the south- than north-facing watersheds during the dormant season. Total and potential radiation patterns were found to be similar in form to theoretical patterns (Swift 1972), and we hypothesized that streamflow response to cutting was inversely proportional to solar energy input.

Figure 1.—First-year increase in streamflow determined from the percent reduction in forest stand basal area and the insolation index of the watershed.



Using data on basal area cut and potential insolation from Coweeta, Hubbard Brook, Fernow, and Pennsylvania State University watersheds, a prediction equation was derived for the first-year streamflow increase after cutting hardwood forests. Potential insolation on a map area basis was calculated by the methods of Lee (1963) and Swift (1973).

The model for predicting the first-year change in yield is:

$$\Delta Q = a \left(\frac{X_1}{X_2} \right)^b$$

where ΔQ is the first-year increase in streamflow in inches, X_1 is the percent basal area cut, X_2 is potential annual insolation in langleyes (insolation index), and a and b are coefficients. For convenience, the insolation index for each watershed was coded by multiplying by 10^{-6} . Regression analysis yielded the equation

$$\Delta Q = .00224 \left(\frac{X_1}{X_2} \right)^{1.1463}$$

This equation whose r^2 is 0.89, is graphically represented in figure 1.

To predict the increase in streamflow for any year after silvicultural practices are applied, the first-year increase, the duration of the increase, and a model for describing the time-duration relationship of the increases in streamflow are required. Douglass and Swank (1972) presented the time-duration model for a regrowing forest as:

$$\Delta Qi = a + b(\log Ti)$$

where ΔQi is the increase in flow in year i , a is the first-year increase, Ti is the i th year after treatment, and b is a coefficient. The total duration of an increase in streamflow with regrowth allowed is estimated from the relationship between the first-year streamflow

increase and duration of increased flow observed on experimental watersheds. The duration of the increase is approximately equal to 1.57 times the first-year yield increase.

To illustrate the use of these equations, consider a hardwood forest, a 50-percent basal area cut, and a potential insolation of 260,000 calories/square centimeter. Using Equation 1, the first-year yield increase is

$$\Delta Q = .00224 \left(\frac{50}{.26} \right)^{1.4462}$$

$$\Delta Q = 4.49 \text{ inches}$$

The duration of the increase is estimated to be

$$T = 1.57 \text{ (first-year increase)}$$

$$T = 1.57 (4.49)$$

$$T = 7.04 \text{ rounded to 7 years}$$

The estimating equation for a yield increase in any year i is obtained by solving Equation 2 for b when $T = 7$ and $\Delta Q_7 = 0$. Thus,

$$\Delta Q_7 = a + b(\log T_i)$$

$$0 = 4.49 + b(\log 7)$$

$$b = -5.31$$

and the final equation becomes

$$\Delta Q_i = 4.49 - 5.31(\log T_i).$$

The expected yearly increases in streamflow are

Year after cutting	Increase, in inches
1	4.49
2	2.89
3	1.96
4	1.29
5	.78
6	.36
Total	<u>11.77</u>

Now consider the second type of experiment. Conversions of vegetative types at Coweeta have produced dramatic changes in streamflow, which should

be of interest to managers of municipal watersheds.

In two experiments, conversion of hardwoods to white pine on a north- and south-facing watershed greatly reduced streamflow. For the first 6 years, the streamflow increases were about as expected for clearcut hardwood forests. Then, streamflow on both watersheds declined at a rate of 1 to 2 inches per year for the next 3 years. By age 10 years, the white pine was using more water than the original hardwood cover (Swank and Miner 1968).

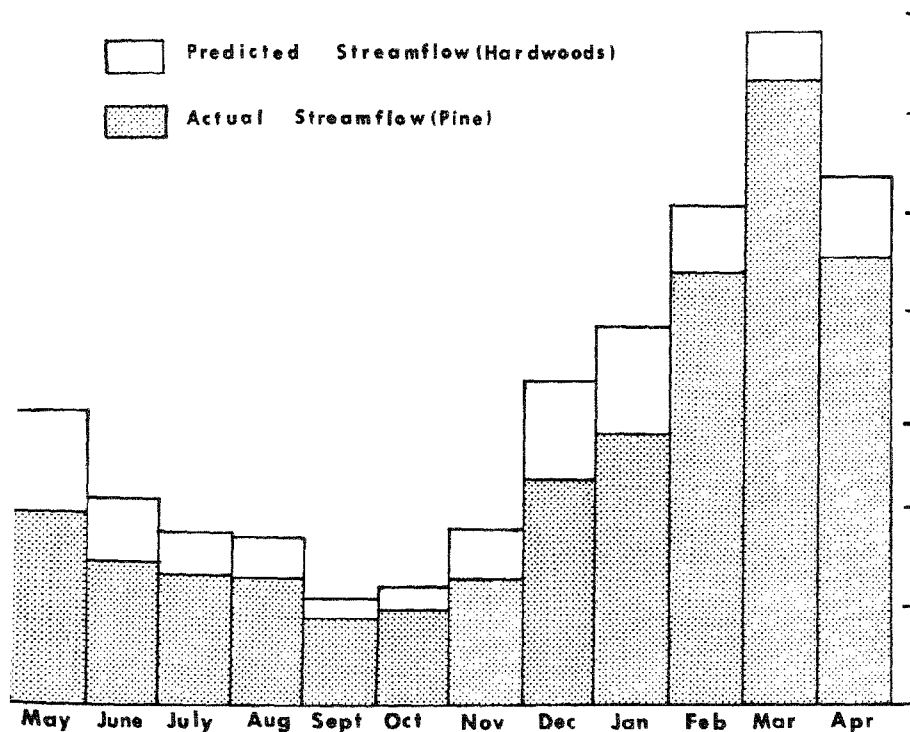
Over the last 4 years, the rate of streamflow reductions has tended to level off; but in 1973, when the pines were about 16 years old, flow was approximately 8 inches (25 percent) less than the flow expected if the watersheds had remained in a hardwood cover.

On a south-facing watershed, monthly streamflow reductions of 0.5 to 1.1 inch were observed during the dormant and early growing season (November through June) of 1972-73 (fig. 2). Streamflow was reduced about 0.4 inch in July and August, and reductions in flow tapered off to about 0.2 inch in September and October. Although reductions appear to be small in August through October, streamflow is normally lowest during these months. These reductions represent a 16- to 30-percent decrease in monthly flow from the previous hardwood cover. Similar reductions in streamflow were observed for the north-facing white pine-covered watershed.

The greater evaporative losses from pine than from hardwoods are due to greater interception and transpiration losses. Experimental data derived from Helvey's studies (1967) showed that interception and subsequent evaporation of rainfall is greater for pine than hardwoods during the dormant season. Interception loss is a function of the plant

Figure 2.—Changes in streamflow after a south-facing hardwood-covered watershed was converted to white pine in 1957.

Coweeta Watershed 1
May - April 1972 - 73



the area, and the surface area of the hardwood stand is drastically reduced by leaf fall. Thus, in the dormant season, the ratio of leaf surface area to ground area (leaf area index or LAI) for hardwoods is less than for conifers. Swank and Schreuder (1973) stated that the LAI was 9.9 for the hardwoods on Watershed 1 in the winter of 1972. Consequently, less precipitation intercepted by the soil under pine caused lower streamflow during the dormant season. Further reduction in streamflow is attributed to greater transpiration within the pine canopy, at least during certain months.

In spring and summer, atmospheric conditions favor high evaporation. In

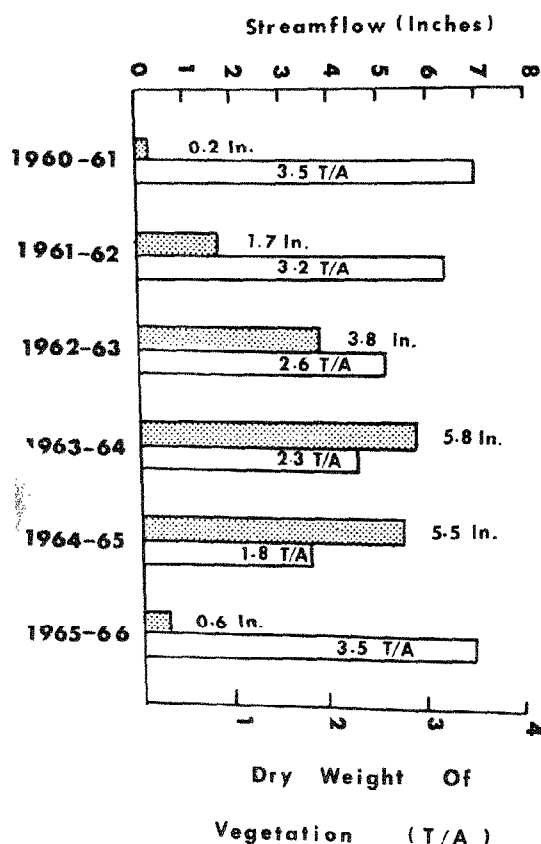
April and May, when pine is in full leaf and hardwoods are leafing out, combined interception and transpiration losses are much greater from pine. Even after hardwoods are in full leaf, maximum LAI is only about 6 (Whittaker and Woodwell 1967) compared to a peak LAI of 17.8 for the pine on Watershed 1 (Swank and Schreuder 1973). Although Raber (1937) concluded that the summer transpiration rate of hardwoods per unit of leaf area is greater than for conifers, transpiration per stand may be greater for pine because of the larger transpiring surface. Greater transpiration and greater interception losses cause streamflow from white pine forests to be lower than from hardwood

forest throughout the year. The conclusion is inescapable: If maximum water yield is desired, conifers are a poor choice for a watershed cover.

Conversion from hardwood to grass also significantly alters streamflow. Hibbert (1969) removed merchantable timber from a 22-acre hardwood forest, prepared a seedbed by burning, grubbing, and harrowing, applied 3 tons of lime and 1 ton of 2-12-20 fertilizer per acre, and seeded Kentucky 31 fescue at a rate of 20 pounds per acre. An increase in water yield was expected, but it did not

appear in the first year after treatment. Grass productivity was very high — 3.5 tons of dry matter per acre — but it declined to 1.8 tons per acre by the end of the 5th growing season. As grass productivity declined, streamflow increased. During the 4th and 5th year under grass, the watershed yielded over 5 inches of extra water each year (fig. 3). To verify the inverse relation between change in streamflow and grass productivity, the grass was refertilized in 1965; productivity increased to 3.5 tons per acre, and streamflow again dropped back to that expected from a hardwood cover. Grass also appeared to evaporate more water in the spring and less water in the late summer than the original forest cover. Thus, a grass cover of low vigor can significantly increase streamflow.

Figure 3.—Annual yield change and gross dry-matter weight per acre after a hardwood-covered watershed was converted to grass.

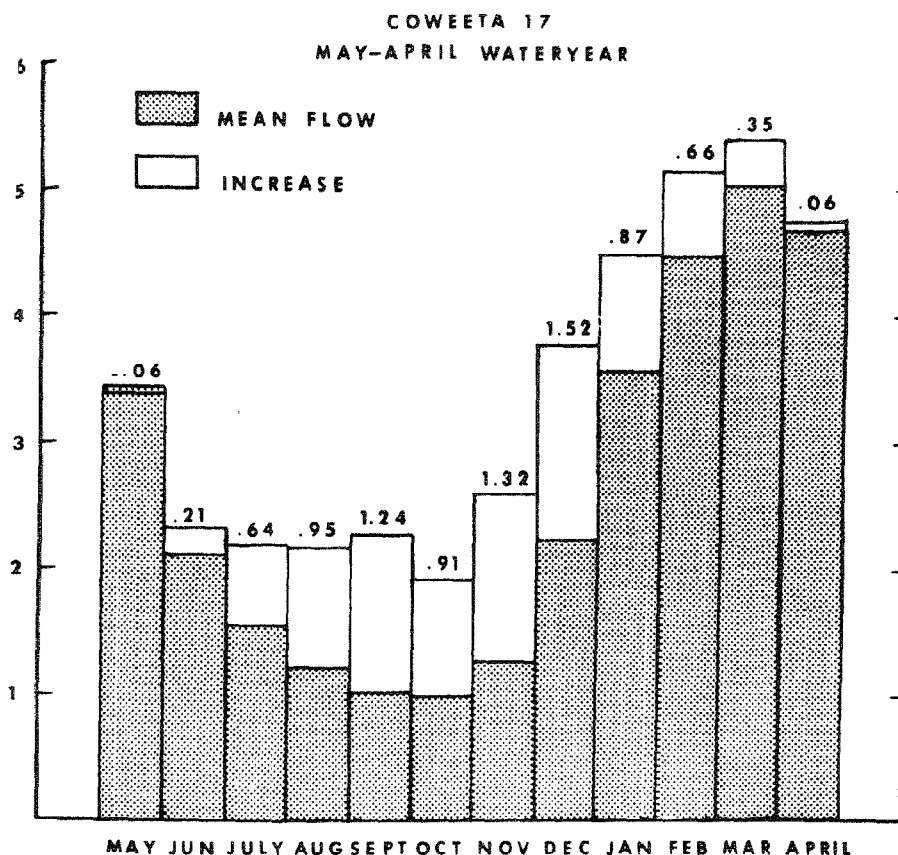


TREATMENT EFFECTS ON DISTRIBUTION OF FLOW

Douglass and Swank (1972) presented data on average monthly flow rates before trees were cut and during 7 years when sprouts were cut annually from Watershed 17 (fig. 4). These data are representative of other experiments at Coweeta. A forest cover had no measurable effect on monthly flow when soil storage space was charged with moisture (season of high flows). Before and after clearcutting, the watershed contained nearly equal volumes of water during late winter and early spring, and the hydrologic response was about the same.

As the growing season progressed, however, the difference in moisture storage between the cut and forested conditions progressively increased. Drainage reaching the stream shortly after a rain was proportional to the moisture storage difference between the forest and clear-cut conditions. Streamflow increases began in about June and increased in magnitude as the growing season advanced. In September, October, and November,

Figure 4.—Average monthly streamflow and the increase in flow during 7 years of annual recutting on Watershed 17.



streamflow was increased by 100 per-

This is precisely the season when and for water is greatest and unaltered flow is lowest. Large increases continued until December and then declined as the difference in moisture storage between clearcut and forested conditions declined. For treatments which use less drastic storage differences, large increases occur more quickly and increases are not delayed as late into the year.

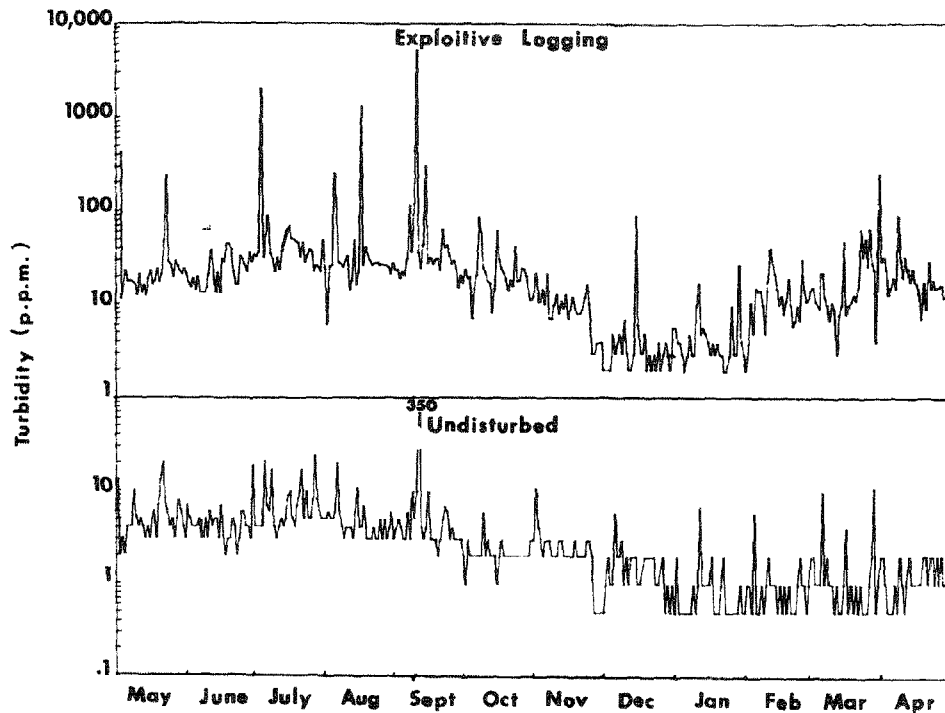
Timing of flow can be improved or delayed by treating the vegetation. Those practices which increase total annual streamflow produce large quantities of extra

water during the low-flow periods. Conversely, streamflow during low-flow months is reduced by practices which decrease annual streamflow. Conversion to pine reduces flows during all months primarily because of interception and transpiration differences between pine and hardwoods at that stand age.

TREATMENT EFFECTS ON WATER QUALITY

The criteria of water quality vary with the intended use of the water. At Coweeta, turbidity, temperature, and mineral content of water have been measured.

Figure 5.—Comparison of turbidity from an exploitive logging and an undisturbed hardwood-covered watershed from May 1947 through April 1948.



Between 1942 and 1954, a 212-acre watershed was clearcut, and the logger selected road sites and logging technique. Roads were poorly constructed, often traversing steep grades without proper drainage, water bars, or grass cover. Between storms, turbidity on the logged watershed was much greater than from an undisturbed control watershed; and during storms, turbidity on the logged watershed was 10 to 20 times greater (fig. 5). Maximum turbidity recorded for the year was 5,700 ppm, but measurements were usually taken at about the same time each day and it is probable that maximum turbidity was often much greater. On a watershed that was logged properly from well-designed roads, turbidity increased only slightly.

Cutting where soils were not disturbed by roads or skidding and converting from hardwood to pine did not discernibly increase turbidity. In general, we at Coweeta have concluded, as did Packer (1966), that poorly designed and poorly located roads are the main cause of deterioration in water quality.

A 23-acre forested watershed at Coweeta was cut in 1940; and 6 acres were planted to corn, 7 acres were put into pasture, and 10 acres were allowed to grow back to hardwood coppice. Before treatment, soil losses averaged 156 pounds per acre. Dils (1953, 1957) found that soil losses varied from about 400 to over 18,000 pounds per acre during the 13 years of farming. Since eroded soil came from the corn field, pasture,

and stream channel, losses cannot be assigned to any single source. After the pasture and corn field were planted to grass and later to white pine and yellow-poplar, soil losses for the next 15 years averaged only 128 pounds per acre annually compared to 2,047 pounds per acre for the farming period.

Manipulation of the forest can also change water chemistry.¹ Mineral cycling in four contrasting ecosystems has been studied intensively at Coweeta since 1968. Annual budgets and seasonal fluctuations of Ca^{++} , Mg^{++} , K^{+} , and Na^{+} for watersheds with a hardwood, a grass-to-forest succession, a hardwood coppice, and an eastern white pine cover were reported by Johnson and Swank (1973). Cation budgets varied by watershed, but drastic alterations of the forest ecosystem have not caused a long-term loss of cations by erosion or drainage waters.

Relatively minor changes in mean annual concentrations of cations and anions on Coweeta watersheds treated in a variety of ways support these findings (table 1). Of the cations studied, only calcium concentrations from two watersheds to which lime had been applied were appreciably higher than would be expected from undisturbed watersheds. Of the anions studied, only $\text{NO}_3\text{-N}$ increased in concentrations after treatment. Mean annual concentration of $\text{NO}_3\text{-N}$ on treated watersheds was from about 4 to 150 times that on undisturbed watersheds, but the maximum concentration observed (grass-to-forest succession) was only 1.23 ppm. The

next-to-highest concentration of 0.25 ppm was observed after hardwood-to-white pine conversion, compared with 0.002 to 0.013 ppm for undisturbed watersheds.

The concentrations of all cations and anions on treated watersheds are quite low, and the increased export of nutrients is insufficient to create pollution problems for drinking water or to degrade fertility. Similar observations on other, more recent clearcuttings in western North Carolina appear to support the findings at Coweeta, but data collection is not complete.

Herbicides and pesticides used in forestry operations can pollute water. On a grass-covered watershed, the grass cover was killed with atrazine and paraquat in May 1966 and re-treated with atrazine and 2,4-D in July of the same year (Douglass *et al.* 1969). During the first spraying, grass hanging directly over the stream was treated, and low concentrations of atrazine and paraquat were detected in streamflow. Concentrations of atrazine were highest (20 to 40 ppb) during rains immediately after spraying, when intercepted water carried herbicides directly into the stream. After 30 days, concentrations of atrazine were always less than 10 ppb, and paraquat could no longer be detected.

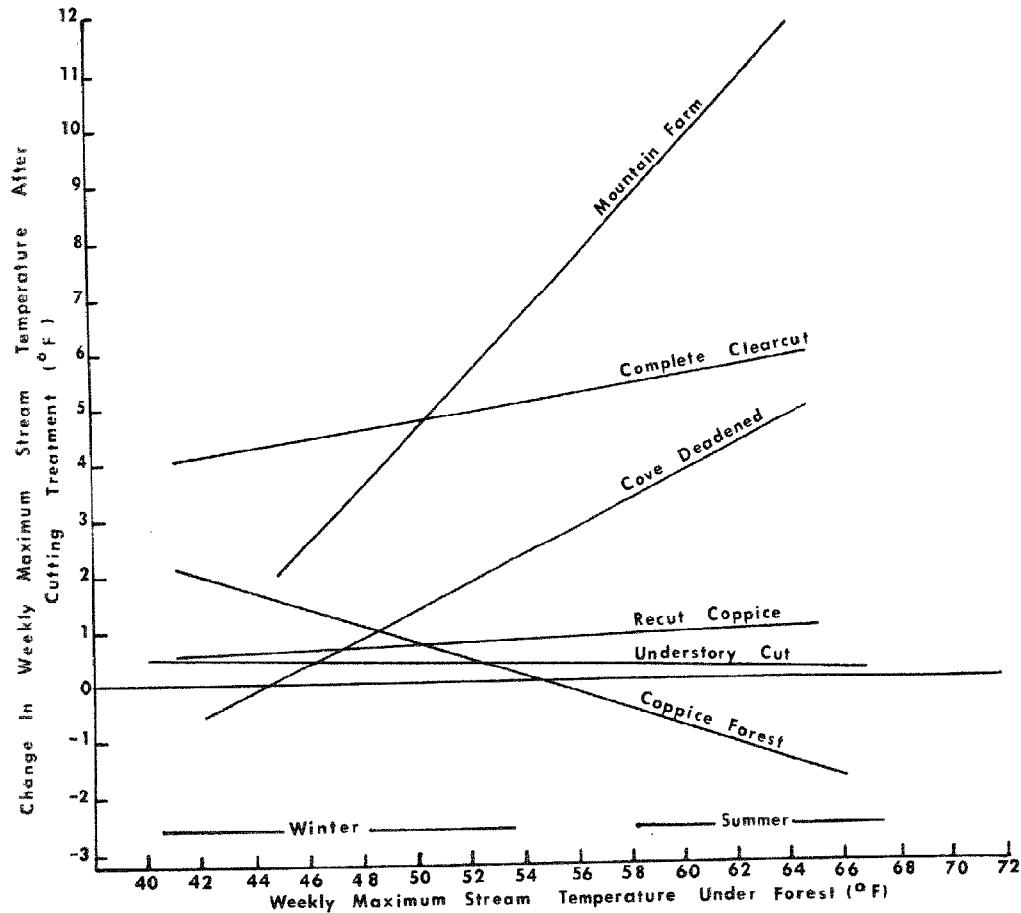
During the second spraying, a 10-foot strip on either side of the channel was left unsprayed. No increase in atrazine and no trace of 2,4-D was detected after the second treatment. Similarly, Grzenda *et al.* (1964) observed that when entire watersheds were broadcast-sprayed from fixed-wing aircraft to control elm spanworm, low levels of DDT were detected in streams. But when spraying was restricted mainly to ridges and slopes away from streams, DDT was not detected in the streams. Since most water reaches the streams at Coweeta through the soil rather than as overland flow, water quality is adequately pro-

¹Water chemistry analyses supported in part by the Southeastern Forest Experiment Station, Forest Service, United States Department of Agriculture, and in part by the University of Georgia, Eastern Deciduous Forest Biome, US-IBP, funded by the National Science Foundation under Interagency Agreement AG 199, 40-193-69 with the Atomic Energy Commission—Oak Ridge National Laboratory.

Table 1.—pH and concentration of selected ions, in ppm, May 1972 through April 1973.

WS No.	Treatment	pH		NO ₃ -N		NH ₄ -N		PO ₄ -P		Cl		K		Na		Ca		Mg	
		Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
1	15-yr-old white pine	4.90		.001		.001		.001		.560		.187		.929		.620		.200	
3	7.4 acres in 16-yr-old poplar	6.71	7.40	.029	.077	.003	.020	.006	.022	.660	.920	.580	1.189	1.111	1.748	.731	1.125	.368	.523
	5.4 acres in 16-yr-old white pine	5.40		.001		.001		.001		.480		.177		.741		4.820		.379	
	10 acres in 32-yr-old coppice (old mountain farm)	6.87	7.50	.015	.038	.004	.033	.006	.022	.568	.970	.441	.935	1.046	1.575	6.057	7.317	.485	.680
6	Grass-to-forest succession	6.73	7.30	.619	1.230	.004	.010	.007	.030	1.381	2.490	.588	1.909	1.140	1.374	1.118	1.493	.640	.820
13	10-yr-old coppice	6.63	7.40	.044	.084	.003	.014	.004	.013	.491	.672	.426	.922	.698	1.220	.501	.849	.285	.617
17	16-yr-old white pine	6.72	7.40	.154	.249	.004	.012	.012	.036	.485	.675	.446	.946	.835	1.338	.577	.827	.247	.374
28	180 acres clearcut, 80 acres thinned, 96 acres undisturbed	6.66	7.40	.094	.208	.003	.017	.004	.020	.493	.880	.465	1.051	.901	1.692	1.021	1.319	.454	.675
37	10-yr-old coppice	6.58	7.35	.149	.246	.004	.038	.006	.095	.442	.783	.424	.975	.667	1.231	.742	1.128	.312	.637
2	Undisturbed hardwoods	6.91	7.85	.004	.017	.002	.020	.006	.020	.673	.922	.589	1.368	1.351	1.676	.713	1.036	.359	.552
14	Undisturbed hardwoods	6.76	7.30	.004	.024	.004	.031	.005	.017	.544	.738	.369	.817	.772	1.087	.513	1.186	.232	.416
18	Undisturbed hardwoods	6.77	7.35	.003	.014	.004	.022	.005	.018	.554	.880	.479	1.022	.930	1.424	.685	.891	.317	.457
21	Undisturbed hardwoods	6.55	7.35	.003	.016	.004	.024	.004	.029	.490	.800	.381	.755	.717	1.097	.530	.864	.228	.364
27	Undisturbed hardwoods	6.60	7.60	.013	.050	.005	.024	.004	.018	.499	.675	.243	.511	.529	.841	.384	.662	.209	.307
32	Undisturbed hardwoods	6.45	7.45	.003	.015	.003	.013	.004	.013	.491	.722	.322	.843	.665	.940	.550	.815	.295	.381
34	Undisturbed hardwoods	6.76	7.50	.002	.019	.003	.024	.006	.019	.556	.775	.429	1.065	.931	1.322	.749	.922	.353	.453
35	Undisturbed hardwoods	6.77	7.30	.008	.030	.003	.030	.004	.014	.545	.778	.342	.740	.824	1.352	.670	1.244	.277	.348

Figure 6.—Effect of six cutting treatments on weekly maximum stream temperature at the Coweeta Hydrologic Laboratory.



tected by the simple precaution of not spraying streamside vegetation where throughfall or stemflow can flush chemicals directly into streams or ditchlines.

Increased stream temperature can adversely affect or even kill trout. Swift and Messer (1971) summarized the effects of 6 watershed treatments at Coweeta on stream temperature (fig. 6). Where forest types and all understory vegetation were completely cut, maximum stream temperatures increased from the normal 66°F to 73°F or more. Mountain farming raised summer maximum temperatures over 12°F above

normal. In other treatments where streambank vegetation was not cut or had regrown, summer maximum temperatures were unchanged or even lowered slightly. Swift and Baker (1973) found that if a buffer strip is retained to shade the water surface, temperatures of streams are not adversely affected by treatment of the rest of the watershed.

SUMMARY

The watershed experiments at Coweeta provide numerous detailed conclusions that are useful to watershed managers. Some of the most significant are:

1. Cutting the mixed hardwood cover in the southern Appalachians increases annual streamflow in proportion to the amount of cover removed.
2. The streamflow increase after cutting is approximately twice as great from north-facing watersheds as from south-facing watersheds. Equations for predicting changes in water yield after cutting are based on the proportion of the stand basal area cut and the potential insolation of the watershed.
3. Converting Coweeta watersheds from hardwoods to white pine greatly reduces streamflow.
4. Converting a hardwood to a low grass cover can significantly increase streamflow.
5. Timing of streamflow can be improved or degraded by treating vegetation. When annual flow is increased, extra water is produced during low-flow periods; those practices that decrease annual flow reduce streamflow during the low-flow months.
6. Poorly designed and poorly located logging roads are the main source of high turbidities connected with logging operations. Road specifications that minimize turbidity are available for mountainous terrain.
7. Water pollution from sprayed herbicides and pesticides can usually be prevented by not spraying streamside vegetation.
8. Stream temperatures are not increased by forest cuttings if a buffer strip is retained to shade the stream.
9. Water chemistry studies to date provide no evidence that forest cuttings in the mountains of North Carolina have rendered streamflow less fit for human use or degraded soil fertility.

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EFFECTS OF MANAGEMENT PRACTICES ON WATER QUALITY AND QUANTITY: FERNOW EXPERIMENTAL FOREST, W. VIRGINIA

by JAMES N. KOCHENDERFER and GERALD M. AUBERTIN, *Research Forester and Research Soil Scientist, USDA Forest Service, Northeastern Forest Experiment Station, Timber and Watershed Laboratory, Parsons, West Virginia.*

ABSTRACT. Results of 22 years of forest hydrology research on the Fernow Experimental Forest are reviewed. Forest influences were measured on quantity and timing of streamflow and on parameters of water quality such as turbidity, temperature, specific conductance, pH, alkalinity, and nutrient concentrations. These results indicate that it is currently not practical to manage forest land for both sustained increased water yield and merchantable timber products, and that forest land can be managed for a variety of uses without impairing water quality if these uses are regulated intelligently.

THE FERNOW Experimental Forest, near Parsons, West Virginia, was established in 1934 for forest research and the demonstration of its results. Containing 3,640 acres and representing the major hardwood types found in the central Appalachians, the Forest is located in the unglaciated Allegheny Plateau region of north-central West Virginia. This section of the Allegheny mountains is characterized by steep mountains and narrow valleys. The average elevation of the study area is about 2,500 feet above sea level. The predominant soil is Calvin silt loam (Losche and Beverage 1967) underlain with fractured sandstone and shale of the Hampshire (formerly Catskill) formation. Soil depth is normally less than 5 feet.

Timber stands on the watersheds before treatment were 40 to 50 years old, with many scattered older residuals. Vegetation on the watersheds fits into Core's (1966) *mixed hardwood forests* floristic province. Common tree species on the better sites are yellow-poplar (*Liriodendron tulipifera* L.), sugar maple (*Acer saccharum* Marsh.), black cherry (*Prunus serotina* Ehrh.), white ash (*Fraxinus americana* L.), basswood (*Tilia americana* L.), and red oak (*Quercus rubra* L.). The dominant tree species on the poorer sites are various species of oak (*Quercus* spp.), hickory (*Carya* spp.), sourwood (*Oxydendrum arboreum* (L.) DC.), and sassafras (*Sassafras albidum* (Nutt.) Nees.). Sawtimber volumes varied from 7,000 to 13,000 board feet per acre.

The growing season extends from 1 May through 31 October, the dormant season from 1 November through 30 April. Annual precipitation is evenly distributed between the dormant and growing seasons, averaging 56 inches on the control watershed for a 21-year period. Annual runoff from the control watershed for the same period of record averaged 24 inches, 6 inches during the growing season and 18 inches during the dormant season. Potential evapotranspiration on the Fernow Forest was estimated to be 22 inches per year (*Patric and Goswami 1968*).

THE STUDIES

We have eight gaged watersheds on the Fernow Forest (fig. 1), ranging in size from 38 to 96 acres. Collection of

streamflow and climatic data began on watersheds 1 to 5 in 1951, on watersheds 6 and 7 in 1957. Stream discharge, turbidity, pH, alkalinity, specific conductance, and temperature data were collected from each watershed for a period of 6 years. Data obtained during this calibration period were used as a base for evaluating changes due to treatment.

After calibration, one of the original five watersheds (No. 4) was retained as an untreated control, and the others underwent different cutting treatments. These treatments and their hydrologic effects have been described by Reinhart et al. (1963). Watersheds 6 and 7 were treated in 1963; results of this experiment have been presented by Patric and Reinhart (1971). Water-quality studies were expanded in 1969 to include measurements of calcium, magnesium, potassium, sodium, phosphate, nitrate-N, ammonium-N, sulfate, iron, manganese, zinc, and copper. A summary of the watershed treatments is presented in table 1.

Stream discharge is measured with 120° V-notch weirs. Precipitation is measured in a network of 4 recording gages and 14 standard 8-inch rain gages. Water temperatures are measured with both recorders and maximum-minimum thermometers. Water samples are obtained weekly by grab sampling, with some additional sampling during storm periods.

WATER QUALITY

Of the many water-quality parameters studied, the best known and most easily obtained are turbidity, temperature, specific conductance, pH, and alkalinity.

Turbidity

Bare soil exposed by road-building and to a much less extent by log landings, has long been recognized as the major source of stream sediment associated with logging operations. Turbid

Figure 1.—Location of the watersheds on the Fernow Experimental Forest, Parsons, West Virginia.

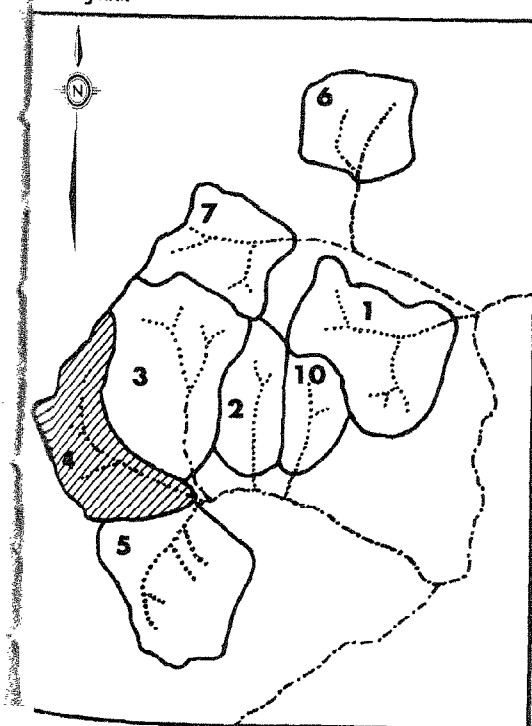


Table 1.—Summary of treatments on Fernow watersheds

Watershed number and size (acres)	Type of treatment	Treatment date	Basal area ¹ cut	Original sawtimber volume ²	Sawtimber cut
			Percent ⁴	Bd. ft./acre	Percent ⁴
1 (74)	Clearcut to about 6 inches dbh except for culls. ³ Applied 500 lbs/acre of 45% urea.	5/57-6/58 5/71	74 —	9,926 —	86 —
2 (38)	17-inch diameter limit cut, entire watershed. 17-inch diameter limit cut, 27 acres of watershed; in both cuts, culls larger than 17 inches were cut.	6/58-8/58 9/72-10/72	32 12	7,145 —	59 —
3 (85)	Intensive selection cut including cull treatment in trees above 5 inches dbh. Same treatment. 0.4-acre patch cuttings totaling 5.6 acres; everything cut down to 5 inches; 1- to 5-inch stems basal sprayed with herbicide. Clearcut to 1-inch dbh.	10/58-2/59 9/63-10/63 7/68-8/68 7/69-5/70	13 8 6 91	8,300 7,848 8,435 7,928	20 12 6 91
5 (90)	Extensive selection cut, including cull treatment in trees larger than 11 inches dbh. Same treatment.	8/58-11/58 2/68-6/68	20 14	11,993 13,020	31 19
6 (54)	Lower half (27 acres) of water- shed clearcut. Maintained barren with herbicides. Upper half (27 acres) of water- shed clearcut. Maintained barren with herbicides. Entire watershed maintained barren with herbicides.	3/64-10/64 5/65-10/69 10/67-2/68 5/68-10/69 2/68-10/69	51 49 100	10,948 11,224 —	51 49 100
7 (59)	Upper half (29.5 acres) of water- shed clearcut. Maintained barren with herbicides. Lower half (29.5 acres) of water- shed clearcut. Maintained barren with herbicides. Entire watershed maintained barren with herbicides.	11/63-3/64 5/64-10/69 10/66-3/67 5/67-10/69 2/68-10/69	49 51 100	13,758 13,193 —	51 49 100

¹Basal area as used in this report refers to the total basal area in trees 1 inch in diameter and larger.

²Trees 11 inches dbh and larger.

³No care was exercised on the road system.

⁴Based on the total basal area and sawtimber volume on the entire watershed.

ity, an optical index of sediment suspended in water, is often interpreted as an index to water quality that is closely related to logging activity. Careless logging caused very turbid water; but logging on carefully located, constructed, and maintained road systems caused

only minor increases in turbidity (table 2).

Watershed 1 (commercially clearcut) produced a maximum of 56,000 turbidity units, measured while logging was in process. Turbidity levels were high during and immediately after logging,

Table 2.—Turbidity values for selected Fernow watersheds

Period	Average turbidity non-stormflow	Range in turbidities, including stormflow
<i>In Jackson turbidity units</i>		
Commercial clearcut (watershed 1):		
During logging operation	490	0-56,000
First year after logging	38	0-5,000
Second year after logging	2	0-170
Silvicultural clearcut (watershed 3):		
During logging operation	6	0-90
First year after logging	5	0-35
Second year after logging	2	0-23
Undisturbed control (watershed 4):		
5/59-11/72	2	0-25

but decreased rapidly after disturbance ended. By contrast, watershed 3 was logged with a carefully planned and maintained road system, and it produced only minor increases in turbidity.

Temperature

Stream temperatures were raised by some of the cutting practices used on the Fernow Forest. Average maximum stream temperature on watershed 1 increased about 8°F during the first growing season after cutting. Temperatures returned to pre-cutting levels within 5 years after cutting. Deforesting and herbiciding the lower halves of watersheds 6 and 7 also substantially increased growing-season stream temperatures, but deforesting and herbiciding the upper halves had no appreciable affect. There was, of course, no channel exposed to direct insolation on the deforested upper halves.

Maximum growing-season stream temperatures for watershed 6 averaged about 10°F higher than those on the control watershed, while watershed 7 averaged about 4°F higher. The marked difference between the results of deforesting and herbiciding the lower halves of watersheds 6 and 7 reflect orientation and the harvesting techniques employed. In south-facing watershed 6, the trees

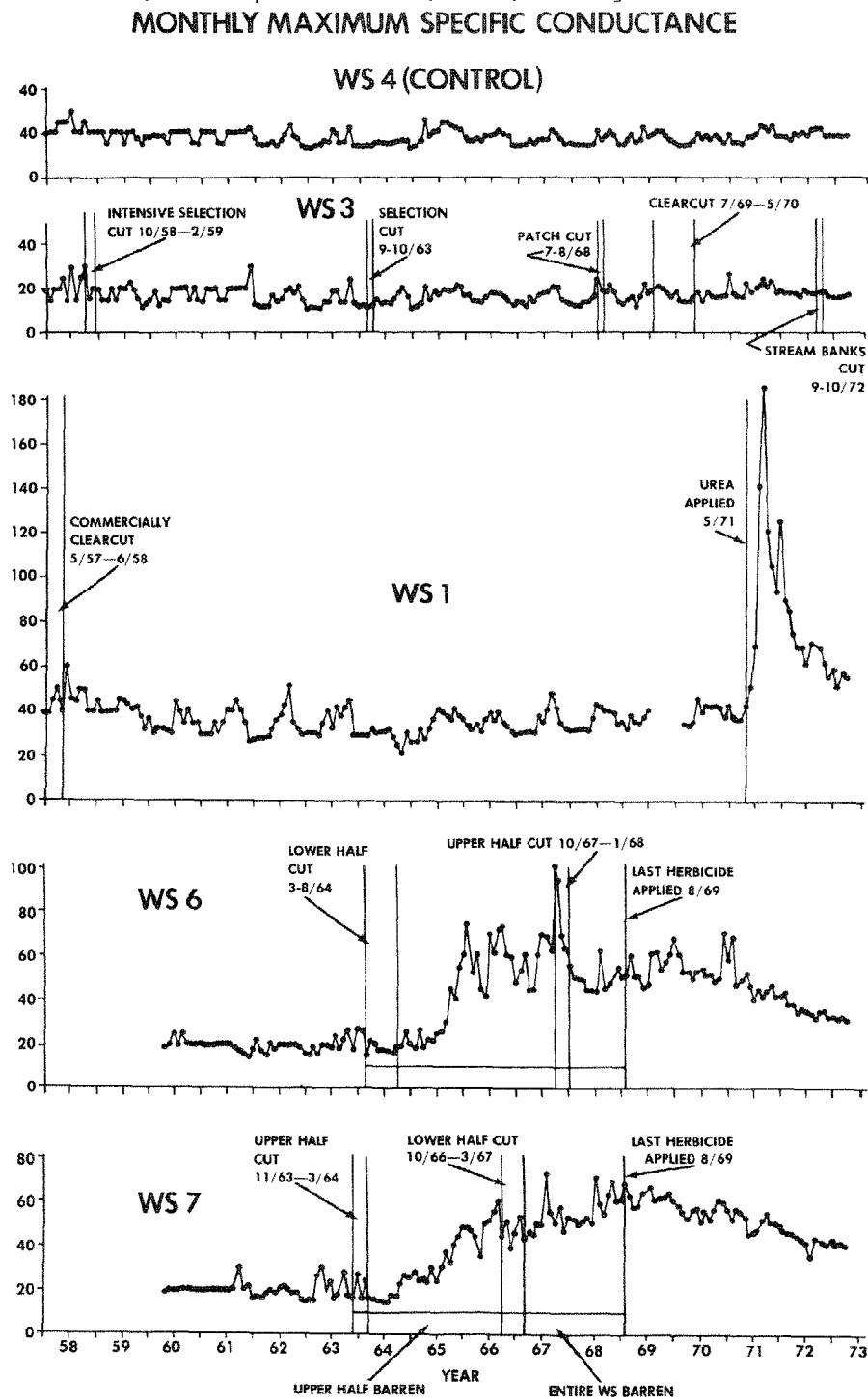
were felled in such a manner that a minimum of slash covered the stream channel area. In east-facing watershed 7, the reverse was true: the stream was partly covered by a large amount of slash that shaded the channel. By contrast, watershed 3 — with two selection cuttings, a patch cutting, and a complete clearcutting of all but the channel area — showed little or no influence of cutting on stream temperature. This reflects the importance of leaving uncut trees to shade the stream channel if maintenance of cool water is an objective of forest management.

Specific Conductance

Specific conductance indicates, within rather wide limits, the concentration of ionized substances in water. These values give no indication of which ionized substances are present, but any increase or decrease in their concentration will cause corresponding changes in conductivity. Thus specific conductivity can be used to infer chemical changes in the water.

The data show that, on the Fernow Forest, a watershed can be clearcut without producing major increases in the stream's specific conductance (fig. 2, WS 3). Under less carefully controlled clearcutting conditions, the resultant increase in conductivity was short-lived

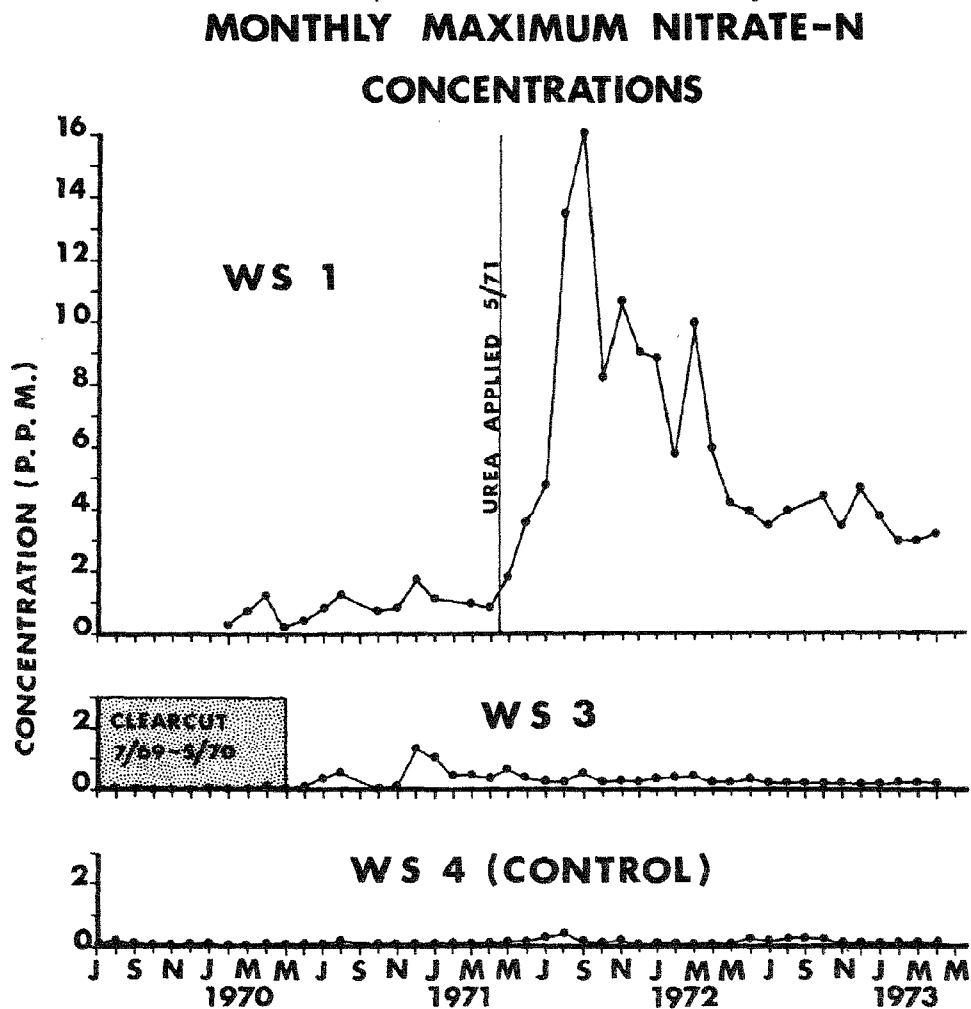
Figure 2.—Monthly maximum specific conductance for selected watersheds, Fernow Experimental Forest, Parsons, West Virginia.



and returned to pre-cutting level as the watershed revegetated (fig. 2, WS 1). Only when we prevented natural regrowth did the streams' specific conductance increase markedly (fig. 2, WS 6 and WS 7). Regrowth and declining specific conductance followed termination of herbicide applications. The major difference between the clearcut and the deforested and herbicided watersheds was prevention of natural revegetation on the latter.

Applying 230 pounds of nitrogen per acre in the form of urea to watershed 1 markedly increased that stream's specific conductance (fig. 2, WS 1). Immediately after application, the specific conductance began to increase, reaching a maximum approximately 6 times higher than normal 4 months after application. Decline has since been steady, and the specific conductance now is approximately 1.5 times the pre-fertilization level.

Figure 3.—Monthly maximum nitrate-N concentrations for selected watersheds, Fernow Experimental Forest, Parsons, West Virginia.



pH and Alkalinity

Timber harvesting had little effect on pH and methyl orange alkalinity levels. The watershed 1 treatment increased the mean pH from about 6.1 to 6.4 and the alkalinity about 2 ppm (*Reinhart et al. 1963*). The other treatments had even smaller effects.

Nutrients

Of the twelve nutrients studied, nitrate-N usually is considered most significant to water quality. Our limited data suggest that Fernow watersheds can be clearcut without appreciably increasing nitrate-N concentration in the streams (fig. 3, WS 3). Another study showed that fertilizing a watershed with urea can cause a marked increase in the stream's nitrate-N concentration (fig. 3, WS 1). Even so, this stream's nitrate-N concentration remained well below the U.S. Public Health's drinking-water limit of 10 ppm, in 811 of 829 samples analyzed during the first year after application.

Nitrate-N levels for watershed 7 have shown a steady decline from about 5 ppm, in January 1971 when determinations were begun, to the present level of about 2 ppm. Watershed 6 shows a similar trend but with corresponding concentrations between 0.5 and 1 ppm lower. Levels of other nutrients were little affected by clearcutting (*Aubertin and Patric 1972*). However, after urea fertilization, the concentrations of calcium, magnesium, sodium, and potassium increased slightly (*Aubertin and Smith 1972*).

WATER YIELD INCREASES

Amount

Equations developed during the calibration period (*Reinhart et al. 1963*) provided a means to demonstrate streamflow changes after forest cutting. Growing-season increases in water yield from the Fernow watersheds generally have been proportional to the severity of cut-

ting (fig. 4). The lightest cutting that produced a statistically significant increase was on watershed 5. There, 20 percent of the basal area was cut; average timber volume removed was 3,690 board feet per acre. Ten years later, a similar cut on watershed 5 removed 13.7 percent of the basal area or 2,453 board feet per acre, but failed to produce a significant yield increase.

The effects of other variables such as tree size, species composition, and spatial arrangement of the cutting have not been tested on the Fernow watersheds. The largest yield increase occurred after watersheds 6 and 7 were deforested and treated with herbicides to prevent forest regrowth. We suspect that increased evapotranspiration after fertilization contributed to the rather large decrease in streamflow on watershed 1 during the 1972 growing season. This decrease will be examined more closely in the near future.

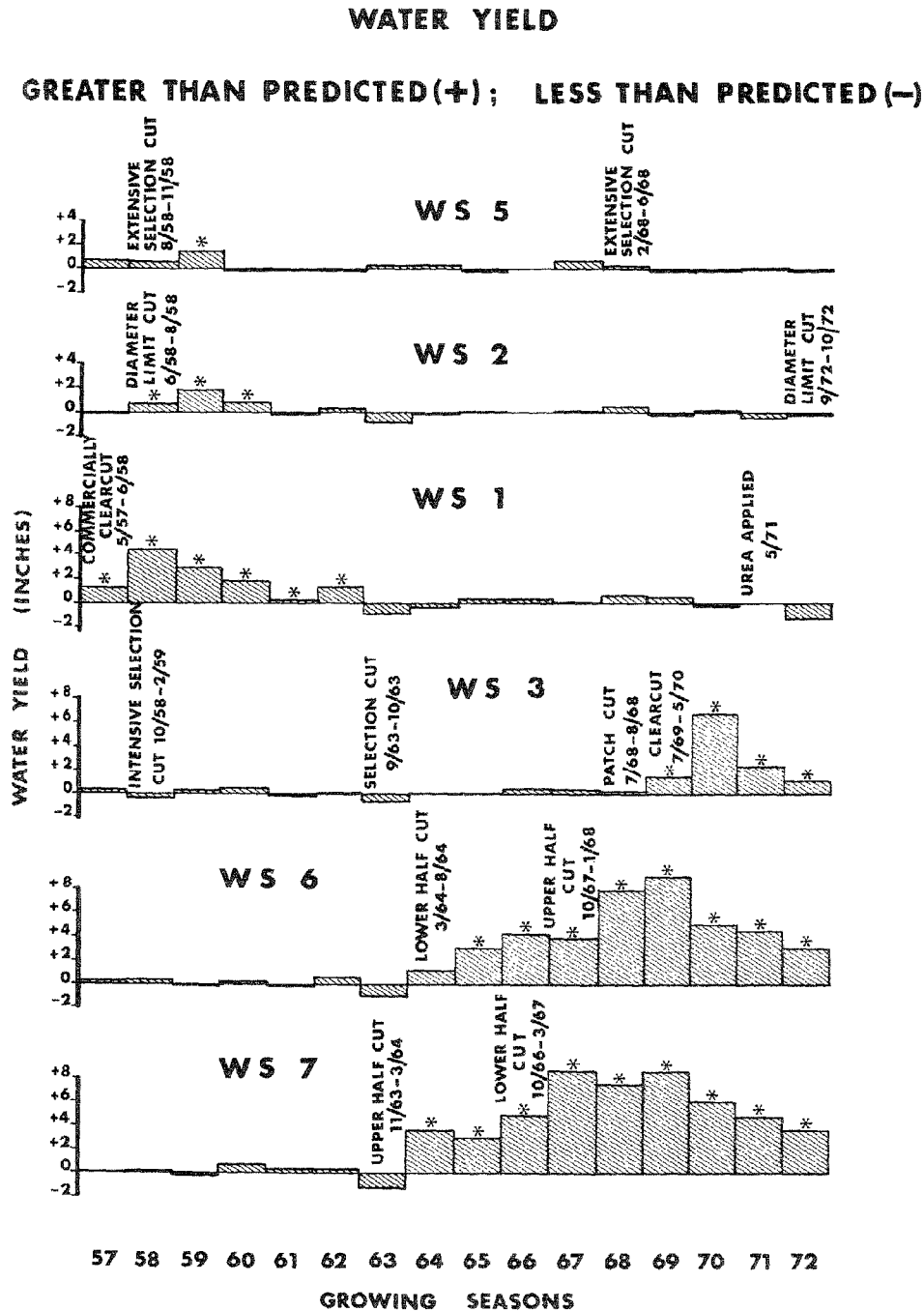
Timing

When a substantial part of the forest was cut early in the growing season, significant increases in water yield were obtained at that time, but the largest increases usually occurred during the first growing season after treatment. Largest increases always occurred from July to November. Dormant-season responses were variable, usually less than half of those obtained during the growing season. The most consistent and usually the largest dormant-season yield increases occurred in November and December.

Longevity

The duration of yield increases also varied with severity of cutting. Streamflow increases resulting from cutting on the Fernow Forest have returned rather rapidly to pre-treatment levels (fig. 4). Yield increases obtained by partial cutting (watersheds 2, 3, and 5) were never significant for more than 2 years.

Figure 4.—Effects of treatments on water yields. Deviation of water yields from amounts predicted for selected watersheds, Fernow Experimental Forest, Parsons, West Virginia.



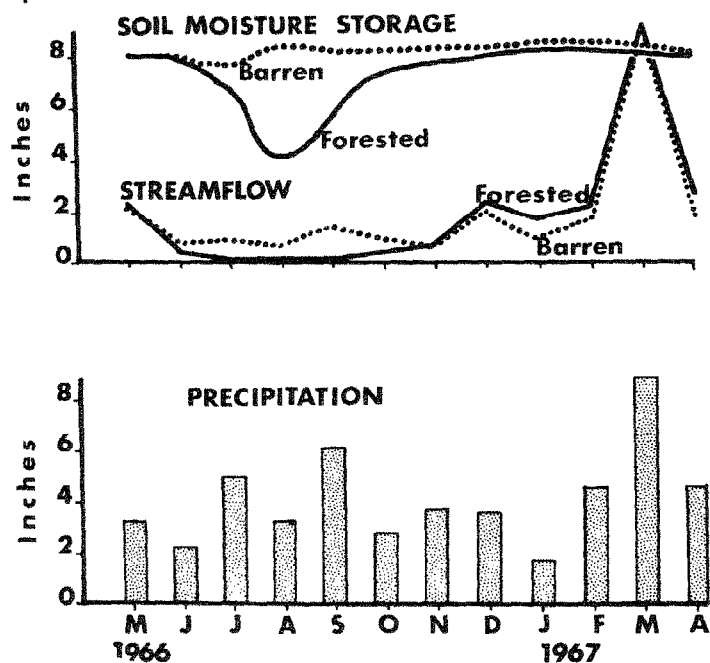
Yield increases after clearcutting lasted 6 years on watershed 1 and 5 years on watershed 3. Clearcutting with herbiciding (watersheds 6 and 7) produced the longest lasting increases. Three years of regrowth have reduced yield increases about two-thirds on watersheds 6 and 7, where revegetation has been slower. After three growing seasons, woody vegetation comprised only 15 percent of the ground cover, most of it of seed origin as opposed to other watersheds where regrowth was primarily of sprout origin. Regrowth from old root systems would at least initially be expected to better exploit soil moisture. The faster recovery of watershed 6 may relate to the fact that the upper half of this watershed was herbicided for only 2 years and that much of the vigorous regrowth there is of sprout origin.

Stormflow

The effects of heavy cutting on stormflow have been variable (*Reinhart 1963*). Generally, growing-season peaks increased; dormant-season peaks were unaffected. *Patric (1973)* reported that instantaneous peak flows were increased during small storms when watersheds 6 and 7 were barren, but this peak effect was minor in large storms and in all storms during the dormant season.

Troendle (1970a) noted that timber-harvesting generally extended periods of high flow and shortened periods of low flow. The effects of treatment were greatest on low flows. Deforestation increased the duration of streamflow on watersheds 6 and 7. Streams draining these watersheds had dried up periodically when the watersheds were fully forested; during deforestation, flows

Figure 5.—Soil moisture-streamflow relationships. Upper, soil moisture and discharge from forested and barren watersheds. Lower, precipitation.



in both watersheds were never less than 0.3 cfs (Patric and Reinhart 1971).

Soil Moisture Influences

Soil-moisture depletion on the Fernow provides an insight into streamflow response to treatment. There was a close correlation between streamflow and moisture content in the upper 2 feet of soil (Troendle 1970b). During the growing season, up to a 4-inch soil-moisture deficit has been recorded on forested areas on the Fernow Forest (fig. 5). Substantial reduction of water normally lost by transpiration and interception maintained soil moisture at higher levels during the growing season on barren or recently cut areas (fig. 5).

Streams draining the wetter soils on barren or recently cut watershed are more responsive to precipitation than those draining the drier, forested areas. After soil became recharged, streamflow responses on treated and forested areas were similar except for small differences due to snowmelt. Soil-moisture measurements indicated that the relatively shallow soils on the Fernow Forest usually are recharged by January and remain so until May.

DISCUSSION

Perhaps the most important finding to emerge from the Fernow research is that timber-harvesting with well-planned, well-constructed, and well-maintained road systems simply does not damage water resources. The severity of cutting has little effect on water quality when enough trees are left to shade stream channels. Thus it is possible to produce potable water from forest land and also manage for other uses such as timber production, recreation, and wildlife habitat.

The relatively short-term effects of removing vegetation and the difficulty of controlling revegetation govern attempts to manage forest land for water. Experience on the Fernow Forest indi-

cates that water-yield increases will not be maintained merely by periodically harvesting merchantable forest products. Increased water yield, resulting from the lightest cut that produced a significant increase of water yield on the Forest, lasted only 1 year. In other words, this cutting would have to be repeated annually to maintain the flow increase. Yet, silviculturally speaking, this heavy a cutting requires at least a 10-year cutting cycle even on the most productive sites. In the Appalachians, it requires at least 20 years for a tree to reach merchantable size. In many areas where there is no market for small products, 40 years would be a more realistic figure.

Economically, the difference between manipulating merchantable and unmerchantable vegetation is very great. No additional costs above those normally associated with harvesting forest products are incurred when it is silviculturally desirable to cut merchantable trees; under these circumstances, increased streamflow can be considered a free by-product. Removal of unmerchantable trees to improve streamflow is an entirely different matter. The vigorous regrowth characteristic of the Appalachians is extremely difficult and costly to control. Aerial application of herbicides would seem to be the only practical way to maintain control of vegetation on areas large enough to appreciably influence water yields. The acceptance of this practice by a public that is concerned about environment is indeed highly questionable.

CONCLUSIONS

- Given current market values, it is not practical to manage forest land for both sustained water yield increases and merchantable timber products.
- Forest land can be managed for a variety of uses without impairing water quality if these uses are regulated intelligently.

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EFFECTS OF MANAGEMENT PRACTICES ON WATER QUALITY AND QUANTITY: BALTIMORE, MARYLAND, MUNICIPAL WATERSHEDS

by EDWARD S. CORBETT and WARREN SPENCER, respectively *Principal Hydrologist, USDA Forest Service, Northeastern Forest Experiment Station, Pennington, New Jersey; and Watershed Forester, Water Division, Baltimore Department of Public Works, Baltimore, Maryland.*

ABSTRACT. To complement its water-management program, the City of Baltimore, with the assistance of the Northeastern Forest Experiment Station, is conducting research on the effects of vegetation management on water yield and quality. Three small watersheds, ranging in size from 22 to 38 acres, have been selected for this purpose. Two of the watersheds, formerly in open land except for hardwoods along the riparian zones, were reforested 17 years ago with white and loblolly pines. Converting the open land to a pine forest caused a substantial reduction in water yield. The effects of removing riparian-zone vegetation and also thinning the young pine plantations are evaluated from the viewpoint of the municipal watershed manager.

THE CITY OF BALTIMORE owns 17,580 acres of watershed land surrounding its three water-supply reservoirs: Loch Raven, Prettyboy, and Liberty. The reservoirs have a combined surface area of 7,000 acres and are located to the north and northwest of the city in Maryland's Piedmont region. Management of the 24,580 acres of land and water is the responsibility of the Baltimore Division of Water Supply.

The watershed lands were acquired between 1910 and 1955. At first, management practices were limited to fire protection and planting a protective forest cover on abandoned land around the reservoirs. There are approximately

4,100 acres of plantations on watershed property. The earliest of these plantations date back to 1912, but most were established in the early 1950s.

The species planted are — in descending order of acreage — white pine, loblolly pine, red pine, Scotch pine, shortleaf pine, and Norway spruce. Small areas of hardwood species such as red oak, yellow-poplar, and black locust have also been planted.

Timber cutting on watershed lands began in 1948 when the area for Liberty Reservoir was cleared. A policy of multiple-use management was adopted at that time. The objectives of the new policy were to plan, manage, and super-

vise a coordinated conservation program of forest, soil, and water resources, for water production and protection, timber-growing, improvement and utilization of timber resources, and recreation. Details of the current management program have been given by Mr. Hartley (1975) at this Symposium.

COOPERATIVE RESEARCH PROGRAM

Experimental Watersheds

To complement its land-management program, the City of Baltimore is conducting, with the assistance of the Northeastern Forest Experiment Station, research on the effects of vegetation management on water yield and quality. Three small watersheds near Liberty Reservoir, ranging in size from 22 to 38 acres, were selected for this purpose. Topography is hilly. Streamflow is measured by 120° v-notch weirs mounted on weir boxes. The percentage of precipitation that leaves the watersheds as surface streamflow is considerably less than from small mountainous watersheds in the East, especially in the dormant season.

Watersheds 1 and 2, formerly in open land (grass with pockets of brush) except for hardwoods along the riparian zones, were reforested in 1955-56 with white and loblolly pines at approximately a 5 x 6 foot spacing. Watershed 3 contains a stand of mixed hardwoods and will be used to evaluate the effects of Baltimore's normal timber-harvesting methods on water yield and quality in a future study. During the study there were short periods when streamflow had to be estimated because of weir-box leakage. A portion of the streamflow from watershed 3 was found to be bypassing the weir box during the early part of this project, so it was not used in this analysis.

Soils

Soils of the Manor series predominate on the watersheds. The Manor soils range from loam to silt loams and gravelly loams and are somewhat excessively drained. Both surface and subsurface soils are very friable. Underlying the subsoil is a very friable, highly micaceous material that can store a large amount of moisture and is easily penetrated by roots. Depth to bedrock ranges from 6 to more than 20 feet. These soils have moderate to high available moisture capacity. Because the Manor soils are so micaceous, they are highly susceptible to erosion (Matthews 1969).

Soils of the Glenelg series are second in importance on the experimental watersheds. They are well drained and the subsoil is underlaid by a friable, micaceous material. Available moisture capacity is moderate to high. The subsoil is rather thin, and sticky when wet. Depth to bedrock ranges from 4 to 10 feet (Matthews 1969).

Soils along the stream channels are of the Delanco series, and these are moderately well drained. They have a high available moisture capacity. The depth to bedrock is 6 to 20 feet. The lower part of the subsoil is mottled, indicating that the soils are wet and poorly aerated at least part of the year (Matthews 1969).

EFFECTS OF REFORESTATION ON WATER YIELD

Method of Analysis

To evaluate the effects of reforesting an open-land watershed, a single-watershed calibration method of analysis was used. Water yield of watershed 2, while in an open-field / seedling stage (1958-62), was compared with yield during a period after the tree crowns had closed (1966-71). Tree heights ranged from 12 to 32 feet in this latter period. A precipitation index was selected as the

independent variable to predict what water yield would have been had the trees not been planted. Differences between predicted and measured streamflow were then computed to quantify the effects of reforestation. Water-yield calculations for growing season (May-October), dormant season (November-April), and hydrologic year (October-September) were made.

Correlations between precipitation and streamflow were weak for both seasonal and annual values. Thus the influence of antecedent precipitation was investigated. Various antecedent precipitation periods were tested. It was determined from the correlations that a significant carryover effect from antecedent precipitation existed for both annual and seasonal periods. This was attributed mainly to the deep soils with their large water-storage capacity.

Therefore, annual and seasonal precipitation values, adjusted for the carry-over effect by adding in antecedent precipitation (forming precipitation indexes), were used in the prediction equations. The strongest correlations were obtained by using a 12-month antecedent period for the seasonal water-yield prediction equations and a 6-month antecedent precipitation period for the annual prediction equation.

Results

Seasonal and annual streamflow from reforested watershed 2 were much less after crown closure than under conditions prevailing at the time of tree planting (table 1). The estimated decrease in annual water yield averaged 8.77 inches during the period 10 to 15 years after planting and ranged from approximately 5½ to 12 inches. Almost 60 percent of this decrease occurred during the dormant season. The average reduction in water yield is equivalent to 238,000 gallons of water per year per acre reforested.

Table 1.—Estimated decrease in water yield from converting an open-land watershed to pine forest.

Years after tree planting	Water yield reduction ¹		
	Annual	May-Oct.	Nov.-Apr.
	Inches	Inches	Inches
10	5.44	2.27	4.79
11	(²)	(²)	(²)
12	11.97	5.68	6.28
13	10.79	4.42	7.79
14	5.92	2.47	4.17
15	9.73	3.07	2.91
Average	8.77	3.58	5.19

¹Seasonal reductions may not equal annual reductions because prediction equations are independently derived.

²Stream-gaging station out of service.

Evapotranspiration differences of the vegetation covers and increased interception losses (especially during the dormant season) are major causes of the decrease in streamflow. They result in greater soil moisture depletion under the forest cover and create larger moisture deficits than would normally occur under open field conditions. To satisfy the deficits, a larger proportion of precipitation during the dormant-season recharge period goes into soil moisture storage and is not immediately available for streamflow.

EFFECTS OF VEGETATION REMOVAL ON WATER QUANTITY

Several cutting treatments have been conducted in watershed 1 since the development of the tree cover, in addition to a vegetation conversion in the riparian zone. The treatments are summarized in table 2.

Methods of Analysis

Two approaches were used to evaluate the effects of the treatments on water yield. A single-watershed calibration was made for watershed 1 as in the previous analysis for watershed 2. Differences between the streamflow reductions on the two watersheds were used as esti-

Table 2.—Vegetation manipulation
on Watershed 1

Years after tree planting	Watershed treatment
10.....	Hardwood vegetation along the main and secondary channels cut back from streams a distance of 30 to 125 feet (fig. 1).
11.....	Mechanical removal of stumps. Cut area seeded with grass.
12.....	Grass cover in riparian area mowed.
13.....	Pine plantation thinned except for 10 percent of stand on upper end of watershed. Every other row was removed, producing 165 cords of wood. Stand not opened up greatly due to closeness of original planting. Grass cover in riparian area mowed.
14.....	Grass cover in riparian area mowed.
15.....	Remainder of pine plantation thinned by removing every other row. Remaining hardwoods along the fringe of the riparian zone were cut. Grass cover in riparian area mowed.

mates of the treatment effects on watershed 1.

In addition, a control-watershed approach was used, utilizing watershed 2 as the control. Streamflow relationships between the two watersheds during a 5-year calibration period (1958-62) were used to develop equations for predicting the streamflow of watershed 1 from the measured streamflow at watershed 2. After modifying the vegetation cover (table 2), differences between predicted and measured streamflow for watershed 1 were used for quantifying vegetation treatment effects on water yield.

In experiments of this type, all watersheds are usually in a fully forested condition at the start of the calibration period. In this case the calibration began when both watersheds were in an open-field/seedling stage. The results of this analysis are based on the supposition that the streamflow calibration relation-

ship between the watersheds will not change significantly as the forest stand develops.

Results

Effects of the vegetation treatments on annual water yields are presented in table 3. Yield increases, as estimated by the single-watershed calibration analysis, were about three times those estimated by the control-watershed analysis. In the control-watershed analysis only the 3.31 inch increase was statistically significant. The size of the increases for both methods was strongly influenced by annual precipitation, the larger increases being associated with years of high precipitation.

Cutting forest vegetation in the riparian zone and converting this area to grass (fig. 1) increased watershed streamflow an average of 1 to 3 inches. The grass was mowed during the summer to reduce the transpiration surface and keep interception losses to a minimum. With equations developed by Corbett and Crouse (1968), adapted to Baltimore conditions, it was estimated that average grass interception losses would be reduced by 1.6 inches in the conversion zone by keeping the grass stand mowed.

The effects of thinning the pine stand (fig. 2) did not appear to contribute any additional water. Roots of trees remaining on the thinned area still were apparently occupying the site fully so that the trees could utilize most of any additional soil moisture made available. In addition, the rapid invasion of black locust and Japanese honeysuckle in the thinned stand contributed to moisture losses.

Low precipitation during this period may also have been a factor. Removing the remaining hardwoods along the fringe of the riparian zone (right side of stream channel in figure 1) seems to have had a substantial effect on enlarg-

Table 3.—Estimated increases in annual water yield following Watershed I treatments

Years after tree planting	Annual precipitation	Based on control- watershed analysis	Based on single-watershed calibration analysis
	Inches	Inches	Inches
10	35.04	0.98	2.66
11	43.26	(¹)	(¹)
12	41.18	1.10	4.03
13	34.13	.03	2.22
14	36.49	.67	1.83
15	54.29	3.31	4.80

¹Stream-gaging station out of service.

Figure 1.—Initial riparian cut on watershed I. Hardwood vegetation to the right of the stream channel was removed in a later cut.



Figure 2.—Removing 50 percent of the pine stand by thinning every other row of trees did not open the stand severely.



ing the water yield increase. These trees were removed from an area that contains a spring and is generally wet most of the year. Above-average rainfall probably contributed to the size of this increase. The observed water yield increases occurred mainly during the summer-fall period.

EFFECTS OF VEGETATION REMOVAL ON WATER QUALITY

Erosion

After the riparian-zone vegetation was cut, a dense stand of hardwood sprouts and herbaceous species began to develop. This regrowth was controlled by mechanical removal of stumps and seeding the area to grass.

Turbidity samples were taken only once a week when the instrument charts were changed. As a result, stormflow turbidities could not be defined. Stream turbidity increased up to 30 times that of the control watershed after cutting the riparian vegetation. Erosion was more severe after the stumps were pulled. Storms caused a great amount of soil movement from the disturbed area, filling the weir box with eroded material.

The next year, after establishment of a dense grass cover, average stream turbidity was 2.4 ppm. Average turbidity on the control watershed was 1.4 ppm for the same period. There was no increase in turbidity from the thinning operation or removal of hardwood vegetation located away from the stream channel.

A debris survey was made after tropical storm Agnes in 1972. Eleven inches of the 14 inches of storm rainfall fell in 1 day at a uniform intensity (about 0.5 inch per hour). Eroded material deposited at the mouths of the watersheds was related primarily to depth of channel. The greatest amount of debris was produced on watershed 3, although it has a complete hardwood forest cover.

Streambanks in this watershed are considerably higher than those in the other watersheds due to much stream cutting in the past. The channel may not yet be entirely stable. Most of the erosion occurring on the watersheds was from streambank cutting and channel slumping.

Stream Temperature

Summer stream temperatures were significantly increased after removal of the riparian forest cover. Average summer maximum water temperatures have been increased 8° to 13.6°F since the initial cut. Minimum stream temperatures were increased by 1° to 2°F during the summer. Maximum water temperatures over 80°F were recorded several times, especially during periods of extremely low flow.

CONCLUSION AND DISCUSSION

Many municipal watershed managers have improved the quality of their raw water supply by reforesting abandoned and eroding lands. Part of the cost paid for this improvement is the reduction in water yielded from these areas. Our study indicates that converting an open-land watershed to a young pine forest caused a decline in water yield of 238,000 gallons of water per year per acre reforested. This is equivalent to a layer of water almost 9 inches deep over the entire watershed.

Conversion of riparian-zone vegetation from hardwoods to grass increased watershed streamflow about 2 inches. The conversion was accompanied by serious erosion problems, as mechanical methods rather than herbicides were used in controlling sprout regrowth. Erosion in the channel areas, even on forested watershed 3 during large storms, showed how sensitive this portion of the watershed is. Protection of the stream channel in any management

program should be a primary concern of the watershed manager. Any accelerated erosion on upstream watersheds will speed up the siltation of reservoirs, reducing their water-storage capacity.

Thinning the pine stand by removing every other row of trees provided \$4,000 of gross income but had little effect on water yield. The remaining trees were able to utilize any additional soil moisture during 2 years of below normal precipitation. Also, the increased light stimulated the growth of Japanese honeysuckle and black locust in the pine stand contributing to soil moisture losses. Honeysuckle had encroached well into the crowns of the pines a year after the thinning. Dragging a dozer blade between tree rows pulled a substantial amount of honeysuckle out of the tree crowns and uprooted many of the black locust. Tight crown closure increased shading and has prevented recurrence of this problem.

In situations where municipal ownership of watershed land is substantial,

vegetation management can have a significant influence on the amount of water yielded to a reservoir system. In such cases vegetation conversion and planting programs should be carefully evaluated. Establishment of a mixed hardwood forest on an open-land watershed would not reduce water yield as much as a pine forest (*Swank and Minor 1968*). Open fields on watershed property would benefit both water yield and wildlife.

Where only a small portion of a watershed is municipally owned, water-yield considerations will be of less importance unless cooperation with other landowners for a coordinated vegetation-management program can be secured. Under these circumstances, high priority should be given to vegetation management for derivation of municipal income along with recreation and aesthetic considerations. Protection of water quality in the reservoir system and maintaining reservoir capacity are of primary importance in both cases.

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EFFECTS OF MANAGEMENT PRACTICES ON WATER QUALITY AND QUANTITY: THE PENN STATE EXPERIMENTAL WATERSHEDS

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ABSTRACT. The results of phase one and phase two of a three-phase clearcutting experiment on a 106-acre watershed in central Pennsylvania are reported. Phase one involved the removal of the vegetative cover on 21.3 acres of the lower-slope portion of the watershed. Phase two consisted of clearcutting an additional 27.0 acres on the middle-slope portion of the watershed. The effects of these treatments on water quality, quantity, and streamflow timing have been evaluated. Water quality parameters investigated include turbidity, temperature, acidity, and selected nutrients. Water quantity data were evaluated on monthly, seasonal, and annual bases. Quickflow volume, instantaneous maximum peak, time to peak, time of recession, and antecedent flow rate of storm hydrographs were also investigated.

WITH INCREASING population growth and industrialization, greater demands are being placed on our Nation's water supplies. An increasing number of communities have experienced problems in obtaining a sufficient supply of high-quality water for both domestic and industrial use during the past 10 years.

In Pennsylvania, forests cover more than half of the land area and hence receive a large portion of the state's precipitation. Moreover, since these forest areas generally occupy mountainous lands, they serve as collection basins for many of the state's municipal water-

supply systems and exert a major influence on the continuity and quality of streamflow. Thus one approach to solving our water problems depends upon research directed towards augmenting water supplies through forest-management practices.

To evaluate management effects on water-supply parameters, the Leading Ridge Experimental Watershed Research Unit was established. It is part of a cooperative research project of The Pennsylvania State University, The Pennsylvania Department of Environmental Resources, Bureau of Forestry, and the Northeastern Forest Experiment Station, U.S. Forest Service.

DESCRIPTION OF WATERSHED UNIT

The Leading Ridge Watershed Research Unit, located in the ridge and valley province of central Pennsylvania, consists of three adjacent watersheds, which are 303, 257, and 106 acres in area. These watersheds are representative of approximately 10 million acres of Pennsylvania forest, much of which lies within established municipal watershed boundaries.

On all three watersheds, modified broad-crested Trenton weirs with a sharp-crested, 90-degree, V-notch in the center were used to measure stream discharge. Each weir is 30 feet wide and has a total capacity of 117 cubic feet per second (fig. 1). The watersheds all have a southeastern aspect; they range in elevation from 900 to 1,450 feet. Mean slopes are 12.1 percent on the treated watersheds and 17.3 percent on the control.

The watersheds are underlain by three

major geological formations. The Rose Hill shale formation, which underlies most of the lower slopes of the watersheds, is approximately 700 feet thick. The upper part of the lower slope, middle slope, and most of the upper slope is underlain by Castanea sandstone having a thickness of approximately 500 feet, while Tuscarora quartzite underlies the ridge top.

Most of the soils are residual, having developed in place through the weathering of the underlying strata. A soil survey resulted in the classification of nine major soil types. Soils on the lower slopes are primarily silt and stony loams that are well-drained and have a high moisture-holding capacity. The middle and upper slopes are classified as cobbly and stony loams, which are also well-drained. Rough, stony land covers the ridge top. The average depth of the soil mantle is 66 inches. Total water-holding capacity is 28 area-inches.

The vegetative cover consists of an uneven-aged coppice forest of oak, hickory, and maple. Predominant species are white oak (*Quercus alba* L.), red oak (*Q. rubra* Ashe), and black oak (*Q. velutina* Lamb) on the lower and middle slopes. On the upper slopes and ridge top, the dominant species are chestnut oak (*Q. prinus* L.), with red oak, black oak, and pitch pine (*Pinus rigida* Mill) as associates. The subordinate layer consists of dogwood (*Cornus florida* L.), red maple (*Acer rubrum* L.), and witch hazel (*Hamamelis virginiana* L.).

METHOD

Since completion of a 7-year calibration period two phases of a three-phase experiment, involving the complete clearcutting of the 106-acre watershed, have been implemented (fig. 2). The purpose of each of clearcutting is to determine the effects of removing forest cover from each area (lower slope, mid-

Figure 1.—Stream-gaging station at Leading Ridge Watershed I. This fully forested watershed provides base data for evaluating the effects of cutting treatments on streamflow.

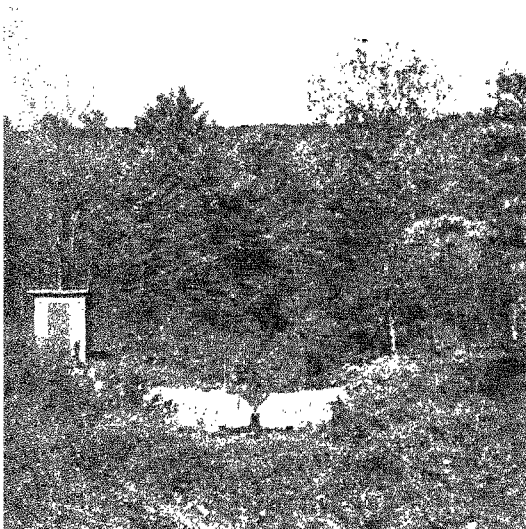


Figure 2.—Aerial view of Leading Ridge Watershed 2. The treatment areas are roughly separated by the road through the center of the clearcut. The first treatment area is the darker section below the road; the second treatment area is the lighter section above the road.



dle slope, and upper slope and ridge top) on water yield and quality.

Phase one (during the winter of 1966-67) involved the removal of 53,878 cubic feet of timber on 21.3 acres of the lower-slope portion of Leading Ridge Watershed 2 (table 1). This clearcut was essentially a complete riparian cut, since all of the main stream channels on the watershed are located within its boundaries. Phase two consisted of clear-cutting an additional 27.0 acres on the middle-slope portion of the watershed during the winter of 1971-72. Total volume removed was 87,476 cubic feet (table 1). To reduce the amount of soil disturbance, cutting was limited to times when the ground was frozen. Skid trails

and logging roads were carefully located to prevent erosion. All slash was removed from the stream channel and lopped and scattered.

After completion of phase one, road areas and log-loading areas were seeded with a mixture of annual and perennial ryegrass along with pulverized limestone and 10-10-10 fertilizer to facilitate rapid revegetation and reduce erosion. During the summers of 1967, 1968, and 1969, the clearcut area was sprayed with a mixture of 2,4,5-T and 2,4-D herbicides (Amchem Weedone) to control stump sprouts. The application weight was 2 pounds of acid equivalent per acre. No seeding or spraying followed the completion of phase two (fig. 3).

Table 1.—Treatment characteristics of Leading Ridge Watershed 2

Characteristic	Treatments		
	Lower slope	Middle slope	Total
Area cut (acres)	21.3	27.0	48.3
Basal area (square feet)	2,103	2,398	4,501
Basal area per acre cut (square feet)	99	89	94
Volume cut (cubic feet)	53,878	87,476	141,354
Volume per acre cut (cubic feet)	2,119	2,015	2,067

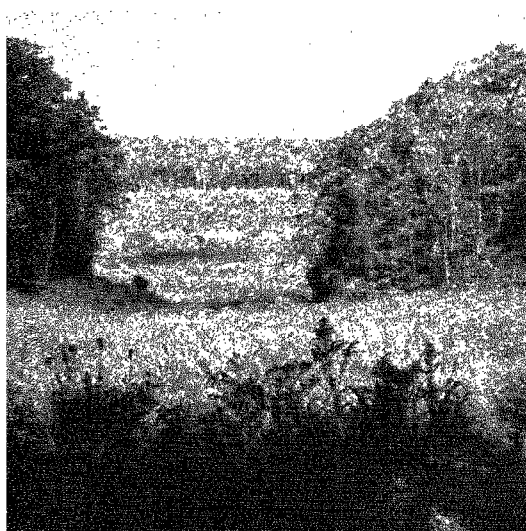


Figure 3.—Rapid regrowth of vegetation on the two clearcut portions of Leading Ridge Watershed 2 prevented serious erosion. The lower slope is now mainly in grass and other herbaceous vegetation. The middle slope contains hardwood sprouts and grasses.

The calibration period started 1 May 1959 and ended 31 December 1966. The treatment period for phase one lasted from 1 January to 30 April, 1967, and the after-treatment period from 1 May, 1967 to 31 October, 1971. The treatment period for phase two lasted from 1 November, 1971 to 30 April, 1972. The after-treatment period involving both clearcuts was 1 May, 1972 to 30 April, 1973.

RESULTS AND DISCUSSION

Water Quality

Turbidity. — Routine turbidity samples were collected three times a week from the control and treated watersheds. Storm samples were taken during storm periods when streamflow was at or near peak discharge. Samples were analyzed with a Hellige Turbidimeter.

The effect of both lower- and middle-slope treatments on streamflow turbidity is presented in table 2. Results indicate that the impact of timber removal on streamflow turbidity was greatest during and immediately after the lower-slope cutting. Maximum storm turbidity during logging was 550 ppm on the treated watershed. Most of this turbidity, which could be traced to scarified log-loading areas, decreased immediately after completion of logging. Average storm turbidity on the treated watershed decreased from 196 ppm during logging to 11 ppm the first year after logging, and ranged from 3 to 13 ppm over the last four after-treatment years. On the control watershed, storm turbidity never exceeded 25 ppm during the logging period and consistently averaged less than 5 ppm during the last four after-treatment years.

Nonstorm turbidity samples were not measured during the lower-slope logging period. However, during the 4-year period after completion of logging, nonstorm turbidity averaged only 2 ppm on

Table 2.—Effect of treatments on stream water turbidity during and after logging
[All values are in ppm]

Period	Treated watershed				Control watershed			
	Storm		Nonstorm		Storm		Nonstorm	
	Ave.	Max.	Ave.	Max.	Ave.	Max.	Ave.	Max.
LOWER-SLOPE CLEARCUTTING								
During logging ¹	196	550	—	—	—	<25	—	—
After treatment	9	119	2	24	3	29	1	17
MIDDLE-SLOPE CLEARCUTTING								
During logging ²	—	—	2	11	—	—	2	7
After treatment	4	13	1	6	2	7	1	4

¹Nonstorm turbidity was not measured.

²Insufficient storm data.

the treated watershed and 1 ppm on the control. Maximum nonstorm turbidity during this period was 24 ppm on the treated watersheds and 17 ppm on the control watershed.

An insufficient number of storms occurred during the middle-slope timber-harvest operation to determine effects on stream turbidity. However, nonstorm turbidity measurements indicate that the effects of the middle-slope cutting on stream turbidity were considerably less than those from the lower-slope cutting (table 2). Nonstorm turbidity measurements made during this period averaged only 2 ppm on both the treated and control watersheds. Maximum nonstorm turbidity measured was 11 ppm on the treated watershed and 7 ppm on the control watershed.

Storm turbidity samples taken the first year after completion of the middle-slope logging averaged 4 ppm on the treated watershed and 2 ppm on the control watershed. Maximum storm turbidity during this period was 13 ppm on the treated area and 7 ppm on the control. Nonstorm turbidity the first year after completion of logging never exceeded 6 ppm and averaged only 1 ppm on both the treated and control watersheds.

Water temperature.—After the lower-slope cutting, summer water temperatures on the treated watershed were considerably higher. Average summer (June, July, and August) maximum water temperature increased 7°F (61 to 68°F) in comparison to the control watershed. Mean water temperature increased 4°F (58 to 62°F) during the same period. Minimum water temperatures during the three summer months were generally unchanged as a result of treatment.

The effects of both clearcuttings on stream temperatures were essentially the same as those observed after the lower slope clearcutting. Average summer maximum water temperature on the treated watershed was 8°F (66 to 74°F) higher than on the control watershed. The highest average monthly maximum water temperature of 77°F, an 11°F increase over the average monthly maximum water temperature on the control watershed, was recorded in July. Mean summer water temperature was 4°F (61 to 65°F) higher on the treated area; minimum water temperatures remained unchanged.

Acidity. — Cutting the lower- and middle-slope parts of the watershed had

little if any effect on acidity expressed as pH. The average pH on both treated and control watersheds during the calibration period was 7.1. During the lower-slope after-treatment period, pH on both watersheds averaged 6.8. Average-month pH values during this period showed little change. After completion of the middle-slope clearcutting, pH averaged 7.0 on the control watershed and 7.1 on the treated watershed. In general, the water on both treated and control watersheds was slightly alkaline (average pH about 7.2) during the growing season and slightly acid (average pH about 6.8) during the remainder of the year.

Nutrient concentration. — Clearcutting had little if any apparent effect on the concentration of the selected elements listed in table 3. This statement is based on the assumption that the nutrient concentrations on the control watersheds represent the uncut condition of the treated watershed and that any major difference would represent a possible treatment effect. This assumption is necessary because no calibration-period data are available and is justified on the basis of the similarities of the vegetation, soils, and geology on the

watersheds. Furthermore, analysis of variance revealed that no significant differences existed between the control watersheds or between the control and treated watersheds for any of the elements studied.

The data listed in table 3 are based on 29 water samples collected after the completion of the middle-slope clearcutting during the period May 1972 to June 1973. Because a complete analyses has not been made, the data are not intended to represent exact concentrations of the listed elements. Instead they are presented merely to show that clearcutting did not result in large increases in the concentration of any of the selected elements.

Water Quantity

Annual water yield. — The hydrologic year used was May 1 through April 30 because correlation analyses indicated that this water year had the highest rainfall-runoff coefficient ($r=0.992$). Annual prediction equations were derived by multiple regression, using runoff from the control watershed and average precipitation as the independent variables.

Findings indicated that the lower-slope clearcutting resulted in increases from 1.22 to 2.87 area-inches in annual water yield during the 5 years after cutting (table 4). This represents an increase of 6.1 to 14.0 inches on an area-cut basis. The treatment effect is also apparent in figure 4, which shows the deviations between actual and predicted annual streamflow during both the calibration and after-treatment periods. With the exception of 1968, it becomes readily apparent from figure 4 that the increase in annual discharge during the lower-slope after-treatment period has remained relatively stable at an average of 2.72 area-inches. This apparent stability is evident despite the fact that since 1969 evapotranspiration has in-

Table 3.—Average nutrient concentration of stream water for treated and control watersheds after completion of middle-slope clearcutting¹

[All values are in ppm]

Ions	Control LR-1	Treated LR-2	Control LR-3
Ca ⁺⁺	3.47	3.27	3.32
Mg ⁺⁺	.89	.67	.73
K ⁺	.58	.60	.60
Na ⁺	.95	.97	1.03
SO ₄ ⁼	9.08	7.95	8.11
NO ₃ ⁻	< .30	< .30	< .30

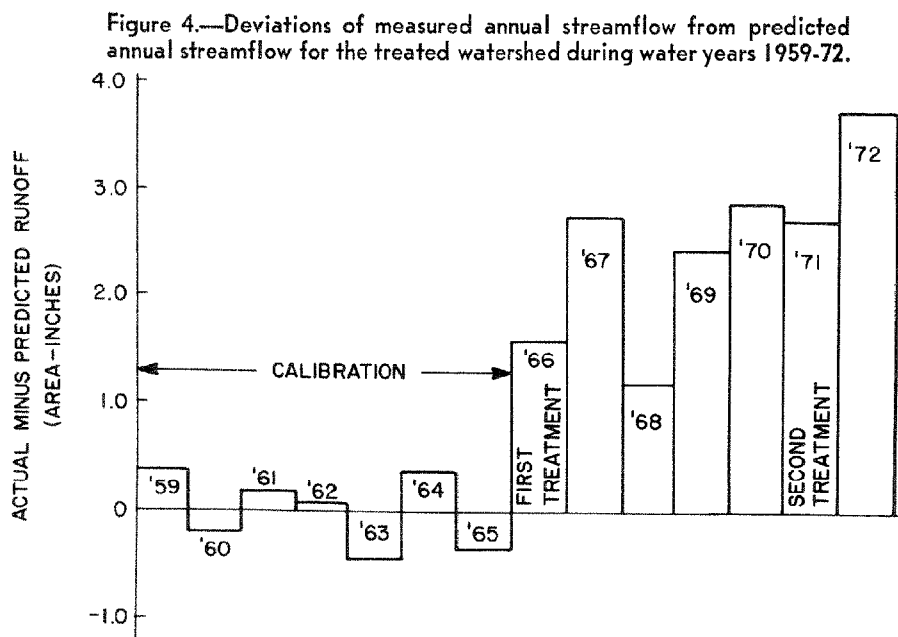
¹Data are based on 29 water samples collected May 1972 to June 1973.

Table 4.—Effect of treatments on annual and seasonal water yield¹
[All values are in area-inches]

Period	Water yield			Precipitation	
	Predicted	Actual	Change	Annual	Departure from 7-year mean
ANNUAL					
1967	15.71	18.54	+2.83*	37.7	+ 1.0
1968	11.53	12.75	+1.22*	35.0	- 1.7
1969	15.40	17.82	+2.42*	39.2	+ 2.5
1970	21.51	24.38	+2.87*	45.5	+ 8.8
1971	18.83	21.58	+2.75*	41.5	+ 4.8
1972	34.98	38.74	+3.76*	56.2	+19.5
GROWING SEASON					
1967	6.62	8.78	+0.92*	25.6	+ 6.6
1968	4.51	5.39	+2.16*	21.6	+ 2.6
1969	1.71	2.63	+0.88*	18.9	- 0.1
1970	2.68	4.35	+1.67*	24.4	+ 5.4
1971	3.36	4.79	+1.43*	22.2	+ 3.2
1972	18.76	20.25	+1.49	32.0	+13.0
DORMANT SEASON					
1967	10.81	9.76	-1.05	12.1	+ 2.6
1968	7.54	7.37	-0.17	13.3	- 5.6
1969	14.30	15.19	+1.61*	20.3	- 4.4
1970	19.02	20.03	+1.01	21.2	+ 3.5
1971	16.32	16.80	+0.48	19.3	+ 1.6
1972	17.08	18.49	+1.41*	24.2	+ 6.5

*Significant at 5 percent.

¹Lower-slope after treatment May 1967 through October 1971; middle-slope treatment November 1971 through April 1972; after treatment May 1972 through April 1973.



creased as a result of the regrowth of the herbaceous and woody vegetation on the lower slope clearcutting.

However, it should be noted that, since 1969, annual precipitation has been greater than the first three after-treatment years. This increase in the 1970 and 1971 annual precipitation, with respect to the previous after-treatment years, has minimized the effects of increased evapotranspiration. That is, the increases in the 1970 and 1971 annual precipitation may approximate the water loss from regrowth, thus causing the stability of increased annual discharge.

The 1972 annual water yield increase of 3.76 area-inches (8.3 inches on an area-cut basis) represents the combined effects of both clearcuttings. A larger increase would have been expected had not saturated conditions existed on both watersheds due to tropical storm Agnes.

Seasonal water yield.—For analyzing the treatment effect on seasonal water yields, 1 May through 31 October was selected as the growing season and 1 November through 30 April as the dormant season. Seasonal prediction equations were derived by multiple regression, using runoff from the control watershed and average precipitation on the watersheds as the independent variables.

The effect of clearcutting on the growing-season water yields for 1967 through 1972 is shown in table 4. Significant increases were measured during each growing season of the phase-one after-treatment period. These increases ranged from 0.88 to 2.16 area-inches (4.4 to 10.7 inches on an area-cut basis) and were a direct result of decreased evapotranspiration and canopy interception. However, the distribution and amount of rainfall appeared to exert a strong influence on the magnitude of these increases. With the exception of 1968, the growing seasons with above-

normal rainfall are also the growing seasons with the greatest response to treatment. When precipitation was near normal, as was the 1969 growing season, a considerably smaller increase occurred. The smallest increase in water yield, 0.88 area-inch, occurred during the 1968 growing season. Although precipitation during this period was 2.6 inches above normal, virtually all this increase fell during May and consequently had little effect on the overall 1968 growing season water-yield increase.

The 1972 growing season water-yield increase reflects the combined effects of both the phase one and phase two clearcuttings. Although an increase of 1.5 area-inches (3.3 inches on an area-cut basis) was measured, it was found to be nonsignificant. Here the effects of tropical storm Agnes on the magnitude of the independent variables used in the prediction equation become apparent. Precipitation during the 1972 growing season was 32.0 inches, 13 inches above normal. Streamflow from the treated watershed was 20.25 area-inches, 17 inches above the calibration period mean.

Since these values greatly exceeded any of the calibration data used in developing the prediction equation, the reliability of the statistical techniques used to determine the treatment effect and its significance became greatly reduced. Furthermore, water yield increases occur primarily during the growing season or recharge periods when a moisture-storage differential exists between the clearcut and forested areas. Because of the extreme rainfall during the 1972 growing season, saturated conditions existed on both treated and control watersheds, minimizing the effects of the timber harvest.

Treatment had a variable effect on the dormant-season water yields, as shown in table 4. Insignificant decreases in

stream discharge occurred in 1967 and 1968; increases were measured in 1969 through 1972. Of these, only the 1969 increase of 1.61 area-inches (8.0 inches on an area-cut basis) and the 1972 increase of 1.41 area-inches (3.1 inches on an area-cut basis) were significant. The 1972 increase represents the combined effect of both clearcutting treatments. These increases in water yield during the dormant season reflect the effects of treatment on soil moisture recharge and possibly on snow accumulation and melt. However, the magnitude of the treatment effect on the dormant-season discharge also reflects the amount of precipitation. Decreases in water yield in 1967 and 1968 were associated with below-normal precipitation. Conversely, the increase during the 1969 through 1972 dormant season were associated with above-normal precipitation.

Monthly water yield. — Regression equations developed from the calibration period were used to predict monthly water yield for watershed 2 for both after-treatment periods. Changes in streamflow as a result of phase one for May 1967 through November 1971 are presented in table 5. The combined effects of both clearcuttings for May 1972 through April 1973 are also shown in table 5. The magnitude of increased flow varied considerably. Significant increases after phase one ranged from a high in August 1967 of 0.64 area-inch to a low of 0.06 area-inch during July 1968. The range in significant increases for the combined effects of phase one and phase two is from 1.20 area-inches in June 1972 to 0.05 area-inch in September 1972. The exceptionally high increase in June 1972 is a direct result of tropical storm Agnes.

A rather consistent pattern in the timing of these increases in streamflow is evident for both after-treatment periods. In general, significant increases in water yield occurred primarily during

the growing season months (May-October) and resulted from decreased evapotranspiration, increased soil moisture, and elimination of canopy interception. Significant increases in water yield during the dormant-season months resulted from the higher soil moisture content on the treated watershed as compared to the control watershed. Because of this, less precipitation is needed to recharge the soil reservoir on the treated watershed, leaving more available for streamflow. Increases in stream discharge that occur after the soil reservoir is recharged on both treated and control watersheds are due to the effect of treatment on snow accumulation and melt.

Low flows. — The number of days per year in which stream discharge was below 0.1 csm (100 gallons per acre per day) was used to determine the effect of treatment on low flows. Analyses of variance and regression analyses were used to determine the significance of change.

On the treated watershed, the number of days that flow was below 0.1 csm decreased from an average of 168 days per year during the calibration period to an average of 51 days per year during the six after-treatment years (table 6). At the same time, on the control watershed the number of days with flow below 0.1 csm decreased from an average of 175 days to 111 days. The effect of the above-normal precipitation during five of the six after-treatment growing seasons resulted in the decrease in the number of days with low flow on the control watershed and also accounted for part of the decrease on the treated watershed. Although analyses of variance indicated that no significant difference existed between the two watersheds before cutting, it was not certain what effects of the treatments alone had on the significant reduction in the number of days with low flow. Therefore, regression analysis was used to determine the treatment

Table 5.—Effect of treatments on monthly streamflow from May 1967 through April 1973¹
[All values are in area-inches]

Month	7-Year mean precipitation	1967-1968		1968-1969		1969-1970		1970-1971		1971-1972		1972-1973	
		Y- $\hat{Y}$ ²	Precipitation	Y- $\hat{Y}$	Precipitation	Y- $\hat{Y}$	Precipitation	Y- $\hat{Y}$	Precipitation	Y- $\hat{Y}$	Precipitation	Y- $\hat{Y}$	Precipitation
May	3.40	+0.096	5.00	+0.336*	6.06	+0.036	2.20	+0.148	3.10	+0.541*	4.12	+0.218*	5.56
June	3.32	+0.264*	1.70	+0.279*	3.86	+0.187*	3.75	+0.199*	5.11	+0.189*	3.86	+1.198*	15.89
July	3.55	+0.402*	7.20	+0.063	2.43	+0.339*	5.98	+0.417*	5.76	+0.160*	5.33	+0.188*	4.16
Aug.	3.49	+0.639*	4.85	+0.039	2.22	+0.274*	3.63	+0.272*	4.50	+0.136*	1.52	+0.094*	1.23
Sept.	3.02	+0.289*	3.02	+0.110*	3.63	+0.030	0.94	+0.109*	2.26	+0.231*	5.03	+0.052*	3.11
Oct.	2.23	-0.101	3.86	+0.206*	3.44	+0.065*	2.36	+0.631	3.62	+0.230*	2.36	+0.138*	2.05
Nov.	2.95	-0.360	2.95	+0.244*	4.54	+0.312*	3.12	-0.428	5.28	+0.155*	2.99	+0.829*	6.29
Dec.	2.10	-0.205	3.01	-0.229	2.86	+0.195*	4.05	+0.105	3.75	+0.048	3.72	+0.118	4.96
Jan.	2.56	-0.112	1.51	-0.100	1.53	+0.113	1.02	+0.105	3.77	+0.091	2.46	-0.182	2.91
Feb.	2.85	-0.028	0.72	-0.093	0.69	+0.366*	3.55	+0.307*	4.85	+0.262*	3.43	-0.049	3.26
Mar.	3.66	-0.130	2.59	-0.220	0.89	+0.454*	3.65	+0.209	2.82	-0.001	1.86	-0.154	2.18
Apr.	3.55	-0.019	1.31	-0.055	2.74	+0.195	4.90	+0.029	0.71	+0.175	4.82	+0.062	4.59

¹See table 4 for specific treatment periods.

²Actual streamflow—predicted streamflow.

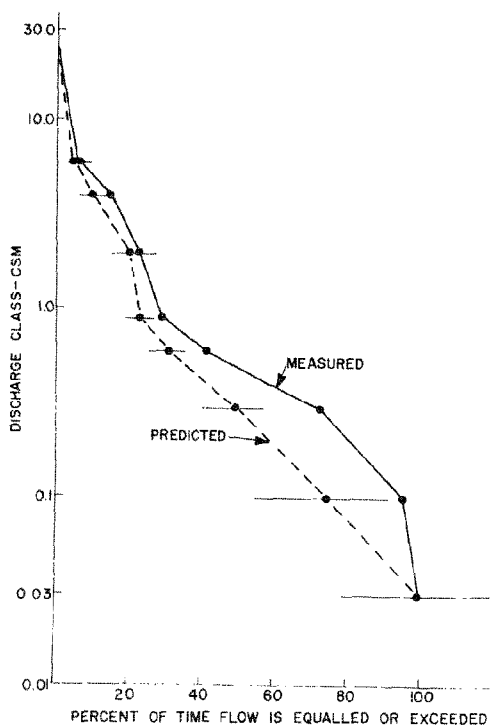
*Significant at 5 percent.

Table 6.—Comparison of the number of days per year that streamflow was below 0.1 csm

Period	Control watershed	Treated watershed Y	Predicted No. of days $\hat{Y}$	Difference $Y-\hat{Y}$
Calibration period mean	175	168	—	—
After-treatment water year				
1967	87	56	16	-40*
1968	115	92	87	-5
1969	158	146	84	-62*
1970	99	71	26	-45*
1971	115	92	53	-39*
1972	95	66	40	-26*
After-treatment mean	111	51	87	-36*

*Significant at 5 percent.

Figure 5.—Effect of partial forest removal on the growing-season flow-duration curve.



effect. The results indicate that treatment alone resulted in significant reductions in the number of days of low flow for five of the six after-treatment years. The significant reductions of low-flow days ranged from 26 in 1972 to 62 in 1969 and averaged 36 days over the after-treatment periods. The 1968 water year, the only year of below normal precipitation, had a nonsignificant decrease of 5 days.

Flow duration.—Flow-duration analyses based on mean daily flow in csm were used to show the treatment effect on various discharge classes. From the calibration data, prediction equations were computed for selected flow classes for the growing, dormant, and annual periods. These equations were then used to predict the average flow-duration curve for the treated watershed for each season during the after-treatment periods.

Average predicted and measured flow-duration curves for the clearcut watershed during the growing season are shown in figure 5. The measured flow-duration curve is above, or to the right of, the predicted curve for almost all flow classes and reflects the treatment

Figure 6.—Effect of partial forest removal on the dormant-season flow-duration curve.

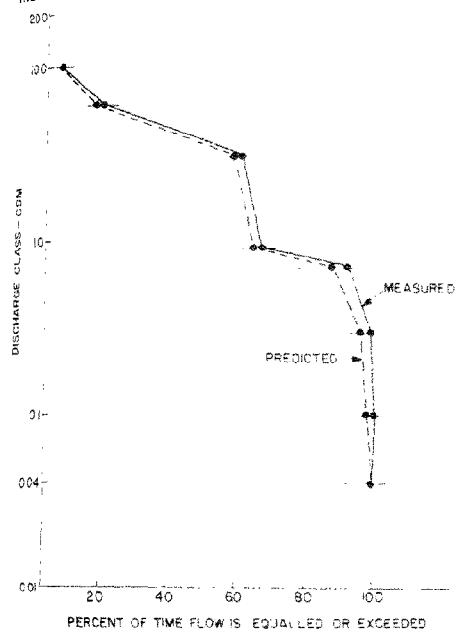
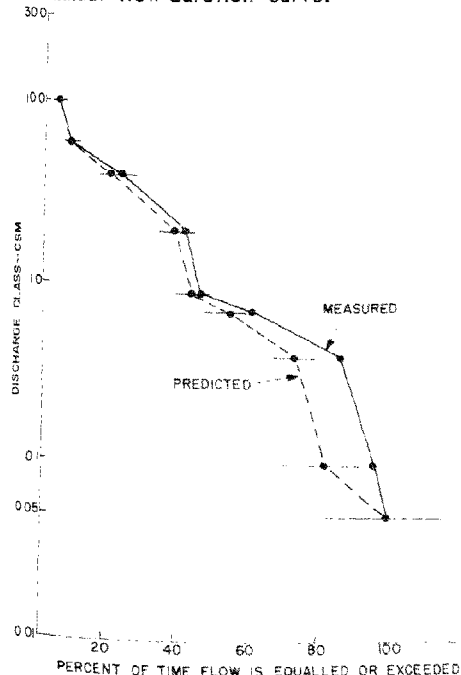


Figure 7.—Effect of partial forest removal on the annual flow-duration curve.



effect. Since the measured curve lies outside the 5-percent confidence interval for each flow class of the predicted curve, the treatment effect is significant. In general, there has been considerable augmentation of the low and median flows (below 0.4 csm) and relatively smaller increases in high flows (above 1.0 csm).

The effect of treatment on discharge during the dormant season is shown in figure 6. Again, the average measured flow-duration curve is above the predicted curve for almost all flow classes. However, the measured curve, for the most part, falls within the confidence intervals about the predicted curve, thus indicating a nonsignificant treatment effect for most flow classes. A significant change was detected for only the 0.1 to 0.3 csm flow class.

Predicted and measured average annual flow-duration curves are shown in figure 7. A comparison of these curves shows an increase in the measured curve for almost all flow classes, the most pronounced change occurring in the median- and low-flow classes. The number of days with flow exceeding 0.7 csm was not significantly changed.

Runoff as a percent of precipitation.—

The effects of clearcutting on runoff as a percent of precipitation for both the growing season and annual water years during both after-treatment periods are shown in table 7. Using regression analysis to determine treatment effect, we observed significant increases in runoff as a percent of precipitation for 1967 through 1971 for both the growing season and annual water years. Significant increases during the growing season ranged from 4.6 percent in 1968 to 9.5 percent in 1967. On an annual basis, significant increases ranged from 4.0 percent in 1968 to 7.8 percent in 1970. In all cases, significant increases in runoff as a percent of precipitation corresponded to significant increases in

Table 7.—Effect of treatments on runoff as a percent of precipitation

Period	Predicted	Actual	Difference
GROWING SEASON			
1967	24.9	34.4	9.5*
1968	20.3	24.9	4.6*
1969	8.5	13.8	5.3*
1970	9.7	17.6	7.9*
1971	14.0	21.8	7.8*
1972	58.7	63.6	4.9
ANNUAL			
1967	43.4	49.5	1.6*
1968	32.7	36.7	4.0*
1969	38.5	46.1	7.6*
1970	46.2	54.0	7.8*
1971	46.1	52.3	6.2*
1972	63.8	69.3	5.5

*Significant at 5 percent.

stream discharge. Although a relatively large increase in runoff as a percent of precipitation occurred during the 1972 growing season and annual water year, they were nonsignificant.

Again, the effect of tropical storm Agnes on the 1972 growing season and annual precipitation and runoff drastically affected the reliability of the statistical techniques used to determine treatment effect and its significance. During the extremely wet conditions of 1972, growing-season runoff as a percent of precipitation increased from a 16 percent average during the calibration period to 64 percent. Approximately 70 percent of this increase resulted from tropical storm Agnes. The annual runoff as a percent of precipitation increased from an average of 35 percent during the calibration period to 70 percent during 1972, tropical storm Agnes accounting for 57 percent of this increase.

Storm hydrograph. — The effects of the lower-slope treatment on storm hydrograph parameters also were studied. The parameters selected were quickflow volume, instantaneous maximum peak, antecedent flow rate, time to

peak, and time of recession. A total of 46 events was selected from the calibration period and 37 from the after-treatment period (April 1967-August 1970). The hydrographs selected were from single storm events that produced a quickflow volume of 0.01 area-inch or more and occurred during non-snowmelt periods. These events were then classified according to whether they occurred in the growing or dormant season. A downward stepwise multiple-regression technique, using maximum rainfall intensity, duration of rainfall before the maximum peak, duration of rainfall after the maximum peak, and total precipitation as the independent variables, was used to develop prediction equations for each of the hydrograph parameters. These prediction equations were then used to detect any change in the selected hydrograph parameters due to treatment.

The results (table 8) indicate that treatment affected the storm hydrograph by significantly increasing quickflow volume, instantaneous maximum peak, antecedent flow rate, and time of recession, while decreasing the time to peak. In general, these increases were most evident during the growing season.

Although the removal of the forest cover did significantly increase the volumes of stormflows and instantaneous peakflows, the large increases occurred primarily in storms during the growing season at relatively low antecedent flow conditions and therefore do not represent any potential increase in flood threat.

The effects of both treatments on five storm hydrographs, excluding tropical storm Agnes, were similar to those encountered after the lower-slope clearcutting. The time to peak decreased for all five storms, while the antecedent flow rate and time of recession increased. The instantaneous maximum peaks and quickflow volumes showed variable re-

Table 8.—Effect of lower-slope treatment on storm-hydrograph parameters

Storm-hydrograph parameter	Growing season	After-treatment period ¹
Quickflow volume	+171% (0.07 inch)*	+ 32% (0.02 inch)*
Instantaneous maximum peak	+351% (25.6 csm)*	+118% (10.5 csm)*
Antecedent flow rate	+123% (0.20 csm)*	+ 12% (0.10 csm)*
Time to peak	— 3% (0.11 hrs.)	— 3% (0.11 hrs.)
Time to recession	+ 33% (4.2 hrs.)*	No change

¹April 1967 through August 1970.

*Significant at 1 percent.

Table 9.—Comparison of the average storm-hydrograph parameter during the calibration period with tropical storm Agnes

Storm-hydrograph parameter	Control		Treated	
	Calibration period average	Tropical storm Agnes	Calibration period average	Tropical storm Agnes
Quickflow volume (inches)	0.075	9.16	0.076	9.75
Instantaneous maximum peak (csm)	9.4	177.0	10.7	190.0
Time to peak (hours)	5.7	49.0	5.2	40.0
Time of recession (hours)	16.1	111.2	16.0	114.5

sponse. Increases were observed for some storms, while for others, decreases were measured. Although the middle-slope clearcutting significantly altered some of the storm-hydrograph parameters for some storms, the overall effects of both treatments were not significantly different from those resulting from the lower-slope treatment.

For tropical storm Agnes, the effects of treatment on the storm-hydrograph parameters did not follow the general trends in all instances. Quickflow volume, instantaneous maximum peak, and time of recession show large negative differences between the actual and predicted values rather than positive differences. Deviations from the trends shown by the other storms can be attributed to the magnitude of Agnes when compared with the relatively small storms on

which the prediction equations were based (table 9). Total runoff from Agnes on the treated watershed amounted to 10.94 area-inches. This represents 92.8 percent of the 11.79 inches of rain that fell during Agnes. On the control watershed, total runoff amounted to 10.09 area-inches or 85.5 percent of the total rainfall. The quickflow volumes (table 9) accounted for 91 percent on the total runoff on the control watershed and 89 percent on the treated watershed.

CONCLUSIONS

The two-phase clearcutting of approximately 48 acres of Leading Ridge Watershed 2 (106 acres) produced the following effects on water quantity and quality:

1. During the lower-slope logging period, maximum storm turbidity was 550 ppm on the treated watershed;

- the control watershed never exceeded 25 ppm. Most turbidity, which could be traced to scarified log-loading areas, decreased immediately after completion of logging. Increased water turbidity as a result of cutting the middle-slope portion of the watershed was negligible. Maximum storm and nonstorm water turbidity on both watersheds never exceeded 13 ppm. In general, restrictive logging practices prevented any serious stream sedimentation.
2. Maximum water temperatures increased an average of 7°F (61 to 68°F) during the summer months (June through August) as a result of the lower-slope clearcutting and 8°F (66 to 74°F) after completion of both treatments. Minimum water temperature showed little change as a result of either clearcutting.
 3. The combined lower- and middle-slope clearcuttings had little, if any, apparent effect on the average concentration of calcium, magnesium, potassium, sodium, sulfate, and nitrate.
 4. Clearcutting had no effect on stream water acidity expressed as pH.
 5. Water-yield increases resulting from clearcutting occurred primarily during the growing season and ranged from 0.88 to 2.16 area-inches (4.4 to 10.7 inches on area-cut bases) after completion of the lower-slope logging.
 6. Dormant-season flows showed a variable effect. Only the 1969 increase of 1.61 area-inches and the 1972 increase of 1.41 area-inches were significant. These increases are equivalent to 8.0 and 3.1 inches on an area-cut bases.
 7. Annual water-yield increases ranged from 1.22 to 2.87 area-inches (6.1 to 14.0 inches on an area-cut bases) after the lower-slope clearcutting. The combined treatments resulted in an annual water-yield increase of 3.76 area-inches (8.3 inches on an area-cut bases).
 8. Both the lower-slope and middle-slope treatments had major effect on low flows. The number of days per year of flow under 0.1 csm on the treated watershed decreased from an average of 168 to 51 during the after-treatment periods.
 9. The lower-slope treatment affected the growing-season storm hydrographs by significantly increasing quickflow volumes, instantaneous maximum peaks, and time of recession, while decreasing the time to peak. Storm antecedent flow rates were also increased. The middle-slope clearcutting significantly altered some storm-hydrograph parameters for some storms; however, the overall average effects of both treatments were not significantly different from those following the lower-slope treatment.

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EFFECTS OF MANAGEMENT PRACTICES ON WATER QUALITY AND QUANTITY: THE NEWARK, NEW JERSEY, MUNICIPAL WATERSHEDS

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ABSTRACT. The 36,000-acre Pequannock Watershed, owned by the City of Newark, New Jersey, provides about one-half of the water supply of Newark and adjacent cities. The collection and delivery of high-quality water to the city is the primary management objective. The Newark Division of Water Supply and the Northeastern Forest Experiment Station in 1959 initiated a cooperative study of the effects of chemical control of vegetation on water quality and yield. Three forested watersheds (oak-hickory type) in the Pequannock drainage, ranging from 24 to 68 acres, were used. Riparian zone vegetation was deadened on one watershed with herbicides (using tree injection and mistblower application) to stimulate a streamside treatment that has been practiced on the Pequannock in the past. Herbicides were used to deaden overstory vegetation on another watershed. The effects of gypsy moth defoliation on water yield are quantified. The use of vegetation treatments in the management of a municipal watershed is discussed.

A WATERSHED MANAGER is interested in water production and quality as related to forest conditions, in addition to all the other problems of tree growth, disease and insect damage, planting, fire protection, property locations, timber sales, recreation pressures, etc. This interest may vary from year to year depending on the amounts of precipitation and the level of water in storage reservoirs during the summer and early fall when streamflow is lowest.

Newark's 36,000-acre Pequannock watershed provides about one-half of the water supply for the city and surrounding communities. It is almost entirely forested. The main objective of the management program on the Pequannock watershed is to collect and deliver high-quality water for domestic and industrial use. Many of the city's industries are geared to a plentiful supply of clean, soft water and could be affected by a

decrease in either quantity or quality of supply. In recent years the watershed is also being looked to for recreation and education, for new revenue-producing uses that may aid in decreasing the property tax burden of the city, and for open space that future generations may enjoy.

To obtain a quantitative evaluation of how the forest-water yield relationship may be affected by control of vegetation on municipal watersheds, the Northeastern Forest Experiment Station and the City of Newark, New Jersey, Division of Water Supply, initiated the study described in this paper.

EXPERIMENTAL WATERSHEDS

Three adjacent watersheds within the Pequannock basin were selected for the study. The watersheds have a southeast aspect and lie between 900 and 1,200 feet in elevation. Slopes are gentle near the stream-gaging stations but steeper near the ridge of Copperas Mountain. Watersheds 2 and 3 are 42 and 23 acres in area, respectively. Watershed 1 is 68 acres, and its stream-gaging station is at the end of a long flat stretch of bouldery stream channel. All watersheds had intermittent summer flow during the drought period years 1962-65.

Forests of the oak-hickory type completely covered all three watersheds. Soils range from very poorly drained and swampy to well drained and very stony to bouldery. Soils are usually less than 24 inches deep, and much of the surface is covered with stones or boulders, especially on the upper portions of the watersheds. Rock outcrops are common. Mid-slope soils are deeper and are moderately well to poorly drained. Site quality is generally low. Repeated cuttings for charcoal and a series of wildfires have reduced the forest quality to a level probably lower than the site would normally support.

HYDROLOGIC EFFECTS OF DEADENING FOREST VEGETATION ON AN ENTIRE WATERSHED

Application of Herbicides by Injection

Partly because of their substantial transpiring surfaces and extensive root systems, trees use a lot of water compared to other forms of vegetation. Experiments in several parts of the East have shown that harvesting trees on a watershed can save a considerable amount of water (*Lull and Reinhart 1967*). Because there was no market for the low-grade timber on the experimental watershed, we decided to deaden the trees with herbicides, simulating a clear-cutting, to find out if water yield could be increased.

On watershed 3, all trees larger than 1 inch in diameter (approximate diameter at ground surface) were injected with a herbicide (either Tordon or Weedone) in the fall of 1965. In addition, Weedone was applied by mist-blower on several areas of dense undergrowth. By the summer of 1966, live overstory vegetation had been reduced to 31 percent of the watershed area. Live trees less than 1 inch in diameter were present on 10 percent of the area. In general, a good tree kill was achieved on the drier sites in the upper portion of the watershed. The kill varied from moderate to poor on the deeper soils where moisture conditions were more favorable. The incomplete kill was due in part to missed stems, especially in areas containing many small ones. Grasses and herbs increased in response to the reduction in overhead shading and in 1966 covered 26 percent of the watershed.

Application of Herbicide by Aerial Application

To complete the deadening of forest vegetation on watershed 3, an aerial application of herbicide was made by helicopter in June 1967. The 2,4,5-T

(low volatile ester) was applied at the rate of 4 pounds acid equivalent mixed with 3 gallons of water and 1 gallon of fuel oil per acre. Watershed boundaries were marked with fluorescent bags filled with brush and tied to the tops of trees. Criteria were established to permit spraying only when wind speed was less than 3 mph, to minimize drift. The job was conducted in the early morning, and wind speeds never exceeded 1 mph.

To check on possible contamination of streamflow by the herbicide, water samples were collected. Control samples were taken at the stream-gaging stations at watershed 2 (the control watershed) and watershed 3 before the spraying operation. Other samples were taken at the same stations during and at the conclusion of the spraying operation and at 1, 2, 4, 8, 24, and 48 hours afterwards. Samples were also taken 1 mile downstream from the experimental watersheds. Additional samples were collected after rainstorms into July. Samples were refrigerated until analyzed by an independent laboratory, using gas chromatography with electron capture techniques.

By late summer, live overstory vegetation had been reduced to 3 percent of the 1965 stocking. Ground cover continued to increase and covered 41 percent of the watershed. There was no evidence of vegetation damage outside the boundaries of the experimental watershed.

Only one water sample, taken in an open channel area just after a helicopter pass, showed a trace of herbicide. All other samples were negative.

Effects of Treatments on Water Yield

Treatment effects were based on changes in streamflow during the May 1 — April 30 water-year. Growing season (May-October) and dormant season (November-April) evaluations were also made.

Table 1.—Increases in annual water yield from deadening vegetation on watershed 3

May 1 water- year	Increase ¹	Equivalent increase
	<i>Inches</i>	<i>Gallons/acre</i>
INJECTION OF HERBICIDES FALL 1965		
1966-67	4.67	126,809
AERIAL APPLICATION OF HERBICIDES JUNE 1967		
1967-68	7.79	211,530
1968-69	5.06	137,899
1969-70	5.52	149,890
1970-71	3.53	95,854

¹Significant at 1-percent level.

Reduction in vegetation cover following the injection of herbicides resulted in a water-yield increase of 4.67 inches (table 1). This is an increase in water production of 127,000 gallons of water per acre per year.

A larger increase in water yield was obtained after the aerial application of herbicide. An annual increase of 7.79 inches was measured, which amounts to about 212,000 gallons of water per acre (table 1). This additional water totaled 5 million gallons from the 24-acre watershed. Most of this increase was yielded during the growing season.

In summer 1968, ground cover had increased to 90 percent while overstory vegetation covered 4 percent of the watershed (fig. 1). Fifty-seven percent of the ground cover consisted primarily of the tall densely-growing white fireweed (*Erechtites hieracifolia*).

In contrast, ground cover was virtually absent in the forested control watershed (fig. 2). Some hardwood sprouts and new seedlings developed in the treated watershed. About 1,500 Scotch and Austrian pine seedlings were planted. The watershed still had

Figure 1.—Watershed 3 had a heavy cover of grasses and herbs a year after the aerial application of 2, 4, 5-T. Live trees in the right center of photograph are on the control watershed.



Figure 2.—Ground cover is virtually absent in the forested control watershed.

a continuous cover of litter 2 to 3 inches thick. No areas of bare soil or surface erosion were discernible. Firewood cutters were allowed to remove the dead trees to reduce the fire hazard and improve the safety and appearance of the area.

The increased water production began to decline in response to vegetation regrowth (table 1). Four years after the aerial application, the water-yield increase had been reduced by 55 percent. According to methods of Lull and Reinhart (1967) and Douglass and Swank (1972) there would be a water-yield increase for 12 years. However, the increase would be less than 1 inch after the 8th year.

The rate of decline is not always accurately defined because of precipitation variations in the after-treatment years. For instance, the 15 inches of rainfall in May-June 1968, 2.3 times normal, minimized the effects of the vegetation treatment during the early growing season. This influence is shown in the 1968-69 water-year (table 1).

Effects of Treatment on Other Hydrologic Parameters

Low-flow days.—The number of days per year in which stream discharge was below 0.1 csm (cubic feet per second per square mile), or approximately 100 gallons per acre per day, was used to determine the effects of treatment on low flows. The herbicide treatment resulted in considerable augmentation of low flows. During the 5 years after the first treatment, the number of low-flow days was reduced from an average of 81 days per year to an average of 35 days per year.

Streamflow timing. — Streamflow timing (concentration) can be characterized by the shortest number of consecutive days that accounts for high flows and the longest number of consecutive days that accounts for low flows (Sopper and Lull 1970). The half-flow

interval for high flows is defined as the shortest winter-spring period that includes one-half of the annual flow. The 5-percent flow interval for low flows is defined as the longest period that accounts for 5 percent of the annual flow.

The shorter the time period in which half the annual flow runs off, the greater the concentration of flow and possibility of wide variation in annual streamflow. Where half-flow intervals are longer, flow is discharged over a longer period of time, and the annual regimen shows less variation. The shorter the low-flow interval, the less spread out the low flow, with consequently less variation in the annual regimen.

After treatment, the half-flow interval increased by an average of 26 days per year for the five after-treatment years. The 5-percent flow interval was reduced by 33 days per year for the same period. This influence was most pronounced during years of low precipitation. Both results confirm that the treatment tended to provide a more uniform flow of water into the reservoir system by sustaining streamflow during the low-flow period of summer and fall.

Peak flows. — A peak-flow analysis was made for all storm events that produced flows exceeding 10 csm on the control watershed. Instantaneous peak flows on watershed 3 were increased by 17.3 percent (8.2 csm) during the growing season as a result of the vegetation treatment. These increases occurred during periods when soil moisture was higher on the treated watershed due to the reduction in interception and transpiration losses. Because relatively low flows prevail during this summer period, increases are much below flood magnitude. Effects on peak flows during the dormant season were minor or nonexistent, because little or no difference in moisture storage existed between the forested and deforested watersheds.

Stream temperature. — Stream water temperature increased during the growing season as a result of removing overstory vegetation. Average summer (June, July, and August) maximum water temperature increased 6°F (68° to 74°F) compared to the control watershed during the first 3 years after treatment. Mean water temperature increased 4°F (62° to 66°F) during the same period. Minimum water temperatures during the summer months were generally unchanged, as were temperatures during the dormant season. Temperatures approached pretreatment normals by the fourth and fifth year after treatment as vegetation began to shade the stream channel again.

Turbidity. — Stream turbidity was measured once a week at the time of chart changing. Stream turbidity after

the herbicide treatment was 1.6 ppm for the control watershed and 1.8 ppm for the treated watershed. Maximum turbidities measured were 7.5 ppm on the control watershed and 6.5 ppm on the treated watershed. Highest flow sampled on the treated watershed was 26.2 csm.

EFFECTS OF GYPSY MOTH DEFOLIATION ON WATER YIELD

The Situation

A severe gypsy moth outbreak occurred in the spring of 1971 on the Pequannock Watershed. Defoliation on the forested portions of the experimental watersheds was extensive. The timing of the outbreak provided an opportunity to evaluate one of nature's defoliation techniques on water yield.

Five growing seasons after the first



Figure 3.—Gypsy moth defoliation under way on watershed 2 in the spring of 1971. Area in right foreground is watershed 3.

herbicide treatment, watershed 3 still had a relatively small percentage of its area in overstory vegetation. Consequently there was little defoliation damage. However, trees on the control watershed (No. 2) were severely defoliated (fig. 3). By the end of June and early July, trees in the top half of the watershed were completely defoliated, while trees on the rest of the watershed were partially defoliated. By July, approximately 75 percent of the overstory leaves had been destroyed. The trees put forth a second crop of leaves at the end of the summer following heavy rains in late August.

Methods Used to Determine Change in Water Yield

Two methods were used to estimate the effects of gypsy moth damage on water yield. In one method the herbicided watershed was used as a control, and an equation was developed to predict streamflow of watershed 2 from streamflow measured at watershed 3. The calibration period was the 5 years during which vegetation on watershed 3 was deadened and watershed 2 was forested. Admittedly, vegetation on Watershed 3 was in a state of flux during this period. However, we felt the calibration would be sensitive enough to detect a large change in streamflow, if one occurred, as a result of the defoliation.

In addition to the control-watershed approach, we tried to obtain another independent estimate of the defoliation effects on water yield. An estimate based on calibrating a single watershed was used. Regression equations were developed to predict streamflow of watershed 2 from precipitation parameters. Twelve years of data were available for this calibration. A correlation coefficient of 0.978 was obtained for the annual water-yield equation.

Water-Yield Increases Following Gypsy Moth Defoliation

The gypsy moth defoliation had a substantial influence on water yield. Annual water yield was increased by 5.82 inches as estimated by the control-watershed technique, while the single-watershed calibration method estimated the increase at 4.89 inches. Both values were statistically significant at the 5-percent level. Eighty percent of the yield increase came during the growing season. If we accept an average of the two estimates, 5.36 inches, as our quantitative estimate, water production was increased by 146,000 gallons per acre.

CONTROL OF STREAMSIDE VEGETATION: EFFECTS ON WATER YIELD

Vegetation Treatments

On watershed 1 all trees 1 inch in diameter (approximate diameter at ground surface) and larger within a zone 20 feet on each side of the stream channel were injected with ANSAR 160 herbicide in May 1965. The remaining live vegetation was sprayed with Weedone herbicide applied by a portable mistblower. Sopper *et al.* (1966) have shown that phenoxy herbicides can be used to control riparian vegetation on municipal watersheds, if properly applied, without constituting a water-pollution hazard.

This treatment was designed to simulate the program in streamside vegetation control that has been in operation for many years on the Pequannock Watershed. Vegetation has been cut and removed, or deadened by herbicide, within a strip 20 feet wide on each side of the feeder streams. The purpose of the program is to remove vegetation (1) that dropped its leaves into the stream, causing color and chemical build-up in the raw water, and (2) to prevent debris build-up that might cause stream blockage. Reducing the amount of vegetation in this zone of moist soil



Figure 4.—A heavy grass cover was already established when trees in the treated zone were cut.

might also affect water yield by lowering transpiration losses.

The chemical treatments were not completely effective. As of mid-June about one-half of the normal transpiring surface still remained. Red maple and yellow birch were the least damaged. Generally the amount of damage was related inversely to the diameter of the trees. The amount of live vegetation in the treated zone was lower in 1966 following some retreatment. In the winter and early spring of 1967, all trees in the treated zone were felled. A vigorous ground cover and some tree reproduction had developed in the cleared area by this time (fig. 4).

At the end of the 1967 growing season, the treatment zone was widened. Herbicide injection was used to treat all

trees in an area up to 5 feet in elevation above the stream channel. This widened the treatment area to approximately 40 feet on each side of the channel. The treatment was 50 percent effective. After the 1968 growing season, all trees in the expanded treatment zone were felled and the slash was burned.

Analysis of Treatment Effects

There were slight but statistically nonsignificant growing-season streamflow increases following treatment. The increases averaged 0.12 inch for the three after-treatment years. The nonsignificant increases in streamflow may be due to the small area treated, 1.2 percent of the watershed area, or to the incomplete vegetation kill. In addition, it is suspected that some of the stream

channel is above the groundwater table, and that deep seepage may be discharged downstream from the stream-gaging station, reducing the sensitivity of this experiment.

There was a definite reduction in diurnal fluctuation of streamflow during the 1967 growing season, indicating that transpiration losses had been reduced. This reduction had been slight in 1965 and 1966 following the herbicide treatment.

The effect on water yield of widening the treatment zone was also difficult to determine. Growing-season streamflow for 1968 through 1970 averaged 0.23 inch above predicted values. The increases in streamflow would represent approximately 9.5 inches additional water per acre treated for both the 40-foot and 80-foot treatment zones. However, changes in streamflow, as determined on a growing-season or an annual water-year basis, were not statistically significant. There was a substantial reduction in diurnal fluctuation during the 1968-70 growing seasons. This reduction disappeared after 1970 as a dense crop of aspen and birch developed in the treatment zone.

There was a slight increase in mean maximum stream temperature during the growing seasons on the order of 3°F. Stream turbidity was not increased as a result of the treatments. All felling of trees had been done during the winter months on snow or frozen soil. A low channel gradient and development of an early grass cover after the first herbicide treatment were important factors in preventing erosion. Average turbidity during the treatment periods averaged 1.6 ppm for both control and treated watershed. Maximum turbidity measured on watershed 1 was 7.9 ppm.

DISCUSSION

Information gathered during this study showed that water production can be substantially increased by deadening vegetation on a watershed. The increased water is yielded primarily during the summer and early fall months.

The limited riparian vegetation treatment was not effective in producing statistically significant increases in water yield. There was a definite reduction in transpiration losses by streamside vegetation and indications that increases in water yield occurred during the growing season.

Gypsy moth defoliation caused a substantial increase in streamflow. However, we do not recommend it as a water-yield improvement method. Resulting tree mortality in 1971 was estimated at 16.5 million board feet on the Pequannock Watershed (*Newark Division of Water Supply 1971*).

One might ask if vegetation treatments, either timber-harvesting or chemical vegetation control, are really needed or are practical for increasing water production in the Northeast? Look at one case history.

1965 was the fifth consecutive year of below-average precipitation on the Pequannock Watershed. Precipitation totaled 32.50 inches, 16.51 inches less than the 73-year average of 49.01 inches. At the start of 1965, Pequannock water storage was 2.8 billion gallons or 19.5 percent of the total storage capacity. This was 840 million gallons less than storage at the start of the previous year. Loss in storage continued until February 3, 1965, when it reached 2.05 billion gallons (14.3 percent of total storage), the lowest storage on record up to that date. Gains in storage were very gradual and reached a maximum of 4.83 billion gallons (33.5 percent of storage) on May 11, 1965. Depletion then started. Emergency measures

slowed the rate of drawdown, in spite of which storage dropped to 1.08 billion gallons (7.6 percent of total storage capacity) on December 13, 1965. This is less than one-third of the 25 percent reserve, which is not considered a part of the storage in figuring safe yield of the water supply (*Newark Division of Water Supply 1965*). At 1966 delivery rates, this represented a 20-day water supply, a portion of which was not obtainable without pumping. At 1970 delivery rates, the supply would have lasted for 16½ days.

A slight gain occurred by the end of the year to 1.48 billion gallons (10.3 percent of storage capacity). Threat of complete depletion was averted only by the narrowest of margins. Thirty percent less water was sent to the city in 1965 than in 1964. One and a half billion gallons of otherwise unavailable water was pumped into the Pequannock system from Lake Wawayanda, Echo Lake, and Hanks Pond (*Newark Division of Water Supply 1965*).

Such situations are especially critical for communities with small water-storage capacities. In such cases there is little carryover from years of plentiful supply to years of shortages.

From 1945 to 1972, 34 percent of the water yield from the Pequannock Watershed was lost through overflows in the reservoir system. In many of those years this water was not needed. However, overflows for the two years preceding the 1962-66 drought were 44 percent and 49 percent respectively of the total water yield. Creation of additional storage capacity may be one answer. But this can be expensive, and in many parts of the Northeast the best reservoir sites are already in use.

During extended drought periods, additional storage capacity may not be entirely sufficient unless this capacity is large. Under such conditions a program of vegetation management to augment

low water yields in the summer and fall would be extremely beneficial.

For example, an even-aged sustained-yield management program on the Pequannock Watershed, such as harvesting timber on 500 acres per year in small blocks, could substantially increase water yield. Twelve years into such a program, and as long as the program was maintained, an increased average annual water yield of 440 million gallons could be expected and would come primarily in the summer and fall months. Partial cutting under all-aged management would have a much smaller and shorter-lived effect on water yield. Additional benefits would include deriving municipal income from the timber sales and improvement in the growing stock. Other management programs to augment water yield by periodically harvesting timber on portions of a municipal watershed have been described by Lull and Reinhart (1967).

Before any program of vegetation management is put into effect, there are several values to consider in addition to water supply. How will the proposed vegetation treatments affect aesthetic values? Many municipal watersheds in megalopolis are major open-space areas and provide visual relief from a man-created urban-industrial landscape. The creation of vistas within the watershed property is also an important consideration.

How will the proposed vegetation treatments affect recreation values? Pressures are mounting for increased use of municipal watersheds for recreation. Recreation areas may have to be managed differently than other parts of the watershed. What are the possibilities for wildlife enhancement? A dirt road through watershed 3 has been frequently used by hikers because they can see for a distance and observe wildlife, vegetation changes taking place, and plants and songbirds of openings (ones

not found in mature forests). Increases in stream temperatures due to removal of forest vegetation will have to be evaluated in terms of their effects on the aquatic habitat. Use of buffer strips to shade the stream might be considered.

How will the proposed vegetation treatments affect timber values? Many forestry practices can benefit both timber and water production. While merchantable timber could be salvaged before or just after deadening by herbi-

cide, the future value of the growing stock would be entirely lost.

Perhaps we need to work out procedures to brown-out a canopy without killing the trees in years of water shortages. Even better would be the development of effective anti-transpirants and methods for their application to reduce the use of water without damaging vegetation. This would be especially helpful near recreation areas and where aesthetic considerations are important.

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EFFECTS OF MANAGEMENT PRACTICES ON WATER QUALITY AND QUANTITY: HUBBARD BROOK EXPERIMENTAL FOREST, NEW HAMPSHIRE

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ABSTRACT. A hypothetical dialogue between forest hydrologists and a municipal watershed manager illustrates the knowledge gained from research at Hubbard Brook. When forest vegetation is cut, water yield increases, especially when it is most needed during critical low-flow periods in late summer and early autumn. Unless measures are taken to control regrowth, the water yield returns to pre-treatment levels within several years. The normally high quality of streams from northern hardwoods can be lowered by any reduction in vegetative cover sufficient to materially increase water yield. Nutrient leaching is accelerated after cutting and dissolved solid content of streams is subsequently increased. Erosion, sediment, and increased water temperature are also problems associated with cutting; however, they can be minimized by taking known precautions.

WE HAVE CHOSEN to present research results from the Hubbard Brook Experimental Forest in the form of a dialogue. Our intent is to illustrate kinds of information available for assisting watershed managers in decision-making. Participants in our hypothetical dialogue are forest hydrologists (FH) involved in the Hubbard Brook experiments and a municipal watershed manager (MWM) for a community in upland New England.

MWM. The town I work for gets most of its water from a forested upland watershed several square miles in

area. It's covered with old-growth northern hardwoods interspersed with patches of conifers. Climatological data from the nearest weather station show that precipitation is evenly distributed throughout the year and averages about 40 inches. Snow cover is usually continuous from December through March and gets to be about 2 or 3 feet deep. The soil seems to be coarse-textured and shallow.

Our water supply is drawn from a small dam in the stream channel near the base of the watershed. Late-summer flow is usually too low to satisfy our

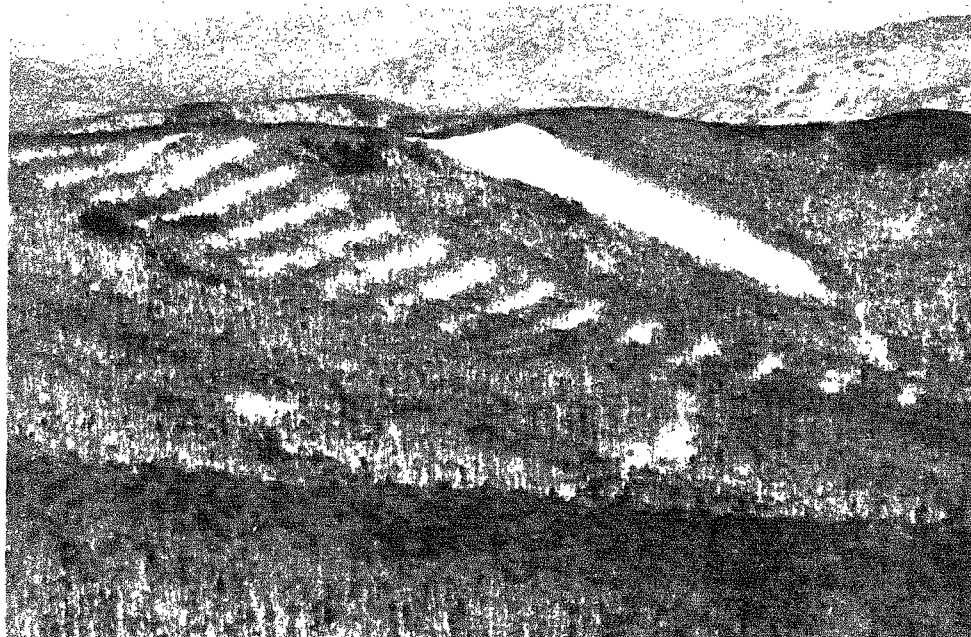
demands, and we must augment from alternate, more expensive, and lower quality sources. So my first question is: What information is available on how we might increase water yield, particularly in late summer?

FH. We might first point out that low summer flow is characteristic of streams and uncontrolled rivers throughout the Northeast. Although precipitation is evenly distributed throughout the year, less than 10 percent of annual streamflow occurs from June through September. Small streams often dry up; but in larger river valleys, flow is maintained by groundwater stored in the valley alluvium. The reason is that nearly all the precipitation falling on forests during this period is returned directly to the atmosphere by evaporation and transpiration (termed evapotranspiration or ET). The water

never has a chance to reach the stream. Of that 40 inches of annual precipitation of yours, only about half of it becomes streamflow. The other half becomes ET. And in summer nearly all the rainfall becomes ET. So the key to increasing summer yield is to decrease ET.

In the forest, ET dries the soil, producing what we call a soil-water deficit. When rain falls, it first rewets the soil. Only after the soil is fully recharged — that is, the soil-water deficit is eliminated — can additional rain move through the soil and become streamflow. In northeastern summers such full recharge seldom occurs if the summer rainfall is normal or below normal. However, when trees are cut or killed, ET is reduced and soil-water deficits are smaller. A smaller amount of rainfall is then required to recharge the soil, and a larger amount finds its way to the stream.

Figure 1.—Strip-cutting and complete forest clearing experiments in progress on gaged watersheds at Hubbard Brook.



MWM. So cutting the forest reduces ET and increases streamflow in summer. How much of an increase could I get by cutting?

FH. We have treated two watersheds at Hubbard Brook to study possible increases in water yield (fig. 1). The first treatment began in late 1965 and involved complete forest clearing by cutting all woody vegetation and leaving it where it fell. Herbicides were then applied for three successive summers to minimize regrowth of vegetation. For each of the 3 years in which herbicides were used, water yield increased an average 11.4 inches, nearly 300,000 gallons per treated acre. Nearly all of the increase came in late summer and early autumn.

A second watershed treatment that involves progressive strip-cutting was started in autumn 1970. One-third of the watershed is being harvested every other year by cutting a series of 80-foot-wide strips. This practice is a recommended form of management for regenerating a forest that will have a high proportion of valuable birch species. For the 2 years after cutting the first set of strips (one-third of the watershed area cut over), streamflow from the watershed increased by an average of 1.3 inches per year, or 35,000 gallons per watershed acre. Most of the increase was found to occur in late summer.

MWM. So complete clearing will give me 11 inches more water over the cleared area at the time I need it the most?

FH. On the order of 10 to 14 inches. More in a wet summer and less in a dry one.

MWM. The strip-cutting experiment puzzles me. The yield increase seems small considering that one-third of the total area was harvested.

FH. Based on the area cut, the water-yield increase from the first cycle of strip-cutting would be roughly one-third

of the first-year increase after complete forest clearing, or between 3 and 4 inches. So the actual increase of just over 1 inch does seem surprisingly small.

There are two explanations for the small increase. First, regrowth was not inhibited on the strip-cutting as it was on the completely cleared watershed, so some transpiration occurred from the cut strips. A second explanation may lie with the cutting configuration. The strip-cutting greatly increased the crown exposure and transpiration rate of trees on the borders of the uncut strips. Water was available for the increased transpiration because roots extend into the wetter cut strips.

MWM. So cutting 25 one-acre patches is not likely to produce as much water as a single 25-acre clearcut?

FH. Yes, and single-tree selection cutting should be even less efficient — although we have not studied it at Hubbard Brook.

MWM. How long will the increased water yields persist?

FH. Sprout growth, utilizing previously developed root systems, herbaceous vegetation, and tree seedlings can re-establish pre-cutting transpiration in 3 or 4 years. Our complete forest clearing experiment has provided a dramatic illustration. The last of three annual herbicide applications was made in the summer of 1968. In the 4 years after, regrowth was profuse, and water yield increases nearly disappeared (fig. 2).

Rapid regrowth on the cleared watershed occurred despite 3 years of herbiciding. Natural regrowth occurring immediately after a forest cutting may be even more rapid and reduce the yield increase more quickly. So it is clear that maintaining a water-yield increase will require extra effort. Possibilities include the use of some mechanical or chemical means to hold back regrowth

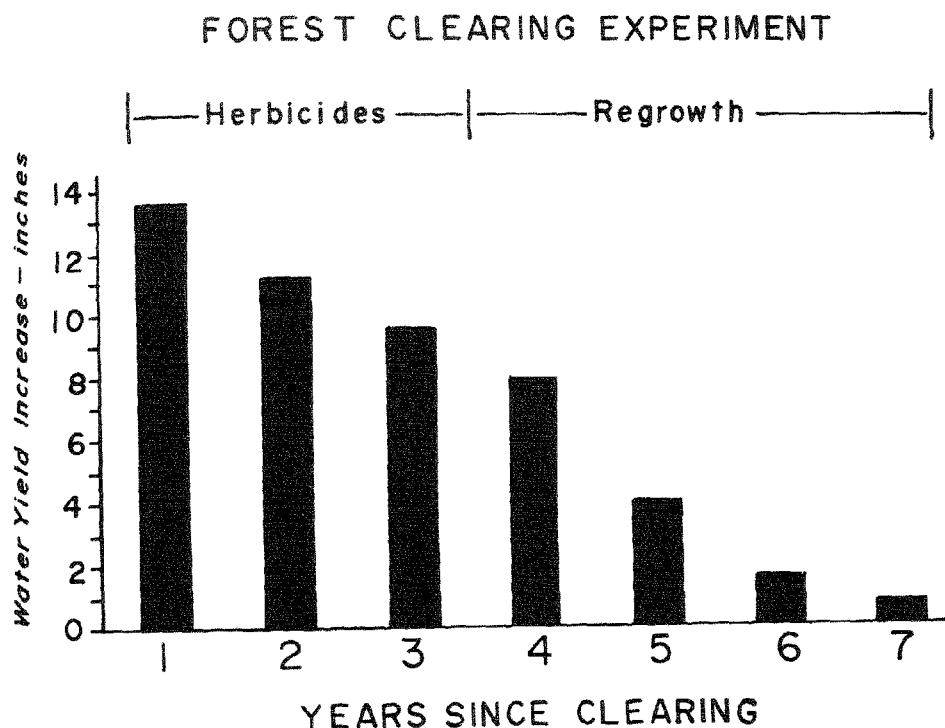


Figure 2.—Results of forest clearing experiment at Hubbard Brook.

or the use of a rotation system whereby some portion of the watershed is always recently cutover.

MWM. Will cutting the forest during dry periods cause an immediate increase in streamflow?

FH. Our studies at Hubbard Brook indicate that soil-water deficits of 4 inches can occur in dry spells. Since ET from forests is about 1 inch a week, a month with no rain or 6 weeks with 2 inches of rain would produce such a deficit. Cutting when such a deficit exists will nearly eliminate any further ET, but will not provide greater water supply for streamflow. The expected water-yield increase from cutting will not come until after the soil-water deficit has been satisfied by rain, in this case not until there has been more than 4 inches of rain.

MWM. Once a sizable soil-water deficit has occurred, is there anything I can do to get more streamflow quickly?

FH. We've spent considerable effort on this and have come up with only three possibilities: rain dances, cloud seeding, and paving the watershed.

MWM. I'd like to ask about some of the other effects of forest cutting on streamflow. Doesn't increased streamflow mean bigger floods?

FH. If the soil-water deficit at the time of a flood is smaller in the cut-over area than in the forest, the streamflow will be correspondingly higher. For the 13 major storms occurring in the first three summers after our clearing experiment, the average increase in stormflow was 0.5 inch and the maximum increase was 1.2 inches. The simultaneous occurrence of a heavy rainfall and a

large difference in soil-water deficit between cut and uncut forest is very rare, we think. Furthermore, seldom would more than 25 percent of a watershed be clearcut at any one time, so the effect would be further minimized. If rain falls when there is no soil-water deficit, there is no difference in streamflow from cut and uncut areas.

MWM. What about snow. Doesn't snow melt more rapidly in open areas?

FH. Yes, snowmelt runoff was several days earlier in our clearcut and strip-cut experiments. But partial clearing of a watershed has a beneficial effect on snowmelt floods because the melt runoff is desynchronized. Snow is gone from the cleared areas while snow in the forest is still melting. Here, too, the effect is very quickly lost or diluted downstream. Snowmelt floods are regional in nature, and local forest-management activities cannot have any significant effect on them.

MWM. It doesn't seem that increased flooding is a problem with cutting. But what about erosion, turbidity, and water temperature changes? Can they be protected against during and after forest treatments?

FH. As a precautionary note to any type of watershed treatment, the forest floor must be disturbed as little as possible to maintain its characteristic high infiltration capacity. This precaution is necessary to prevent increased storm runoff by overland flow and to protect against erosion and subsequent sedimentation of streams.

The completely cleared watershed at Hubbard Brook illustrates the protection capability of the forest floor. The experiment did not involve harvesting, so the only disturbance to the forest floor was the slight disturbance during the felling of trees. In the years since cutting, including the 3 years in which there was little or no vegetative cover, the only apparent erosion has been small

amounts along streambanks and channels. For the most part, stream turbidities have remained at less than 1 turbidity unit, well within the drinking-water standard of 10 turbidity units.

If timber is being harvested from a watershed, the principal concern is careful location and construction of roads and landing areas as well as necessary maintenance during and after logging operations. By following known precautions when logging the strip-cut watershed, we were able to keep turbidity changes to a minimum. In the 2-year period during and after cutting the first set of strips, only 6 of 147 streamwater samples had turbidity values exceeding the drinking-water standard. The maximum value was 38 turbidity units.

With regard to stream temperature, any cutting that opens up the stream channel to direct sunlight will increase stream temperatures. After our complete forest clearing, summer stream temperatures increased by as much as 11°F. In the strip-cutting treatment we left a shading strip of trees along the stream channel, and summer stream temperatures increased less than 2°F.

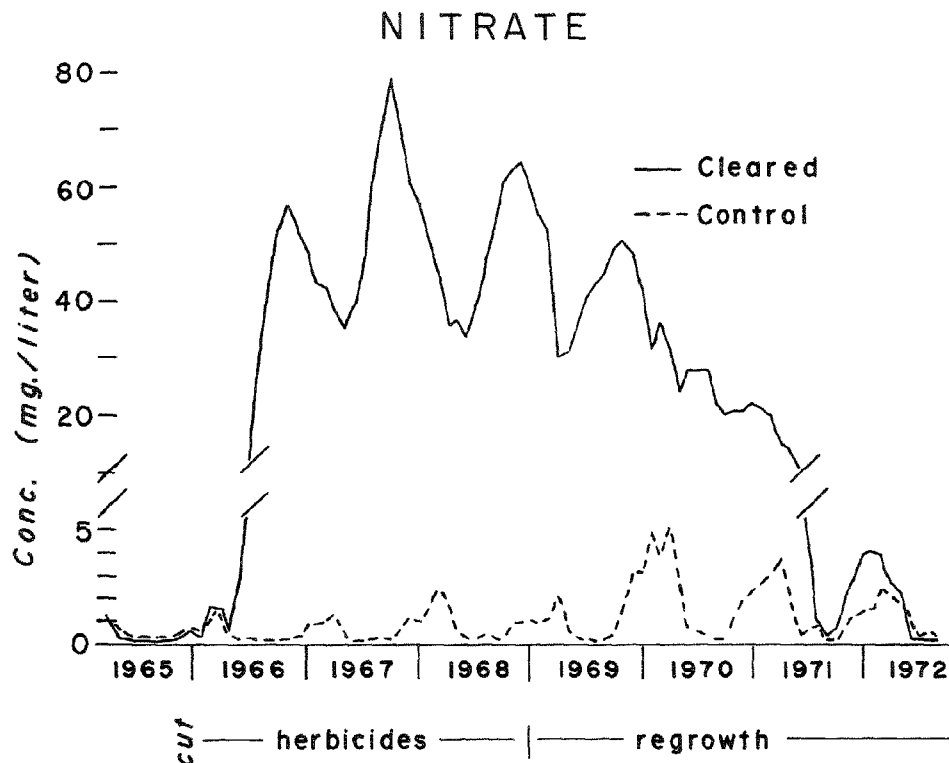
MWM. So keeping the loggers out of the stream, taking care of the skidroads, and leaving trees along the channel ought to eliminate these problems?

FH. That's right.

MWM. I've heard something about dissolved ions increasing in the streams and nutrient loss from the soil after the cutting at Hubbard Brook. What's the story on that?

FH. Our nutrient-cycling studies have revealed a less obvious water-quality problem — nutrient leaching after forest cutting. The problem was most clearly demonstrated by the cleared watershed. Blocking the uptake of available nutrients by eliminating nearly all the vegetation, and exposure of the site to greater-than-normal amounts of heat and moisture, caused an increase in nu-

Figure 3.—Nitrate concentrations in streams of completely cleared and control watersheds.



trient ions leached to streams. The nitrate ion was most responsive to forest clearing, and streamwater concentrations rose from a usual value of about 2 ppm for undisturbed forests to a maximum of 80 ppm (fig. 3).

The increase caused nitrate to exceed the drinking-water standard (45 ppm) and also represents a sizable loss of valuable nitrogen from the watershed. Other dissolved ions — including calcium, magnesium, sodium, and potassium — increased from 3 to 20 times as a result of forest clearing.

We have found that less drastic treatments such as silvicultural clearcutting or strip-cutting also increase nutrient concentrations in streams, but to a

smaller extent than the complete clearing. For example, in streams draining 8 recent clearcuttings in the White Mountains, the average nitrate concentration was 9 ppm, and maximum nitrate concentration from any clearcut area was 28 ppm. In comparison, streams from undisturbed watersheds located near each of the clearcuttings always had nitrate concentrations of less than 5 ppm. The maximum nitrate concentration in the first 2 years of strip-cutting was 11 ppm. None of the streamwater from timber-harvested areas had nutrient concentrations higher than drinking-water standards. However, we have seen evidence of localized eutrophication of small streams after clearcutting.

Results of nutrient-cycling studies at various locations in the United States are beginning to show that New England may be more susceptible than other areas to the nutrient leaching problem. This may be due largely to our coarse-textured soils and their low ability to hold nutrients, particularly in the absence of a plant cover.

MWM. It looks like I will have to worry a little about that nitrogen release; but there's a dilution effect here if only part of the watershed is cut, isn't there?

FH. Yes. A rotation system in which only portions of the watershed are cut-over would insure dilution by streams from uncut areas. Also the nitrate concentration in streamwater after cutting should not be a problem if regrowth is allowed, and as long as there is no reason to make the drinking-water standard more restrictive.

MWM. But what will happen if I try to keep the area devegetated to keep the water yield up?

FH. Then you would definitely have a problem, not only with drinking-water standards but also with eutrophication and loss of important nutrients from the forest ecosystem.

MWM. Thinking of trying to maintain an increased water yield, I suppose I could herbicide the area every few years.

FH. That might work, although we have no experience with it. Certainly the cost and the possible side-effects of the herbicide would have to be considered carefully. We found herbicide applications on our 38-acre cleared watershed to be expensive and time-consuming.

MWM. What about the species of plants? Do any particular species transpire less than others?

FH. This is an area of research we are just getting into and know little about. If there are differences, they are

small, and we have not measured them yet. ET turns out to be a rather difficult thing to measure with less than 10 or 15 percent error. And differences among full covers of different species are less than this. We have tentative evidence that sugar maple and beech may transpire less than yellow birch. If the difference were 5 percent over a summer, a beech-maple stand might yield twice the summer streamflow of a birch stand. However, this is very hypothetical and certainly is not yet a basis for management.

MWM. What about shrubs, grass, or conifers?

FH. We don't know anything about ET from shrub or grass covers in the Northeast, nor whether it would be possible to maintain them. But we know that streamflow from a hardwood-forested watershed is likely to be 2 or 3 inches a year greater than that from a conifer-covered watershed. The difference is primarily due to greater interception of snow and rain in conifers in the dormant season. The conifers may also transpire more water than hardwoods, especially in early spring and late autumn.

MWM. So getting rid of conifers is the only species change that might be useful. But is that going to increase flow in summer?

FH. No, only in the dormant season. You would need a large reservoir to store the extra water if you needed it in summer.

MWM. We've spent a lot of time talking about cutting, but I have to be concerned about recreational use and about the aesthetics of my municipal watershed area. Isn't there anything I can do to get more water without changing the appearance of the area?

FH. We've spent a lot of time on cutting because that is what we know most about. We don't have any other proven ways to increase water yield at present.

There are hormones that can be sprayed on plants to reduce transpiration, but for various reasons they are not yet useful. If a promising hormone is found, we are prepared to test it at Hubbard Brook to see if it can be put to practical use.

MWM. My job seems to be getting increasingly complicated. Even though people want more wood and water, they also want to preserve the forest as it is. I don't know how far I can go with timber cutting.

FH. Management of forest land certainly is not as simple as it seemed 5 or 10 years ago. The public is much more conscious of the forest resource and has definite likes and dislikes about

forest management. Before you embark on a program of forest cutting to increase water yield, you should first investigate the alternatives for obtaining additional water — and the costs. And the dollar costs should not be allowed to totally influence decisions. For example, your water users may not object to paying more for water from other sources if it means they will not have to look at cutover areas on their municipal watershed.

Finally, we recommend that you maintain a close alliance with scientists and other forest land managers. Challenge them for ideas and assistance on how best to manage your municipal watershed.

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MANAGEMENT IMPLICATIONS OF OTHER HYDROLOGIC RESEARCH IN THE NORTHEAST

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ABSTRACT. Research results from a wide array of institutions are reviewed, mostly about the effects of various activities on the amount of water and the timing of its availability; information about the impact on water quality is more limited. Interception effects caused by northeastern tree species and the characteristics and water storage capacities of their associated humus layers are discussed. The significance of the sources of storm runoff and the effects of management of streamside vegetation are also discussed. Fertilizers, road salt, and herbicides may cause local temporary damage; they are chiefly of concern when accidentally introduced into a water body.

THE PURPOSE of this paper is to give an overview of the research programs in watershed management being carried out by the wide array of institutions throughout the Northeast whose efforts have not been covered in other presentations in this Symposium. A wide spectrum of research is included in these programs, and to bring a semblance of common purpose the material will be discussed by subject-matter breakdown; first, research concerned with water quantity and timing as influenced by variation or manipulation of particular portions of the hydrologic cycle, next, research related to water

quality, including both natural and man-induced effects.

EFFECT ON WATER QUANTITY AND TIMING

Canopy Interception Effects

Vegetation covering the land surface influences precipitation as it falls. Forest cover is particularly effective in this respect, and the interception process has been the subject of much research. Water held by trees and evaporated is generally regarded as a loss. Brown and Barker (1970) have shown that significantly less throughfall reaches the ground under immature oak stands in Rhode Island than has been reported for other stands of similar species in the Northeast (Helvey and Patrie 1965).

¹Research reported from the University of Massachusetts Agricultural Experiment Station is supported by McIntire-Stennis Research Project MS-1.

Interception loss was 10 and 13 percent of gross precipitation in the dormant and growing season; throughfall was 85 percent of gross rainfall during the dormant season and 83 percent during the growing season. However, the 5 and 4 percent of the rainfall that appeared as stemflow in the two seasons reduced the apparent total loss to some extent.

Snow reaching the canopy may be lost by vaporization from tree crowns in central New York even under radiation conditions apparently unfavorable for evaporation (*Eschner and Leonard 1968*). The snow that is removed from the canopy by wind may be vaporized in transit and be lost (*Heisler 1970, p. 43*), so that simple redistribution is not its only possible fate.

Although increasing density of forest vegetation usually results in increased interception loss, there is some indication that the forest canopy may increase the amount of snow on a site. Measurable condensation or frost formation on coniferous crowns has been observed in central New York (*Eschner and Leonard 1968*) and may be a factor in reducing or modifying morning evaporation rates. Black (1968) found evidence that widely spaced evergreens invading pasture land may increase the accumulation of snow on a watershed, increasing the spring runoff volume.

Humus Layer Interception and Storage

The surface humus layers developed under forests have long been credited with a considerable sponge-like absorbing capacity of importance in water storage and flood prevention. Recent studies of humus layer characteristics under white pine showed moisture-holding capacity and moisture regimes to be such that only about $\frac{1}{4}$ inch of rain could be absorbed during the growing season on the average — of limited importance in comparison to moisture storage in the soil profile (*Mader and Lull*

1968). The same conclusions were reached in studies of the forest floor under hardwood stands in the Northeast. The results of the studies suggest that management of stands to increase forest floor depth for water storage would not be very effective.

Soil Frost and Snow Accumulation and Melt

Investigations of the occurrence and depth of soil frost at Cadwell Creek have been made under different forest types and densities by the University of Massachusetts. Previous research in northern New England (*Hart 1963*), *Pierce 1956*, *Sartz 1957*) had shown soil frost formation to be negligible in the forest and under a snowpack. The frequency and depth of frost, with consequent possible runoff effects, had not been investigated in southern New England where snow cover may be intermittent. However, during 2 years of investigation of heavily thinned and fully stocked conifer plantations and small openings in central Massachusetts, no soil frost was found because snow cover was persistent through most of the winter (*Wilen et al. 1973*). Although these results do not preclude the possibility that soil frost in forests may on occasion be an important hydrologic factor in this area, they indicate that the probability is not great.

The research at the Sleeper's River Experimental Watershed in Vermont provided some important results on soil freezing in grass pasture areas (*Dunne and Black 1971*). Concrete frost occurred in the topsoil in 1967, resulting in low infiltration rates. About one-half of the water produced by snowmelt left the plots as overland flow. Their results suggest that conversion of forests to grass or maintenance of grass pastures to increase water yield is likely to result in formation of concrete soil frost in some years, causing undesirable surface runoff.

The Cadwell Creek research included snow studies that indicated that, while rate of snowpack accumulation and maximum depth and water equivalent were less (30 percent and 15 percent respectively) under unthinned red pine plantations than in the open, the snowpack under the dense conifers did not disappear until 3 to 10 days later than in open areas. Heavily thinned plots in red pine north of unthinned areas trapped snow in a drift adjacent to the edge of the unthinned stand to the south, increasing the stored water equivalent by about 20 percent. The snowpack in these areas also melted somewhat more slowly than that in the open, suggesting that heavily thinned east-west strips in coniferous plantations may have a substantial effect on snow accumulation and melt. These results are in general agreement with previous reports by workers in the Northeast and the Lake States (Bay 1958, Eschner and Satterlund 1963, Hart 1963, Lull and Rushmore 1960, Weitzman and Bay 1959) and a recent study by Clausen and Mace (1972).

Several modified types of soil-frost measuring devices were tested in these same studies. Small easily-constructed and inexpensive gypsum soil-moisture blocks were found very satisfactory for soil-frost studies (Wilen *et al* 1972) as well as the Fernow-type gage, which was modified to reduce heat conductance into the soil and between layers. A further modification was proposed, which should enable measurement of sub-surface frost below thawed surface horizons. This generally corroborated the findings of Harris (1970), Patric and Fridley (1969), and Sartz (1967) concerning frost-measuring devices.

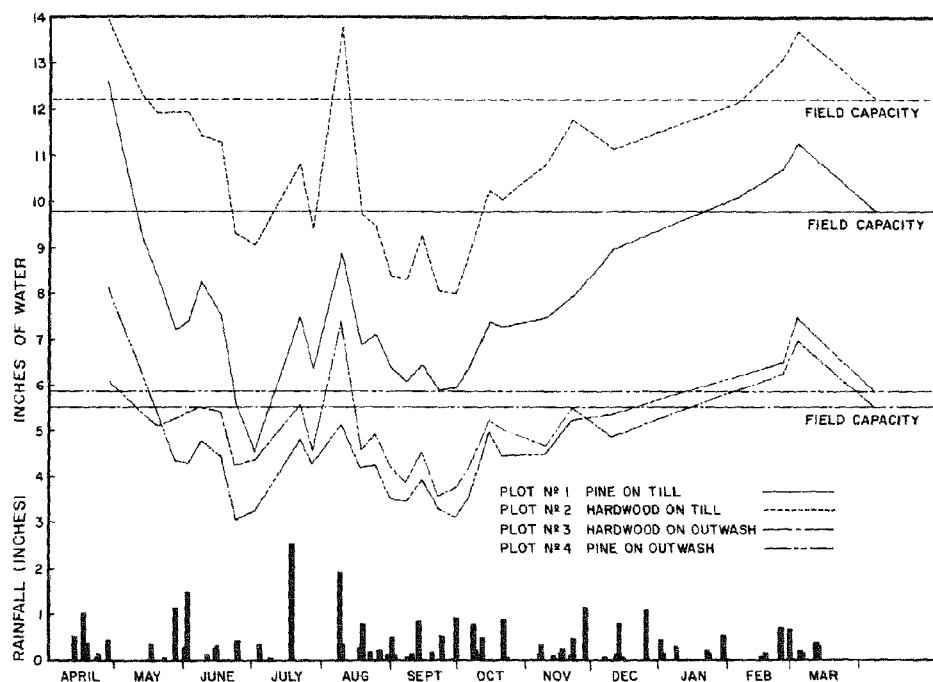
Soil-Moisture-Regime Studies

Soil-moisture-regime studies to compare the hydrologic effects of different cover and soil types have been carried

out at the University of Massachusetts. Comparisons of fully-stocked stands of white pine, mixed oak and other hardwoods, and a grassed area (Affleck 1966, Machno 1966), confirmed the theoretical expectancy and observations of Urie (1959) that pines dry out the soil by using more water in the spring and retard resaturation in the fall compared to hardwoods because of the presence of foliage on the pines during these periods. The importance of such differences in water use in regard to actual surface or subsurface runoff is highly unpredictable because of the dependence on rainfall. However, Affleck's results on till soils (fig. 1) indicated about an additional 3 inches of storage capacity in 4 feet of soil was created on till or outwash soils by pines, as compared to hardwoods, during periods in early and late spring and mid-summer when substantial runoff likely occurred from the hardwood but not pine sites.

Grass cover seemed more conservative in water use in late summer than either pine or hardwood cover, but did show rapid extraction and creation of available storage capacity in the early spring. Because of soil-texture differences, direct comparisons are not possible; but the sandy soil under grass reached minimum water contents in mid-July and showed a recharge trend thereafter, resaturating to field capacity about mid-October so that subsequent precipitation would have gone into runoff. In early June and mid-August, sufficient rainfall occurred to cause probable saturation of the soil and some runoff. The coarse soils under hardwoods and pines did not reach minimum moisture contents until about the end of September and did not resaturate until at least near the end of November and possibly during the winter. The grass site seemed to have been producing considerable runoff for a period of about 1 month in October and

Figure 1.—Soil moisture measured in 4 feet of profile in four 1/5-acre plots of differing soil and vegetative cover in western Massachusetts. Measured rainfall and estimated field capacity of the soils are shown. (From Affleck 1966.)



November, when similar wooded soils were not yet back to field capacity.

Soil-texture differences (fig. 1) seem to have important effects on water yields because of their effects on water-holding capacity (Affleck 1966). The estimated difference between maximum and minimum water content observed in medium-textured till soils to a 4-foot depth was about 6 inches of water under hardwoods, and nearly 8 inches under pine, while on coarse sandy outwash soils the differences were about 4 inches under hardwoods and 5 inches under pine. Though deeper rooting might offset these differences to some degree, the data collected showed small amounts of moisture depletion at lower depths, especially under the hardwood stand;

so it appears unlikely that substantial soil moisture storage is created at lower depths. The high levels of resaturation of the outwash soils in midsummer in relation to experimental field capacity measurements and the excess of rainfall over observed soil moisture recharge both indicated probable greater water yield from the outwash soils than from the till soils.

The recommendations to be inferred from these studies are that hardwood stands are preferable to conifer stands for increasing water production from forested areas, differences in runoff resulting from differences in soil-moisture regimes being likely to occur in late spring and in fall in the Northeast. Maintenance or conversion of stands to

hardwoods can often be achieved by silvicultural practices that incur little or no expense. As suggested by previous research (*Metz and Douglas 1959*), grass cover tends to use less water than forests, especially in late summer, and would probably tend to increase runoff in the fall, but the problems and costs of maintaining such cover versus the benefits are uncertain at present. Recognition of the importance of coarse-textured outwash soils as sources of runoff or groundwater recharge suggests they should be prime areas for acquisition and potential management to increase water yield.

Studies in the southeastern Adirondacks have indicated that soil-moisture recharge in soils of average depth (about 6 feet) is complete by mid-November or early December and is no different from the soil-moisture content of irrigated forest land receiving twice the average amount of growing season rainfall (*Eschner et al 1969*). The "priming" required by western soils before snow melt runoff can take place in spring (*Stockwell 1965*) is not necessary here. This implies a more immediate response by stream levels to spring's climatic changes such as warm air masses or strong solar radiation.

The efficacy and place of thinnings or partial cuttings as a management tool for influencing soil-moisture regimes to increase water yields has been a recurring question in the Northeast. In general we know that the reduction in crown surface and rooting extent caused by removal of trees will reduce the rate and possibly total amount of water transpired and tend to increase water yields. However, the actual benefit achieved by various levels of cutting in different forest types and climatic and soil conditions is not certain, so investigations are in progress in a number of places in the Northeast.

Studies in central Massachusetts of

the effects of thinning levels on soil-moisture regimes and crop-tree growth in 20- to 130-year-old white pine plantations (*Hunt and Mader 1970*) suggest that very heavy thinnings can be safely carried out which result in very rapid increases in growth and value of pruned crop trees while reducing water consumption by 1 to 2 inches, or more, during the growing season. The shortening of the rotation and increased crop value seem likely to more than meet the cost of this procedure so that any increases in water yield would be achieved at little or no cost. A related study of tree growth and soil moisture response to thinning levels and fertilization in 60-year-old low-quality second-growth stands consisting primarily of red and black oak and red maple is under way. Results show that in the first 2 years after a very heavy thinning (about 10 to 15 percent of basal area left), soil-moisture deficits at the end of the summer were 3 to 4 inches less in a 42-inch profile than in comparable unthinned stands. In the first year after thinning and fertilization, diameter growth on residual trees (7- to 12-inch diameter range) was about double that in the unthinned stand (about 0.18 vs 0.09 inches).² The increase from thinning alone was only about half that of the combined treatment. The response was somewhat greater the second year, thinned stands showing diameter growth increases of about 50 percent over the control, thinned plus fertilized stands about 150 percent (0.1 vs 0.25 inches). There were no significant differences in soil-water deficits between fertilized and unfertilized stands. The economics of the treatments in terms of increased timber values versus costs has not yet been determined.

²Francisco Lozano, Univ. Mass. Agric. Exp. Stn. Res. Proj. MS-1.

Riparian Vegetation Effects

The effects of riparian-zone vegetation on soil-moisture regimes and water yields has been an important facet of research at the University of Massachusetts. Removal or deadening of all woody vegetation in the riparian zone of one subwatershed of the Cadwell Creek Experimental Watershed resulted in much higher soil-moisture levels in the riparian zone of the treated versus the control areas. Frequently the increases were from 40 to 75 percent (about 5 inches) in late summer and fall (Mader *et al* 1972). The differences between treated and control areas were greater nearer the stream than farther away in spite of the fact that higher moisture levels were maintained near the stream in the treated area; this supports the view that movement of water into the riparian zone allows very rapid and sustained water loss from this portion of the watershed and that removal of vegetation in this zone will be more effective in conserving water, per unit area treated, than treatment in other areas. The results also suggest that leaving this vegetation, as is often recommended for stream protection, may result in the loss from this zone by transpiration of increases in runoff produced by treatment of other portions of the watershed.

Results of streamflow studies³ to evaluate the effect of the integrated management program on the Cadwell Creek subwatershed showed the possibilities of such programs to increase water yields. The treatments, which represented a combination of practices felt to be feasible and practical for actual watershed management, included a commercial logging operation that removed nearly half of the merchantable

timber in a pattern of small patch or group cuttings, deadening of all trees by injection in the riparian zone (100 feet in distance or 10 feet in elevation from the stream channel) with removal of merchantable stems during logging, mistblowing of a 200-foot strip adjacent to the stream to deaden lesser woody vegetation, and heavy thinning by injection of the small acreage of plantations occurring on the subwatershed.

Substantial increases in water yield were achieved; growing season increases for the first 2 years after treatment were 35 to 40 percent, increases on an annual basis about 22 percent. Subsequently the increases dropped off gradually but were still 21 percent and 14 percent respectively in the fourth year. Preliminary economic analysis indicated that the value of the water produced far exceeded the cost of treatments. The adverse characteristics of the program were primarily the unesthetic appearance of the deadened trees in the riparian zone, the use of herbicides, and increases in the range and maximums of temperatures in the stream. Logging residuum and logging-road use seemed to draw little objection nor have serious impact on the water quality, and the density of lesser vegetation in the riparian zone seemed to preclude much nutrient loss or resulting water-quality change from the treatments.

The widespread practice of planting conifers on the shores around reservoirs has a high cost in the excessive amount of water removed from groundwater. Forest cover along reservoir shorelines can use 1 to 6 area-inches more water annually than upland forest cover (Lull and Reinhart, 1967).

Studies in New Hampshire of the water lost by evapotranspiration in bushy wetlands (Hall *et al.*, 1972) indicated that such areas may use 1.7 times as much water as is lost from open-surface evaporation and that they prob-

³Brian R. Mrazik, Univ. Mass. Agric. Exp. Stn. Res. Proj. MS-1.

ably can be managed to increase water yields at critical times by use of evaporation suppressants. They also may serve as important flood-control storage systems.

Contributing Area

The source of streamflow from a watershed at different times and under different physical conditions has received scrutiny recently. Many of the results conflict with traditional ideas of stormflow and baseflow. Some of the studies in New England support the traditional view. In an agricultural area in Vermont (*Dunne 1970*) snowmelt runoff ran over the surface of frozen soil to the channel. This runoff dominated the daily discharge hydrograph and responded to the rate of incoming short-wave radiation. Usually less than 10 percent of the total watershed area contributed storm runoff. Deep permeable soils produced no storm runoff. Overland flow came from small areas of shallow soil that became saturated in some storms. Generally only a small portion of the total drainage area contributed to storm runoff.

Stomatal Control

For many years the idea of being able to control stomatal diffusion of water vapor has intrigued watershed managers (*Zelitch and Waggoner 1962*). It is assumed that water loss through leaf pores is controlled by pore size of the individual leaf (*Waggoner and Zelitch 1965*). There remains the question whether the transpiration loss from a stand would be reduced appreciably by stomatal closure on individual leaves (*Waggoner 1967*). This question has been explored recently, and both affirmative (*Lee 1967*) and negative (*van Bavel 1968, Idso 1968*) answers were given. Proposed methods of artificial control of stomatal openings are difficult to apply to forests and require the use of com-

pounds that are potentially toxic. The outlook for practical use is not promising.

Wilderness Management

Increasing public pressure is being exerted on the U.S. Forest Service and state agencies to implement the National Wilderness System or a similar alternative in the eastern United States. Areas of wilderness are proposed for inclusion in the system, but the implications of this action may not be recognized. When extensive areas of relatively stable vegetation are set aside for wilderness, man's activities are sharply restricted. However, changes in the vegetation continue, and in some cases the possibility of catastrophic change increases. In the southeastern Adirondacks over a period of 39 years, the forest density and crown coverage of conifers increased after the cessation of logging and the initiation of effective fire protection, but average annual streamflow decreased more than 7 inches (*Eschner and Satterlund 1966*). On the Sacandaga Watershed most of this decrease (5 inches) came in the October-to-April dormant season. A late fall windstorm of hurricane force blew down many big old conifers and brought about an increase in the streamflow.

WATER-QUALITY STUDIES

Water Color

One cause of impaired water quality is dissolved or suspended organic matter. The presence of beaver dam impoundments on watersheds in the Northeast has increased dramatically in recent years. The role of these and other swampy areas (*Hall et al 1972*) in producing organic compounds is being studied by the University of Massachusetts on the Amherst Watershed.⁴ Pre-

⁴B. O. Wilen, Univ. Mass. Agric. Exp. Stn. Res. Proj. MS-1.

liminary results have substantiated that beaver dams are important in color production, and that removal of the dams and increasing channelization will decrease color levels in water. Indications are that increased rainfall and runoff lessen color by dilution, and that color can be predicted effectively from temperature and rainfall data once the relationships have been established. Further study of the factors producing color and their potential control is under way.

Salt Problems

The problems of salt, particularly sodium chloride and calcium chloride, which are used widely to melt ice and snow on streets and roads in the Northeast, have been of concern in recent years because of possible deleterious effects on vegetation and pollution of groundwater. Some states apply as much as 20 tons per mile on a traffic lane, the average is about 300 pounds. The fate of the applied salt is not well known, but several accumulation sites have been suggested: the street itself, roadside soils and groundwater, roadside vegetation, and drainage channels. Studies in New Hampshire (*Rich 1968*), Maine (*Hutchinson 1968*), and Massachusetts (*Holmes and Baker 1966*, *Motts and Saines 1969*) have all shown increased salt in roadside areas and the presence of at least localized areas with sufficiently high levels to cause toxic effects on plants by either sodium or chloride accumulation, and also to cause serious increases in salt content of groundwater. In a suburban Syracuse stream, winter chloride contents as high as 11,000 ppm have been observed (*Hawkins and Judd 1972*). Chloride content has been observed to be higher in areas where calcareous sediments are found (*Mairs 1967*).

Motts and Saines (1969) emphasized the need for study of septic tanks, air

pollution, and drought periods as causes of increased chloride content in groundwater supplies. Salt accumulation in small lakes may cause density stratification and changes in the biota and physical characteristics of the water body (*Hawkins and Judd 1972*). Restriction on use of road salt and strict control of septic tank standards and density are needed on areas that contribute to municipal reservoirs, private wells, or groundwater recharge areas.

Nutrient Problems

Addition of nutrients or use of other chemicals on a watershed carries with it considerable risk that the material may find its way into the stream or groundwater. Nitrates and phosphates have already been identified as serious water pollutants. When an area is covered by forest or other stable vegetation, the result of any application is likely to be different from that on an agricultural or otherwise disturbed area. For example, some workers feel that in forest fertilization, nutrients are being added to natural ecosystems in which they will be absorbed into nutrient cycling systems that will prevent any substantial losses out of the system (*Weetman and Hill 1973*). If the chances of serious stream and groundwater pollution through fertilization are slim because the forest floor is a good natural filter, there are still possibilities of unfavorable changes in other components of the ecosystem, which should be explored because they are not now clearly understood.

Loss of nitrates and phosphates from fertilization of agricultural lands is both a problem to the farmer and a source of nutrients introduced into water supplies. Nitrate and other ions from very high density feeding operations and waste-disposal and septic-tank or sewage effluents are also serious sources of contamination. The forest has been proposed

by Sopper and his co-workers (*Sopper 1971*) as a potential environment suitable for disposal of certain effluents containing organic and inorganic wastes. These wastes may be effectively absorbed and cycled by the vegetation as a nutrient source and thus not cause water pollution or eutrophication while simultaneously recharging groundwater supplies. Studies at Connecticut on disposal in a red pine plantation of poultry manure and associated waste at high rates (*Stephens and Hill 1971*) caused considerable buildup of nitrogen in the soil and accelerated movement in percolating waters so that some potential for pollution can occur. This is particularly true for coarse outwash soils, which are prime groundwater recharge areas.

In addition to the deliberate fertilization of watershed land, there are many elements that are added naturally or inadvertently. It has been found that 13, 38, and 151 pounds of sulphur per acre per year were deposited by rainfall in rural, urban, and industrial locations in Wisconsin, with an overall state average of 27 pounds per acre per year (*Hoelt et al 1972*). In the same study, the amount of ammonium nitrogen and organic nitrogen deposited by precipitation was highest in spring and lowest in winter and was higher in areas adjacent to barnyards. Nitrate-nitrogen addition was fairly constant for all locations and was slightly lower in winter. Total N ranged from 12 to 27 pounds/acre/year, with an overall state average of about 18 pounds.

Preliminary results of a study of lead outputs from a watershed ecosystem indicate that the primary exit for this element is streamflow (*Rolfe and Edgington 1973*). Apparently in the urban part of the watershed, much lead particulate is deposited on paved surface and is quickly washed off during storm periods, resulting in a rapid increase

in the amount of suspended lead in the stream. This does not occur in the rural-agricultural part of the watershed. However, only 2 to 3 percent of the lead input is leaving through the water system; apparently a large buildup of lead is taking place on the watershed, possibly in stream-bottom sediments, soils, and the biota.

Nitrate production from devegetated natural systems has been demonstrated by the Hubbard Brook experiments (*Borman et al 1968*). Another source of nitrates is being investigated by Peterson (*1968*) at the University of New Hampshire, where alder communities are being studied. Older stands of alder appear to produce much more inorganic nitrogen than younger stands, suggesting that they may contribute to increased nitrogen in stream water and cause eutrophication.

The pathways in natural waters of nitrogen and phosphorus — common and important fertilizer elements — have been the subject of considerable research, and the literature on the fate of N and P in water and sediments has recently been reviewed by Keeney (*1973*) and Syers et al (*1973*). They point out that the effect of sediment properties, lake morphology, and physical and chemical characteristics have an important bearing on the pathways and rates of N and P turnover. Suspended particulate material from erosion may act as a carrier for fertilizer elements as well as iron, manganese, and other elements. When deposited as sediments, they may act as a sink for large amounts of chemical elements. Limnologists are concerned about the forms and location of N and P in water, their rates of movement, and impact on the natural eutrophication process (*Werner 1973*). Frink's (*1971*) studies in Connecticut indicate that sediments do act as a sink for nutrient elements and reduce eutrophication of associated surface

waters. The short- and long-range effects of this process need to be evaluated to determine the importance of this aspect of the need for control of sedimentation.

Interpretation of Research Results

The research we have been discussing parallels much that has been presented earlier. It is important to emphasize certain points, from the watershed manager's view, whose significance may be somewhat obscure.

Conifers are able to intercept more snow and rain, and to extract more water from the soil than hardwoods over a range of soil textures in the Northeast. Maintaining hardwood stands or converting conifers to hardwoods is desirable if a high rate of water yield is an objective of management. Manipulation of cover type and strip cuttings in conifer stands have been shown to influence the patterns of snow accumulation and melt considerably, but the practical importance of such practices has not been demonstrated. Efforts to increase forest floor depth for additional water storage for flood control do not appear to be justified.

The low storage capacity of coarse-texture outwash soils makes them naturally high producers of runoff and groundwater recharge. Because of their excellent drainage these soils have been widely used for waste disposal and development in spite of the fact they may transmit pollutants readily to streams and groundwater. Recognition of their importance suggests that they should be prime areas for acquisition and management for water yield.

Several studies suggest that very heavy thinnings or cuttings can produce substantial increases in water yields for several years. These cuttings may be revenue-producing or increase growth and shorten rotations to such an extent as to be economically feasible on the

basis of timber values alone. Woody riparian vegetation appears to be a very large user of soil moisture, and substantial water-yield increases may result from its control or conversion to lesser vegetation types. Current practices advocating the preservation of undisturbed strips along streams to protect them is not consistent with maximum water production.

The use of chemicals for stomatal control or other anti-transpirant effects remains a clouded subject. Reductions in transpiration have been reported, but potential toxicity, difficulty of application, and doubtful cost/benefit relations make the practice unpromising at present.

Treatment of large areas of watershed as wilderness, currently advocated by several interest groups, may not be consonant with management for maximum yields or protection of the areas. On land long-undisturbed use of water by vegetation may be maximized and water yield reduced, while hazards of windthrow, insect, disease, or fire damage may increase.

The sources, characteristics, and control of water color problems have not yet been elucidated but are of growing importance as less favorable water-supply sources must be tapped. Beaver dams, increasing rapidly in number in the Northeast, and natural swamps seem to be prime sources of color. Methods to minimize problems from these areas are needed.

A number of recent studies have demonstrated widespread salt contamination of surface and groundwater supplies, as well as soils, from road-salting. Runoff from fertilized agricultural land, septic-tank effluents, and air pollution from automobiles and other sources are actual or potential degrading influences on water supplies by addition of nitrates, phosphates, sulfates, lead and other undesirable materials. Control

of these contaminants is needed on areas that contribute runoff to municipal reservoirs or recharging groundwater supplies, especially on coarse-texture soils that allow rapid transmission to groundwater and do not filter effectively. Although forest fertilization or disposal of wastes as fertilizers on forests may be safe, effective, and desirable on some sites because of the forest's ability to filter out and cycle the nutrients, over-application on coarse soils is hazardous to groundwater.

Although overland flow is virtually unknown from the Northeast's well-forested watershed areas, there is evidence that overland flow is likely to be an important source of stormflow from open and agricultural land. This form of water movement is likely to be especially important in winter when the soils of open areas are likely to be frozen.

Much attention has been focused on the sediment produced by this overland flow as a form of pollution. There are indications that its role is much more complicated than we have supposed, and is not fully understood. Sediment in water may carry adsorbed nutrients, among other things, and may serve as a source or a sink of troublesome materials in streams and lakes. This relationship merits further study so that its dangers may be realized and its potential advantage exploited.

The wide spectrum of research projects under way suggests a growing appreciation and concern for maintaining or enhancing both quantity and quality of our water-supply sources. The value of the research is already evident, and energetic application of the principles evolved can be very worthwhile to municipal watershed managers.

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THROUGHOUT THE NORTHEAST — AN OVERVIEW

by KENNETH G. REINHART, *Forest Hydrologist, USDA Forest Service,
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ABSTRACT. Forest watershed research has shown how management practices in the Northeast affect water quality (sediment, temperature, and nutrients), water yield, and stormflow. It has demonstrated how water quality can be protected and overland flow controlled. It has not yet shown how vegetation management can be used in a practical way to achieve the big potential for increased water yield.

THIS YEAR we are celebrating the 50th anniversary of the Northeastern Forest Experiment Station. This is also the 40th anniversary of forest watershed-management research in the East — at the Coweeta Hydrologic Laboratory in the mountains of North Carolina. Though Coweeta is not in the Northeast, we welcome its research contributions. In many respects, high-elevation Coweeta resembles the Northeast more than it resembles much of the South.

What do we have to show for these years of effort? I think we can show a great deal. We have even changed many of the basic concepts of the forest-water relationship. The research done and accomplishments made have been well covered in the papers presented at this symposium. Besides the work at Coweeta, we have heard about work on experimental watersheds at the Fernow Forest in West Virginia, at Penn State, at Hubbard Brook in New Hampshire, on mu-

nicipal watersheds at Baltimore and Newark, and other pertinent research at the universities and elsewhere.

To summarize and to highlight, as I see it, research has:

1. Determined sources and amounts of turbidity from forest activities.
2. Demonstrated methods to keep soil erosion and the resulting turbidity under control.
3. Determined streamwater temperature and nutrient problems and measures to control them.
4. Determined that overland flow in the forest is an exception rather than the rule.
5. Determined that vegetation management can substantially influence water yield.
6. Demonstrated that timber can properly be harvested from many municipal watersheds.
7. Made a beginning in development of prediction equations and models.

8. Provided a better understanding of fundamental hydrologic processes.

But research has *not*:

9. Demonstrated how the big potential for increased water yield can be achieved within constraints of ownership patterns, economics, aesthetics, etc.

And in another area, we have not had much research on the effect of recreational activities on water, though much of the research accomplished has some bearing on problems in this field.

DISCUSSION

I want to say a little more about each of these major research accomplishments.

1. Sources and Amounts of Turbidity

Over the years, most research on the quality of water from forested watersheds has been directed at turbidity, caused mostly by soil particles in the water. The Northeast is generally fortunate: because of climate, vegetation, and soil characteristics, its erosion and sediment problems are less acute than those in most other regions of the country.

In the undisturbed forest, erosion rates are almost universally low, and the quality of the water produced is high. When the forest is disturbed, as by timber harvesting or other operations, the picture may change drastically. Research and general observation have amply demonstrated that it is not the cutting of trees, but the baring and compaction of mineral soil incident to removal of products that causes major erosion and sediment damage. This observation may seem simple and self-evident, but it is often ignored in present-day arguments about forest practices.

2. Keeping Erosion under Control

Guidelines have been developed to help watershed managers operate on lands they control without generating turbidity problems. However the impacts of land use on watershed lands — both forest and nonforest — that the manager does not control may be serious. This problem calls more for educating and providing incentives for operators and landowners than for developing new technical know-how.

3. Streamwater Temperature and Dissolved Nutrients

I doubt that these were even recognized as problems when watershed research began at Coweeta, or even later at the Fernow or Hubbard Brook. But research, and probably astute observation in its absence, has shown that cutting the forest can cause appreciable rises in stream temperatures. These may be harmful to cold-water fish species. But considering the relative exposures of water surfaces in impoundments and streams, I doubt that there is any great effect on water as supplied to consumers. In any event, the simple expedient of reserving all or most of the trees immediately adjacent to watercourses apparently solves any problem there might be.

Interest in and study of nutrient concentrations in streamwater, as affected by forest practices, is of recent origin. Clearing the forest and repressing regrowth in New Hampshire caused alarming increases in nutrient concentrations — especially concentrations of nitrate-nitrogen. Regular timber-harvest clearcutting in New Hampshire caused smaller but still appreciable increases. The few studies made in other locations all showed relatively small effects. Considering drinking-water standards, we conclude from the evidence to date that tree cutting in most of the Northeast will not cause nitrate-nitrogen concen-

trations to even approach the danger level. And in New Hampshire and similar areas, no problem should arise so long as most of the watershed is not heavily cut at the same time.

On a related subject, research has shown that carefully planned and conducted applications of herbicides to watershed lands can be made with only a minimal danger of pollution. However, in this environmental age, this may not be good enough. Any slight pollution may be considered too much. And in some situations even the idea of applying such chemicals to water-supply areas may not be acceptable to the public.

4. Overland Flow the Exception

Years ago, all stormflow was often considered to stem from overland flow, often ambiguously labeled surface runoff. However, as early as 1943, Hoover and Hursh noted at Coweeta that overland flow does not occur under natural forest conditions. It is now generally recognized that subsurface flow, not overland flow, is the important process in the forest. This recognition has had a major impact on our concepts of erosion and stormflow in the forest. However, even though most flow is subsurface, much of it can still reach the stream soon enough to contribute to damaging high flows when flood-producing storms occur.

5. Increasing Water Yield

Annual precipitation in the Northeast averages about 41 inches. Probably a little more than half of this is used up where it falls (in evapotranspiration). Can we do anything to reduce this on-site use and thus increase the water yield for domestic and other uses? Research has shown that this can be done; but because of environmental and economic restraints, such management is rarely attempted.

As Douglass and Swank said, we have for the Appalachian Highlands the most

complete and detailed information available anywhere on the response of streams to management of their watersheds by man. Their formulas for determining the amount and duration of water-yield increases after cutting provide a long-needed yardstick. Our knowledge for areas in the Northeast outside the Appalachian Highlands is not so complete and detailed, but we are still in pretty good shape to make reasonable predictions about the effects of vegetation removal on water yield. In brief, heavy cutting of a forested watershed provides substantial increases, but these increases diminish rapidly with regrowth. For any given area, increases are about in proportion to the intensity of cut. As a corollary, establishment of full forest cover on bare or sparsely vegetated land will reduce water yields.

We have relatively little information about the effect of conversion from one type of cover to another. However, there is evidence that conversion of hardwood forest to grass will increase yield by several inches, and that conversion from hardwood forest to pine will decrease yield. Even with our limited information, I think these research results provide useful guides to management. For instance, when the pine plantation on your municipal watershed matures and is harvested, consider replacing it with something else.

6. Timber Can Be Harvested from Municipal Watersheds

Over the years, many people have feared that harvesting timber on municipal watersheds would greatly increase turbidity and might cause reduced flows in dry spells. With careful planning and supervision, it is possible to log without undue erosion and turbidity. And timber harvesting will increase rather than decrease water yields, especially in the drier seasons of the year — though if only a portion of the

watershed is logged at one time, the amount and duration of increase may not be enough to help much with water-supply problems.

More recently, fears have been expressed about pollution by nutrients as a result of timber harvesting. Nutrient pollution should pose no problems, at least if only part of the timber on the watershed is logged at any one time.

7. Prediction Equations and Models

The development of prediction equations and models helps bridge the gap between research and application. The equations by Douglass and Swank, relating water yield to forest cutting, mark a start in this direction. Another start is a mathematical model for streamflow being developed at Hubbard Brook. I expect that in the next few years we will see many more developments in this direction.

8. Fundamental Processes

We have discussed mostly the results of empirical experiments because these seem more easily applied to the evaluation of management practices. But the study of the fundamental processes in forest hydrology is perhaps even more important, because without a thorough understanding of these processes, we can hardly hope to manage intelligently. Much has been done — and much remains to be done — in the study of solar radiation and how it affects evapotranspiration, of the interception process, of the paths of subsurface flow, and of other aspects of forest hydrology. As our understanding improves, we will be better able to develop prediction equations and mathematical models and to apply research results in solving the everyday problems of municipal-watershed management.

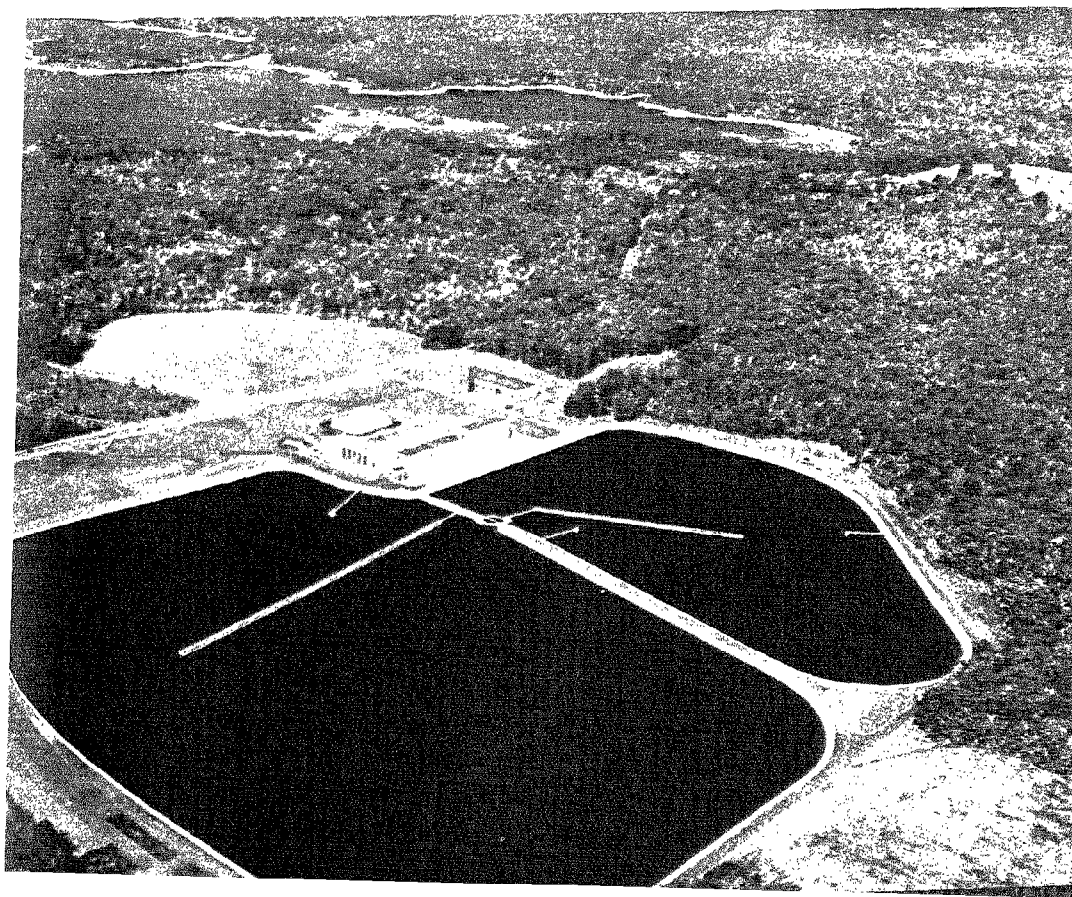
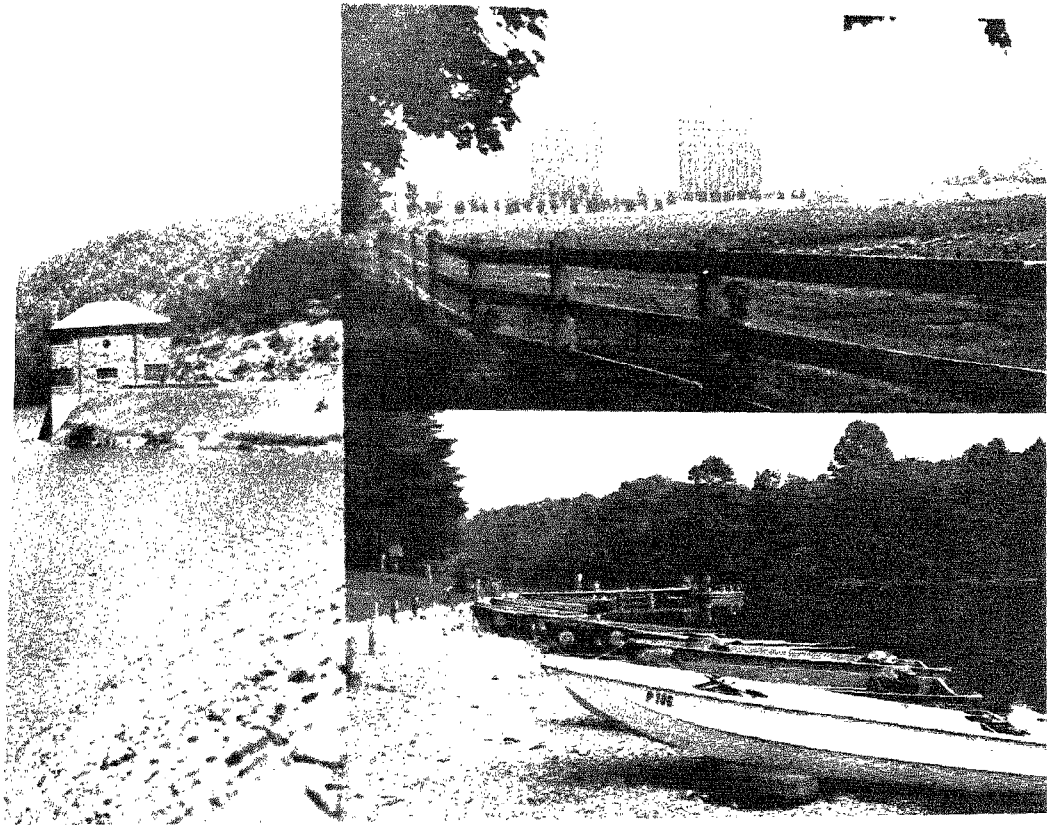
9. Increasing Yields within Existing Constraints

It has been amply demonstrated that cutting the forest can increase water

yield — by as much as 16 inches in the first year after one treatment at Co-weeta. Why then haven't we seen widespread application of this practice? There are many reasons, including economics, the temporary effects of cutting alone, aesthetics, resistance to use of herbicides, and land-ownership patterns. I don't know whether we can ever achieve any appreciable part of the potential for increased yield within these formidable restraints. But I do have a few suggestions:

- Aim for a positive approach. Rather than proposing destruction of the forest, advocate management to favor mountain laurel, to provide recreational blueberry picking, or to increase diversity in the landscape by providing some grassy park-like areas.
- Study ways to repress vegetation with common salt, heat-torch, defoliants, and other methods less objectionable than conventional herbicides.
- Study methods of type conversion that cause minimum site disturbance.
- Study the water use and methods of establishing and maintaining types of vegetation — mountain laurel, blueberry, grass, and others — that may use less water than the ordinary high forest.
- Study possibilities for initiating treatments in water-short periods. If your reservoir is low in the spring, you may have supply troubles in the summer even if summer precipitation is near normal. May or June treatment might help here.

Research has shown a number of possibilities for protecting water quality and improving yield. Undoubtedly many questions remain to be answered. This meeting, bringing together the watershed scientists and managers, should help both groups do a better job in the future.



CURRENT MANAGEMENT PRACTICES ON THE BALTIMORE MUNICIPAL WATERSHEDS

by BRENT A. HARTLEY, Watershed Manager, Water Supply, Treatment and Pumping Division, Bureau of Operations, Department of Public Works, Baltimore, Maryland.

ABSTRACT. The City of Baltimore supplies water to an estimated 1.5 million people in a 215-square-mile service area. To meet the water needs of this area, the City has developed three sources of supply and maintains three municipal watersheds. Management of Baltimore's watersheds is complicated by the fact that the City owns less than 6 percent of the total drainage areas of the two upland sources of supply. In addition, management of Baltimore's watersheds differs from that of many others in the Northeastern United States due to the fact that we harvest timber on our watersheds and operate our own sawmill. We have also tried to provide recreational opportunities compatible with our primary function of supplying the city's filter plants with an adequate supply of high-quality raw water.

THE CITY OF BALTIMORE supplies water to an estimated 1.5 million people in a 215-square mile service area consisting of Baltimore City and parts of Anne Arundel, Baltimore, and Howard Counties. In addition, Carroll County, which borders in part on Liberty Reservoir, purchases raw water from the City. Average daily consumption in 1970 was 245.37 million gallons per day. Water use was as follows: residential or domestic use, 143.93 million; large industrial use, 68.03 million; commercial use, 33.41 million.

SOURCES OF SUPPLY

To meet these demands, the City has developed three sources of supply: Gunpowder Falls (safe yield, 148 million gallons per day), the North Branch of the Patapsco River (safe yield, 95 mil-

lion) and the Susquehanna River (initial capacity, 150 million).

The Gunpowder Supply

There are two impoundments on Gunpowder Falls. Loch Raven, a 2,400-acre terminal reservoir, has a 223-square-mile drainage area and an initial capacity of 23 billion gallons. Prettyboy, a 1,500-acre upstream reservoir, has a drainage area of 80 square miles and an initial capacity of 20 billion gallons. Prettyboy Reservoir provides storage to supplement the supply at Loch Raven. When the water storage at Loch Raven drops to 87 percent of capacity, two 36-inch needle valves at Prettyboy Dam are opened, and water is allowed to flow down the bed of Gunpowder Falls into Loch Raven Reservoir.

Baltimore City owns less than 6 per-

cent of the 303 square miles in the Gunpowder Falls drainage area above Loch Raven. The City owns and manages 5,600 acres of forested watershed land surrounding Loch Raven Reservoir and 5,880 acres of forested land surrounding Prettyboy Reservoir.

Land use on the Gunpowder watershed is estimated as follows: 20 percent forested, 40 percent agriculture, 40 percent residential-commercial.

The Patapsco Supply

Liberty Reservoir, on the North Branch of the Patapsco River, is a 3,100-acre terminal reservoir with a drainage area of 164 square miles and an initial capacity of 43 billion gallons. Here too, the City owns less than 6 percent of the total watershed. City holdings are limited to approximately 6,100 acres (9.53 square miles) of forested watershed lands surrounding the reservoir itself. There is no upstream reservoir on the Patapsco supply.

Of the 164 square miles in the Liberty watershed, approximately 20 percent is forested, 40 percent is in agriculture, and 40 percent in residential-commercial use.

The Susquehanna Supply

The Susquehanna supply is presently used in time of drought or emergency only.

Unlike the Gunpowder and Patapsco, which are both gravity sources of supply, water from the Susquehanna must be pumped to reach the City. Susquehanna water flows by gravity from the intake located above the Philadelphia Electric Company's hydroelectric dam at Conowingo, Maryland, to the Deer Creek Pumping Station, approximately 3 miles below Conowingo. Deer Creek Pumping Station then pumps the water over a high ridge near the town of Level. From here the water flows by

gravity to the Montebello Filtration Plant in Baltimore.

The intake structure has an initial capacity of 250 million gallons per day and an ultimate design capacity of 500 million. The Deer Creek Pumping Station has an initial capacity of 150 million and an ultimate design capacity of 243 million. Connecting the Intake and the Montebello Filtration Plant are over 38 miles of tunnel and pipeline ranging in size from 144-inch to 96-inch diameter.

FORESTRY

In 1948, the City recruited a woods crew and purchased heavy equipment, including a sawmill, to salvage timber from the area to be flooded by the new Liberty Dam. Before this time, no timber had ever been cut by the City on any of its watershed land. Management practice was limited to fire protection and reforestation of land formerly used for grazing and agriculture.

When the clearing for Liberty Reservoir was completed, attention was shifted to the forests surrounding the other two reservoirs. The experience gained and equipment used at Liberty was put to work removing overmature and defective trees and — stand conditions permitting — undesirable species. The objective was to maintain a residual stand of approximately 3,000 board feet per acre of high-quality timber.

After the initial sanitation cut we adopted the selection system of management and cutting. Although this is not the most economical system of cutting to use, it leaves sufficient cover to protect the watershed and maintain the aesthetic value of the forests while providing a continuous source of timber to meet the City's limited lumber needs. Trees to be cut are selected and marked by our watershed forester. Trees are cut when at their highest value, and the

healthy young trees of desirable species are left to continue protecting the soil and to produce future timber crops.

Our woods crew, which consists of twelve men, processes the timber from the felling of trees to the production of lumber at the sawmill. Weather and ground conditions permitting, these men work in the woods. In inclement weather and when necessary to meet our lumber commitments, these same men operate the sawmill.

Logs are sawed into lumber for use primarily as sheeting and shoring for trenches for underground utilities being constructed by the City. We also produce all of the hubs and stakes used by City survey parties, along with other specialty items such as fence posts, guard rail posts, pier timbers, etc. Only slabwood is sold to the public. All other products are consumed by the City and are accounted for through a system of interdepartmental work orders and debit tickets.

Prices charged are as follows:

- | | |
|--------------------------------|----------------------------|
| (1) Rough lumber and timbers | |
| (2" sheeting thru 12"x12"x18') | \$125.00/MBF |
| (2) Finished lumber | \$175.00/MBF |
| (3) Blocking — ranges from | |
| 1"x6"x12" to | .05 each |
| 6"x6"x16" | .90 each |
| (4) Surveyor's hubs | |
| (2"x2"x12") | .10 each |
| (5) Surveyor's guard stakes | |
| (1"x2"x24") | .18 each |
| (6) Wedges | .20 each |
| (7) Slabwood | |
| | \$2.00 per 1/2-ton pick-up |
| | 4.00 per 3/4-ton pick-up |
| (8) Sawdust | Free for taking |
| (9) Shavings | Free for taking |
| (10) Locust posts | \$1.50 each |

Forest-related income in 1972 amounted to over \$80,000, and since 1955 has totaled over \$1,900,000. Sawdust and shavings not used by City

school and recreation agencies for mulch, jumping pits, playgrounds, etc., was given away. Thinning of pine plantations yielded 521 long cords of pulpwood and added \$14,588 to the forest-related income for the year.

To facilitate logging and other forestry operations and to provide access to remote areas of the watersheds for fire-fighting and other emergencies, we have constructed over 200 miles of permanent unpaved woods roads. These roads were laid out and constructed in strict compliance with the recommendations of the U.S. Forest Service.

In 1969, the City invested \$46,000 in a new automatic sawmill to replace the old belt-driven mill, which had been in service since 1955. The new mill produces between 500,000 and 750,000 board feet of lumber per year and requires five fewer men to operate than did the old mill.

Careless logging practices on municipal watersheds can be detrimental to water quality. However, by locating, constructing, and maintaining our logging roads in accordance with the recommendations of the U.S. Forest Service, erosion and sedimentation have been minimized.

All roads are laid out with the lowest possible grade (allowable 10 percent maximum) on side-hill slopes away from streams. Culverts are installed where the roads cross the smaller streams, and at major stream crossings we have constructed fords, using concrete paving slabs salvaged from abandoned roads on the watershed. Cross drainage is provided in the form of water bars (based on the rule of thumb: water-bar spacing = 1,000 feet/percent of grade) by making shallow sweeps with a dozer blade.

After completion of logging in a compartment, the slash is lopped and placed on the skid trails in such a way as to divert surface runoff out of the

trails thereby preventing erosion, logging roads are regraded, water bars rebuilt, and the landings and portions of the road having grades approaching the 10 percent maximum are revegetated. Roads are checked annually and after major storms, to make sure the drains are clear and the roads are passable in case of emergency.

MAINTAINING WATER QUALITY

Maintenance of water quality in our reservoirs also requires good sanitation practices on our own property and the surveillance of tributary streams to determine the quality of water entering the reservoirs.

To simplify trash clean-up and sanitation, we try to channel visitors to a few areas where we provide parking, comfort stations, and trash cans. Comfort stations have sealed concrete holding tanks to prevent pollution of the water supply. Fishermen, hikers, and picnickers who venture into the more remote areas of the watersheds where we have no comfort stations or trash cans are a problem. The containers in which they bring their food, drinks, bait, etc. are often left strewn along the roads and shoreline. Boat fishermen too, contribute to the litter problem. However, from time to time, ecology-minded citizens volunteer to clean up this litter. We usually accept their offers and assist where possible.

Stream Surveillance

Streams tributary to our three impounding reservoirs are sampled and tested regularly to detect any marked change in the quality of water entering the reservoirs. All sewage-treatment plant effluents and most streams are sampled monthly. However, those streams having relatively small sparsely inhabited drainage areas are checked only quarterly. Samples are collected

by watershed personnel and analyzed by chemists and biologists of the Water Division's Purification Section. Should the lab find a marked change in the quality of any sample, that stream is resampled immediately. If the second sample shows similar abnormality, we work our way upstream where practical, searching for the source of pollution. Samples are tested for pH, color, turbidity, dissolved solids, alkalinity, chlorides, total coli, fecal coli, dissolved oxygen, total phosphates, nitrates, NH_3N , ABS, and trace metals.

In April of this year a new problem came to light when the monthly sample taken of the Hampstead Sewage Treatment Plant (300,000 GPD activated sludge, extended aeration sewage treatment plant) effluent was found to contain 50,000 chlorella algae cells per ml. Subsequent samples, taken weekly for 14 weeks, contained concentrations ranging from 4,000 cells/ml. to 200,000 cells/ml. and averaged over 55,000 cells/ml.

Algae is first detected in the treatment units themselves and rapidly multiplies in the holding or polishing pond, which has a 3-day flow-through time.

The nutrient discharge from the Hampstead plant is also high. For the five samples taken of the effluent between January and May 1973, total phosphates ranged from 20.0 ppm to 60.5 ppm and averaged 31.6 ppm; nitrates ranged from 10.0 ppm to 33.6 ppm and averaged 26.1 ppm.

Though the State of Maryland has no regulations governing the discharge of nutrients into state waters, we feel that the quantities being discharged from this facility could and should be reduced. Consequently, a letter was written to the State Department of Natural Resources requesting that corrective measures be instituted.

We intend to continue our fight for tertiary treatment for any future sew-

age-treatment plants built on the Gunpowder and Patapsco watersheds. The Hampstead plant should serve as an example of why this is needed.

MAINTAINING AND IMPROVING WATER YIELD

Fortunately precipitation and water yield on the Baltimore watersheds are generally adequate to meet the current water demand of the area served. Manipulation of vegetation to increase water yield on the 6 percent of the total watershed of either upland source of supply which we control would be of little consequence. It appears, however, that the change from agricultural and forest use to residential and commercial use of the 94 percent of the watersheds under private control is influencing streamflow regimen by concentrating stormflow timing.

Although we have no program for improving water yield, we are concerned with the effects of changing vegetative types and land uses on the watershed and are cooperating with the Northeastern Forest Experiment Station in conducting related research on three subwatersheds on the Liberty Reservoir watershed.

WATERSHED PROTECTION

To protect our reservoirs and watershed lands and to regulate recreation, we have adopted rules summarized in "Regulations Governing the Loch Raven, Prettyboy and Liberty Reservoirs."

To enforce these regulations we have six watershed patrolmen. They hold special police commissions issued by the Maryland State Police, wear uniforms, and are armed. They patrol the watersheds in 4-wheel-drive vehicles equipped with two-way radios. The reservoirs are patrolled in outboard motorboats, which are also radio equipped.

Until this year, repeated efforts to

enlarge the six-man patrol force have failed due to budget limitations. In 1972 the U.S. Environmental Protection Agency conducted a survey of the Baltimore water-supply system in accordance with provisions of the Interstate Quarantine Regulations. Thanks to recommendations by EPA contained in the report on this survey, eight new watershed patrolman positions were approved by the Department of Finance for fiscal 1974. In addition, signs are posted to remind the public that swimming, wading, ice-skating, camping, firearms, fires, vehicles (except on paved roads), dumping, and boating, except by permit, are prohibited.

All the foregoing of course protects only the City-owned portion of the watersheds. By 1971 it became obvious that the time had come for the City to speak out about the other 94 percent.

On 15 March, 1971, the Board of Estimates of Baltimore City (Mayor, President of City Council, City Solicitor, Comptroller, Director of Public Works) approved a "Policy for Future Development within the Gunpowder and Patapsco Watershed", providing definitive guide lines covering five major areas of concern: zoning, building, pollution control, appropriation of water, and recreation.

Briefly summarized, the City's position on these subjects is as follows:

Zoning. — The City encouraged Baltimore and Carroll Counties to adopt low-density residential zoning as a minimum around the periphery of the reservoirs for a distance of at least 1 mile where feasible.

Building. — Building on the watersheds should conform to local and state laws regarding storm water runoff, soil erosion, and sedimentation. Regulatory agencies should exercise strict inspection controls to limit any possible pollution of the reservoirs from storm runoff, soil erosion, and sedimentation.

Pollution control. — Citing pollution from sewage-disposal systems and effluents from industrial plants, the City urged construction of interceptor sewers to carry sewage out of the watershed areas.

Appropriation of surface water. — The City will not permit any private developer to appropriate water from tributaries within the Gunpowder and Patapsco watersheds for any purpose.

Recreation. — Any expansion of recreational facilities must be weighed against the pollution and erosion that may result.

The City has the right to prevent appropriation of water and to regulate recreation on its reservoirs and watershed property. However, we must depend on the governments of Baltimore and Carroll Counties to exercise good judgment in regard to the zoning, building, and pollution-control recommendations.

RECREATION

According to a recent study (*Corbett 1970*), Baltimore City allows as great

a variety of recreational activities on its reservoirs and watershed lands as any municipality or private water company in the Northeast. Activities permitted include: boating, boat and bank fishing, picnicking, hiking, horseback riding, bow-and-arrow hunting at Prettyboy and Liberty, skeet shooting, and golf.

With the exception of the boating and boat fishing concession at Loch Raven (fig. 1), which is operated by the Baltimore County Department of Recreation and Parks, and the skeet-shooting range and golf course also at Loch Raven (fig. 2), which come under the jurisdiction of the Baltimore City Department of Recreation and Parks, all recreational activities on the three watersheds are managed and controlled by the Watershed Section. However, the Watershed Section retains control of the land occupied by the Loch Raven Fishing Center, skeet range, and golf course and reserves the right to take appropriate action in case of mismanagement of the land.

A good example of why we feel that

Figure 1.—Fishing from shore or boat is allowed in the recreational areas on Loch Raven Reservoir. For those who do not wish to row, electric motors are available for rent.

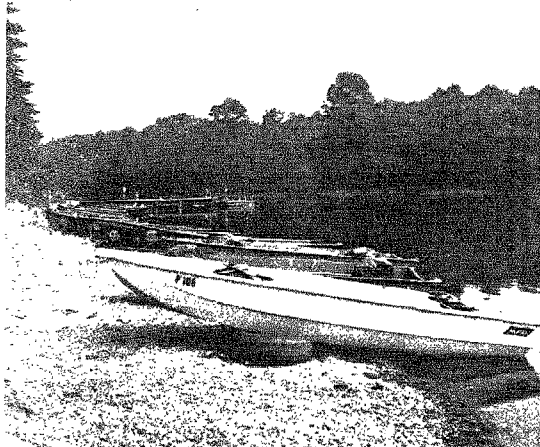


Figure 2.—Pine Ridge Golf Course, built on watershed property, attracts many golfing enthusiasts. Loch Raven Reservoir is in the background.



it is imperative that control of land management remain in the hands of the watershed superintendent occurred a few years ago at the Pine Ridge Golf Course at Loch Raven, when we learned that a mercury-base fungicide was being used there in quantities considered potentially dangerous. We notified the Department of Recreation to cease using this product immediately. They complied.

Boating

Boating at Liberty and Prettyboy reservoirs is controlled by the City Watershed Section. Holders of the 700 annual permits are allowed to use either or both reservoirs for boating and fishing between sunrise and sunset from 15 March through 30 November. No inflatable or collapsible boats, sailboats or power boats are allowed. Propulsion must be by rowing or by battery powered electric outboard motor. Canoes and kayaks are permitted only at Prettyboy.

Each boat is assigned a number, and two color-coded stickers bearing this number are issued with each permit. This sticker and the assigned number in numerals 2½ inches high must be displayed on the port and starboard quarters of each boat. The permit itself must be carried by an occupant of the boat and be shown to watershed personnel on request. By rotating the sticker color annually, we can tell at a glance whether or not a boat belongs on the lakes.

Income from the sale of permits by the City is deposited in the General Fund. None of this money is returned to the Watershed Section for improvement of the facilities. Loch Raven Fishing Center Rates for 1973 were:

Daily fee for fishing from boats, 50 cents for those 14 and over.

Daily rowboat rental, 2 hours or less, \$2; full day, \$3. No more than three fishermen to a boat (57 boats available).

All-day electric motor rental, battery included, \$5.

Launching fee for daily use of private boat, \$1.50.

Season-long launching permit, \$25.

Season fishing permit, \$15.

Season boat-docking permit, which enables one to keep his boat on the reservoir, \$20 (90 docking spaces).

In 1972 the Center operated at a profit of \$7,000 - \$8,000 which went into a capital-improvement fund for the Center.

Fishing

Bank and boat fishing are permitted at all three reservoirs. No fee is charged by the City for fishing, but fishermen over 16 years old must have a state fishing license. However, the Baltimore County Department of Recreation and Parks, which operates the fishing center at Loch Raven, charges a fee to fish from boats there. No wading is allowed, and fishing is prohibited from shore where banks are steep or rocky or otherwise considered to be hazardous.

The major problems generated by fishing are the litter thrown overboard and left strewn along the shorelines by thoughtless fishermen, plus the fact that few fishermen return to the boat dock areas to avail themselves of the sanitary facilities provided there.

Picnicking

Free picnic facilities are provided at all three watersheds and are available on a first-come basis. Although fires of any description — including charcoal grills — are prohibited, the facilities are heavily used, especially on weekends and holidays.

We have built over 200 picnic tables for use in these picnic areas, using lumber milled from timber cut on City watershed lands. Comfort stations, also built by our own forces, are located at

or within easy walking distance of each area.

Hiking

Hiking on our 200-mile woods road system is becoming increasingly popular, not only for individuals and family groups, but also for large groups as well. The local chapter of the Sierra Club and the Maryland Physical Fitness Commission conduct several organized hikes annually.

Horseback Riding

Horseback riding is permitted, but only on the woods roads. Riding is not permitted in areas where the public normally congregates. In the beginning, riders were few in number — mainly neighboring property owners who owned their own mounts. Now, however, a number of privately owned stables have opened on property adjoining ours. Elaborate facilities have been built to house large numbers of horses, but little land is available for riding trails. Consequently, increasingly large numbers of riders are flocking to our woods roads, and our problems with them are increasing.

When the roads are dry, the horses' shoes break the soil surface and leave a trail of pulverized dirt, some of which is washed into the reservoirs and tributary streams when it rains. When the roads are muddy, the hoofs leave holes that hold water and are difficult to drain. Another problem stems from the riders' tendency to ride single file down the center of the road, wearing a depression in the road, which becomes an avenue of erosion during heavy rain.

Other aspects of horseback riding that create problems include: riding and washing horses in the reservoirs and tributary streams, urination and defecation by horses on roads and in streams, failure to stay to woods roads,

and short-cutting on steep slopes between woods roads.

Hunting

Hunting of any description is prohibited at Loch Raven. However, hunting is permitted at Liberty and Pretty-boy only with bow and arrow. Firearms are prohibited because they present too great a hazard to the safety of our visitors, our neighbors, and our own personnel. State Fish and Wildlife Administration officers assist in enforcing our ban on firearms.

Future Recreation Considerations

In considering requests for new recreational activities on the reservoirs and/or municipal watershed lands, several questions must be carefully considered:

1. Will the proposed activity adversely affect water quality?
2. Will the proposed activity adversely affect watershed lands?
3. Is the proposed activity safe for participants?
4. Will the proposed activity endanger others on and near city property?
5. Will the proposed activity require new or enlarged facilities now or at a later date?
6. Will the proposed activity conflict with other activities already permitted?
7. Are other sites available where the activity can be conducted?

PUBLIC RELATIONS

Realizing the importance of making the public aware of the problems associated with protecting the reservoirs and watershed lands, we accept all invitations to speak to students, sportsmen, and civic and fraternal groups.

Hundreds of students, ranging from kindergarten to college, visit the watersheds annually. Each group is met by

one of our supervisory personnel, who speaks to them and answers any questions they may ask. More formal presentations are made at area colleges.

LONG-RANGE MANAGEMENT PLAN

No drastic change in present management policies is anticipated for the foreseeable future. However, more attention will be directed toward locating and reporting sources of sediment and other pollutants entering the reservoirs from the privately owned portions of the watersheds. We also plan to continue resisting the efforts of pressure groups to turn the reservoirs and contiguous watershed property into gigantic playgrounds. We plan to continue harvesting and milling watershed timber and hope to embark on a pulpwood operation to harvest the estimated 30,000 cords available through plantation thinning and the harvesting of mature Virginia pine stands.

Should funds become available, we would recommend that the city assist our farmer neighbors in the disposal of barnyard waste and drainage, a major source of pollution on the watersheds. This assistance would be in the form of the loan of heavy equipment and manpower to operate it.

MANAGEMENT PROBLEMS

Many of the problems we face in managing the Baltimore watersheds are complicated by the fact that the city owns less than 6 percent of the total watershed of both the Gunpowder and Patapsco supplies and none of the Susquehanna watershed. We are therefore dependent on the cooperation of other governmental agencies in protecting our water supply on the 94 percent of the watersheds over which we have no control.

For example, we must rely on the planning and zoning agencies of neigh-

Figure 3.—Changing land use patterns.

A, a former golf course now becomes a new source of erosion and runoff for the municipal watershed manager to worry about.

B, impervious areas in the watershed drainage increase as agricultural lands go out of production.

C, suburban development can create serious sedimentation problems if control measures are not instituted. Sediment-laden stormflow runs directly to the storm sewer inlet. Flow is eventually deposited in a reservoir feeder stream.



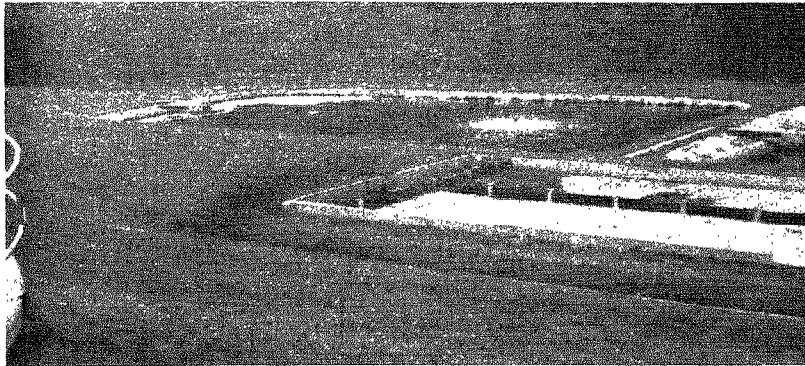


Figure 4.—Nutrient loading and resultant algae populations generated at this waste-treatment plant may lead to algae problems in the downstream water-supply reservoir. Some type of tertiary treatment is needed to alleviate these problems.

boring counties to consider the impact on the watershed and water supply of new development. Domestic sanitation problems, such as failing septic systems, are referred to the local health agencies for correction, and industrial effluent or practices potentially harmful to the water supply are reported to the State Department of Water Resources for corrective action. Erosion and sedimentation problems must be reported to county and state sediment control agencies for action.

Each year more and more of the privately owned watershed lands are being converted from farm, forest, and pastureland to residential developments, industrial parks, shopping centers, etc. (fig. 3). According to the Soil Conservation Service, erosion on lands being so converted is about 10 times greater than on land in cultivated row crops, 200 times greater than on land in pasture, and 2,000 times greater than on land in timber (*Soil Conservation Service 1970*). Developers are simply not following basic principles of erosion and sediment control. The resultant sediment not only reduces the storage capacity of our res-

ervoirs, but also carries with it fertilizers, pesticides, and other chemical pollutants that lower water quality (fig. 4).

SEDIMENTATION SURVEYS

Sedimentation surveys were conducted by the Soil Conservation Service at Loch Raven and Prettyboy in 1943 and 1961. The 1943 survey of Loch Raven determined that the annual rate of sediment accumulation was 0.618 acre-feet per square mile of drainage area. Eighteen years later, in 1961, the annual rate of sediment accumulation was found to have been reduced to 0.187 acre-feet (*Holeman 1955*).

The 1943 survey of Prettyboy Reservoir found that the annual rate of sediment accumulation was 0.699 acre-feet per square mile of drainage area. By 1961 the annual rate of sediment accumulation had been reduced to 0.391 acre-feet.

According to the Soil Conservation Service report on the surveys, the reduction in sediment accumulation was attributed primarily to the large acreage that went out of agricultural use into

residential and other nonfarm uses and to the adoption of soil conservation measures on much of the remaining farmland. Had the transition from agricultural use to residential and commercial use been more abrupt, consisted of larger projects that left large areas without plant cover for extended periods of time, and been closer to the reservoirs, the sediment accumulation rate would probably have increased. However, the changeover was limited mostly to residential construction some distance from the reservoirs and caused very little disturbance to soil and grass. In addition, the forested municipally owned watershed lands surrounding the reservoirs trapped some of the sediment.

Since the 1961 survey, development in the counties, especially Baltimore County, has been on a much larger scale. Housing developments consisting of hundreds of home sites, apartment complexes, shopping centers, and huge industrial parks are being constructed closer to the Loch Raven Reservoir and along tributary streams.

Sediment Control Legislation recently enacted by the State, and subsequently by the counties and Baltimore City, is not being as rigidly enforced as we in the water-supply field would like. Sediment-control procedures are included on all developers' plans, but are not always implemented. In addition, tropical storm Agnes, which struck the Maryland area on 22 June, 1972, dumping up to 14 inches of rain, caused unprecedented flooding and heavy erosion.

As expected, the sediment survey conducted at Loch Raven in 1972-73 by the Soil Conservation Service found that the sediment accumulation rate there had increased markedly. The review draft of the report stated that "during the 11-year period between the 1961 and 1972 sediment surveys of Loch Raven Reservoir, sediment deposits increased 114 percent or from .187 to .401 acre-feet

per square mile as a result of increased development within the watershed." The review draft contained the following recommendation: "Because of the rapid increase in the sediment accumulation in Loch Raven Reservoir, it is strongly suggested that strict sediment control procedures be implemented in all future developments; and efforts be made to increase good conservation practices on all farms and woodland in the watershed."

SANITATION SURVEYS

Sanitary surveys were conducted on all three watersheds in 1970-71 to determine the quality of water in the watersheds. Sanitarians walked the streams tributary to the reservoirs from mouth to source looking for sources of pollution.

Agricultural pollution was found to be the most prevalent. Problems cited included overgrazing, lack of good soil conservation practices, barnyard drainage, and little if any animal waste removal procedures. Industrial discharges and disregard for soil conservation practices and regulations by developers and builders were the second major pollution sources noted in these surveys. Failing septic systems, raw sewage effluents, and privies within 100 feet of the streams were found to be few and were generally located in rural towns.

The surveys found that there was no existing public health hazard from the water being drawn out of the reservoirs, which is treated, filtered, and chlorinated before being delivered to the consumer. However, pollution was found to occur in the tributaries in the form of fecal coliform pollution, biochemical oxygen demand (BOD) overloading, and excessive siltation. It is believed that the natural physical and biological processes at work in the reservoirs are sufficient to diminish most of these pollutants.

WATERSHED STAFF

Operation and maintenance of Baltimore's three municipal watersheds is the responsibility of the general superintendent of watersheds (watershed manager). His staff includes an assistant superintendent of watersheds (assistant watershed manager), a watershed forester and three watershed maintenance supervisors (one for each watershed). Other employees include a maintenance mechanic foreman, 6 watershed patrolmen, a principal clerk, and a 42-man labor force, 12 of whom are assigned to the logging-sawmill crew.

Duties of Watershed Manager

Baltimore's watershed manager is responsible for directing and supervising all activities connected with the operation, maintenance and administration of the city's watersheds, dams, reservoirs, and related impounding facilities, including: reforestation; timber-cutting; sawmill operations; lumber disbursement; road-building and maintenance; enforcement of sanitary regulations; enforcement of watershed regulations; control of recreational activities; maintenance and repair of equipment; ordering of equipment, materials and supplies; negotiating for the purchase of any land and/or rights-of-way necessary within the watershed areas; and attending all meetings and handling all correspondence related to the watersheds. He is also responsible for inspection and maintenance of the 38.4-mile Susquehanna River Raw Water Conduit, appurtenances, and the intake structure at Conowingo.

Handling Personnel

Our policy of "treating our employees as we would like to be treated", coupled with our hiring practices, have resulted in good supervisor-employee relations and extremely few problems.

Many of our men are career employees and several newer employees are relatives or friends of these men.

Unlike some other agencies in the Department of Public Works, none of our laborers are hired through political influence. In fact very few are even city residents. Most of our employees live in the vicinity of the watershed to which they are assigned. Wherever possible, vacancies are filled by local residents, and preference is given to qualified applicants recommended by our employees.

All 55 employees are known and addressed by name, and outstanding performance is always acknowledged. Our men are conscientious, reliable, hard-working individuals who still believe in giving a day's work for a day's pay. This makes our job a lot easier.

RELATIONS WITH MUNICIPAL AUTHORITIES

Despite the fact that we are a city agency, we have surprisingly little contact with elected city officials. When we do hear from them it is usually in regard to special privileges sought by a constituent (usually recreation oriented).

Inquiries received and/or correspondence forwarded to us for reply are processed promptly. If our reply is negative, we include our reasons for making such a decision. In so doing we often point out considerations overlooked by the official. Generally speaking, we recommend the open, honest approach in dealing with elected officials.

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APPENDIX

(Exerpts from Baltimore County Sediment Control Manual)

Procedures for Incorporating Erosion and Sediment Control in Construction and Development Plans

Under this sediment control program, the following procedures are provided to assist land owners, developers, engineers, county agencies and contractors in the planning and construction stages of projects. These projects include residential, commercial and industrial subdivisions, schools, highways, recreation sites and other large scale construction where sediment and erosion problems are anticipated.

Mechanics within the County Organization to incorporate erosion control procedures in subdivisions and other construction plans:

1. Prior to any development or construction, optional discussions between developers, builders, contractors, engineers or architects with Baltimore County and the Baltimore County Soil Conservation District are available. Technical advice concerning sediment control measures and other information can be given at these sessions.
2. Individual building permits for residential housing, where a public works agreement is not involved, will be processed for sediment control recommendations and enforcement entirely within the Building Engineer's Office.
3. With regard to subdivision processing, general sediment control advice will be given at the time of the Joint Subdivision Committee Review. A member of the USDA, SCS, representing the Baltimore County Soil Conservation District will be assigned to assist the County at these reviews. A grading plan in conjunction with all sediment control plans will be necessary. A grading permit will be required of the developer and/or owner prior to any grading, including the stripping of topsoil if sediment control measures are recommended. The Public Works Agreement will be revised to include a paragraph with sediment control requirements.
4. The Developer's and/or owner's consulting engineer will provide sediment control drawings which may or may not be a part of the grading plan. The technical guidelines in conjunction with this program should be used in preparation of plans. These plans will be reviewed and approved by the Developers Design Approval Section of the Bureau of Engineering. Further assistance may be obtained through the Baltimore County Soil Conservation District. Comments in written form will be transmitted through the Bureau of Public Services to the developer and/or owner. Some sediment control provisions may be part of the contract specifications as in highway construction. Industrial, commercial, etc., building permits will also be subject to the Sediment Control requirements and procedures.
5. Where sediment control measures are necessary, no grading permit or building permit may be released until sediment control plans are approved. The Buildings Engineer and the Department of Public Works will have to coordinate their efforts to assure proper operation in this area. Also, no record plat may be recorded until sediment control plans are reviewed and approved.

6. Agencies such as the School Board and the Department of Recreation and Parks may provide their own sediment control measures in conjunction with the Soil Conservation District or they may call on the Department of Public Works for assistance.

Other areas of construction such as County highways and buildings are expected to incorporate erosion control features within their speci-

fications using the technical guidelines prepared in conjunction with this program.

7. During the construction stage the Buildings Engineer, the Department of Public Works or the Soil Conservation District will be available for technical consultation.

However, only three (3) men are assigned to inspection of grading and erosion control measures in all of Baltimore County.

CURRENT MANAGEMENT PRACTICES ON THE BETHLEHEM MUNICIPAL WATERSHEDS

by JOHN C. ANSPACH, R.P.F., *City Forester, Department of Public Works, Bethlehem, Pennsylvania.*

ABSTRACT. Bethlehem, Pennsylvania, derives its water from two watersheds located in the Pocono Mountains, 30 miles north of the City. The Wild Creek and Tunkhannock drainage areas measure 25,500 acres, of which the City owns 72 percent. Water from the forested watersheds does not require filtration and flows by gravity through a 23-mile transmission line to a service area of 90 square miles with a population of 105,000. The watersheds and the management practices used on them are described, including use of watershed lands for recreation and educational purposes.

BETHLEHEM, PENNSYLVANIA, is located 60 miles north of Philadelphia in the center of the Lehigh Valley metropolitan area. For many years the Lehigh River was the city's main water supply, but in the mid-twenties it became obvious that, because of increased pollution of the river, a better water supply should be located. This supply was found in the Wild Creek drainage, located in Carbon County, approximately 30 miles north of the city.

In 1938 construction was started on a dam across the creek, a chemical treatment plant near the dam, and a 23-mile transmission line to the city. In 1941 the new water supply was inaugurated.

The watershed contains two impounding reservoirs: Wild Creek reservoir, with a capacity of 4.1 billion gallons, and Penn Forest reservoir, built upstream to retain the water that was normally lost over the Wild Creek spillway.

Its capacity is 6.5 billion gallons. The total water surface of the two lakes is 765 acres. The reservoirs are fed by 10 streams.

In the late forties a second watershed was developed to back up the Wild Creek supply in years of drought: the upper Tunkhannock Creek, located in Monroe County, approximately 12 miles northeast of Wild Creek. When needed, water from the Tunkhannock Creek watershed is diverted to Wild Creek by means of a 9.1-mile gravity-flow transmission line.

THE WATERSHEDS

The watersheds are owned by the Bethlehem Authority, which is the legal owner of all the real estate and improvements in the watersheds as well as in the city pertaining to water collection, treatment, and distribution, and wastewater treatment.

The City leases the right to use and operate these facilities and pays a yearly rental to the Authority. The lease agreement stipulates that the City of Bethlehem employ a professional forester for the management of the watersheds.

Two features of the Bethlehem water supply are worth mentioning. First, Wild Creek water does not require filtration. Basically it is rainwater, very soft, with a low alkalinity and a pH in the 6.2 to 6.6 range. The bacteria count of the raw water is very low. The only problem is turbidity, which averages 4 Jackson turbidity units. This factor may eventually impel the City to construct a filtration plant.

Second, the water flows from the watershed to the city by gravity; no pumping is required. From the northernmost lake in the Tunkhannock Creek watershed to the southernmost customer in Hellertown, the distance is 46 miles. This gravity flow is possible because of a 1,580-foot drop in elevation; but two tunnels had to be constructed in the transmission main. A small section in the Bethlehem service area, on South Mountain, is served by a pumped high-pressure system.

The ownership of land in the catchment area determines to a great extent the quality of the water. Ideally all land use in the watershed should be controlled by the water utility. Of a total of

25,526 acres of catchment area, the city owns 18,387 acres or 72 percent (table 1). Acquisition of additional acreage is being considered to protect the city's water interests.

The Wild Creek watershed is hilly, and the soil is susceptible to erosion when not protected by vegetation. The drainage area is almost totally forested (98 percent). The city-owned lands — 10,891 acres — are 100 percent forested.

The Tunkhannock Creek watershed, on the other hand, is flat, and there is little danger of erosion. In this watershed, 1,417 acres are cleared for farming. The watershed area is 88 percent forested. The city-owned properties are 95 percent forested. Where farming practices do not create turbidity in the Tunkhannock watershed streams, the fields are rented to a commercial farming company.

WATER SERVICE

Bethlehem's water-service area includes not only the City proper but also several of the surrounding boroughs and townships. The total service area amounts to 90 square miles, with 105,000 customers.

Water for domestic purposes accounts for 20 percent of the total volume used in the district (table 2). The average daily flow from watershed to service

Table 1.—Areas of the Wild Creek and Tunkhannock Creek watersheds owned by the City of Bethlehem, 1973

Watershed	Total watershed area	City-owned land		Total
		Inside watershed	Outside watershed	
	Acres	Acres	Acres	Acres
Wild Creek	13,726	10,891	1,818	12,709
Tunkhannock Creek	11,800	7,496	1,508	9,004
Total	25,526	18,387	3,326	21,713

Table 2.—Percentages of total volume of water transmitted to service area by different categories of use, City of Bethlehem, 1972

Use	Volume Percent
A. Domestic	20.2
B. Commercial	6.9
C. Industrial	49.8
D. Other	0.3
E. Bulk sales to other suppliers	0.4
F. Unmetered use and leakage	22.4
Total	100.0

area in 1972 was 26.2 million gallons. The projected requirements of the system are 29 million gallons per day for 1975 and 35 million for 1980.

WATERSHED STAFF

The watershed work force at the present is 23 men, including the city forester and his assistant (fig. 1). A regular work crew, under the supervision of the foreman, is made up of five woodsmen I to carry out routine watershed maintenance and development work. This involves logging, road-build-

ing and road-maintenance work, planting seedling trees in the watershed, building maintenance, etc.

Performing more sophisticated work are five woodsmen II who may, for instance, be scheduled for maintaining boundary lines, reading piezometers, planting large street trees in the city, and operating special equipment such as hydroseeders, rotobeaters, and forest fire-fighting equipment. The two heavy-equipment operators and the garage mechanic are classified as woodsmen III.

The three treatment plant operators are usually scheduled on day shift; they perform specialized duties within the plant and on the watershed.

The watershed patrolman works full time on sanitary and security patrols. There are two assistant patrolmen who also may be assigned woodsman II work.

The forest technician works directly under the forester and carries out all watershed technical fieldwork. He is in charge of all planting of seedling trees in the watershed and shade trees in the city.

The city forester's duties involve normal daily supervisory and administra-

Figure 1.—Organization chart for the City of Bethlehem Bureau of Water, Division of Collection and Treatment.

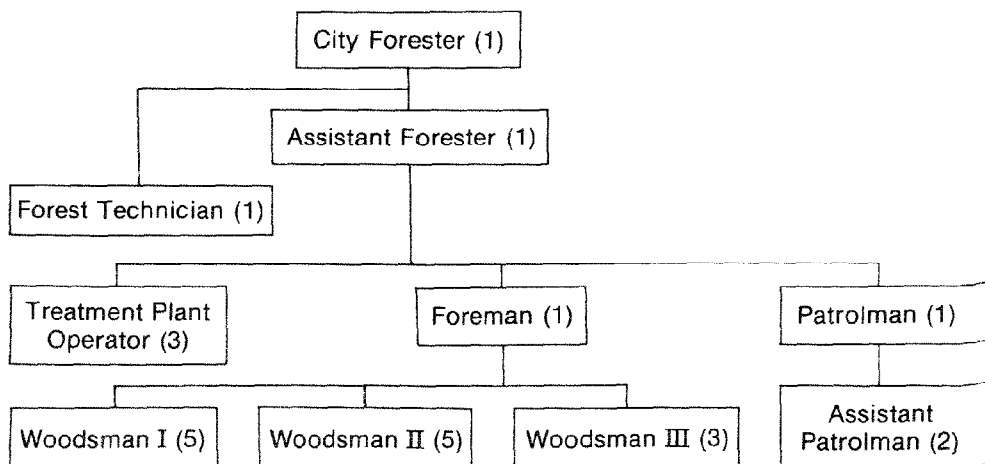


Figure 2.—Wild Creek reservoir and intake tower. The burned area at left was reforested immediately after the fire.



Figure 3.—The Wild Creek lookout tower built by the City of Bethlehem to aid in detection of fires on watershed property. Through cooperation with State fire towers, complete surveillance of the entire watershed is obtained.

tive tasks as well as the planning for watershed developments in the future. The assistant forester supervises the routine daily operations of the watershed.

FORESTRY PROGRAMS

The Reforestation Program at Wild Creek, 1963-68

In 1963 a forest fire burned 2,300 acres of prime watershed forest land bordering the Wild Creek reservoir. This burnt area included 20-year-old spruce and pine plantations, which were a total loss (fig. 2 and fig. 3).

The burnt area was reforested in a city-conducted operation in 1963-68. The watershed staff was temporarily increased from 6 to 32 men. These crews were equipped with chainsaws, a front-end loader, a timber skidder, and trucks. The reforestation project was financed by Bethlehem Authority and coordinated by the city forester and the assistant forester.

The reforestation work consisted of

salvaging 1 million board feet of burnt sawtimber, chipping all fire and logging debris, stabilizing eroding soils by hydroseeding, and planting 600,000 tree seedlings.

After the reforestation project was completed, city council agreed to maintain a watershed work force of 25 persons for watershed development work.

Timber Harvesting Practices

The timber-harvesting practices applied in the watersheds since 1963 have consisted of work by city logging crews and commercial logging in piecework and stumpage sales.

It should be pointed out, however, that only a small portion of the timberstands in the watersheds are classified as mature (table 3). In the Wild Creek watershed, only 42 acres in the white pine-hemlock type are classified as sawtimber.

In the same watershed, 3,500 acres (30 percent of the total timbered area) are stocked with large pole-size timber in which a selective type of cutting might also produce small dimension logs. Nevertheless a start has been made with selective cutting operations or sanitation cuttings removing mostly dead and diseased timber. In the 1969-73 period, 437 acres were so treated. The selective cuts were carried out in compartments close to some of the important feeder streams and bordering on one of the lakes.

Because of the hilly topography in the Wild Creek watershed, harvesting operations close to watercourses and lakes are carried out by the watershed logging crew. No timber was sold on the stump in Wild Creek because poor logging practices by contractors could cause turbidity in the streams.

On the other hand, stumpage has been

Table 3.—Forest type areas, special land use areas, and lake areas in the Wild Creek Watershed, City of Bethlehem

Forest type	Size class (dbh) of dominant and codominant trees	Area
	<i>Inches</i>	<i>Acres</i>
Mixed oak	8-14	2,995
	4-8	3,445
	<4	3,128
Aspen — gray birch	<4	36
Oak — pitch pine	8-14	493
	4-8	668
	<4	217
White pine — hemlock	14>	42
	8-14	10
Plantations	4-8	133
	<4	308
Nonproductive forest land, understocked areas		77
Noncommercial forest land, well-stocked but inaccessible		235
Special use areas (picnic areas, rights-of-way)		157
Wild Creek and Penn Forest reservoir		765
Total		12,709

sold in the Tunkhannock Creek watershed, where the flat topography caused little concern for turbidity.

In watershed timber cuttings, the skidding of logs is a critical operation, and for the city's watershed logging crew a small open track-type timber-skidder with a built-in logging arch was selected. The damage to the logging area, we found, was considerably less than that caused by rubber-wheeled skidders.

Plantation Management

From the start of the Bethlehem municipal watersheds in 1941, seedling trees have been planted every spring to reforest unproductive fields. Once all available land was reforested, an annual tree-planting program was continued to replenish burned-over and understocked areas.

Including a "Green Foot" tree-planting operation by city volunteer forces in 1963, following the disastrous fire, over 1 million seedlings have been planted in the watersheds.

In addition, seedling trees have been planted in a scrub-oak conversion project. The unproductive scrub oaks were pushed aside by bulldozer and rootrake and replanted with commercial timber species such as red pine, Japanese larch, black cherry, and European alder. The results of this conversion have been very satisfying, and so far 210 acres of plantation have been established. In 1968 the cost per acre averaged \$67.

The Norway spruce and red pine plantations established in 1941 have now reached pulpwood size. In 1963 they were found to be overstocked and stagnating in growth. A plan of plantation thinning was developed, and every fall approximately 20 acres of plantations are thinned. The evergreen boughs are sold to Christmas-green dealers, and the trunks are shipped to a pulp mill.

WATERSHED PROGRAMS

Experiments to Reduce the Color of Tunkhannock Creek Water

One problem of the Tunkhannock Creek water is its color. At several points of low elevation in the watershed, clear water of unexcelled quality bubbles up through layers of white sand. However, once this water has drained through the swamps into the creek, it shows a high color level.

It is assumed that in the poorly drained Tunkhannock Creek area, because of the acid parent material and acid-tolerating vegetation, the normal decomposition of plant debris is interrupted. Humic acid is formed, the stain of which is chiefly responsible for the color of the Tunkhannock Creek water.

To remedy this color problem, two watershed experiments have been carried out. One field experiment involved the application of alkaline cement-plant stack dust on a 15-acre lake. The second experiment dealt with channeling a swamp for faster draining. Both experiments resulted in negative answers, and the problem of colored water has not been resolved.

Work Conducted for Improving Water Quality

Throughout both watersheds, streams are periodically checked for fallen logs and other obstructions. In several locations rhododendron and other vegetation that crowds the streambanks have been removed.

The banks above the 14 miles of shorelines of both reservoirs are planted to a 100-foot-wide evergreen belt to hold the soil on the steep slopes and to prevent leaves of the surrounding hardwood forest from blowing into the water. Hemlock and spruce are the most effective species.

RECREATION

The forests, streams, and reservoirs of the city-owned lands in the Wild Creek and Tunkhannock Creek drainage areas have potential recreational values. This potential, however, is restricted by the fact that the city does not filter its water. The forest soil and humus layer, as well as the water storage reservoirs, act as a natural filtration plant. For this reason the 756 acres of lake area and the surrounding safety zone of 1,389 acres are fenced off to the public. Allowing recreation on the reservoirs would necessitate filtration. A conservative estimate for a filtration plant would be \$20 million.

Because of the lack of sanitary facilities and limited staffing, overnight camping is not permitted on the remaining 19,568 acres.

Vehicles are not allowed on the forest access roads and fire trails because unlimited use would create a serious road-maintenance problem.

On the other hand, the city's watersheds are open for public hunting under the regulations of the Pennsylvania Game Commission.

Watershed roads and trails are open to the public for hiking and skiing. The public is also encouraged to use the three picnic areas, two of which are equipped with restrooms. Camping is permitted at one location on city land outside the catchment area.

Opening up of the nearby Beltzville reservoir in 1971 for total recreational use has eased the pressure for boating and fishing on the city's reservoirs.

The Pocono International Raceway, located in the Tunkhannock Creek catchment area, has caused increased public pressure in that area.

Considering the proximity of the watersheds to major highways, such as Interstate 80 and the northeast extension of the Pennsylvania Turnpike, heavier demand may be expected in the future.

Notwithstanding the restrictions on the watershed use because of sanitary reasons, the city operates its water-collection areas under the concept of multiple land use, and recreation is one of the recognized types of land use.

PUBLIC RELATIONS PROGRAM

Since its founding, the Wild Creek watershed has enjoyed the community's confidence. This has resulted largely from the emphasis that those in charge have given to the image of the watershed's green forests, clean air, and pure water.

In the later years it was found, however, that few people were aware of the true functions and services conducted in the watershed.

To make this information available to a wider audience, the city forester's office has initiated the following programs:

- A 20-minute movie called "Wild Creek" was produced, in color and with sound. This movie has been shown on the local educational television programs and is used regularly by the Bethlehem Area School District.
- It has proved to be a very effective public relations tool.
- Talks with slides and the film are available for service clubs, Boy Scouts meetings, etc.
- A contact has been established with the Bethlehem Area School District wherein, as a part of their urban-studies program, all seventh-grade students visit the watersheds. Through this program more than 1,000 school children receive first-hand information on the Wild Creek project each year.
- Similar tours on a more professional level in the field of forestry and ecology are being conducted once or twice a year for the local colleges and university.

CURRENT MANAGEMENT PRACTICES ON METROPOLITAN BOSTON'S MUNICIPAL WATERSHEDS

by BRUCE A. SPENCER, *Forester, Water Division, Metropolitan District Commission, Commonwealth of Massachusetts, Belchertown, Massachusetts.*

ABSTRACT. The Metropolitan District Commission is a state-municipal agency that directs an active management program to supply water, sewage, park, and some police needs for 32 towns and cities of the metropolitan Boston area. Four major aspects of the management program are described: watershed management, regulation and control of management activities, silvicultural practices, and wildlife management proposals.

THE METROPOLITAN District Commission (MDC) is the state-municipal agency directed to supply the water, sewage, park, and partial police needs for 32 cities and towns of metropolitan Boston. The Water Division of MDC has water rights to approximately 500 square miles of watershed from which it consumes 100 billion gallons of water per year. The principal watersheds in this system are the Quabbin and Ware River Watersheds, on which we manage 75,000 acres of land.

Historically this land had very limited management except for protection and the planting of open land to conifers. Eventually, the obvious responsibilities of ownership manifested themselves, and MDC initiated extensive watershed-management practices in 1960. The primary concern of this management is to maintain a healthy forest that is directly related to sustained yields of clean water.

WATERSHED MANAGEMENT

In our region the forest is a major influence in the detainment and consumption of water between the time the land receives it as precipitation to the time it reaches the reservoir as streamflow. Evapotranspiration on our watershed is relatively constant regardless of rainfall, and consequently streamflows vary tremendously from dry to wet years. To increase water yields, our management efforts are concentrated on reducing the natural density (stocking) of the forest to lower the levels of evapotranspiration.

Therefore our efforts between 1970 and 1980 will be directed toward the following tasks:

- Commercial silvicultural treatments on 12,000 acres of forest, removing approximately 40 percent of the merchantable basal area or 2,600 board feet per acre.

- Thinning 3,000 acres of conifer plantations by cutting 15 to 20 percent of the basal area.
 - Converting 500 acres of stagnated red pine plantations to fields of grass and herbaceous growth.
 - Maintaining healthy wildlife populations to control the regrowth of premature undesirable regeneration.
3. Practically all species and grades are merchantable to 8 inches dbh.
 4. Moderate terrain that allows commercial logging on most of the watershed.
 5. Large populations of deer and beaver, which control the normal forest regrowth following a harvest cutting through browsing and complete control of much of our riparian vegetation through beaver flowages.

I feel that the impact of this work on water yields is significant for our watershed. This significance is backed up by the following research studies.

The MDC, in co-operation with the University of Massachusetts, carried out several types of cuttings and treatments on a gaged watershed of 400 acres. The principal treatment was a timber sale employing various silvicultural cuttings ranging from single-tree selection to shelterwood on 200 acres. Noncommercial treatments involved deadening 40 acres of riparian overstory and 80 acres of riparian understory, plus heavily thinning 40 acres of pine plantations. These combined treatments increased water yields 12 to 22 percent for the first five years.

Research on the New York State Forest Preserve showed a decrease in water yields by 23 percent over a 35-year time span when no cutting took place on a gaged watershed. (*Eschner 1965*). I am well acquainted with the forest conditions that produced both of these results and feel confident we can create forest conditions on our watersheds that will maintain a 10-percent increase in water yields over natural forest conditions.

The following are some of the main factors that will assist us in creating and maintaining the necessary forest conditions on most of the watershed.

1. Ownership of two-thirds of the watershed.
2. Average forest age of 55 years.

The type of forest being produced from these influences is a healthy park-like forest of quality trees that will provide the source of a new forest when this becomes appropriate.

In the past 10 years, watershed-management operations treated 10,000 acres of forest, and should have yielded an additional 3.3 billion gallons of water, valued at \$200,000, plus 33 million board feet of stumpage valued at \$658,000. This decade (1970-1980) we will treat 12,000 acres and produce similar yields but of greater value. This increased water yield seems like a small contribution, but it is more economical and of higher quality than other additional sources of water.

REGULATION AND CONTROL OF MANAGEMENT ACTIVITIES

Boundaries

The maintenance of property boundaries is vital to our program and requires a constant care of property corners and lines to control activities from without and within.

Management Zones

Delineation of management zones is necessary to recognize boundaries of areas that received different types of uses. A specific management policy is developed for each zone. The following six zones have been established and mapped.

<i>Area use</i>	<i>Percent</i>
1. Watershed management	83.0
2. Esthetics	6.0
3. Protection	6.0
4. Administration	0.5
5. Wildlife	3.5
6. Recreation	1.0

Each area requires specific silvicultural practices or protection to preserve the necessary environmental conditions. Basically, our silvicultural goals are to maintain and improve the health and quality of the forest; salvage defective, mature, and dead trees, especially unhealthy pine plantations; and prepare sites for the regeneration of native species.

Records

A supplementary control function is an accurate record system designed to record all management activities on watershed lands. Several management blocks of similar size are delineated by natural and man-made boundaries. A single record book is used for each block that has an average of 16 compartments of 700 acres in size. For each compartment we have an 8½ x 11 USGS topographic map with a scale of 1,000 feet to the inch, on which to record and note all activities.

Continuous Forest Inventory (C.F.I.)

Our present CFI program was adopted in 1960, with the establishment of 350 one-fifth acre sample plots. These plots were located by drawing a ½-mile grid on a USGS map of MDC lands. Under the CFI system, the plots are re-measured at 5-year intervals. Consequently, the forest is monitored over time to determine the effects of all influences imposed by man and nature. The growth, vigor, damage, mortality, quality, desirable silvicultural practices, etc. for each tree within the sample

plots is determined in the field. These data are then processed by a computer program, which produces both plot and tree reports and forms the basis of our management plan.

Planting

Although a minor aspect of our management program, approximately 15,000 white pine seedlings are planted each year. These are planted in forest openings made by recent harvest cuttings.

Weeding

There are relatively few acres of forest in the seedling and sapling age class, consequently only a small amount of this type of work has or will be done. This work entails the mechanical cutting of gray birch and other weeds from pine and hardwood stands.

Thinnings

With many thousands of acres of conifer plantations, there will be a continuing need for thinning. Some plantations have stagnated, and thinning is too late for them. When row thinning was carried out in these stands, the slight opening was soon filled with broken and bent trees.

Consequently, our precommercial thinning has been and will continue to be carried out in stands that have expressed dominance. In these stands the cull trees are brought to ground level and lopped. Stumps are cut low to facilitate commercial thinnings that follow.

Commercial thinnings have been removing one or two complete rows of every three to four rows. Several hundred acres have been thinned in this manner.

Natural hardwood stands have been thinned by local firewood dealers. Approximately 10 cords per acre is marked for removal, primarily black oak, birch,

and maple. One dollar per cord stumpage is generally the selling price. Many thousands of acres need this work, but only 40 to 50 acres per year have been thinned in this manner.

Harvesting

The commercial harvesting operation has been and will continue to be the main silvicultural practice on the watershed. This silviculture has been concentrated primarily in mature and over-mature pine, hemlock, and mixed hardwood forest composed chiefly of oak and maple. A commercial timber sale removes one-half of the merchantable volume from these stands, chiefly of dying, poor quality, hurricane-tipped, and diseased trees.

Various silvicultural methods are employed, ranging from single tree selection to group selection. The diverse nature of our forest, along with the requirements of logging, dictate these methods of silviculture.

Only a small percentage of our timber sales are designed to produce a new forest. Consequently, we are planning two to three harvest operations in all stands before a seed tree or final shelterwood cutting is made. Any premature forest regeneration is prevented mainly by our sizable deer herd.

The resulting residual stands consist of only one or two age classes. Practically all of our present forests originated prior to 1938. They were established by an MDC planting program, the 1938 hurricane, and private logging operations prior to MDC ownership.

The three main forest types and species combinations that will comprise most of our future forest will be red oak, white pine, and hemlock.

Potential adverse forest influences — other than man-caused fires — are chiefly wind, snow, and ice damage. The 1938 hurricane certainly pointed out the

problems of growing white pine on exposed sites. Oak forests in these same areas suffered minor damage. Ice damage is also severe for pine at higher elevations, so that only 20 percent or less of the watershed should ever be in this type, and then only in certain locations.

Fire damage can be kept to a minimum by maintaining a good road network for access to practically all areas. Also, all logging slash will be lopped close to the ground to speed decomposition.

The esthetic appearance of all silvicultural operations is very important to us and to the public that visits the watershed lands. To create an esthetically pleasing harvest operation depends on both the forester's skill and the logger's skill. Factors considered in maintaining acceptable forest esthetics are the logging road layout, slash disposal, intensity of silviculture, and the careful treatment of stands adjacent to historical sites, reservoirs, administration areas, natural areas, brooks, and rivers.

Before a timber sale is marketed, the terms of the contract are fixed. The overall timber sale contract is much the same for all sales in order to regulate the operation and insure the fulfillment of all goals. There are some specifications that vary from sale to sale, such as time limit, seasons when logging will be permitted, road requirements, and equipment allowed.

All other restrictions are standard for all sales, including sanitary rules and regulations, method of slash disposal, expected workmanship, penalty clauses for breach of contract, and other restrictive measures to insure good harvesting practices.

Probably the most important ingredient for success of a timber sale is the logger's pride in workmanship. If he possesses this characteristic, then supervision by the forester is made easier and damage to the residual stand and to

the land will be practically nonexistent. Foresters have attempted to reinforce this pride by evaluating the performance and workmanship of the completed timber sale. This evaluation sheet not only records good work, but also poor work, which will bear heavily on the selection of logging contractors for future jobs.

Although we carefully supervise logging operations to attain good results, we cannot control the weather, which has significant impact on the quality of a logger's work. Therefore some flexibility on our part as well as his part is absolutely necessary. Mud conditions can develop overnight from heavy rainfall; this is a good example of the necessity for flexibility. Mud is the enemy of the logger, landowner, and the land. We try to work around these conditions, which may come at any time of the year, but is usually a problem for only a month or two in the spring.

WILDLIFE-MANAGEMENT PROPOSALS

The Quabbin Reservation is a wildlife sanctuary created by a legislative act. Since it consists of practically 50,000 acres in one contiguous block surrounding the Quabbin Reservoir, it is an extremely productive and effective sanctuary. Deer and beaver have been a major influence since the early 40s and 50s respectively. Their populations are enjoyed by the visiting public, and it behooves us to keep them as healthy as the forest since the public, the forest, and wildlife are essential to our watershed-management program.

The proposals for this decade are concerned with the following: timber-harvesting operations, power-line maintenance, creating and restoring open land, and plantation elimination. All these activities are aimed at enhancing our deer habitat.

Timber-Harvesting Operations

Our harvesting operations are a continuous operation, so that any wildlife-management aspects applied along with these operations will be extremely important to the wildlife. A timber sale of any sort is beneficial to most wildlife, but by planning our sales carefully we can exert a much greater beneficial influence on the whole wildlife community than would normally be expected of a harvesting operation. There are many ways an operation can be improved for wildlife, and we work to incorporate some or all of these methods into our timber sales.

First, since our forest is on a plan of sustained yield, we will be theoretically harvesting timber forever, and therefore the impact of the sales will also be continuous. For deer management purposes we feel that these cuts should be distributed as evenly as possible throughout the watershed, and in this manner we can be sure that no one large tract of land is without food and cover.

Second, there are many marking guidelines that we will follow to increase the desirability of our wildlife habitat. Presently our marking is centered around cleaning up the forest by cutting the overmature, diseased, and defective trees. Elimination of these poorer trees creates hardwood sprouting and underbrush. Hemlock stands are treated very carefully so this valuable deer cover is not lost. Also, all large healthy oaks are left for the production of acorns. All these activities create and maintain food and cover for the white-tail deer.

Food and cover become very critical for the deer during winter months. We cannot create cover quickly, but large amounts of food are soon brought to ground level by the cutting of hardwoods. For this reason many of our hardwood sales are planned for winter months near areas of cover and little

food. Once spring arrives, all logging is curtailed, because of potential damage to the land and forest. This suspension of work is also beneficial to the thousands of newborn birds and animals, some common and some not so common. Therefore, as in the past, all logging will be done in the months July through March and, except for very rare cases, no logging will be done in the three spring months.

The logging techniques and methods used on the watershed are fairly well defined in our contract, but many things should be done which cannot be defined in the legal document. Presently, we are getting excellent cooperation from our loggers, and if this continues the wildlife will benefit in many ways. A good logger will cut many small suppressed trees to facilitate his operation, and these trees supply food from both their tops and sprouts. This also makes the harvesting operation much neater in appearance. We also require the logger to cut all his main skid roads, which not only produce more sprouting but creates both good trails and small openings for the animals to travel. Once the operation is completed, all log landings are planted with various species of plants beneficial to wildlife.

Right-of-Way Management Plan

There are significant portions (500 acres) of power line right-of-ways, which provide important wildlife food and cover. Since the power company is continually maintaining their line, our work will coincide with theirs. By zoning certain areas of the line to specific treatments, we believe an important food supply may be protected and even propagated. The spraying crews try to leave blueberry bushes wherever possible, and by doing this have maintained some excellent patches. The determination of other plant species that are beneficial to

wildlife will be continued, and in the next 10 years we hope to recognize all valuable forage and have all our power lines under intensive vegetation management practices.

Open Land

In the next 10 years we are going to try to reclaim 50 acres of old abandoned field annually. Once these fields are cleared of pioneer weed species, they may be planted to various grasses or left to grow into low brush, depending on location and site characteristics. We hope that this program will supply not only deer browse but also the badly needed openings that our forest is lacking.

Elimination of Plantation

The elimination of some of our poorer plantations is the last but certainly not the least project to be undertaken for our wildlife in the next 10 years. From a forester's and wildlife manager's point of view, these nonproductive plantations are wasteland, and we feel that a minimum of 50 acres per year should be eliminated. Because of heavy deer pressure, they will be maintained in native grasses and low herbaceous growth.

I believe that the success of this program or any watershed-management program depends upon balancing the needs of both man and nature and then implementing the necessary silviculture practices to the highest possible degree.

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CURRENT MANAGEMENT PRACTICES ON THE HARTFORD MUNICIPAL WATERSHED

by IRVING A. HART, Superintendent, Water Bureau, Supply Division, The Metropolitan District, Hartford, Connecticut.

ABSTRACT. This is an upland reservoir gravity-flow system serving 391,000 people, an average of 53 million gallons daily. Total watershed area is 133,664 acres, of which 30,424 are owned. Practically all ownership is forested. Employees number 56, including 11 uniformed patrolmen. The Superintendent is a professional forester, assisted by a second forester and a full time forestry crew of 3 men with modern equipment. Standing timber is marked and sold by bid under formal contract. Vegetative manipulation for improvement of water supply is minimal. Major distribution reservoirs are not open to the public, but an active recreation area is located on one reservoir not used for drinking water. Major trouble spots are the recreation area, control of trespass, pressure by special interests to influence usage, and those problems generally related to a bureaucracy supplying public services.

THE METROPOLITAN DISTRICT evolved from the Hartford Water Works, which was formed in 1852 and used the Connecticut River for its water source. Formal organization of the Metropolitan District occurred in 1930 under an Act passed by the Connecticut General Assembly, which provided for water and other services to towns in the vicinity of Hartford.

The main water supply is from Ne-paug and Barkhamsted reservoirs. There are also four small older reservoirs in West Hartford. In addition to these water-supply reservoirs, there is the Compensating reservoir which was built to supply riparian right commitments and is now the site of an extensive recreation system. The Colebrook River reservoir was built by the Corps of Engineers as a multi-purpose reservoir

and supplies the MDC with water in conjunction with its other uses. The gravity-flow system serves 391,000 people, and the average daily consumption in 1972 was 53 million gallons. The categories of use were 50 percent domestic, 26 percent industrial, 19 percent commercial, and 5 percent municipal.

WATERSHED LANDS AND OPERATIONS

About 85 percent of our drainage area is forested. Of these 133,600 acres, the MDC owns 30,424, of which 5,121 are water surface and the remaining 25,303 are almost completely forested.

There are 56 people concerned with source-of-supply functions, including 11 uniformed and armed patrolmen. The superintendent in charge of reservoir lands is a professional forester, and another forester is in charge of the de-

tailed forestry work, including timber sales, supervision of a full-time three-man logging crew, and supplemental operations.

FORESTRY PROGRAM

We are active in the production and sale of forest products. Although all cutting is done with stand improvement in mind as the primary consideration, actually most of it is more of a salvage nature. The cutting in young stands is minimal except for fuelwood and log-cabin poles — we would like to expand this part of our program. Large sales of standing timber over 50,000 board feet are marked and sold by formal contract to the highest bidder.

The logging crew normally is concerned with smaller operations and salvage work, resulting in sawlogs delivered to local mills at standard prices. They have modern equipment, including a skidder, hydraulic log loader, and heavy truck.

The 1972 gross income from the sale of forest products was \$45,108. The sources were as follows: standing timber, 319,000 board feet sold for \$5,420; sawlogs, 462,000 board feet sold for \$28,000; log-cabin poles, 86,000 board feet sold for \$4,481; and fuelwood (standing, wholesale, and retail), 848 cords sold for \$6,526. Stumpage rates in this area have always been low, averaging a consistent \$16 per thousand board feet for over 20 years. This is probably due to an abundance of timber and too few conversion facilities. However, a recent (August 1973) sale of average timber was made for \$38 per thousand board feet and 9 bids were received.

There is no pulpwood market except for asphalt shingle material, which sells standing for 35¢ per ton and the fuelwood stumpage of \$1.00 per cord.

WATER-SUPPLY CONSIDERATIONS

The manipulation of vegetation for improving water yield is minimal, although we have that in mind in all our activities. Extensive harvesting of timber under the selection system of silviculture on a watershed equipped with a weir and continuous measuring device showed no detectible increase in the several years when the sales were made. We aim for a mixed hardwood-softwood stand of less than maximum density and attempt to reduce evapotranspiration along streambanks by cutting the large trees that have their feet in the water. We are still trying to maintain shorelines of coniferous trees, although the theory that it is important to keep hardwood leaves out of the water to improve quality is not critical, in our opinion.

We regard Barkhamsted Reservoir water as very good quality, but we have algae problems at Nepaug. Our water supply is sufficient to meet current needs, but additional supplies, probably from the Connecticut River, will be necessary by the year 2000. We are improving a 100-mile network of roads to facilitate control over our operations, and we find it vital for fire protection, trespass control, and timber harvesting.

Herbicides are not used in our forest-management practices, but we use Ammate X for control of shoreline and rights-of-way vegetation. However, where possible, we are trying to convert to mowable rights-of-way and to shorelines of conifers, laurel, and the sweet fern-bayberry type of ground cover. Ortho Diquat was successfully tried for aquatic weed control in one West Hartford reservoir.

RECREATION

In general MDC lands in Connecticut adjacent to distribution reservoirs are not open to the public. This involves about half our acreage. Much of the

remainder is open to hunting and fishing, particularly in the less populated areas in Massachusetts. Camping is not allowed anywhere. Our patrol force tries to keep close control of all activities on our properties, including those activities that are sanctioned.

We maintain intensive recreation activities, including boat livery and bathing beaches on the Compensating Reservoir, which is not a drinking water supply reservoir. Less intensive recreation, swimming excluded, is allowed at the Colebrook River Reservoir, but is not under MDC jurisdiction. Although the problems involved with recreation are many, acute, and expensive, it is only in areas of intensive use that much deterioration of resources occurs.

PROBLEM AREAS

Our problems are people-oriented, not resource-oriented; and we could be worse off than we are. The major problem is the recreation area and its attendant annoyances. The small fraction of the public that could charitably be described as ungrateful, unappreciative, and uncooperative contaminate the whole outlook. The recent Occupational Health and Safety Act (OSHA) requirements on capital facilities ran up our costs, and operating revenues are considerably less than our costs.

We have found it difficult to formulate a cohesive overall recreation plan to guide our future actions, and the problems get worse yearly. We tend to react instead of planning and acting. A recent evaluation of our organization by a management consulting firm mentions the need for clarification of the policy and approach to recreation and points out that its scope and propriety have never been established as a policy.

While the same might be said of the forest-management program, the problems are not acute and are of a nature

reflecting the ambitions of the foresters versus the fact that management of the watershed forests is only a small part of the MDC water program. There is a general understanding about the objectives of the watershed-management program, but no formally written policy or plan with objectives. For 20 out of the last 25 years the problem was inability to get out of low gear, but recently progress has been made to the point where we are harvesting more than half of what we should yearly.

A related problem is the conflict between the need for more man-hours to be spent on forest management and the concern for liability and sanitation problems involving outside contractors on our land. At present the attitude is that the results in many cases do not justify the risk, and the solution has been to use our own more expensive employees to a greater extent.

Also, I sense a general lack of appreciation, both on the part of management and the general public, of the potential for improving the yield of forests by cutting, and of the related characteristics of forest products in that they are abundant, renewable, bio-degradable, and low energy-consuming in their manufacture. Although these facts are well spelled out in national policy, they seem to be easily forgotten when some exponent of a shallow special interest group writes to the editor.

It seems to me that the nub of our present problem lies in the conflict between the understanding by foresters that cutting signifies improvement, whereas others associate it with disaster. I prefer the consideration and establishment of policies that are definite and aggressive approaches to these matters rather than a defensive posture, with decisions being made without consulting those knowledgeable in the total national picture. This has been described

as the Age of No, and with the national of instant ecologists waiting in the
climate of destructive criticism without wings, one needs all the faith and opti-
plausible alternatives, plus the millions mism he can muster.

CURRENT MANAGEMENT PRACTICES ON THE PROVIDENCE MUNICIPAL WATERSHED

by HANS T. BERGEY, *Watershed Manager, Water Supply Board, City of Providence, Rhode Island.*

ABSTRACT. The water supplied by the City of Providence Water Supply Board is obtained from a 92.8-square-mile watershed on the north branch of the Pawtuxet River. The City owns 23.93 square miles or about 25 percent of the drainage area. Surface water is collected in the main Scituate Reservoir and five tributary reservoirs, which have a total surface area of 7.13 square miles. The Providence Water Supply Board provides potable water to over half the population of Rhode Island in 11 cities and towns, representing an estimated 431,000 persons. The average daily consumption is 64,400,000 gallons per day. Management of departmental watershed and forest lands include forest culture and harvest practices; forest protection; and care of related facilities such as fire lanes, access roads, fences, turfed areas, and dams; and resolution of a myriad of associated people problems in an urbanizing environment.

THE WATER SUPPLIED by the City of Providence Water Supply Board is obtained from the 92.8-square-mile watershed on the north branch of the Pawtuxet River. The City of Providence owns and controls 23.93 square miles or about 25 percent of the drainage area. Surface water is collected in the main Scituate Reservoir (fig. 1) and five tributary reservoirs, which have a total surface area of 7.13 square miles.

The Providence Water Supply Board provides potable water to over one-half the population of Rhode Island in 11 cities and towns. The total population supplied is an estimated 431,000 persons. The average daily consumption is 64,400,000 gallons per day. The maximum daily use recorded was 109,000,000 gallons on 30 June, 1971.

Under the enabling act of 1915, the City of Providence was authorized to condemn land and establish a water supply for Providence and specific outlying areas. A total of 1,195 buildings, including dwellings, schools, churches, power plants, and six large cotton mills were condemned. Six villages and portions of two others were within the area to be flooded or on land condemned for marginal protection. The area condemned was sparsely settled, with a considerable portion in woodland, brushland, or pasture, and a relatively small area under cultivation (*Craig 1926*).

Departmental lands marginal to the reservoirs total 11,000 acres and are covered by forest vegetation. The 68.87 square miles of watershed not owned by the Water Supply Board are esti-

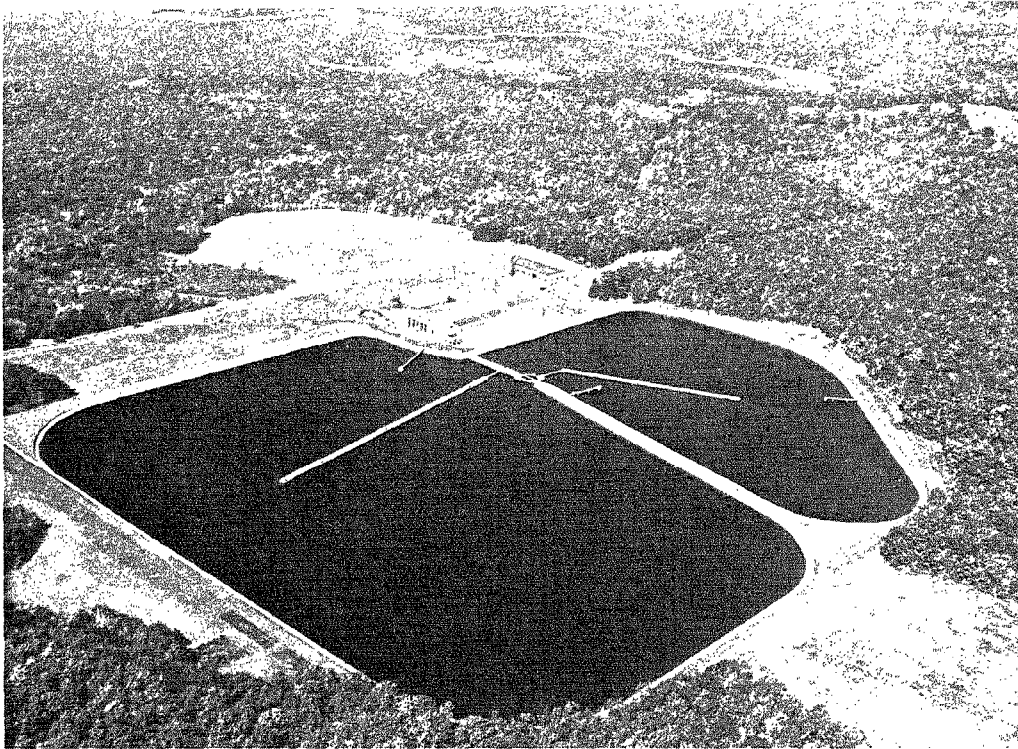


Figure 1.—Philip J. Holton Water Purification Works in Scituate, Rhode Island. Coagulation basins in foreground; portion of main Scituate Reservoir in background.

mated to be 10 percent cleared, 20 percent residentially developed, and 70 percent forested. Cleared land consists of agricultural, recreational, or idle acreage. Primary agricultural uses are pastureland and orchards. Residential and commercial developments are generally concentrated along state and town roads. Existing industry is light and has little effect on the water resources.

Lull (1968) described the forest region in which the watershed is located as white pine-hemlock-hardwood. Fires, hurricanes, and past cutting practices have had a major effect on present forest-stand composition. Extensive stands of mixed oak (*Quercus* sp.) of sprout origin are common on the well-drained and droughty sites. Swamps are prevalent and are characterized by red maple (*Acer rubrum*) and other wetland species.

Interesting aspects of managing the property are the past reminders of habitation such as stone walls, foundations, old cemetery plots, abandoned town roads, and unusual relics. Village and dwelling sites have influenced tree species found in woodland. For example, a significant forest stand of potentially valuable sugar maple (*Acer saccharum*) has resulted from seed dispersed by trees which at one time cast shade over a cotton mill and mill houses.

The Water Supply Board initiated a reforestation program in 1926, soon after construction of the Scituate Reservoir dam was completed. Extensive tree planting was accomplished between 1935 and 1943 when approximately 5,000,000 trees were produced in a nursery operated by the Department. Limited forest-culture work began in 1946 and continued till 1951, when the first professional forester was employed. The

watershed management program has increased progressively in scope to what now exists.

The present staff of the Department's Forestry Division consists of two professional foresters with job titles of watershed manager and forester, two security inspectors, and a work-force crew of 10 men headed by a foreman. The watershed manager is responsible to the chief engineer for all watershed-management programs. The forester supervises security personnel and woodland operations. The foreman reports directly to the watershed manager in the conduct of work activity on the watershed and parts of the distribution system.

Watershed-management programs can be described generally as follows:

- Forest management on departmental lands to include forest culture, timber harvest, and forest protection.
- Care of facilities on the watershed such as fire lanes, forest access roads, fences, turfed areas, and dams.
- Maintenance of aqueducts, covered reservoirs, rights-of-way, and grounds within the distribution system.
- Enforcement and security.
- Sampling and gaging of tributary streams and reservoirs; obtaining climatological data.
- Surveillance of the entire watershed to identify existing and potential threats to the quality of the raw water supply.
- Resolution of a myriad of associated people problems in an urbanizing environment.

MANAGEMENT OF WATERSHED AND FORESTS

Management and administration of property owned by the Water Supply Board is facilitated by complete sets of records, plans, aerial photographs, and maps. Property lines and bounds are

identified. Departmental lands are divided into compartments by a mapped grid system and the forest into working blocks by natural or man-made features. Statistical records of trees planted, wood products harvested, and management practices have been consistently maintained over the years. This information proved valuable in recent survey work conducted by Hadfield (1972) on *Fomes annosus* in forest plantations.

Boundary lines and bound locations are reviewed periodically. A system of painted tree blazes has been established to mark unfenced property lines. Forest access roads are identified on maps and in the field by a letter-number code. The letter corresponds to the block in which the road occurs. Blocks are designated by both proper names and letters.

Much of the forest-culture work centers on the more than 7,000,000 trees planted on departmental lands. In the 1950s, pruning of plantations was a major activity. Esthetics, fire control, and upgrading of tree quality were considered in giving priority to this type of work. Another reason for extensive pruning was to induce pulpwood operators to thin plantations. Today, delimbing presents no problem to woods operators who work with direct-drive chain saws.

After open fields and arable areas had been reforested, substantial acreages of upland hardwood were underplanted with various coniferous species. The species planted in greatest numbers was white pine (*Pinus strobus*), which has competed successfully in the understory. Shading by overstory hardwoods minimized damage by the white-pine weevil (*Pissodes strobi*). Over 500 acres of understory conifers have been released by girdling and killing overtopping hardwood of inferior quality. Overstory hardwood has also been removed by harvest cutting. This practice is ad-

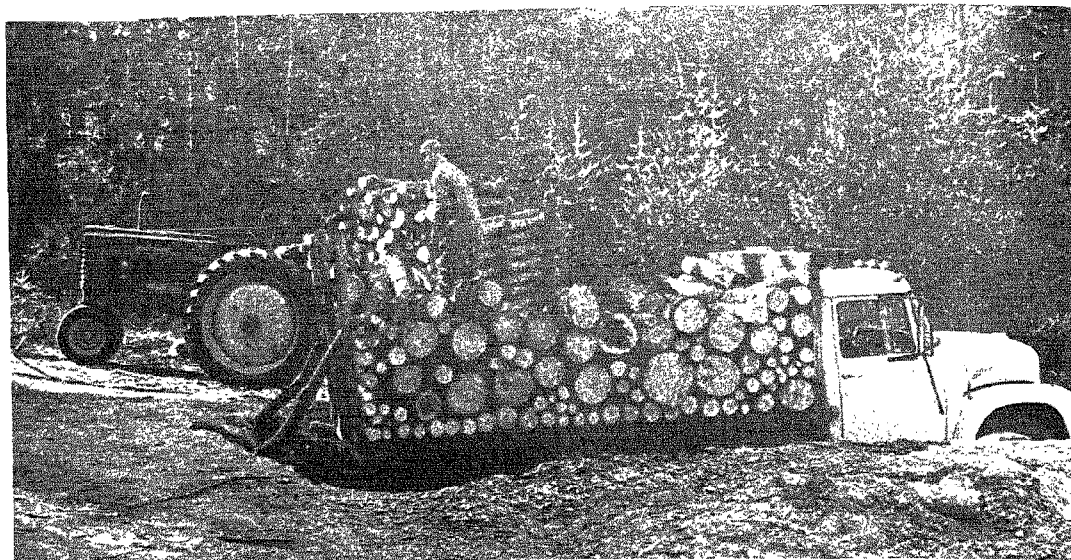


Figure 2.—Loading pulpwood onto hauling truck in contractual thinning operation conducted on watershed property.

vocated if woods operators and markets are available.

In recent years reforestation has consisted of planting conifers in occasional open areas and on upland oak sites where conversion to conifers or diversity of species is desired. Native conifers, white pine, and hemlock (*Tsuga canadensis*) are preferred species in our planting plans. Experience has shown serious insect, disease, and other environmental problems with exotics and species planted out of their natural range. Hardwood species, including yellow poplar (*Liriodendron tulipifera*), black cherry (*Prunus serotina*), and white ash (*Fraxinus americana*) have been planted in coniferous plantations that have incurred extensive mortality caused by the root-rotting fungus *Fomes annosus*.

Thinning of plantations is conducted on a contractual basis by private woods operators (fig. 2). A local pulpmill has provided a continuing market for material removed in intermediate harvest operations. Plantations are selectively marked for thinning by the forester. Pulpwood cutters pay a fixed rate per ton for pulpwood stumpage.

Sawlog harvest operations have been carried out on over one-tenth of the watershed property in the past 10 years. After stands are marked and volume determined, sawtimber sales are approved by the Water Supply Board, based on recommendations received from the watershed manager. Reliability, quality of work, and attention to watershed protection are criteria given weight over stumpage return in selection of woods operators. In addition to pulpwood and sawlogs, forest products such as posts, poles, piling, witchhazel brush, cedar for animal bedding, and fuelwood have been harvested from watershed property (fig. 3).

Esthetic improvement of forest land adjacent to roads, communities, and facilities such as Gainer Memorial Dam has been common practice. Development of scenic vistas overlooking portions of the reservoirs has enhanced the appeal of the property. Press photographers utilize open-vista sites as evidenced on a number of occasions in the local newspapers. Main and secondary highways passing through the watershed are jammed with sightseers on Sundays and holidays, particularly in the spring and fall.

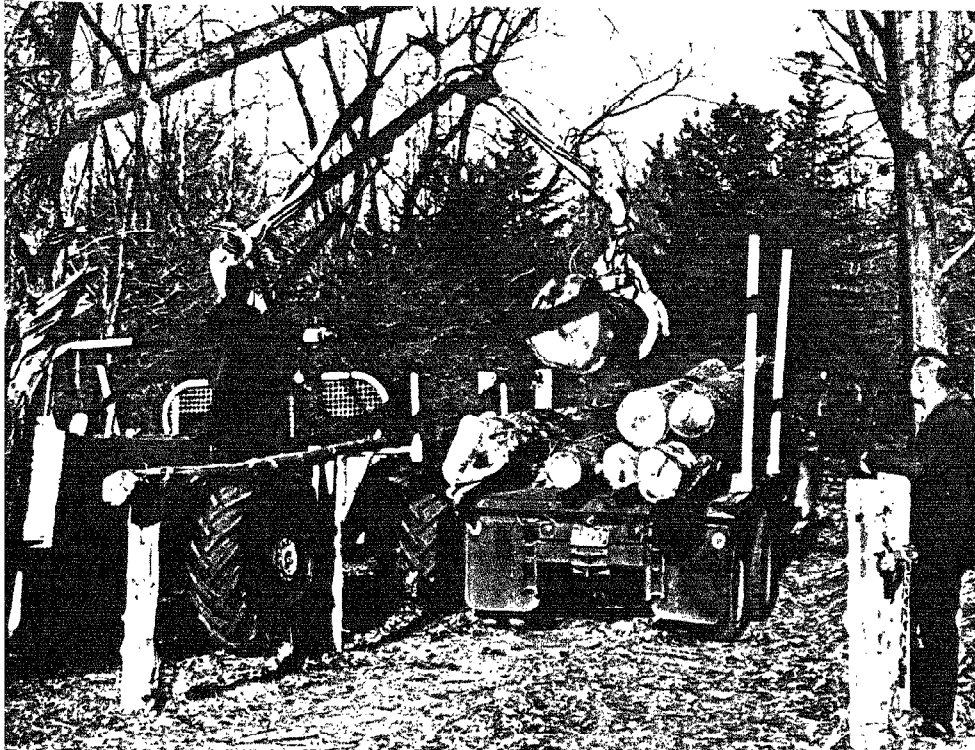


Figure 3.—Transferring hardwood logs from forwarder to hauling truck in sawlog-harvest operation.

The thinning of coniferous plantations, initiated in 1946 and continued in greater measure since 1951, has brought about the spread of *Fomes annosus* root rot. When serious instances of tree mortality became apparent, a stump-treatment control program was undertaken. Present practice consists of application of borax in granular form to freshly cut stumps. Woods operators apply the borax immediately after felling trees. The stumpage rate paid by operators is adjusted to accommodate for the treatment.

Major forest-insect problems have been experienced with white-pine weevil, larch sawfly (*Pristiphora erichsonii*), and gypsy moth (*Porthetria dispar*). An infestation of gypsy moth is presently spreading throughout watered forests. The impact of the insect may be particularly severe in upland areas where damaging defoliation of planted and volunteer conifers will affect diversity in stand composition.

The Department supported an aerial-spray program in 1973, which involved the application of carbaryl on a portion of the watershed.

The Department owns and operates a strategically placed fire tower for detection of forest fires. During the critical fire seasons, the tower is manned by a member of the forestry labor force. Radio communications are maintained with State fire towers, patrolmen, and Water Supply Board personnel. Security inspectors are equipped with fire-fighting pumpers on their pickup trucks; however, the Department depends primarily upon volunteer fire departments in the local towns for suppression of forest fires. Acreage burned over in recent years has been negligible despite forest-cover types that are characterized and sustained by frequent fires. A good record in fire control can be attributed to prompt detection and suppression, access, and good luck.

CARE AND MAINTENANCE OF FACILITIES

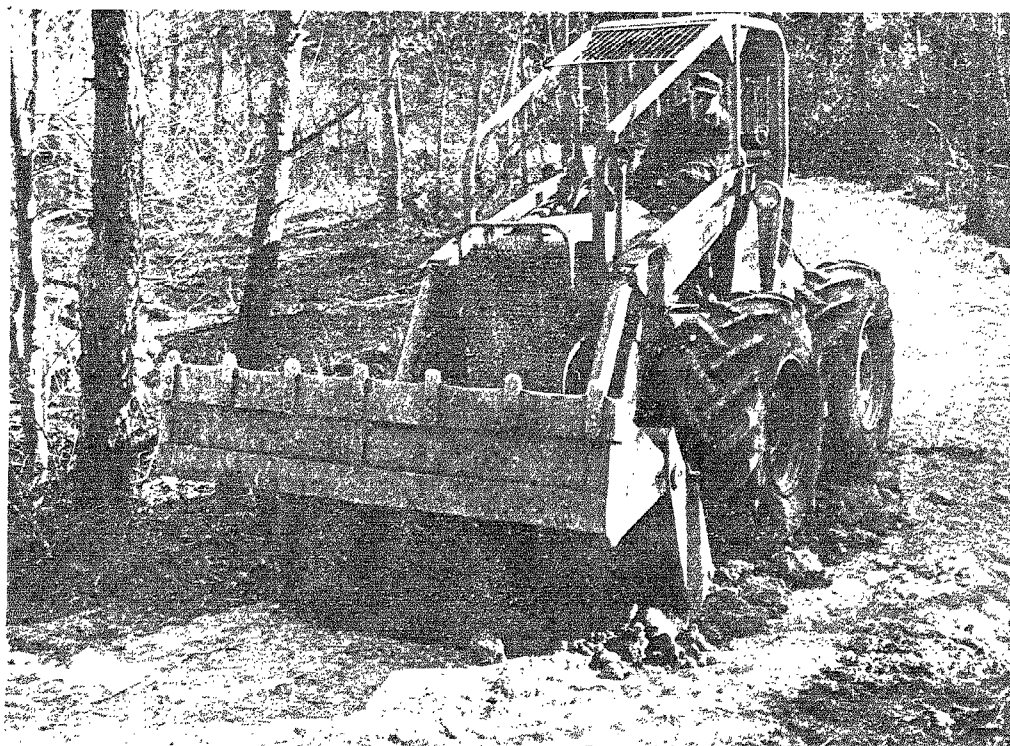
Maintenance of watershed facilities such as forest access roads, fire lanes, fencing, dams, and grounds takes priority year-round. Access roads are being developed continually to permit reaching all regions of the watershed forest (fig. 4). Improvement work consists of rough grading, gravelling, and herbicidal brush control. The Department presently accounts for over 50 miles of forest-access roads, some of which are limited to travel by four-wheel-drive vehicles.

The use of herbicides has proved effective for controlling brush on forest-access roads, fire lanes, accessible shorelines, and adjacent to roadside fencing. The Department is limited to use of non-inhibited Ammate-X (ammonium

sulfamate) in watershed areas. The non-selectivity of Ammate has created problems in its use; however, by exercising caution and good judgment, the herbicide has been employed in a variety of forest-culture and maintenance operations.

Turf management is an integral part of watershed management practice. Turfed areas at water-works structures, the main Gainer Dam, three underground distribution reservoir sites, and portions of the aqueduct system require varying degrees of turf maintenance. Much of the turfed area consists of steep embankments requiring specialized equipment to mow, fertilize, and tend. Fourteen acres of slope on the earthen Gainer Dam have presented a real challenge. The downstream turfed side of the dam faces to the south, and in all

Figure 4.—Improvement of forest access road by utility tractor.



seasons of the year the turf is exposed to extremes in temperature. During the droughty years of the mid 1960s, heavy insect infestation coupled with the drought resulted in almost complete loss of the turf cover on the steepest top slope. We worried through such questions as selection of grass species, means and time of application, and degree of erosion during the renovation period.

A problem worthy of mention in respect to turf management, particularly on sloped areas, is trespass by off-road vehicles. The motorized cycle is the primary offender; however, automobiles, snowmobiles, toboggans, and other conveyances have contributed their share of damaging trespass. The Department has found existing laws inadequate for prosecuting those who violate property in pursuit of recreation with off-road vehicles.

The Water Supply Board maintains a cemetery containing 427 burial lots in which remains were interred from cemeteries within and in close proximity to the flooded area. Occasional interments still occur, and a function of the Watershed Manager is to coordinate burials and maintain records.

DISTRIBUTION SYSTEM

Within the Watershed Manager's realm of responsibility is grounds maintenance of certain portions of the distribution system, including aqueducts, underground reservoirs, pumping stations, and the main administration building. Horticultural, agronomic, and public-relations skills must be applied to a variety of circumstances that arise in the urban environment.

Aqueducts and pipelines provide avenues of travel for off-road vehicles, spreading points for poison ivy, collecting areas for discarded rubbish and litter, and extensions of many back yards. Wire fencing is little deterrent to the motorcyclist with a wire cutter in

his back pocket. Boundary-line trees give shade to some back yards and are considered a threat to dwellings and personal safety to others. High shrubbery is desired as insulation from the neighborhood, but is denounced as a contributor to humidity and a harboring place for vermin.

RECREATION POLICY

To safeguard its water supply, the Water Supply Board has established and enforced a policy of prohibiting recreational use in all reservoirs and on all marginal lands surrounding the reservoirs. The Department supports the 26 January, 1958 American Water Works Association "Statement of Policy on Recreational Use of Domestic Water Supply Reservoirs" (AWWA 1958). Holton (1967) described the Department's current policy, which permits no recreational use on the terminal Scituate Reservoir. Recreational use, limited to boating and fishing, would be allowed on upstream reservoirs under proper safeguards and controls. The Water Supply Board feels that its water consumers should not be required to underwrite the cost of a recreation program. Collins (1971) provided a detailed review of literature describing problems associated with recreational use of public water supplies.

ENFORCEMENT AND SECURITY

Enforcement activity has become a significant part of the watershed-management program. The encroachment of suburbia, and proximity of the watershed to the metropolitan center of the second most densely populated state in the Union, are important considerations.

The Providence Water Supply Board paid over \$800,000 in property taxes to various cities and towns in its 1971-72 fiscal year. The Department depends upon these communities for strong sup-

port in protection of its vital resources and facilities.

Department security personnel call upon local police authorities for assistance when violations are detected, and formal apprehension or arrest are required. Permanent records are maintained on all violators. Weekly reports are submitted to the Chief Engineer on all violations of departmental property.

Experience has shown a low incidence of trespass when prompt and effective action is taken to prosecute violators. Within the past several years, it became necessary to outfit security personnel with uniforms and badges. Adverse attitude from violators is becoming common. Recorded acts of vandalism exceeded either fishing or swimming violations in 1971-72. Examples of vandalism include destruction of signs, gates, locks, fences, rustic stone walls, planted shrubs, turf, gate houses, pipeline structures, and windows of facilities.

SAMPLING AND OBTAINING CLIMATOLOGICAL DATA

In addition to enforcement activity, security personnel are given the duty of gathering water samples for bacteriological and chemical analysis of watershed streams, tributary reservoirs, and the Pawtuxet River. Samples are collected daily from designated points throughout the distribution system. Elevations of the five upstream reservoirs are measured weekly.

The Water Supply Board has established five stations for the purpose of obtaining climatological data on the watershed. The stations are situated to provide optimum coverage of the drainage area. With the exception of the Gainer Dam station, part-time employees man the stations at their residences. Two additional stations are located at points off the watershed.

Daily observations of precipitation, temperature, and weather conditions have been recorded since 1 November, 1915 at two of the watershed stations. The Rocky Hill Station has been operated by the same keeper for the past 53 years.

SURVEILLANCE OF THE WATERSHED

During the decade of the 1960s, the platting of sizable acreages jumped significantly on the watershed as the urban sprawl reached into the reservoir town of Scituate. The Water Supply Board recognized the potential impact of unchecked development within the drainage basin and gave testimony indicating this concern at appropriate town meetings. The towns also noted the effects of increasing population and attendant problems. As a result of both environmental and economic considerations, planning boards imposed tighter regulations, and zoning ordinances were adopted. Residency in Scituate has enabled the Watershed Manager to become a member of the zoning board, which presents an opportunity to monitor and have a voice in community development.

There is no formalized program for reviewing and policing existing septic systems on that portion of the watershed not owned by the Water Supply Board. The Department depends upon sampling of tributary streams, citizen complaints, and occasional checking of suspected problem areas by its personnel. The State Department of Health is the responsible agency for overall pollution control in sources of water supply. Despite prompt attention by the State Health Department when violations are reported, remedial work frequently proves to be only temporarily effective because of perennially poor drainage conditions. The best control is to recognize potential pollution sources and take necessary action before development

occurs. Recent passage of a State wetlands act, and adoption of restrictive regulations by the State Health Department in the design and construction of individual sewage-disposal systems, should provide greater protection in the future.

WATERSHED MANAGER'S ROLE

The role of watershed manager is a challenging experience. He must supervise and manage personnel; work with colleagues in other professions; deal with politicians, unions, and ecology-minded citizens; cooperate with law-enforcement officers, public officials, fire fighters, and educators; appease adjacent property owners, neighborhood youngsters, and recreationists; and answer for a myriad of associated people concerns. In meeting these problems, it is often necessary to entrust the watershed's natural resources to the Great Caretaker above.

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CURRENT MANAGEMENT PRACTICES ON PRIVATE MUNICIPAL WATERSHEDS

by JAMES F. HEAGY, *Forester, American Water Works Service Co., Inc.,
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ABSTRACT. Since 1954, sawtimber, pulpwood, and mine props have been harvested from 17 forested watersheds in Pennsylvania. Drainage from 15 areas flows into reservoirs used as sources of supply serving 14 communities. Potable water delivered from 8 of these reservoirs is not filtered. In no instance does the total acreage owned comprise the total drainage area of a reservoir. The harvesting and cultural practices used in the upland oak and bottomland hardwood types are emphasized. Other watershed programs discussed include recreational use, problem areas, and use of herbicides.

THE AMERICAN WATER Works Service Company, Inc., is a stock company operating water companies in 20 states, serving almost 5 million residents of 500 communities. All water companies are subsidiary utility companies, operating under regulatory processes. American Water Works Service Company, Inc., is a subsidiary of the parent company, having a general office in Philadelphia. In addition, there are eight division offices and three regional engineering offices strategically located throughout the system. Each division office has a president who is responsible for the operation of all water companies in his division. The engineering offices are staffed with mechanical, electrical, and civil engineers, draftsmen, estimators, and chemists. They are responsible for construction, purification, planning, and problems relating to delivering potable water to company customers. As forester for the company, I am respon-

sible for management of all forested watersheds throughout the company system.

I will deal primarily with management practices used on watersheds located in all of the three major forest regions of Pennsylvania. Five in the oak-yellow poplar region contained 4,000 to 15,000 board feet per acre. In the white pine-hemlock-hardwood region, volume per acre on ten watersheds ranged from 5,000 to 19,000 board feet. In the northern hardwood region volume per acre varied from 4,000 to 12,000 board feet per acre in two watersheds.

Drainage from all watersheds flows into streams feeding reservoirs. In no instance does the acreage owned comprise the total drainage area to a reservoir. Potable water delivered from eight reservoirs is not filtered.

Watershed areas vary in size from 50 to 2,500 acres. All except one are 100 percent forested. Populations served by

companies owning these watersheds vary from 1,350 to 81,000. The yearly amount of water delivered by the smallest company is 16 million gallons as compared to 3 billion gallons by the largest company. Residential use of water varies from a low of 16 percent to a high of 85 percent.

FORESTRY PROGRAMS

Before 1954, the noise of a chainsaw was never heard in these 60- to 150-year-old stands. Since then sawtimber has been harvested from all 17 watersheds, pulpwood from 5, and mine props from 1. Single and group-selection regeneration methods have been used in harvesting timber along streambanks, on steep slopes above reservoirs, and in two uneven-aged stands.

Clearcutting was used in two situations. A 14-acre island in a stream channel in the white pine-hemlock-hardwood region was clearcut. Seven years after cutting, yellow-poplar, ash, soft maple, and advanced reproduction of white pine dominated the new stand. Clearcut strips 60 feet wide were made on 50 acres of an upland oak stand badly butt-scarred by repeated past fires. After ten years, dominant reproduction is a mixture of oak stump coppice, seedlings, and seedling sprouts.

The shelterwood system was applied in making sawtimber cuts in the bottomland hardwoods type. In these high-volume stands, oak reproduction was sparse or nonexistent. On two sites, weeding was necessary for red and black oak to become established after shelter-

Figure 1.—Group selection cutting on the Warren Water Company Watershed in Warren, Pennsylvania.



wood cuts 12 years apart. On a third site, oak has not become a component of the reproduction 10 years after a shelterwood cut removed 50 percent of stand volume. When a heavy invasion of brush is finally controlled by herbiciding, a second cut will be made. Predominant composition of the new stand will probably be yellow-poplar, ash, and soft maple rather than red and white oak.

Ten years ago, improvement and thinning cuts were made in three upland oak stands. Larger scattered red, black, and scarlet oak trees of poor form and quality were harvested as low-grade sawtimber. Pole-size trees were sold as pulpwood at two locations and as mine props in the third location. Income from these sales paid for the expense of marking and supervision of logging operations.

Thinning and removing scattered old-growth trees in two northern hardwood stands yielded sales of pulpwood and sawtimber. Sodium arsenite was used as a debarking agent for pulpwood sold from 1963 to 1968. After 1968, mechanical debarkers were installed at the pulpmill, eliminating the need for delivering peeled wood. During 1971 and 1972, pulpwood was skidded and hauled in tree length to a centralized debarking and chipping operation.

In 1955 in an area lacking a pulpwood market, a white pine-scotch pine planting was thinned, and crop trees pruned to a height of 17 feet. Carrying charges for this type of operation were too high to justify continued application of this procedure. Row thinning in a 40-year-old white pine-red pine planting in an area having a pulpwood market was financially feasible.

Since prices paid for pulpwood stumpage are standard for any given region, the operator was selected for harvesting pulpwood rather than using bid procedure. All sawtimber has been sold on a sealed-bid basis. To date, 7 million

board feet of sawtimber and 14,000 standard cords of pulpwood have been harvested from 8,300 operable acres on 17 watersheds.

WATERSHED PROGRAMS

Silt-collecting dams upstream from two Uniontown Water Company reservoirs have been cleaned. In certain areas, truck and skidroads used in logging were fertilized and seeded with a mixture of orchard grass, domestic rye grass, red top, and Kentucky 31 fescue. The banks of a breached impoundment were also seeded to the above mixture. After brush and seedling tree growth were eliminated with 2,4,5-T, one reservoir bank was seeded with crown vetch.

To reduce interception of snowfall, 40-foot-wide strips were cut through a small pole-size hemlock understory on a steep west-facing slope. At the foot of the slope, springs erupt that supply a small reservoir. Since disturbance of the litter layer could have resulted in turbidity reaching the springs, all felled trees were left lying on the ground. I have left the large pole-size soft maple overstory intact.

During and after logging operations, I have eliminated cull and undesirable components not designated for cutting, using the frill method. Frilling is done with a 2-pound marking ax. A 2-quart oil can is used to apply the herbicide. Brush and sapling growth on certain reservoir banks have been controlled with the use of a brush-killer in a water solution applied with a backpack mist-blower. Brush in pipeline rights-of-way and a dense beech understory in a northern hardwood stand have been controlled in the same manner. Potamogeton pond weeds were controlled in one reservoir by using a granular type 2,4-D applied in early spring.

RECREATION AND PUBLIC RELATIONS

Wooded areas adjacent to reservoirs that supply unfiltered water are posted with NO-TRESPASSING signs. All other forest holdings are open to the public for hunting, hiking, snowmobiling, and fishing. On company-owned property in northwestern Pennsylvania, the highway department has established a roadside rest area, maintaining a spring-fed water supply, picnic tables, and toilet facilities.

Near Muncie, Indiana, recreational activities on a company-owned reservoir site are operated and controlled by the city. Fishing, house-boats, swimming, and water skiing are permitted on different parts of the reservoir.

Local managers arrange tours of water-company facilities for school groups, usually of junior high age. These same groups have been shown logging operations adjacent to reservoirs supplying unfiltered water. A talk entitled "Watersheds — Our Source of Supply" illustrated with colored slides, has been presented to local service clubs. In both instances, the main objective is to prove that controlled logging operations on a watershed and a potable water supply from that watershed are compatible.

PROBLEM AREAS

Any disturbance of the forest floor due to logging and the establishment of skid and truck roads can result in turbidity reaching stream channels and reservoirs. On steep terrain, particularly above reservoirs, skidroads can be built on the level, and timber can be winched to these roads rather than running logging equipment up and down the slopes. Excessive turbidity entered a stream on one watershed during and after logging operations because of incorrect location of a bridge crossing in a draw. But I am thoroughly convinced

that any regeneration system can be used in harvesting timber on a watershed, if logging operations are properly planned and controlled.

Some of the watersheds are located in areas populated with a large deer herd. A major task every spring is the removal of dead deer carcasses from streams and reservoirs.

Indiscriminate dumping is a universal problem. Watershed land along public roads, even though heavily posted, is subjected to this abuse.

Arson on one watershed was finally stopped with the arrest and conviction of offenders by Game Commission personnel.

When urban development started on one watershed, turbidity entered a stream feeding three contiguous reservoirs and supplying unfiltered water. To circumvent the problem, the upstream reservoir is now used as a sedimentation basin. The surface supply had been augmented with a well supply. Future development of the well supply will result in the abandonment of the reservoirs as a source of supply.

Silvicultural treatment may have to be changed on watersheds when mineral rights are owned by a second party. The group-selection method was being applied in an uneven-aged mixed hardwood stand. When rigs started to drill oil wells on 450-foot centers, all timber had to be hurriedly removed. This was necessary to keep ahead of bulldozers leveling 50-foot strips through the forest. Turbidity from all cleared areas had been controlled by the well drillers.

FUTURE MANAGEMENT

Since the drainage area of all these 17 watersheds constitutes only 2 to 50 percent of the total drainage area to a reservoir, any effect management practices would have on water quantity would probably be negligible. Maintenance of water quality and silviculture

tural practices have been the primary factors considered. In the future, these same objectives will be emphasized.

On two uneven-aged high-density mixed-hardwood stands, reproduction was inadequate 8 years after removing 40 percent of the board-foot volume. Block cutting was then initiated on north-facing slopes, removing an additional 25 percent of the volume. This procedure will be continued at 5- to 10-year intervals, using a wait-and-see policy for the final regeneration cut. South-facing slopes are predominantly oak. Some oak reproduction is present in openings created by the removal of scattered older trees in the original cut. Hopefully a two-cut shelterwood system can be applied to regenerate these slopes.

Openings on the better sites are often invaded with sassafras, black locust, black gum, grape vines, and various shrubs. Cleaning will probably be required to assure the successful establishment of preferred species.

Hundreds of excellent research publications are available that give the watershed manager insight into the various facets of watershed management — evapotranspiration, interception, the forest floor, albedo, etc. Research has shown that cutting can increase water yield. Watersheds maintained for runoff supplying domestic and industrial use can and should be used for other purposes. They are not sacred groves from which recreation or economic use has to be excluded.

CURRENT MANAGEMENT PRACTICES ON NATIONAL FOREST WATERSHEDS: WHITE MOUNTAIN NATIONAL FOREST

by GORDON STUART and WILLIAM M. ALDEN, respectively Watershed specialist, White Mountain National Forest, U.S. Forest Service, Laconia, New Hampshire, and Timber Management Assistant, Androscoggin Ranger District, White Mountain National Forest, Gorham, New Hampshire.

ABSTRACT. Municipal water supply is one use of National Forest land. The Berlin, New Hampshire, municipal supply is an example of current management practices on the White Mountain National Forest. This is part of the Kilkenny Management Unit, which will be the first area to be completed under the current planning program to develop a fully integrated management unit for obtaining a good balance of resource use as related to land capability and resource demands. The Berlin supply has been and will continue to be managed for water, timber, wildlife, and recreation. Recreation use — primarily hunting, fishing, and off-road vehicle use — is not generally restricted. No campground development is planned, but hiking use is expected to increase. The timber-management program is designed to improve wildlife habitat and provide additional water yield. Protecting water quality is the primary concern.

THERE ARE 20 MUNICIPAL watersheds on the White Mountain National Forest. These vary in size of drainage, amount of public land involved, and type of installation. In most of them, daily stream flows are relied on to provide water. Installations range from only an intake to a small instream reservoir. Treatment is generally limited to chlorination; therefore there is special concern for any type of land use that may increase suspended sediments.

Land use on municipal watersheds has developed over many years. Hiking, camping, and hunting were established public uses of land before many municipal supplies were organized. We have copies of some of the early land-use restrictions on municipal watersheds.

These, dating from 1915, seem to indicate that many activities were accepted. Such critical items as sewage disposal were restricted only where it would cause "defilement" of streams.

When these lands were purchased for National Forest purposes, most municipal watersheds and the land use on them were already established. Through the years, many agreements have been reached between municipal managers and the Forest Service on management activities. In most cases, established restrictions on watersheds have not changed. However, New Hampshire is requiring all surface supplies to provide full treatment in the future. This may have some influence on the future need for restrictions.

National Forest land use on the Berlin, New Hampshire, municipal watershed is presented here as an example of our current management practices (fig. 1). This watershed is in the Kilkenny Management Unit, the first unit to be completed under our current planning program. Reference is made to the Kilkenny Unit because our management practices are based on the resource zones of this entire block of National Forest land.

BERLIN MUNICIPAL WATERSHED

The Berlin Municipal Watershed (fig. 1) is located in the headwaters of the upper Ammonoosuc drainage. National Forest land totals 12,150 acres of the 15,800-acre drainage. The upper portion of the drainage is owned by the Brown Paper Company. Elevations range from 1,500 feet to 3,890 feet, and the drainage is about 95 percent forested. The other 5 percent is a large alder swamp, which is located along the main stream channel.

The Ammonoosuc intake provides two-thirds of the water used by the 16,000 people served, approximately 2 million gallons per day. Berlin has two other sources of water on privately owned land east of the Androscoggin River.

MANAGEMENT PROGRAM

The Kilkenny Management Plan provides the 10-year action program for the entire unit. Details of what, when, and how management activities are to be conducted are based on resource inventories. Functional activities have been coordinated by the planning process to provide a good balance of resource use as related to land capability and resource potentials. Within the unit there are several distinct resource zones. Therefore the unit has been divided into

sub-areas and management objectives have been established for each sub-area.

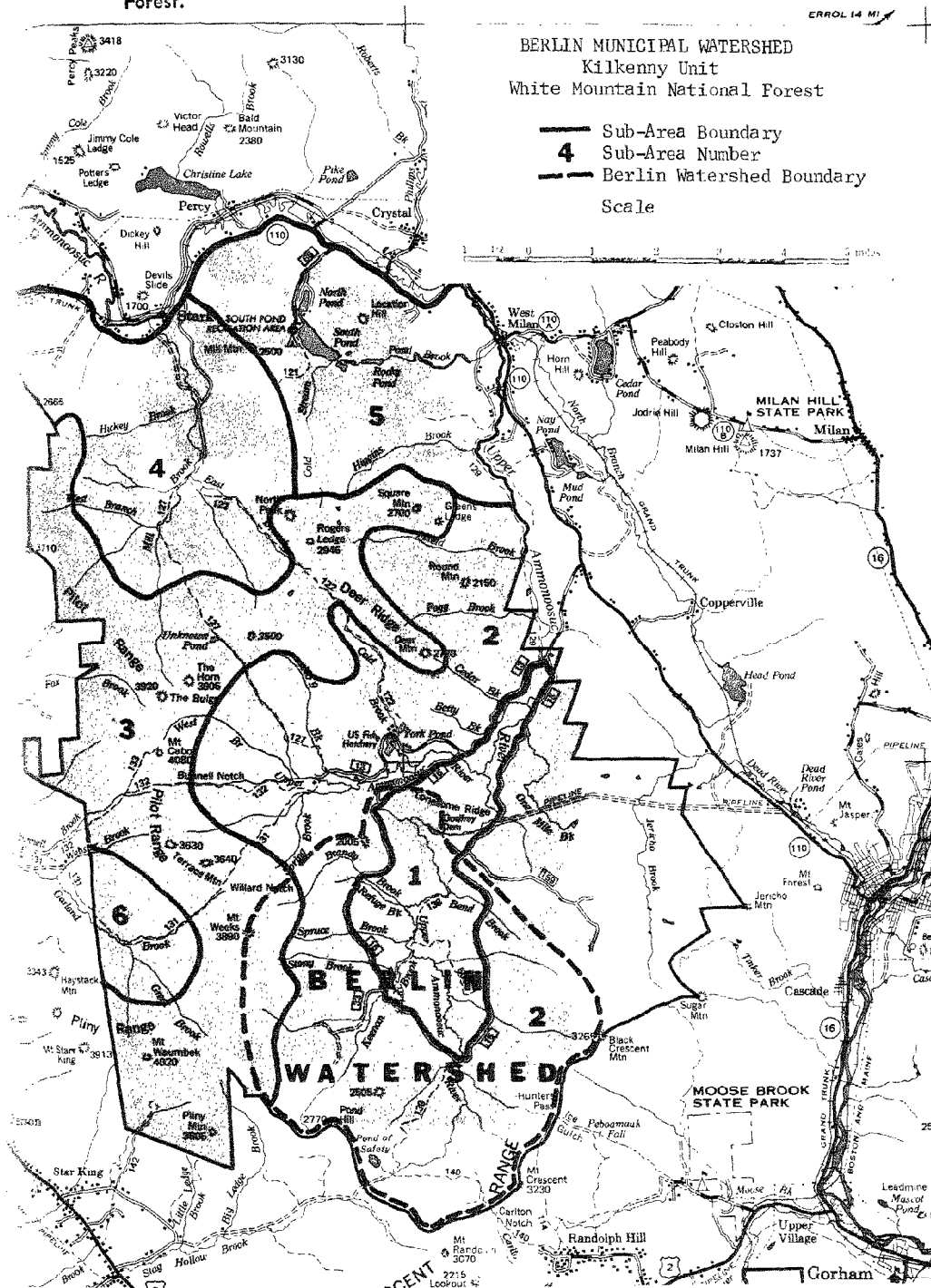
The Berlin municipal watershed is located in portions of three sub-areas. This watershed has been and will continue to be managed for timber, wildlife, recreation, and water resources. While maintaining water quality for municipal use is the overriding concern, we have utilized the timber-management program to benefit directly the wildlife and water resources.

Sub-Area 1

The lower slopes and streamside zones inside the loop road (FR15, Fig. 1) contain a major winter deer yard and a variety of wildlife habitats. The deer yard has been intensely managed for a number of years to maintain adequate softwood cover and optimize available winter browse. During the winter months, 100 to 200 deer utilize the yard. Logging is scheduled during periods of snow cover to provide additional browse during the critical winter period. Winter logging also minimizes soil disturbance on the wet soils in this sub-area. Current inventory data indicates that 40 acres can be regenerated annually on the 3,670 acres of this sub-area within the municipal watershed. Clearcuttings are the most common type of regeneration method.

Recreation use is primarily hunting and fishing. There is an active stocking program in the intake reservoir above Godfrey Dam. Native trout are relied on to provide the stream fishing in the remainder of the watershed. Off-road vehicle use is increasing, and there is growing concern about snowmobile use in the deer yard. At present, there is an unofficial closure on snowmobiling inside the loop road. Swimming is not allowed in the reservoir.

Figure 1.—The Berlin Municipal Watershed on the White Mountain Forest.



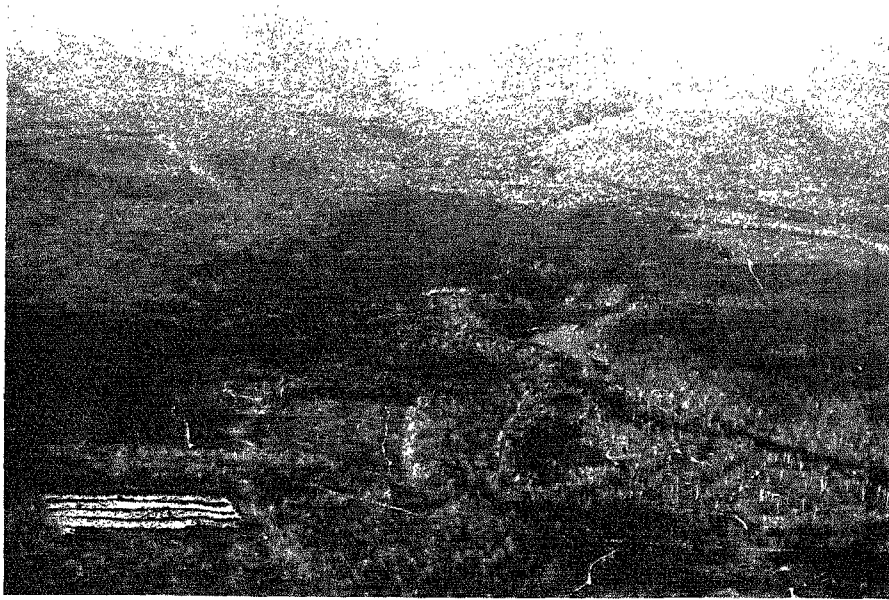


Figure 2.—Cutting units in sub-areas 1 and 2 are on either side of the intake reservoir. The loop road is in the foreground. Sub-area 3 is on the upper slopes in the background.

Sub-Area 2

The middle slopes above the loop road are primarily commercial forest land. Timber-harvesting activity has been scheduled to achieve specific purposes such as improvement of age-class distribution, stand quality, and wildlife habitat (fig. 2). Current inventory data indicate that 60 acres can be regenerated annually in the 6,500 acres of this sub-area that are within the municipal watershed.

Timber stands in sub-area 1 and 2 generally do not qualify for thinning cuts because of quality and age-class distribution.

Hunting use is heavy all along the loop road. Camping has been allowed near the road during the hunting season and will be permitted to continue at designated sites away from streams. Snowmobiling is increasing along the loop road, and there are plans for extensive snowmobile networks in this sub-area.

Sub-Area 3

The upper slopes above the 2,500-foot contour will be managed as a back-country area, primarily for dispersed recreation. For the entire Kilkenny Unit, sub-area 3 totals 17,500 acres. Only 2,000 acres are in the Berlin municipal watershed.

Presently, there is little hiking as compared to other areas on the Forest, and there are no developed camping sites. Through the planning process, we will take the opportunity to preplan for the anticipated increase in hiking use. Camping will be restricted to designated areas, and toilet facilities and tent platforms will be provided.

SPECIAL RESTRICTIONS

There are many coordinating requirements on National Forest land uses, which have been established to protect water quality. Furthermore, it is National Forest policy to meet state water-

quality standards and the restrictions on class-A municipal drainages. Therefore we do not have a separate list of forest-wide restrictions for municipal watersheds. Municipal use is taken into account in management plans.

IMPACT ON WATER RESOURCE

The key item in any type of land use on a municipal watershed is its impact on the water resource.

Research results have established that clearcuttings will increase water yields during summer low-flow periods (*Lull 1967, Hornbeck 1970*). By applying research results to the planned timber-management program on the municipal watershed, we estimate that flows can be increased 700,000 gallons per day during the summer (*Douglass 1972*). This increase will be dispersed over the watershed, due to the scattered locations of the cutting units, and the increase may not be easily noticed at the reservoir. However, there is no doubt that increases in water yield occur below clearcut units.

Impacts on water quality are more varied, and the management key is to control use so that any adverse effects can be corrected before they reach significant levels. The control of suspended sediments is a major concern in any type of activity that involves the exposure of mineral soil — such as temporary road construction for timber harvesting. However, we make use of research findings to protect against erosion and sedimentation of streams. Such items as providing filter strips between roads and streams, and stabilizing roads after logging, are forestwide requirements.

Changes in water chemistry due to land use is another concern. As has been reported by research, nitrate levels do increase in the streamflow from clearcut units (*Pierce et al 1972*). There are

three key aspects of this nitrate increase that pertain to municipal watersheds. First, the increased levels of nitrate that have been monitored in normal clearcuttings or regeneration cuts seldom exceeds 20 mg/l. The U. S. Public Health Service standard for drinking water is 45 mg/l. Second, this standard is placed on water quality at the intake. Finally, the increase has been found only in the White Mountain area of Maine and New Hampshire.

We have checked nitrate levels starting on the 10 to 20 acres of the drainages where the increase is most noticeable, and we have sampled downstream. Nitrate levels decrease rapidly below the clearcut unit and return to normal on drainages larger than 1,000 acres. Therefore we believe that the established Forest requirements of clearcutting less than 25 percent of a 1,000-acre drainage during a 10-year period and keeping cutting units small and dispersed are adequate for controlling adverse impacts.

There has been some question about managing the deer yard and whether concentrations of deer would increase bacteria levels. We have begun to collect some data on bacteria levels. Though our data are too limited for firm conclusions, it appears that during the winter most waste matter is frozen in the snow-pack. In the spring melt, there is a large volume of water for dilution, and bacteria levels remain low. During the summer and fall low-flow periods, bacteria levels increase. Results to date do not indicate any relationship between the deer yard and bacteria levels. Total coliform has exceeded the state standard once out of 16 samples and this was above the deer yard. The main point is that the wildlife habitats of sub-area 1 will attract migrating birds, beaver, deer, etc. even if unmanaged. By improving the browse we are maintaining the herd in a more healthy condition.

Increased backcountry hiking can lead to waste-disposal problems. The mountain ridge lines of sub-area 3 are generally areas of shallow or rocky soils. Through proper planning, any future campsites will be located in suitable areas. However, we have had waste-disposal problems at other backcountry sites on the Forest. Our monitoring has indicated that, when these problems occur, they are primarily a local health hazard in the camping area. We have not found any significant downstream pollution from backcountry use. Because of the health hazard, the Forest requirement is that there will be no contamination of surface waters by waste-disposal installations.

There are two other aspects of water quality. First, the main stream is highly colored from natural causes. Color levels are about double the state standard even above the main swamp in sub-area 1. Second, there are naturally-occurring areas of streambank erosion. Because of

location, it is unlikely that they have any effect on water quality at the intake, but stream turbidities are increased by the bank erosion that occurs during storms.

CONCLUSION

The National Forest management program on the Berlin watershed has been cited as an example of current land-use practices. However, considering management activities on all our municipal watersheds, it has been our experience that properly planned and controlled land uses can provide many goods and services for the public and not significantly affect water quality. We have been conducting an intensive water-quality monitoring program on all types of National Forest activities for several years. Our monitoring results substantiate the fact that many land uses are compatible with municipal watershed management.

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THE CONSULTANT'S ROLE IN MUNICIPAL WATERSHED MANAGEMENT

by CURTIS H. BAUER, *Consulting Forester, Jamestown, New York.*

ABSTRACT. Consulting forestry firms are in business throughout the Northeast. Their activities include formulation of watershed-management policy and objectives; financing forestry services; management plans; maps; boundaries; timber sales; timber harvesting; logging control and supervision; watershed protection; aesthetics; and public relations. Consultants can manage most forest watersheds in a suitable fashion to satisfy municipal policies and objectives.

I BASE MY REMARKS upon experience gained in managing two small watershed forests in western New York State and 19 years of experience as a consulting forester.

Those of you who are not acquainted with consulting forestry might well ask: What is a consulting forester? His formal training is similar to that of other foresters. Most consultants have a bachelor of science degree in forestry, and many have advanced degrees. Consultants, as do other foresters, frequently avail themselves of short courses offered by the various educational institutions. Consultants generally have gained experience in forestry through work with public agencies, industry, research, or educational institutions before venturing into this business.

A consulting forestry firm may be a single forester, or it may have a staff consisting of professionals with a number of specialized skills. The consultant is a businessman. Services rendered

are charged to the client on a fee or contingency basis. The cost of services varies considerably from one part of the county to another, the range generally being between \$50 and \$125 per day plus expenses. Consultants usually have a contract with a client for a specific time period, covering all aspects of the services to be rendered and the remuneration to be received.

Many consultants belong to the Association of Consulting Foresters (ACF), which has headquarters at Wake, Virginia. A larger organization, the Society of American Foresters, to which most foresters belong, regardless of their type of professional forestry employment, has adopted a strict code of ethics, to which members of the Association of Consulting Foresters subscribe. The Association maintains a membership directory. Those in need of consulting forestry services can obtain the names and addresses of consultants by directing inquiries to the ACF headquarters.

WESTFIELD WATERSHED PROPERTY

The Westfield property is situated in Westfield and Chautauqua, Chautauqua County, New York. The Village of Westfield owns 1,067 acres in the Chautauqua Creek watershed, which comprises approximately 23,000 acres. Steep slopes characterize the Westfield land holdings.

Parts of the Westfield property are poorly drained, and it contains some small swamps. There is a lack of a flood plain, and many V-shaped valleys indicate that stream-incising is the prevalent geologic process. The entire Chautauqua Creek Watershed is geologically characterized as youthful.

The bedrock geology has been described by Tesmer (1963). The bedrock is Upper Devonian, consisting of the Ellicott and Dexteville members of the Chadakoin Formations, about 250 feet thick. The Northeast, Westfield, Shumla, and Leona members, about 680 feet thick, make up the Canadaway Formation. Superficial deposits described by Muller (1963) within the Village property are basically ground moraine.

The property is covered mostly by deciduous forests. Sugar maple is the predominant tree species; it is associated with beech, black cherry, white ash, yellow-poplar, red oak, hemlock, and other tree species. Some stands contain large overmature trees; others are of pole size. In 1962 the forest contained many large cull trees, and most of the stands were overstocked.

There are two water intakes in Chautauqua Creek. The Minton Reservoir has about 10 surface acres. Approximately 1,000,000 gallons per day are used for 47 weeks of the year, and during the food-processing season about 2,000,000 gallons per day are used. The average annual precipitation is 40 inches.

ORGANIZATION

The Village of Westfield Mayor appoints and the Village Board of Trustees acts to approve members appointed to the Board of Public Utilities (BPU). The BPU, consisting of a chairman and four members, all unsalaried, govern both the water department and the electric department. There is a superintendent for each department. The forester works directly under the BPU and in conjunction with the superintendent of the water department.

POLICY AND OBJECTIVES

It is necessary to establish a policy and set objectives for the management of a forest watershed. Too many municipalities that own watershed forests have no watershed policy. Policy formation and many management decisions are often promulgated by a board of public utilities or similar body that lacks the understanding and knowledge to fashion watershed policy or to set watershed objectives. Some BPU members are amazed to learn that the trees on their watershed are competing with their customers for the same water.

Watershed policy formation can be a joint effort between the consultant and the BPU members. Before meaningful policy can be developed and objectives established, it is often necessary for BPU members to learn about the existing natural resources and the relationships among plants, soil, and water. The consultant can provide much of the technical background necessary to develop the policy and establish goals.

The Village of Westfield Board of Public Utilities adopted a watershed policy to increase streamflow in the creek where the intakes are located and above the reservoir; to permit little or no water pollution from erosion; to maintain a vigorous and healthy forest; to maintain an esthetically pleasing

forest, particularly along the main watercourse and roads; to purchase additional property to fill out and enlarge the watershed holdings; and to carry out the policy and objectives as much as possible within the limits of income produced from the forest.

COMPREHENSIVE INVENTORY

Before developing a watershed management plan it is necessary to have an inventory of the property. Good property maps are frequently lacking. It is often necessary to locate deeds that describe the property and work out boundary descriptions from legal records. Tract maps, county maps, survey notes and sketches, tax maps, USGS quadrangles, and aerial photographs of the areas in which the properties are located are most helpful in developing maps.

The inventory on the Westfield watershed included topographic data, soils information, location of watercourses, all existing roads, location of water intakes, pipelines, rights of way, buildings, the reservoir, boundary references, and other physical features. Considerable information about the vegetation was gathered. Data about the species, size classes, density, health, vigor, and volume of the timber were collected. This information was related to maps and tables and later incorporated into a watershed management plan.

WATERSHED-MANAGEMENT PLAN

The plan becomes the working document to guide all management decisions. The plan blends the policy and objectives with the collected inventory information. The Westfield plan was developed for a 10-year period. A plan must not be rigid, but fluid enough to incorporate changes. The Westfield plan contains timber-harvesting schedules,

timber-stand improvement schedules, timetable for road construction, erosion-control recommendations, tree-planting schemes, boundary-line maintenance program, logging standards, land-acquisition goals, and a sub-plan on how all of these objectives can be achieved within the funds available.

Execution of the Westfield plan happens only after approval by the BPU. As an example, before a road is constructed, approval must be given by the BPU. Approval is based on the cost, availability of funds, and how the road fits the overall plan. This procedure enables the BPU to participate in the management decisions and to keep control of the forester's activities.

BOUNDARIES

Seldom are the boundaries of forest properties in good condition. It is necessary to locate property boundaries before certain forest management practices can be conducted. Frequently the old boundary lines and property corners can be located. Sometimes certain lines must be surveyed. Many consulting foresters are licensed surveyors.

On the Westfield watershed, the old lines and corners were located, blazed, and painted. Boundary signs were posted along the lines and at the corners. Maintenance of all the boundaries are on a 10-year schedule.

TIMBER MANAGEMENT

Timber harvesting is viewed as a method of manipulating the vegetation. Considerable research has been done on increasing water yields through timber harvesting. Increased water yield is a policy objective of the Westfield BPU. Timber harvesting not only increases water yields but results in timber sales, which in turn provides income.

During the first 10-year plan, it was

decided to remove timber from about 500 acres. Since 1963, ten timber sales have been made on forest compartments ranging in size from 30 to 80 acres, including altogether 421 acres.

One objective of the timber-harvesting program has been to remove the large overmature trees, which consume much water. All cull trees have been cut or deadened in each sale area. Selective cuttings have been in stands overstocked with sawlog-size trees.

There is considerable variability in age classes throughout the watershed forest. None of the stands are ready for reproduction cutting. It seems desirable to reproduce these hardwood forests at a later date by the shelterwood or group-selection methods. The possibilities of timing the last stages of a shelterwood cutting on certain compartments at a time when high water yields from the watershed are needed, appears to have intriguing prospects.

Sawtimber sales are made by marking trees to be harvested. A prospectus is developed, outlining the conditions of the proposed sale and listing the marked timber by species, number of trees, and volume. A map of the sale area is prepared. The logging conditions are specified. The prospectus is sent to area timber buyers, and sealed bids are required. A contract is executed between the buyer and the seller. Payment for the timber is made when the contract is executed.

To control the logging, we require the purchaser to post a bond. The bond money can be used to correct logging damages. The seller reserves the right to stop all logging when weather conditions or poor logging practices are such that damages become unacceptable. Other restrictions are placed in the contract to protect the watershed. The job is inspected periodically to insure that the contract specifications are met.

As the logging progresses and at the end of timber cutting, truck roads are ditched, waterbars are placed where needed over skid trails and truck roads, culverts are cleaned, and wheel ruts are filled. Log landings and roads subject to erosion are seeded and mulched.

Overstocked pole stands have been thinned by deadening undesirable trees. Silvicides, girdling, and cutting have been used in thinning. Vines and cull trees outside the sale areas have been deadened. A considerable portion of this work has been done under the provisions of the Agricultural Conservation Program and its successor, the Rural Environmental Assistance Program. A total of 230 acres has been treated in this fashion.

Trees have been planted to create vegetative snow traps. Conifer trees were used. The trees have not been in the ground long enough to prove their effectiveness in holding snow.

The results of the applied timber-management practices are evident. The forests are healthy and vigorous. The old-growth forest is being replaced by younger better-formed trees. Reproduction in the openings is vigorous. Stocking of trees is good, and species composition is improving.

WATER PRODUCTION

We have little data about the effect of forest manipulation on water yields on the Westfield properties. This is a working forest, not an experimental forest. Lessons learned in watershed research in other parts of the Northeast are used where applicable and as conditions permit and usage and needs demand.

Techniques used to manage the forests fall into two categories. First, practices that watershed researchers have found effective for increasing water yields are used. Second, standard silvi-

cultural methods are applied in many portions of the forest. Changes in water yields as a result of the practices applied are not now measured, and we have no plans for installing measuring devices.

In 1967, John Osborne and A. R. Eschner of the State University of New York College of Environmental Sciences and Forestry at Syracuse made a study to determine the effects of timber harvesting on soil moisture in the watershed. The study resulted in some interesting observations and excellent recommendations for increasing water yields.

FINANCES

Before forest-management practices were initiated on this forest, ad valorem taxes were paid yearly as they still are. It is difficult to place a dollar value on increased streamflow resulting from forest-management activities. Income from other sources, however, is merely an accounting matter. Expense and income records have been maintained for the forest activities since management began in 1962.

All professional forest-management service costs to date total \$9,837. This includes inventories; boundary-line work; management plans; road design, layout, and maintenance supervision; land acquisition; inspections; tours, and consultation. Boundary signs were purchased for \$194. Timber-marketing and harvest-inspection fees totaled \$6,562. Road maintenance and erosion-control expenses amounted to \$703. The total expenses were \$17,296.

Capital improvements, land acquisitions, and easements incurred expenditures. About 2 miles of forest road was constructed, and easements were purchased for \$6,900. Timber-stand improvement was done on 225 acres for \$4,977. Tree planting cost \$799. Five properties of 290 acres adjoining the forest were purchased for \$14,101. Total capital expenditures totaled \$26,777.

Income resulted from federal cost-sharing in the ACP and REAP. Cost sharing from timber-stand-improvement work totaled \$3,779. Tree-planting cost sharing was \$275. Timber sales revenue was \$54,186. Total income since 1963 to date is \$58,240.

Income over direct expenses, not including land taxes, is \$40,944. When adding the capital expenditures to the expenses and deducting the sum from the income, there remains a cash balance of \$14,167.

The forest is due to be reinventoried in 1974.

There now seems to be more sawtimber on the Village property than in 1963. This sawtimber is more valuable than what was present in 1963. Because of the valuable timber resource on this forest, it appears possible to achieve sound watershed management and allow timber production to pay the costs.

PRESERVATIONISTS & RECREATIONALISTS

Certain timber-management policies have evolved as a result of pressure from preservation-oriented groups. Some fishermen have been upset about timber-harvesting practices. There is repeated pressure to turn portions of the Chautauqua Creek watershed, including the Village lands, into a public park. Recently a public hearing was held in Chautauqua County to amend the New York State Wild, Scenic and Recreation Rivers System Law to include Chautauqua Creek.

The Westfield BPU has steadfastly withstood efforts to remove the property, or its control, from their jurisdiction. It is time-consuming and expensive to engage in public-relation efforts to explain and demonstrate the importance of the Village lands to the protection and production of the Westfield water supply, but the BPU feels that this effort is worthwhile.

Certain accommodations have been made with the recreation public. The lands are not posted. Hiking along Chautauqua Creek is permitted. Fishing and hunting are permitted. Picnickers use the property. Tree screens are left along Chautauqua Creek and public roads. The current policy is to allow these recreational activities, but if the users become destructive or their presence becomes detrimental to water quality, then trespassing will not be permitted. It will be exceedingly difficult to stop recreational trespassers if and when it becomes necessary to do so.

CONSULTANT'S ROLE

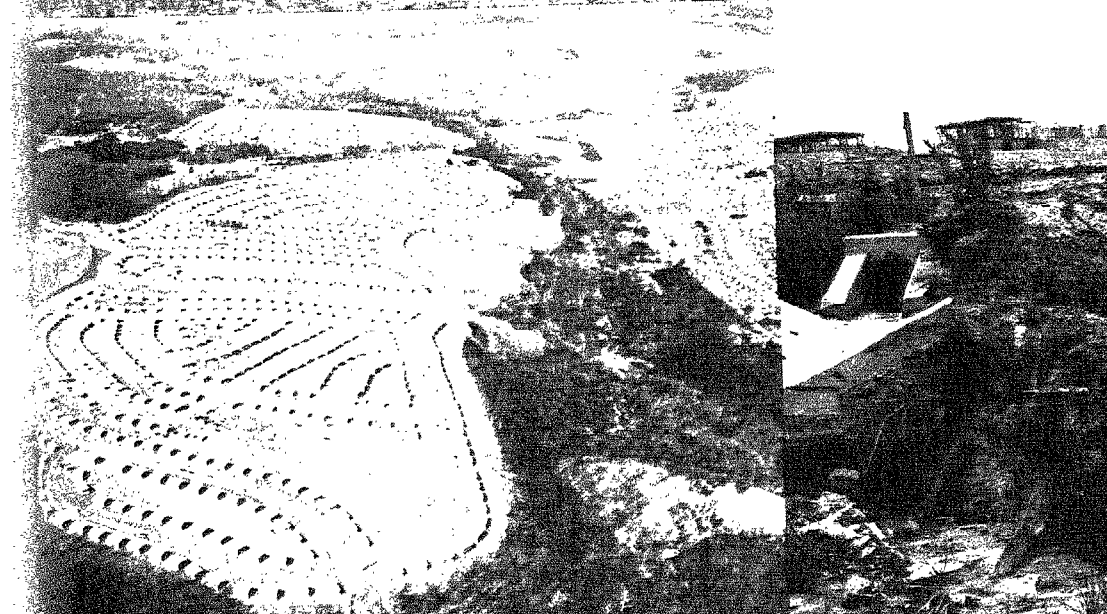
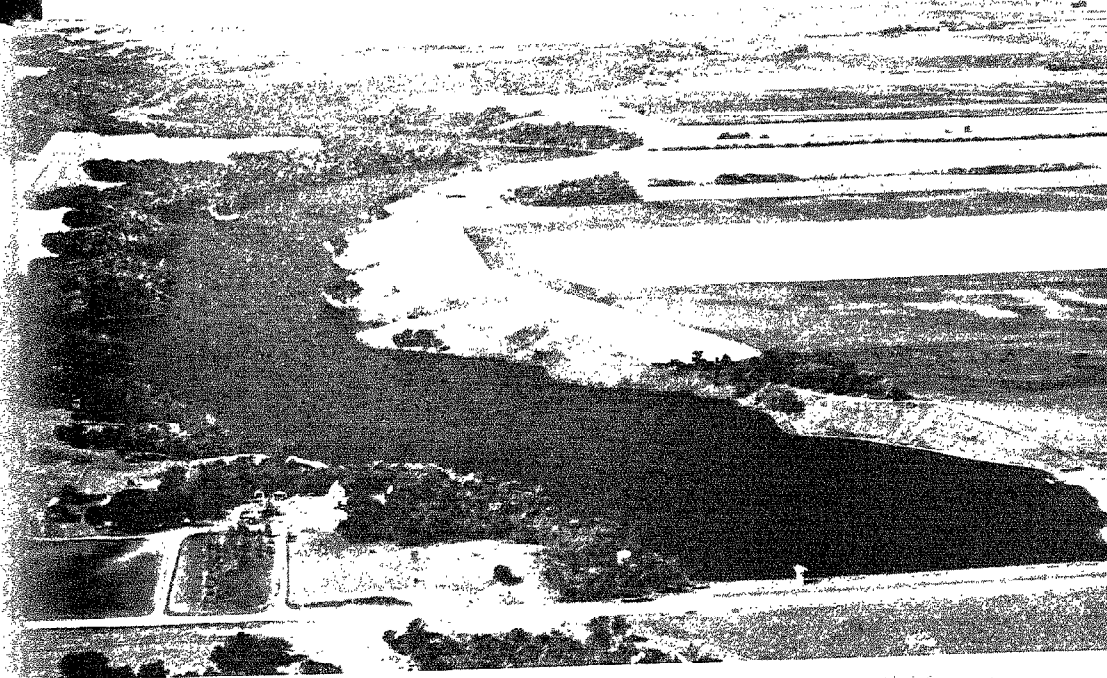
Forestry consultants are prepared to participate in the management of municipal watershed forests. Municipalities with small (100 acres) to medium (10,000 acres) watershed forests may find it difficult to justify the expense of a full-time watershed forester. An advantage in employing a consulting forester is that his fees are based on specific work performed and he is not a full-time municipal employee.

Consultants and their employees are covered by the normal insurances required by state and federal laws. Most consultants are covered by general liability insurance, error and omission insurance, and manufacturer's liability insurance.

Most consultants bring to a job considerable experience in forestry. Many are versed in the practices of sound watershed management. Forestry consultants are generally well informed about forest product markets and know how to sell forest products to bring the best prices possible. They understand logging, the problems, and what can and what cannot be logged. They can generally locate boundary lines and engineer access roads; they have a working knowledge of and license for using silvicides and herbicides. Consultants understand the language and important aspects of timber-sale contracts, and they can be helpful in the development of watershed policies.

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MEETING CURRENT AND FUTURE DRINKING-WATER QUALITY STANDARDS

by KENNETH E. SHULL, *Vice President, Water Treatment, Quality Control and Research, Philadelphia Suburban Water Company, Bryn Mawr, Pennsylvania.*

ABSTRACT. Drinking-water standards were first adopted by the United States Public Health Service in 1914. Theoretically, these standards are applicable only to suppliers who provide water for common carriers operating interstate. Practically speaking, however, they have been endorsed by the American Water Works Association and are enforced by most state departments of health. The 1914 standards were revised in 1925, 1942, 1946, and most recently in 1962. This last revision includes, for the first time, limiting concentrations of radioactivity in water and other substances that have become significant because of our accelerating technology. Standards are again under revision. But this time an effort is being made to legislate them so they will legally apply to all waters throughout the country. Three bills, now under consideration by Congress, emphasize state enforcement responsibility but give the federal government authority to step in where states fail to act.

WATER IS ONE of the essentials of life, and the importance of assuring a clean and safe supply of water to the American people for drinking and other uses was never greater than it is today. Just about every activity we can think of involves the use of water. It is used for drinking, cooking, bathing, washing, laundering, heating, air conditioning, agriculture, stock-raising, industrial processes, water power, fire protection, disposal of wastes, swimming, fishing, and boating.

Obviously the water quality required varies for these different uses; what is satisfactory for one use may be completely unsatisfactory for another. One example is chloride content: it should not be greater than 250 mg/l in drink-

ing water; but it must be less than 1 mg/l in modern ultra-high-pressure steam boilers.

There was a time, perhaps, when one could drink water directly from a stream or river and not be adversely affected by it. But that day is long past. It would be very difficult now to find any surface source that is not polluted to some extent. Even groundwaters are not immune from pollution and contamination. In primitive times, when populations were small, human wastes and other impurities were readily assimilated by rivers and streams. But the tremendous amounts of pollutants, including many sophisticated chemicals we discharge daily into our watercourses, have overtaxed those water's ability to absorb the pollutants.

A NATIONAL EFFORT

With the passage of the Federal Water Pollution Control Act and its 1972 amendments (Public Law 92-500), a real effort is being made to clean up our Nation's waters. The objective of the Act is "to restore and maintain the chemical, physical, and biological integrity of the Nation's waters." In essence, the new law requires that every company discharging water into any waterway must receive a permit from a state agency that will set emission limits under EPA guidelines. By 1 July, 1977 companies will have to employ the "best practicable control technology", and by 1 July, 1983 they will have to use the "best available technology." The ultimate goal, although not enforceable under the law, is the complete elimination of water pollution — zero discharge — by 1985.

This is Utopia, and, according to many, it is not attainable. Among the experts who believe it is not is Philip Abelson, President of the Carnegie Institution. Abelson recently pointed out that "the enthusiasm for environmental perfection will double or triple the prices of gas, gasoline and heating oil in a few years." Further, he said, "Americans are right to want to lower pollution, but it is unrealistic to strive for no pollutants at all. The earth would be polluted even if no man lived on it."

Naturally, the cleaner the raw water source, the easier it is to produce a quality finished product from it. But with the technology available today it should be possible to take almost any water source, even though it is highly polluted, and manufacture it into a product that meets the U.S. Public Health Drinking Water Standards — provided people are willing to pay the cost.

Just what do we mean by quality water? According to the American Water Works Association (1971), it is

"those chemical, physical, biological or radiological characteristics by which one evaluates the acceptability of the water." The term *quality* is relative, depending upon the use of a particular water. What is a good quality water for one purpose may be of poor quality for another. The only way we can evaluate the quality of a water is to compare the concentration of the various constituents present in it with standards.

In 1880, under the direction of J. W. Mallet, the National Board of Health began a study of various tests that had been suggested for determining pollution in water. A report of this work, published in 1882, pointed out, among other things, that "it is impossible to judge the sanitary character of drinking water by any methods of chemical analysis investigated." And further, "there are no sound grounds for establishing standards of purity based upon the amounts of certain constituents present."

At this time bacteriological procedures were not even as far advanced as chemical methods. In fact, the German biologist, Emmerich, tested polluted waters, not by chemical or bacteriological methods, but by swallowing samples of water and by feeding them to animals. A positive test was the onset of fever or other physiological changes—sometimes even death. During the next 30 years, various laboratories throughout the country established their own chemical standards for potable water. And meanwhile, useful bacteriological procedures were developed.

On 21 October, 1914, upon recommendation of the Surgeon General of the Public Health Service, the first bacteriological standard for drinking water was adopted by the Treasury Department. Those who developed this standard were 15 leading chemists, bacteriologists, public health experts, and sanitary engineers. The standard applied only for

water supplied to the public by common carriers in interstate commerce. It is interesting to note that, during development of the bacteriological standard, considerable discussion took place about whether it should also include a statement that water shall "be free from injurious effects upon the human body and free from offensiveness to the senses of sight, taste or smell." So it is obvious that even in those early days some thought was given to chemical and physical parameters.

The bacteriological standard was in two parts: First, the total bacteria count on agar plates was not to exceed 100 organisms per ml. And second, not more than 1 of the 5 portions planted in lactose broth shall show the presence of *B. coli*.

Standards Revised

The first revision of the standard took place in 1925 when the plate count was eliminated and the *B. coli* count was further refined. In this revision there were recommended limits for color, chlorides, iron, magnesium, and sulfate. The water was to be clear, colorless, odorless, pleasant to the taste, and was not to contain an excessive amount of soluble mineral substances or any chemicals used in treatment processes.

By 1942 our knowledge about the effect of various impurities in water on humans had increased sufficiently that changes in the standards were again indicated. This time there was a distinct separation of the text into two parts — one part containing the standards and the other the Manual of Water Works Practice. Both the bacteriological and chemical sections were updated and expanded. One key addition was the requirement that a minimum number of samples, depending upon the population served, was to be examined each month.

In addition, laboratories were subject to inspection.

The main difference in the 1946 standards was the removal of the Manual of Recommended Water Sanitation Practices and its issuance as a separate publication.

In 1962 the standards were revised again. Although the bacteriological section was left essentially the same as it was in the 1942 revision, the membrane-filter technique for bacteriological examination was permitted for the first time. The number of samples that have to be collected each month, based on population served, was increased. A number of changes were made in the recommended limits for chemical constituents, and new constituents were added. For the first time, limits for radioactivity were included; and values that should not be exceeded were given for them.

The 1962 standards (table 1), are the ones we use today. Officially they are still applicable only to the approximately 800 municipal water supplies that provide water for loading on common carriers operating interstate. Practically, however, they have been endorsed by the American Water Works Association and have been adopted by most state departments of health. Thus, in general, they have been accepted for use by all public water suppliers throughout the country.

During the last couple of years a rather extensive revision of the 1962 standards has taken place. The actual work has been done by a technical committee with the help of a public advisory committee. Originally the revised standards were scheduled to be issued in 1972. But they were held up pending action in Congress, because, for the first time, safe drinking-water bills have been introduced in both the House and Senate. HR 1059 was introduced in the House

Table 1.—U.S. Public Health Standards for Chemical and Physical Characteristics of Potable Water

Substance	1962		Proposed 1973	
	Recommended limits	Tolerance limits	Esthetic limits	Health limits
	<i>Mg/l</i>	<i>Mg/l</i>	<i>Mg/l</i>	<i>Mg/l</i>
Alkyl benzene sulfonate	0.5	—	—	—
Arsenic	0.01	0.05	—	0.1
Barium	—	1.0	—	1.0
Cadmium	—	0.01	—	0.01
Chloride	250	—	250	—
Chromium	—	0.05	—	0.05
Color	15*	—	15*	—
Copper	1.0	—	1.0	—
Cyanide	0.01	0.2	—	0.2
Fluoride	0.6–1.7	—	0.6–1.7	1.4–2.4
Foaming agents	—	—	0.5	—
Iron	0.3	—	0.3	—
Lead	—	0.05	—	0.05
Manganese	0.05	—	0.05	—
Mercury	—	—	—	0.002
Nitrate (as NO ₃)	45.0	—	—	45
Odor (T.O. No.)	3*	—	3*	—
Organic-carbon adsorbable	—	—	—	—
CCE	0.2	—	—	0.7
CAE	—	—	—	3.0
Phenols	0.001	—	—	—
Selenium	—	0.01	—	0.01
Silver	—	0.05	—	0.05
Sulfate	250	—	250	—
Total dissolved solids	500	—	—	—
Turbidity	5*	—	—	1.0*
Zinc	5.0	—	5.0	—

*Units

by Congressman Paul Rogers and S433 was introduced in the Senate by Warren Magnuson. In addition, the administration has also introduced a bill. Although there are some differences in these bills, they all establish, by law, national drinking-water standards in two categories: primary constituents related to protection of the public health; and secondary constituents (esthetics) that effect the senses — taste, odor, and general appearance of the water. The pro-

posed standards are also listed in table 1. According to all three bills, the states will have the primary responsibility of enforcing the standards, but EPA is authorized to step in in case the states fail to act.

On 5 June the Senate Commerce Committee, after many hearings, ordered S433, with several amendments, reported out on the floor of the Senate, where it was passed. That is the status at this time, although we have every ex-

pectation that the standards will become law sometime in 1973. It actually became law in December 1974.

Neither the current nor proposed standards represent a high-quality water. Instead they establish "the furthest deviation from purity considered permissible, so that the health of the public can be protected" (Buswell 1951).

For those who want to produce a high-

quality water — and we all should — there are *Quality Goals for Potable Water* to use for comparison (Bear 1968). Established by the American Water Works Association in 1965, these goals (table 2) are "substantially more exacting than existing (and proposed) Drinking Water Standards with respect to both health and esthetic qualities. They are generally attainable by correct application of known treatment processes and methods."

Table 2.—Ideal Quality Water
[A.W.W.A.]

Item	Criteria
Turbidity	Less than 0.1 scale units
Non-filterable residue	0.1 Mg/l
Microscopic and nuisance organisms	None
Color (true)	3 units
Odor	No change on carbon contact
Taste	None
	Mg/l
Lead	0.03
Barium	0.5
Fluoride	Variable inversely to temperature
Arsenic	0.01
Cyanide	0.01
Silver	0.02
Selenium	0.01
Cadmium	0.01
Chromium (Hexavalent)	0.01
Iron	0.05
Aluminum	0.05
Manganese	0.01
Copper	0.2
Nitrate (N)	5.0
Filterable residue	200
Zinc	1.0
Phenolic compounds (as phenol)	0.0005
Chloroform Sol. from carbon adsorption	0.04
Alcohol-soluble material from carbon adsorption	0.10
Alkyl benzene sulfonate (ABS)	0.2
Hardness (as CaCO ₃)	80
Coupon tests (90 day)	
Stainless steel	Not to exceed 0.01 mg/sq cm
Galv. iron	Not to exceed 5.0 mg/sq cm
Coliform (multiple-tube or membrane filter)	1 per liter

NOTE: All figures above are maximum concentrations in ideal water.

These then are the drinking water standards and the water quality goals. The questions are: First, can we treat highly polluted and contaminated waters to bring them into conformity with the standards and goals? And, second, if we can, what kinds of treatment do we have to use?

PRICE IS THE KEY

There are two schools of thought on these questions: One is represented by Leonard B. Dworsky, director of the Water Resources and Marine Sciences Center at Cornell University. Recently in testimony before a Congressional committee, Dworsky said that "chemicals in our natural water supplies and in our drinking water supplies is a matter that has not been given enough consideration by this Nation, by our water supply industry or by the water pollution program." . . . "I am afraid," he said, "we are at the stage whereby some day — and it might be very close — we might have one overly harmful chemical pass through this thin wall in an amount dangerous to humans. We cannot emphasize too strongly that our present technology is not capable of taking out many of the contaminants that exist in the surface waters of the United States, or in the ground water."

Then, too, Shuval and Gruener (1973) writing in the July issue of *Environmental Science and Technology*, expressed their concern about trying to produce a quality water from waste water, either direct or indirect. They pointed out that "the mere comparison of the quality of the final effluent against those standards currently listed in USPHS Drinking Water Standards leaves too many questions unanswered to be accepted as adequate evidence that such an effluent is completely safe from the public health point of view."

On the other hand, Hartung and Tuep-

ker (1969) believe that "theoretically any raw water can be processed into quality water." They did point out that the procedures used might have to be specialized industrial techniques that go beyond those now considered feasible for public water-supply application. And Abel Wolman, that dean of water works men, recently wrote that: "one can undoubtedly produce any tailor-made water the consumer needs or desires. The important questions in each instance remain as to when, where, why and at what price" (1970). The key word is price. People must be willing to pay a lot more than they do now if they want a quality product from a highly polluted source.

Unfortunately, too many plants today use only conventional water treatment processes consisting of coagulation with aluminum sulfate (alum) or one of the iron salts, sedimentation, rapid sand filtration, and disinfection with chlorine and ammonia to form one or more of the chloramines. Actually, in many cases more specialized kinds of treatment are necessary to reduce the concentration of pesticides and other organic compounds, fluorides, nitrates, and the so-called heavy metals (lead, arsenic, cadmium, and mercury) to acceptable limits. Such processes as aeration, adsorption, oxidation with chlorine, chlorine dioxide, ozone or potassium permanganate, filtration through granular carbon beds, ion exchange, and even distillation or reverse osmosis may be necessary.

At this point I shall select several impurities, or classes of impurities, known to exist in water-supply sources, and show how various treatment processes can be used to reduce their concentration to a long-term safe level.

Turbidity

All surface supplies contain some turbidity, due to clay and silt from land

erosion, finely divided organic matter, algae, and other microscopic organisms. Although the larger particles will settle by gravity, colloidal matter will not. It requires destabilization by one of the polyvalent metal salts — aluminum sulfate, ferric sulfate or ferrous sulfate and chlorine, or a cationic polyelectrolyte — followed by sedimentation and rapid sand filtration. The process is known as coagulation/flocculation.

Although the present drinking-water standard for turbidity is 5 units, it has been reduced to 1 unit in the proposed standards. The AWWA Water Quality Goals limit turbidity to 0.1 unit.

The presence of turbidity is undesirable esthetically. But it also has indirect public health significance. For example, Hudson (1962) has shown that turbidity and microorganism removal generally parallel each other. Moreover, the incidence of viral disease and the degree of clarification attained, as indicated by measurements of filtered water turbidity, also parallel each other. Riddick (1961) has shown a similar relationship between the removal of colloids by coagulation and tastes and odors.

Few studies have been made on the removal of algae by conventional treatment. In 1961 Borchardt and O'Melia reported that algae are removed not only at the surface but throughout the bed of the sand filter. As a result, some algae always pass through the filter during its operation. More recently, work by Speedy, Fisher, and McDonald (1969) indicated a wide disparity in the efficiency of algae removal by various unit processes. For example, sedimentation basins, following coagulation, were found to remove an average of 37 percent of the algae. Addition of chlorine had no appreciable effect on removal, even though it killed the algae. Softeners showed a fairly high degree of removal with 50 to 100 organisms per ml in the effluent regardless of the number

in the influent. Best removal occurred with the use of lime, without alum, for both clarification and softening (97 percent removal). Experiments performed in Philadelphia Suburban Water Company laboratories showed that coagulation with iron salts, followed by sedimentation, is much more effective than aluminum sulfate in removing algae. This is undoubtedly due to the heavier iron floc that forms. Certainly there is no reason why a well-operated plant, using only conventional treatment, can't consistently produce a water with an effluent turbidity of less than 0.2 units.

Bacteria

Present standards do not have a limit on total plate count. However, it looks as though the proposed standards will have a limit of 500 organisms per 1 ml when the agar plates are incubated for 48 hours at 35°C. Total counts include some pathogenic organisms as well as a variety of nonpathogenic organisms, some of which can become serious secondary pathogenic invaders in postoperative infections. *Pseudomonas*, *Flavobacterium*, *Klebsiella*, and other organisms can act in this way.

The bacteriological quality of a water is presently determined by the presence or absence of coliform organisms. This group is defined in *Standard Methods* (1971) as including all the aerobic and facultative anaerobic, gram-negative, non-spore-forming rod-shaped bacteria that ferment lactose with gas formation within 48 hours at 35°C. Harmless themselves, they serve as indicator organisms. They are always present in the intestinal tract of humans and warm-blooded animals and they are eliminated in large numbers in fecal wastes. If coliform bacteria are absent in a sample of water, chances are that water is free from waterborne disease organisms such as typhoid fever, paratyphoid fever, dysentery, and cholera.

The 1962 bacteriological standards require that when 10-ml standard portions of a sample are examined, not more than 10 percent in any month shall show the presence of the coliform group. And further, the presence of the coliform group in three or more 10-ml portions of a standard sample shall not be allowable if this occurs:

(a) in two consecutive samples, (b) in more than one sample per month when fewer than 20 are examined per month, or (c) in more than 5 percent of the samples when 20 or more are examined per month.

Coliforms and the pathogenic organisms often associated with them are readily destroyed by the right dose of chlorine — provided it's in the free available state and sufficient contact is given. An important point to remember is that turbidity can act as a shield, thus protecting the organisms from contact with chlorine.

When small amounts of chlorine are added to water, a reaction occurs with ammonia whether present or added, to form monochloramines and dichloramines. Both compounds are relatively poor disinfectants. When more chlorine is added, however, (about an 8:1 ratio) the ammonia is oxidized and a free available chlorine residual results. This is a potent disinfectant, one that will destroy all pathogenic organisms if a residual of 0.5 mg/l is maintained for at least 30 minutes. Other useful disinfectants are ozone, chlorine dioxide, and iodine.

Viruses

A virus can be defined as a micro-organism considerably smaller than a bacterium and capable of multiplying only within the living cells of a susceptible host. There are many viral diseases, any one of which theoretically can be transmitted from person to person by water. But up to now infectious hepa-

titis is the only viral disease proven to be waterborne. Unfortunately no satisfactory method has thus far been developed for determining either the presence or quantity of virus in a water supply. For this reason no standards have been developed, nor are any planned for the 1973 revision.

Most experimental work has shown that viruses are more resistant than bacteria to chlorination and other treatment processes. Thus the coliform standard may not necessarily apply to viruses. Fortunately the ratio of coliforms to virus is large: 92,000:1 for sewage and 500,000:1 for polluted surface water.

We do know, however, that there are a number of treatment processes that, if used together, are effective in producing virus-free water. In work done at the University of Illinois, Chaudhuri and Engelbrecht (1970) demonstrated that good chemical coagulation and flocculation are effective in removing between 98.0 and 99.9 percent of the viruses present. But they found that the removal efficiency decreased in the presence of organic matter.

Experience has shown that different enteric viruses show wide variations in their resistance to chlorine. Yet Clarke and Chang (1959) found that all enteric viruses they studied were destroyed by a free chlorine residual of about 1.0 mg/l, provided a contact time of at least 30 minutes is used. Around a pH of 7.0, activated carbon has the ability to adsorb some viruses. And a recent report indicated that diatomaceous earth filtration, preceded by polyelectrolyte feed, is capable of removing up to 99 percent of T2 virus for *Escherichia coli* B.

It would appear from these studies that a combination of the processes — coagulation, flocculation, sedimentation, filtration and chlorination with free available chlorine (or other viricide) — will destroy all viruses likely to be present in a water source.

Mercury

A German chemist, Alfred Stock, spent most of his career testing for and finding mercury in almost everything he tested. Up until his death in 1946 he tried in vain to alert his fellow scientists to the dangers of mercury. Now his ignored warnings have become a matter of concern to people all over the world.

Four weeks after Stock's death, fishermen and their families and pets around Minamata Bay, Japan, were stricken with a mysterious illness. The symptoms included muscle weakness, loss of vision, impaired cerebral functions, and eventual paralysis. In more than 40 cases coma and death were the end result. Since the people, birds, and animals who had the disease subsisted mainly on fish, this product was examined as a possible source of the trouble. High concentrations of mercury were found in both fish and shellfish, and its origin was traced to a factory effluent.

Since then there have been other incidents involving mercury. One of these that received a great deal of publicity in the press was the discovery of high mercury concentration in fish in Lake Saint Clair. Restrictions were immediately imposed on fishing and on the sale of fish from this lake. The source of the mercury was found to be several electrolytic chlorine manufacturing plants, each of which was releasing between 5 and 60 pounds of mercury to the water every day. Further investigation disclosed that there were high mercury levels in the waterways of 33 states, and 18 states imposed some restrictions on water use.

Mercury is used in the manufacture of electrical equipment and control instruments; as a biocide in agricultural products; in pulp, paper, and paint manufacture; in pharmaceutical and dental preparations; as a catalyst; and in chlorine production. Moreover, the ele-

ment is found in trace amounts in the atmosphere, in rocks and soil, and in the tissues of plants and animals.

The mercury compound found in seafood was more toxic than the usual inorganic compounds. This was finally explained by the fact that inorganic mercury is biologically converted to the much more toxic organic methyl mercury by microorganisms in water. After ingestion, plants and animals tend to concentrate this organic mercury in their tissues. So when algae consume mercury compounds, they concentrate it many times over what it is in the water in which they live. When fish eat algae, they further concentrate the mercury — and so this concentration continues up the biological ladder.

Although the FDA has recommended a maximum limit of 0.5 ppm for fish, none of the drinking water standards thus far have included a limit for mercury. The proposed standard, however, sets a limit of 0.002 mg/l in water.

Compounds of mercury, especially those that are soluble, are difficult to remove from water. However, if they are present in an insoluble form, a substantial concentration will most likely be removed by conventional treatment. Soluble compounds will require more drastic treatment, such as passage through an ion exchange unit. This process will remove the toxic mercury and replace it with a nontoxic cation.

Studies carried out in the laboratories of Westvaco have shown that activated carbon has good adsorption potential for mercury (*Sigworth and Smith 1971*). Our own studies with powdered carbon have also established its effectiveness. In one experiment, for example, we found that a dose of 50 mg/l of carbon reduced the mercury content of a sample of water from 0.01 mg/l to 0.001 mg/l. Passage through granular carbon filters should do an even better job.

The removal of mercury, and other heavy metals, is also enhanced by those water-softening processes that involve chemical precipitation; for example, lime or limesoda softening. Finally, a recent report indicated that if a water containing divalent mercury is treated with starch xanthate-cationic polymer complex, considerable reduction takes place. Unfortunately, organic mercury compounds are poorly precipitated by this system.

Pesticides

Paris green (copper acetoarsenite) was probably the first chemical to be used against insects. At about that time (1874), a German chemist synthesized a compound called dichlorodiphenyltrichloroethane (DDT). This chemical sat on the shelf until the late 1930s when Paul Muller, a Swiss entomologist, discovered that it was an extremely effective insect killer.

Other synthetic organic pesticides followed DDT, until in the early 1940s production in the United States was approximately 25 million pounds. By 1970 more than 1,000 million pounds were being produced. These organic pesticides have been most valuable in killing insects known to transmit the organisms responsible for typhus, malaria, yellow fever, plague, and other diseases. At the same time, with the help of Rachael Carson's popular book, *Silent Spring* (1962) people became concerned about possible health risks involved in the use of pesticides and their accumulation in the food chain. This concern increased when it was realized that these compounds were soluble in fat and thus would tend to accumulate in the fatty tissues of plants and animals. A good example was given by Wagner (1971), who reported that an analysis of bottom mud of Green Bay, Wisconsin, showed 0.014 mg/l DDT. Small crustaceans showed 0.41 mg/l (three

times as much), fish 3 to 6 mg/l, and herring gulls 99 mg/l. If man were to eat fish with this concentration of DDT, he too could accumulate enough of it to have an adverse physiological effect.

There are two groups of organic pesticides that are dangerous from the standpoint of environmental contamination. The organophosphates and the organochlorines (also called chlorinated hydrocarbons). Parathion and malathion are organophosphates, whereas endrin, heptachlor, aldrin, toxaphene, dieldrin, lindane, DDT, chlordane, and methoxychlor are organochlorines. Because of their persistence, the last group has the greatest effect on the environment.

In the mid 1960s, waters from 99 streams and rivers in the United States were examined for pesticides, and a wide range of values was obtained. Although the Mississippi River water contained 4.23 μ g/l, others showed only a trace or none at all. The average of all 99 was 0.002 μ g/l. The source of these pesticides is very likely runoff from agricultural land, industrial waste discharges, the washing of application equipment, and drifting during aerial spraying.

Up until now there have been no standards for pesticides, although there has been much discussion about the need for such standards. In 1965 the Public Health Service advisory committee suggested that certain limits be set for pesticides. Their recommendations, although never formally adopted, served as guidelines in evaluating a water supply. These guidelines and the values proposed for the 1973 standards are shown in table 3. According to Robeck, the proposed standards are based on the latest experimental mammalian data and incorporate a factor of safety of approximately 500.

Evidence from laboratory studies and plant practice indicates that conven-

Table 3.—Pesticides

Chlorinated hydrocarbons	Old guideline	Proposed 1973 standards
	<i>Mg/l</i>	<i>Mg/l</i>
Aldrin	0.017	0.001
Chlordane	0.003	0.003*
DDT	0.042	0.05
Dieldrin	0.017	0.001
Endrin	0.001	0.0005
Heptachlor	0.018	0.0001
Heptachlor Epoxide	0.018	0.0001
Lindane	0.056	0.005
Methoxychlor	0.035	1.0
Toxaphene	0.005	0.005*

*Limit selected on basis of odor although the toxic limits are similar.

tional treatment will not remove any significant amount of pesticide, except for DDT. But when Cohen et al (1960) studied the effect of various water-treatment processes in reducing the concentration of toxaphene, they concluded that activated carbon was the most effective treatment. A 9 mg/l dose of powdered material removed 95 percent of a 0.3 mg/l concentration. In addition to removing the pesticide, carbon will also adsorb the solvents and emulsifiers usually present.

Later Robeck et al (1965) studied the effect of conventional treatment, and powdered activated carbon, but in addition, included chlorine, potassium permanganate, and ozone. They found that DDT was easily removed by coagulation and settling followed by filtration, but lindane and parathion were not. Chlorine and potassium permanganate at 1 to 5 mg/l did not oxidize chlorinated hydrocarbons. Actually parathion was converted to a more toxic compound. Some oxidation occurred with large doses of ozone, but the toxicity of the new compounds is not known. Activated carbon gave the best results, although the dose varied with each pesticide.

A reduction from 10 ppb to 1.0 ppb required 29 mg/l of carbon for lindane, but only 5 mg/l for parathion. In general, it takes more carbon to remove endrin, dieldrin, and lindane than it does to remove parathion. Granular carbon filters were very effective in reducing the concentration of all pesticides studied.

To Meet the Standards

In 1969 the Bureau of Water Hygiene of the Public Health Service made a nationwide survey of community water-supply systems (McCabe et al 1970). The purpose of the survey was to find out if the American consumer's drinking water met the drinking water standards.

And what did they find? Just this:

Out of 969 public water-supply systems, serving about 18.2 million people, 496 do not disinfect, clarify, or buy chlorinated water; 311 do not clarify but only disinfect or buy chlorinated water; 7 clarify but do not disinfect; and only 155 (16 percent) clarify and disinfect.

Is it any wonder then that only 59 percent of the systems inspected met all of the drinking water standards? Admittedly many of the deficiencies were

due to faulty procedures rather than deficiencies in quality of water served. But there were enough systems serving waters with too great a concentration of coliforms, heavy metals, pesticides, or total organic content for us not to be concerned about them. These plants need to incorporate more sophisticated treat-

ment processes, better laboratory control procedures, and more highly trained operators. To do this, a great deal of money will have to be spent. But only by doing this will all plants produce a high-quality water that consistently meets all of the drinking water standards — present and proposed.

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RECREATION PROBLEMS AND OPPORTUNITIES

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ABSTRACT. Demand for water-oriented outdoor recreation continues to increase, especially near urban areas. As these demands rise, municipal watershed managers can expect to feel increased pressure for recreational use of land and water resources under their jurisdiction. The authors discuss some of the problems associated with recreational use of municipal watersheds and present some ideas for managers who anticipate recreational use pressures. Problems and opportunities are reviewed for watersheds on which all forms of controlled recreation are permitted, for watersheds on which no recreation is allowed, and for watersheds that permit only selected types of recreation.

SEVERAL FACTORS have influenced the rate of reservoir construction during the past 15 to 20 years. Flood control, navigation, low-flow augmentation, rising per-capita water consumption, and water-oriented outdoor recreation are the reasons that most people cite. Recreation, of course, is always listed last because it is so difficult to assign a value or benefit to a day's outing on a reservoir. But recreation is often a very important use of new reservoirs.

As the federal government tightens the screws in its attempt to curb inflation, the rate of reservoir construction will slow down. This type of capital expenditure is always a prime target during periods of tight money. But will the rate of increase in water-oriented outdoor recreation slow down? No. Room for recreation, especially on water, will

shrink as the rate of reservoir construction diminishes. Reservoirs will become more and more crowded, and managers of municipal water-supply reservoirs can expect to feel increased pressure to allow recreation on the land and water resources under their jurisdiction.

A recent nationwide survey of resource development indicated that most forms of recreation will be allowed on municipal watersheds by the year 2000. This national trend may or may not reflect the future situation in the Northeast. Growing pressure is sufficient justification for investigating expected problems and opportunities associated with recreation on municipal watersheds.

The problems and opportunities are those that have been found on watersheds operated under an open-door policy, under which all forms of outdoor recreation are permitted under super-

vision. Also, problems and opportunities might be encountered on watersheds that do not allow recreation, and on watersheds where selected activities are permitted.

With a mandate to provide a safe and adequate supply of water, we can eliminate equalizing reservoirs from our discussion. Likewise, terminal reservoirs could be eliminated.

Class-C upstream reservoirs generally are multiple-use reservoirs. Recreation commonly occurs on Class-C reservoirs. Class A and B upstream reservoirs contain water derived from sparsely inhabited areas; they are near the point of rainfall or snowmelt, and water from them generally is considered clean enough to consume with minimal treatment. Water in them is considered ideal for water-oriented outdoor recreation. But recreation is restricted or prohibited on them. Class A and B upstream reservoirs are where watershed managers can expect to feel pressure for recreational use in the future.

Recreation activities that have impacts on watersheds might be classified as either land-based, such as hiking, photography, and bird watching; or water-based, such as swimming and

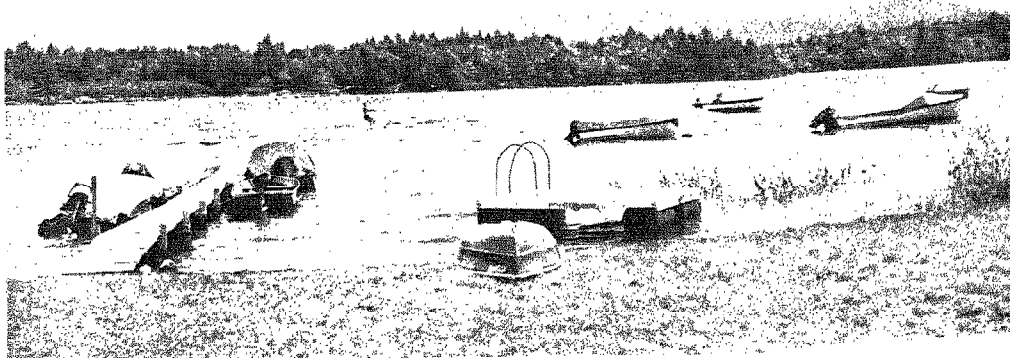
boating. Land-based recreation activities do not present much of a problem as long as the carrying capacity of the land is not overtaxed. Water-based recreation requires much closer scrutiny because it is often more detrimental to the water resource and is usually done by greater numbers of people.

WATERSHED WITH OPEN-DOOR POLICY

We have defined a watershed with an open door policy as one on which all forms of recreation are permitted under controlled conditions. Development or construction of facilities on the watershed must be reviewed and approved by a board or agency; most forms of recreation activities such as swimming, waterskiing, and camping are permitted at specified areas under proper supervision (fig. 1).

The most obvious problem one thinks of when discussing the watershed with an open-door policy is the need for up-graded water treatment facilities. The prime objective of the water-supply system is to provide an adequate supply of potable water; and if recreation is to be permitted, full treatment of the water will probably be necessary. In many cases, this amounts to increased levels of

Figure 1.—An open-door policy permits all forms of recreation on reservoirs under controlled or supervised conditions.



disinfection, new equipment, and possibly higher paid personnel to operate and maintain the equipment. What this all boils down to is a larger water-supply budget (*Price 1966*). An immediate side effect might be a change in water color or taste.

If a municipality permits all forms of controlled recreation on its water-supply reservoir, some form of recreation facility development will be required. Recreationists' needs will have to be accommodated by provision of facilities. Should toilet facilities be primitive or modern? How many and where should toilet facilities be placed? Who should pay for taking care of recreationists' needs on a municipal watershed? If the recreationist is to pay, how much should he pay and how will fees be collected?

All forms of controlled recreation include swimming and boating. Is the reservoir large enough to support a marina? Should power boats be allowed? If so, should horsepower limits be imposed? Should swimmers have a beach, change house, snack bar? What kind of recreation staff will be needed?

Not only will more money be needed to maintain an adequate and safe water supply, but recreation-facility developments and maintenance might put a heavy strain on present levels of municipal appropriations. Finally, under an open-door policy, the budget for recreation management might become greater than the water-supply management budget.

In addition to financial problems, a second set of problems arises in management. Consider the water purveyor suddenly becoming a team leader who must deal with people problems such as clogged toilets, drownings, or broken playground equipment. If he is not able or willing to take on the added responsibility, he will have to arrange for an assistant to handle the job. The water-supply superintendent must then be

careful not to permit recreation objectives to overwhelm the water-supply objectives of the organization (*Reigner 1965*).

The political attractiveness of a recreation program presents a very real threat to the primary objective of a water-supply system. Recreation personnel are liable to raise issues that conflict with the original purpose of a reservoir. Policy conflicts may be compounded by philosophies, background orientation, or personality conflicts that tend to detract from the organization's total program effectiveness.

Public-relations problems must also be considered by the reservoir manager. If a town decides that all forms of recreation will be allowed, the needs of the recreationist must be considered in every management decision. This new clientele desires such things as steady water levels, easy access, and some sort of a developed recreation program and facilities.

A midwestern water-supply superintendent provided an example of what happened when all forms of controlled recreation were permitted. He felt that water-supply objectives had become secondary to recreation objectives on a 3000 +-acre reservoir that served a community of nearly 15,000 residents. Three camping areas had been established. Some trailers were located less than 150 feet from the reservoir shoreline. The seasonal campers used buried 50-gallon drums to hold sanitary waste. The drums are supposedly pumped out once per week.

Lake frontage was leased around the lake, and construction of seasonal docks was allowed. Camps soon appeared all around the reservoir, and the lake's boat marina now has many empty slips. Road access to the new sites had been encouraged by providing gravel on trails hacked out of the woodland that surrounds much of the reservoir. Waste dis-

posal on these dispersed campsites was not controlled at all.

Recreational use of the reservoir provided some additional revenue to the city, and continued development seems imminent. In many instances advice and suggestions of the lake recreation supervisor are heeded by the city council over opposing views of the water-supply superintendent.

Despite these problems on the reservoir property, the water-supply superintendent hastened to point out that his major problem was with the landowners in the watershed. The estimated life of the 15-year-old reservoir is another 10 to 12 years, at which time siltation is expected to render it useless. If simple, and in many cases basic, soil-conservation measures were to be started immediately, the siltation problem could be decreased by 50 percent. Recreation problems, although very real, appeared to be a mere thorn in the side compared to the impending siltation of the lake.

On the plus side of the situation, the water-supply superintendent was confident that, when siltation finally caused abandonment of the present reservoir, the local populace would not hesitate to find another site for a new reservoir.

One opportunity available to managers of municipal watersheds that have an open-door policy is the expanded base of support for the water-management program. This support is often at the grass-roots level.

Managers sometimes have trouble stimulating interest on water management issues. As an example, the director of utilities for San Diego said that there had never been any negative reaction from the general public about their program — which, by the way, has as its main purpose “to maintain a high quality domestic (water) supply” (*Graham 1963*). “On the other hand”, he went on to say, “thousands of sportsmen are

boosters for the municipal water supply and its administration.”

As mentioned earlier, one of the problems associated with an open-door policy is that the watershed manager finds himself in a different ball game — different clientele, different sets of problems, different types of personnel, and different financial obligations. For the man that appreciates the challenge of managing a multidisciplinary team, an open-door policy can provide the opportunity of a lifetime to make a meaningful contribution to the well-being of his community. Chances are that he will be the only man in the community who has a real feel for the needs of safe and potable water (and all that that entails) and the many needs for a developing recreation program.

This opportunity may not be just the challenge of a lifetime for an individual: it may be the turning point in a water-supply organization's history from one of providing water to a dynamic multi-purpose service to the community. Under the proper supervision and administration, recreation may become a vehicle for improving a water-supply organization's financial status without indirectly detracting from a watershed's ability to produce high-quality water.

WATERSHED WITH CLOSED DOOR POLICY

In some cases a municipal watershed ecosystem will be unable to accommodate recreation activities. This could be so when funding for a modern water-treatment plant is not available or the watershed is in a geomorphic area of shallow or fragile soils.

The decision to prohibit all recreation on the watershed must be based on factual information. The watershed manager and the water-supply governing board must have valid justification for their decision. Citizen groups are active in many areas of the recreation field, and



Figure 2.—A closed door policy need not preclude all forms of outdoor recreation or educational activities such as nature walks.

any decisions to exclude recreation may come under very close scrutiny.

As long as population growth and the demands for water-oriented recreation space continue, the pressure for greater use of watershed areas will be a problem. Continued and strong justification will be needed to cope with the problem. The watershed-management staff should not attempt to do their own police work. Police enforcement should be handled by state and local groups. A significant element of expense will be incurred in the construction and maintenance of fences, road blocks, signs, and other facilities. A segment of people, hopefully small, may be expected to disobey the exclusion regulation.

By definition, a watershed with a closed-door policy on recreation should have no problems. But as we have pointed out, there are problems. There

are also opportunities. For instance, if people are truly kept out of an area, that area soon may become a refuge for wildlife. It may also be considered a natural area in which environmental monitoring can be carried out.

The reservoir itself provides an amenity that is difficult to price, but nevertheless has value. And herein lies an opportunity for the alert watershed manager to tell his story of why recreation would be detrimental to the well-being of the community. People seem to be more activated by signs that proclaim RECREATION PROHIBITED rather than by signs stating RECREATION PERMITTED, particularly if public land is involved.

An information booth located outside the watershed boundary, but still commanding a view of the reservoir and parts of the watershed, could inform interested citizens of the water problems as well as the values to be derived from not recreating inside the boundary. This may then become the starting point for a nature trail along the boundary edge (fig. 2).

WATERSHED WHERE SELECTED ACTIVITIES ARE PERMITTED

A watershed where selected activities are permitted is defined as one on which non-polluting recreation activities are permitted. These may include activities such as fishing from shore or from rowboats, hiking, and picnicking at designated areas away from the shoreline. Generally speaking, activities such as swimming, boating in sailboats or canoes that may capsize, powerboating, and other potentially polluting activities are prohibited (*Reigner and Ningard 1967*).

Any kind of access to a water-supply reservoir results in a chance of contamination. Most managers will do all they can to reduce or eliminate that chance. Therefore selected activities on a reser-

voir would be a strong incentive to provide water treatment. In a study of municipal water-supply areas in Maine, Monteith and Corcoran (1967) concluded "that institutional, political and social considerations probably weigh more heavily" than treatment considerations in the decision of whether or not to allow recreation on water-supply reservoirs. Bauman (1969) found a regional variation in recreational use of domestic water-supply reservoirs. Reservoirs in the South and mid-continent have policies that tend to permit recreation while those in the Northeast and far West have policies that tend to prohibit recreation. Foster (1961) felt that in Massachusetts "the chief barrier to the relaxation of restrictions governing public use of water supply reservoirs would appear to be, on the surface, not technological but legal." As Commissioner of the Massachusetts Department of Natural Resources he favored "voluntary sensible change", rather than "crisis action."

The problems encountered on areas that allow only selected recreation activities may not be much different from those that arise on areas that allow all forms of recreation or those that allow no recreation. If access is permitted on a watershed for selected activities, enforcement efforts are needed to prevent the visitor from engaging in excluded activities. For instance, bank fishing may be permitted, but boys have been known to "fall" into the water on a hot summer day. The big question then becomes: How many boys can be tolerated before pollution levels become dangerous?

In a review of five studies carried out between 1960 and 1967, Carswell et al (1969) described some of the problems encountered on watersheds that permitted selected types of recreation. Body contact with the water was prohibited in all cases. Shoreline litter was found,

ranging from bait containers to human defecation. Evidence was abundant that visitors abused the privilege of access by building illegal fires, cutting down trees, destroying signs and other property, and shooting up signs and other property (fig. 3). When administrators attempted to enforce rules of conduct, they were rebuffed by abusive visitors.

There are numerous opportunities available to the administrator of a watershed that permits selected activities. If body contact with the water is prohibited and the water purveyor can convince his superiors that full treatment is still necessary, he is assured on the latter half of his main objective — an adequate supply of pure water. Recre-

Figure 3.—Permission of access and selected activities on watersheds may result in an undue amount of vandalism, as evidenced by this badly mutilated tree.



ation seldom has an impact on the *adequacy* of a watershed's supply (*Gomez and Crane 1968*). If some recreation is allowed, the water purveyor should obtain the resources to carry out a public-relations program that will explain how recreation can be made compatible with water supply. This might go a long way in relieving some of the problems cited previously.

As with the watershed on which all forms of recreation are permitted, the watershed on which selected activities are permitted will probably have a broad base of support for its total program. This support often comes from the recreating public rather than from a few concerned citizens. A public-relations program would be the logical way to develop the broad base of support.

If the water-supply supervisor can successfully integrate water supply and recreation objectives, he can be a top-level municipal administrator who will have the advantage of experience over most of the elected officials in the administration. This experience and wisdom will be called on in many decision-making situations. We aren't sure whether this should be classed as an opportunity or as a problem!

CONCLUSIONS

Recreation may be common on many municipal watersheds by the year 2000. What forms of recreation and on which watersheds or reservoirs is hard to predict, but managers of municipal watersheds in the Northeast should be aware of the problems and opportunities that other managers have faced.

If a watershed has an open-door policy, the biggest problem the municipality may have to overcome is the increased burden that recreation puts on a fixed budget. The biggest problem the water-supply supervisor must overcome is to not allow his water-supply objec-

tives to become diluted by recreation objectives. The main benefit that recreation on municipal watersheds offers is the opportunity to provide a needed community service in addition to water supply.

If the decision is made to forbid all forms of recreation, then the management team should be ready to defend this decision before interested citizen groups. The management team should capitalize on the opportunity to explain the contribution the watershed and reservoir make to the community.

The greatest problems for managers of watersheds where selected recreation activities are permitted are money and rule enforcement. If money is made available for full treatment, then recreation might be considered the catalyst for safe water in the community.

It would seem that managers of municipal watersheds would gain money, time, and effort by preparing a working plan of what their watersheds and reservoirs can handle in the way of recreation. Contingency plans for the three possible alternatives should be developed. For instance, can the watershed handle an open-door policy? What would that cost in terms of additional water treatment and more or higher paid personnel? How would recreation objectives be integrated with water-supply objectives? Are the two objectives possible on the watershed, and, if so, can they be compatible?

If a water-supply governing board decides on a closed-door policy, what steps should the management team be prepared to take? Where are you likely to find support or opposition to a closed-door policy? How much effort will be needed to maintain or even enforce the policy?

The water-supply superintendent of a watershed on which selected recreation activities are permitted should ask him-

self all the above questions, because he will be faced with all of the problems. Why can't his reservoir handle the impact of an open-door policy? How much should that door be opened — halfway? three-quarters of the way? or just enough to permit land-based recreation such as hiking or bird-watching at some distance from the shoreline?

We suggest that water-supply managers prepare themselves to answer these questions.

Contingency plans should also include estimates of what full-treatment costs are now and will be 5 or 10 years from now. In preparation of each plan, questions such as these should be considered:

1. What level of pollutants is introduced to a system of a given size if recreation activity A or B or C is permitted?
2. Are these levels additive when introduced in combination?
3. What levels of investment in treatment facilities would be required to permit various levels of pollutants to be introduced with no ill effect on water quality?
4. Would the community pay for recreation on their watershed? Would the community pay for the additional treatment that would be required? Costs may include water color and taste as well as money.
5. Are there any alternatives to permitting recreation on a community's water-supply system? For example: construction of another reservoir for flood control and recreation (Wilson 1966)?

Answers to questions such as these, a knowledge of what the water-supply system can handle, and a more thorough understanding of the problems and opportunities of recreation on municipal watersheds will be needed by managers between now and the year 2000.

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SOIL CONSERVATION — A PARAMETER OF QUALITY WATER YIELDS

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ABSTRACT. Reviews (1) soil conservation methods used by landowners, (2) conservation objectives in small watershed projects, (3) conservation work in multicounty resource conservation and development projects, (4) the use of soil surveys as natural resource planning aids, and (5) a newly authorized system of land inventory and monitoring.

THE WORK of the Soil Conservation Service is of special importance to you who are concerned with managing municipal watersheds. Nearly two-thirds of America's land — even a higher percentage in the Northeast — is privately owned. How carefully this private land is used — how sediment from this land can be kept out of streams, bays, and reservoirs — is of extreme importance to municipal watershed managers. And SCS provides a nationally coordinated effort to control erosion and sedimentation on private land.

A brief history of the soil conservation movement may be helpful before discussing program, progress, and prospect.

It was in August 1933, during the depression and in the midst of the great drought, that this Nation initiated a program of soil conservation and erosion control. The Soil Conservation Act, enacted in April 1935 and later amended, established the Soil Conservation Serv-

ice in the Department of Agriculture, with authority to provide technical assistance, soil surveys, and other activities (*SCS 1973*).

A model soil conservation district law was distributed in draft form to the states in May 1936. The states were asked to enact the model law, permitting the creation of individual soil conservation districts. A district would have the power to develop a comprehensive erosion-control program and formulate tentative regulations governing land use. The struggle within the bureaucracy, the political climates within the states, the conservative orientation of farm leaders, and other circumstances constrained the early role of soil conservation districts (*Morgan 1965*). They chose to work with individual farmers to plan and apply conservation practices.

Now, some 37 years later, soil conservation districts blanket nearly the entire Nation. The Soil Conservation Service — which has about 13,000 employees

providing assistance in nearly 3,000 counties — has been given increasing authority and responsibility. Here are examples of work by the Soil Conservation Service (*USDA 1972*).

1. More than a million farmers or other landowners received technical help from SCS in 1972.
2. More than 26,000 agencies of state and local governments received assistance in 1972.
3. Assistance under the Small Watershed Program included completion of 29 projects, engineering on 11 more, starting construction on 41 projects, starting planning on 28 projects — a total of more than 1,000 projects in some stage of planning or construction.
4. The Great Plains Conservation Program, which covers parts of ten western states, has provided conservation contracts with about 42,000 farmers, covering more than 77 million acres.
5. Plant Material Centers released or registered six new plants for soil conservation use during 1972.
6. More than 42 million acres of land were soil-surveyed in 1972. A cumulative total of 40 percent of the entire nation has been surveyed.
7. Twenty-five new multicounty Resource Conservation and Development projects were authorized in 1972, making a total of 123 projects.

CHANGING TIMES

Questions began to develop about the earlier decision of soil conservation districts and the Soil Conservation Service to work almost exclusively with farmers to preserve and build basic productivity into the soil (*Held and Clawson 1965*).

Economic growth, technological advance, and — most important — the automobile started a migration from the farms to cities and, later in the 1950s

and 1960s, to the suburbs (*U.S. Census Bureau 1970*). Construction activity laid bare more than 1 million acres of land each year for long periods of time, causing dramatic erosion and subsequent sediment damage (*Berg 1973*).

The nation's number one pollutant, by volume and weight, is sediment. About half of it comes from cropland erosion; the other half comes from highways, streambanks, public lands, and suburban development.

The principal way that pesticides, plant nutrients, and infectious organisms leave the land and enter water bodies is by attachment to soil particles. Rough estimates of the suspended solid loading that reaches the Nation's streams from surface runoff shows these to be at least 700 times the loading caused by sewage discharge (*SCS 1972*).

Sediment yield from areas under construction activities are 10 to 2,000 times that of agricultural or forested areas (*USDA 1969*). After development, the increased runoff places additional burden on the drainage system, causing unprotected channels to become unstable; and erosion and sediment damage result.

Our study of the rate of silting of Lake Barcroft in Fairfax County, Virginia, showed that the watershed sediment yield from 1938 through 1957 was more than double that from 1915 through 1937. The increase was due mainly to areas left unprotected during construction. In 1957, two-thirds of the 15-square-mile watershed behind the Lake Barcroft Dam was urban, compared with the predominantly rural situation 20 years earlier (*Holeman and Geiger 1959*).

In 1967, the Wisconsin chapter of the Soil Conservation Society of America began a survey of roadside erosion in Wisconsin. The study showed that secondary roads accounted for 97 percent of all roadside erosion. Stabilization of

state roads generally rated excellent; they accounted for the other 3 percent (*Briggs 1970*).

It is estimated that there are 549,000 miles of streambanks in the United States that are subject to erosion. The more severe erosion on 148,000 miles of streambank is causing about 90 million dollars of damages each year (*Committee on Public Works 1969*).

Public land in the eastern United States is not considered a major erosion source or major contribution of sediment.

The future outlook is not good. Between now and the year 2000, we expect that building in and around the metropolitan areas will be equivalent to everything built in the 350 years since the English started colonizing North America (*Berg 1973*). Because of general ignorance of the land's capabilities, we as a nation are on the path to untold damage from sediment. The costly and ugly misuse of the land is distressing to more and more Americans. People are demanding legal action to control erosion and sedimentation.

STATE ACTIONS

Maryland was the first state to pass a statewide sediment-control program. The 1970 law requires that proposed earth changes be submitted to and approved by the appropriate soil conservation district. The counties and cities cannot issue a grading and building permit until the developer submits a grading and sediment-control plan approved by the appropriate soil conservation district and certifies that all work will be done pursuant to the plan. The counties and cities are given the enforcement responsibility (*Bowen 1972*).

Virginia has passed erosion and sediment-control legislation requiring adoption of standards and guidelines by the State Soil and Water Conservation Commission. Conservation district programs

must be consistent with the guidelines (*SCS 1973*).

The Iowa Conservation District Law, enacted in 1971, (1) created six conservancy districts, covering the entire state; (2) declared erosion a public nuisance if it results in sediment damage to the property of others; and (3) charged soil conservation districts with setting soil loss-limit regulations, along with receiving and acting upon landowners' complaints of sediment damage (*Cox 1972*).

A 1971 amendment to the Soil and Water Conservation Law of Illinois required that copies of proposals for variances to existing ordinances or for subdividing vacant or agricultural land be provided to soil and water conservation districts. The district has 30 days to submit a written opinion on the proposal (*Silliman 1972*).

Pennsylvania has established an Environmental Quality Board with responsibility for developing and implementing regulations for erosion and sediment control. The aim of a September 1972 regulation is to control accelerated erosion from land-disturbing activities. Erosion and sediment-control plans must be prepared by persons trained and experienced in the field. Guidelines, standards, and specifications have been provided by some soil conservation districts (*Sediment Committee 1972*). Others are expected to follow. The regulations include farmland and require erosion and sediment-control plans for all tilled land by 1 July, 1977.

The achievement of soil conservation districts and the technical quality Soil Conservation Service assistance is recognized. The National Association of Conservation Districts and the Council of State Governments are recommending a model state act for soil-erosion and sediment control. The model act would amend the state soil conservation districts law and would involve the state

soil conservation commissions and soil conservation districts.

The National Symposium on State Environmental Legislation held in Washington, D.C., in March 1972, adopted resolutions (1) supporting the placing of the responsibility for an erosion and sediment-control regulation program with conservation districts, and (2) suggesting that state sediment-control legislation should be in the form of amendments to existing enabling conservation district law.

LOOKING AHEAD

The Soil Conservation Service has developed a long-range plan to guide future efforts. In it, we focus on the task needed to improve and maintain resource-management systems so that they meet quality standards for current and long-term use. Along with other goals, the plan calls for broadening our activities in land inventory and monitoring (SCS 1971). The Rural Development Act of 1972 provided authority, under Section 302, for land-inventorying and monitoring activities.

In 1958 and again in 1967, the SCS, along with other agencies, conducted conservation-needs inventories on private land, state and local government land, federally owned cropland, and Indian land. Data on soils, land use, and conservation treatment were collected from about 170,000 statistically located random sample areas averaging about 170 acres each and covering nearly 29 million acres. These data were expanded to provide estimates for 1.4 billion acres of land.

Plans are to obtain data for the remaining 0.9 billion acres of federal and urban land. In addition, the basic data for all land will embrace other resource uses that decision-makers need to know about for planning the use of the nation's soil, water, and related resources.

Our studies show a need for knowing the location of prime farmland, wetland, flood plains, and critical eroding land, and for locating potential impoundment sites.

The question of where these are to be located can be answered by overlaying basic resource elements like soils, plant cover, land use, flood frequency, and topography. The collection and overlaying of these data will be done manually at the start. However, a program is proposed to include automatic storing, retrieving, and displaying of the results. We envision that a national report of the changing quality of resources will be issued at 5-year intervals; the first report is due in 1979. County, state, and regional reports on inventoried items or resource elements are expected at more frequent intervals. Of course, the data will be made available as collected.

In summary:

1. The control of erosion and sediment on private land is important to municipal watershed managers.
2. The work of the soil conservation districts and the Soil Conservation Service in controlling agricultural erosion and sediment is well recognized.
3. New state laws are requiring all land users to exercise greater control over erosion and sedimentation.
4. Conservation districts with SCS technical help are being given an important role under these new laws.
5. The National Association of Conservation Districts and the Council of State Governments are recommending a model state act for controlling erosion and sediment.
6. In a new program of land inventory and monitoring, under authority of the Rural Development Act of 1972, SCS envisions an expansion of collection of data on the condition of land and water resources.

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USE OF HERBICIDES IN TIMBER – AND RESERVOIR – MANAGEMENT PROGRAMS

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ABSTRACT. Herbicides *can* be used in timber- and reservoir-management programs. Knowledge of herbicides, application methods, timing, and nature of the area to be managed will enable the land manager to control and manage watershed vegetation with minimum contamination of water and minimum impact on the environment.

A LIMITED NUMBER of herbicides are registered for use on stream banks and around lakes, ponds, and streams. Other herbicides may be used in watershed areas for vegetation control and timber management if a suitable buffer strip is left between the treated area and the stream bank. The application of herbicides today is governed by label uses and restrictions, which are printed on the herbicide product label. Since most land is a watershed of some sort, there is room for some common sense in the interpretation of herbicide uses.

To help us make more enlightened choices on the use of a particular herbicide for a particular watershed use, I will first discuss methods of applying herbicides and their rates of disappearance, which are usually governed by the methods of dispersal or decomposition.

NO TWO ALIKE

At the outset we should be aware that no two herbicides are identical, and no two formulations are exactly identical. The physical and chemical characteristics of each specific herbicide will help us to determine where each may be used safely in a watershed environment with a minimum chance of environmental contamination.

The herbicides 2,4-D, diclorprop, 2,4, 5-T, and silvex are in a group of herbicides called the phenoxyacetic acids, also called phenoxies. In general, they have a short persistence in the soil. The phenoxy herbicides are usually applied to the foliage or stems of woody plants and certain annual and perennial broad-leaf species. They have little or no activity in the soil.

Two other herbicides — dicamba and picloram — have longer persistence in

the soil and may be applied to the foliage, stems, or soil to control woody plants. Other herbicides such as MSMA or TBA may be used in combination with the phenoxy herbicides for improved control of certain woody species. Dicamba and picloram are also usually applied in combination with a phenoxy herbicide. Bromacil, fenuron, and karbutilate are active through the soil only and are commonly applied as granular or pelleted treatments.

Laboratory studies by Altom and Stritzke on a forest soil from the Ouachita Highlands near Lamar, Oklahoma, indicated that the soil half-lives of four phenoxy herbicides, dicamba, and picloram were: 2,4-D, 5 days; dichlorprop, 12 days; 2,4,5-T, 24 days; silvex, 21 days; dicamba, 32 days; and picloram, greater than 100 days. Half-life on a grassland soil from the same location was shorter for each herbicide.

PRECAUTIONS NEEDED

When a herbicide is applied to a watershed area, precautions are normally taken to prevent it from getting into the runoff water. Herbicides can find their way into runoff water by airborne drift, surface runoff, or movement in the ground water. Drift is the physical movement of spray particles at the time of application. The particles are moved with the current of air into the adjacent bodies of water.

With certain herbicides there is also a possibility of herbicide contamination by volatilization or by wind erosion, but these are minor sources. Herbicide contamination by surface runoff refers to the movement of herbicides with suspended soil particles or on surface litter or by being dissolved or emulsified with actual surface runoff waters. When herbicides on the soil surface are leached into the ground, they may eventually reach the ground water. Loss of herbi-

cides by leaching will vary with the solubility of the particular herbicide and also the degree of adsorption on the soil. In addition to the nature of the herbicide itself, the nature of the surface litter, soil texture, and other factors will also affect the likelihood of groundwater contamination by herbicides.

The amount of herbicide available for contamination of the aquifer will of course be determined first of all by the total amount of herbicide applied per unit of surface area. Application techniques in which lower total amounts of herbicides are applied will offer less opportunity for contamination. In general, individual-stem applications such as basal sprays, tree injections, or spot sprays will apply less herbicide than broadcast or blanket sprays.

Another characteristic of herbicide sprays that may help to determine the contamination potential would be formulation. For example, the phenoxy herbicides may be formulated as esters, emulsifiable acids, oil-soluble amines, water-soluble amines, or water-soluble salts. The type of formulation used will be determined to a great degree by the method of application used. However, there is less contamination potential from certain formulations than from others. The phenoxy herbicides are generally synthesized as acids, which are usually dry crystalline solids. The acid itself may be dissolved in a suitable solvent, which may then be emulsified in water and used as a foliage spray or basal spray.

The acid may be combined with an amine. The resulting amine salt of a phenoxy acid is soluble in water. These water-soluble salts may be applied in water as foliage sprays or injected into the stem of the woody plant. A phenoxy acid may be reacted with an alcohol molecule to make an ester. Esters may be emulsified and used as foliage sprays

or may be diluted in oil and applied as basal sprays or injected into woody plant stems. Phenoxy esters may be classified as volatile or low-volatile, depending on the alcohol used in esterification.

Oil-soluble amines are a recent development in phenoxy formulation. They are made by combining certain non-water-soluble amine salts with a phenoxy acid. The resulting oil-soluble amine may be emulsified and applied as a foliage spray or used as a basal spray or injected into the woody plant stem. Since oil-soluble amines are not volatile, they combine the activity of an ester with the non-volatility of an amine salt. This reduces the possibility of environmental contamination by volatilization.

When using any herbicide near water, the most effective way to reduce or eliminate water contamination is to avoid direct application to the water surface. Studies by Norris indicate that this is the source of most water contamination by herbicides.

TECHNIQUES

Injection of herbicides with a tree injector or hatchet applicator uses little herbicide and gives almost no opportunity for stream contamination, even when used near a body of water. Basal sprays of dicamba, picloram, a phenoxy herbicide, or a combination of these in an oil carrier to the lower 18 to 24 inches of brush to be controlled are also very free of contamination potential. The backpack mistblower basal, which has recently been developed, does give more opportunity for droplets to escape the site of application, so a reasonable buffer strip should be left near water. Ground foliage sprays and aerial sprays require wider buffer strips between the application and the water's edge. Width of this strip will vary with wind direction, spray technique, and foliage den-

sity. Reasonable specifications should be developed for various spray techniques by the land manager.

Drift control agents, such as inverters, foams, thickeners, and the new polymers should be used with properly designed equipment to increase droplet size of herbicide sprays and improve targeting of spray applications. Pelleted herbicides do not drift, but may contaminate in areas with a high water table or when used on steep slopes adjacent to streams or reservoirs.

Norris made the following observations for the land manager concerned with the planning and use of herbicides:

1. Herbicides can be used safely in the forest in most instances.
2. Avoid the treatment of areas which have a high water table.
3. When operating in areas which are particularly sensitive from a biologic or public relations standpoint, stream contamination can be held to an absolute minimum by recognizing and avoiding those situations which lead to direct application to streams or surface water.

Herbicides *can* be used in timber- and reservoir-management programs. Knowledge of application methods, herbicides, timing, and nature of the area to be managed will enable the land manager to control and manage watershed vegetation with minimum contamination of water and minimum impact on the environment.

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MULTIPLE USE ON MUNICIPAL WATERSHEDS? ONE WAY TO FIND AN ANSWER

by DAVID P. WORLEY, *Project Leader in Economics of Timber Growing,
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ABSTRACT. A sampling of the pressures for various multiple-use activities shows the complex situations created by multiple-use management, the concerns that municipal watershed managers should have, and the importance of preplanning, with particular reference to facilities shared by all the uses eventually selected as the watershed's multiple-use package. A five-step approach is described and illustrated by example for selecting multiple-use activities to feature and for adjusting a package of activities to match the funds available for shared facilities.

THE YAHOO Municipal Water Company owns most of its watershed and has locked it up for many years. Willy Watershedmanager checks the gates to the fire road frequently and renews the NO TRESPASSING signs whenever they are torn off or rotted in place. Willy is well satisfied with conditions as they are. The water quantity and quality he delivers from company reservoirs are both satisfactory. The board of directors is happy, and his pay check, although too small, is adequate and regular and on time.

Ophelia Outdoorsportenthusiast parked her pickup truck at one end of a bridge that spans a company reservoir and walked onto the bridge to look at the water. She noticed bass rolling to the surface after flies and wondered what harm a little fly fishing would do. Her husband made an issue of fishing in the Yahoo Municipal Water Company reser-

voir at the next Isaak Walton Club meeting. Her daughter Cathy pictured herself waterskiing under the bridge, waving to her boyfriend on the bridge, who was intently watching her every graceful move. Cathy talked about waterskiing at the Girls' Athletic Association meeting in high school.

Billy Boyscoutleader wandered onto company land between a couple of missing signs and walked down to an oak grove near the water's edge. What an ideal spot for an overnight scout camp; good place to put in canoes too, he thought. He raised the question at the next district scout meeting.

Annie Ardentbirdwatcher trespassed onto company land at the same place and saw a pileated woodpecker and a snowy owl; both were the first she had seen in years. She reflected that a few nature trails on the watershed would enhance the community. She suggested

the desirability of such trails at the next Birdwatcher's Club meeting and at the Flower and Garden Club meeting, as well.

Sam Squirrelhunter entered company land via a steep narrow valley where he couldn't see the NO TRESPASSING signs. He found some turkey scratchings and active squirrel-den trees where the oaks and hickories merged into the beech and maple. Why is this area closed to hunting?, he thought. He asked this question at the Sportsman's Club meeting later in the week.

Fred Furnituremanufacturer, who was with Sam, didn't say a thing, but duly noted the big maples and black cherry in the upper hollows. He waited to talk about these trees to Shorty Sawmiller over lunch the next day.

As far as the Yahoo Water Company and Willy Watershedmanager are concerned, the fat's in the fire. Multiple use has caught up with him and his watershed. Sooner or later one or more of these demands are going to hit the stodgy old water company like an avalanche. Eventually, either the Yahoo Municipal Water Company is going to plan for these kinds of policy changes and move successfully when the demands become evident, or the company may be forced to move precipitously and maybe disastrously if they wait till the demand overwhelms their ability to resist. Water companies must expect social pressures to demand much less limited use of their watershed properties.

MULTIPLE-USE CONCERNS OF WATERSHED MANAGERS

Ordinarily the watershed manager's primary goal is to deliver predictable quantities of water to meet specific quality standards for urban communities. When this isn't done, the rest of the water company's operations become difficult. Often the manager can't do much

about water quantity except to predict how much is likely to be available and to keep a record of water stocks on hand. On the other hand, the standard procedure for dealing with water quality has often been to keep human activity on the watershed to a minimum. Furthermore, additional uses of the watershed introduce risks and uncertainties that challenges the manager's primary responsibility.

Other presentations at this symposium and in watershed-management literature tell us that on a finite watershed, water quantity and temporal distribution are altered significantly only by large-scale and drastic manipulation of vegetation. Such vegetation changes are unlikely to occur on municipal watersheds in the Northeast as a result of the kinds of outside use pressures already described. They can be expected only from a deliberate attempt to increase water yields.

We also know that water quality is subject to deterioration by human activity and by the facilities required to serve the people for the variety of uses being considered. Probably the most important facility is roads for access appropriate to the various uses.

Roads for access need to be planned for all possible uses at the outset so as to be part of the whole multiple-use watershed-management system. Parts of the whole system needed for a particular use can be implemented when the demand for that use becomes great enough to justify its implementation. Failure to do this overall planning job in the first place may result in inordinately high costs and increased water-quality risks brought about by creating redundant facilities. A road system, for example, may be designed to provide access for several uses on a shared basis if prior planning is done carefully. In the absence of such planning, a separate access road may be needed for each use. The

lack of planning in this case would increase the mileage of road, thereby increasing risks to water quality and increasing road costs. Long-range planning is the answer to these problems.

When confronted with other uses on the municipal watershed, the water company and the watershed manager have justifiable apprehensions about their ability to manage for these foreign uses. How many people can I have on a nature trail at one time, and how do I control them? Is there really enough wildlife-habitat potential on the watershed to justify habitat management and hunting? Will the potential income from the timber be worth the time and trouble to manage for timber production? Will the net returns from timber be large enough to really mean anything to the water company income statement and balance sheet? Should we open up this multiple-use can of worms for good will, or as protection from or control of the inevitable? What might we expect in the way of capital costs and management expenditures? What chance do we have of recovering money outlays? If multiple use is going to be expensive, who will pay? Is it cheaper to stand and fight the enforcement and legal battles to keep the status quo, or to plan and implement multiple use?

AN APPROACH FOR DECIDING ABOUT MULTIPLE USE

The demands and problems surfaced here pinpoint a clear need to develop the kinds and mixes of multiple uses appropriate to a particular municipal watershed in a direct and systematic manner. Five procedural steps will be discussed which are designed as a planning framework for executives to use (1) to decide if multiple use is viable, and if so, (2) to channel resources to those uses that offer a worthwhile potential, (fig. 1).

Define and Describe Each Activity

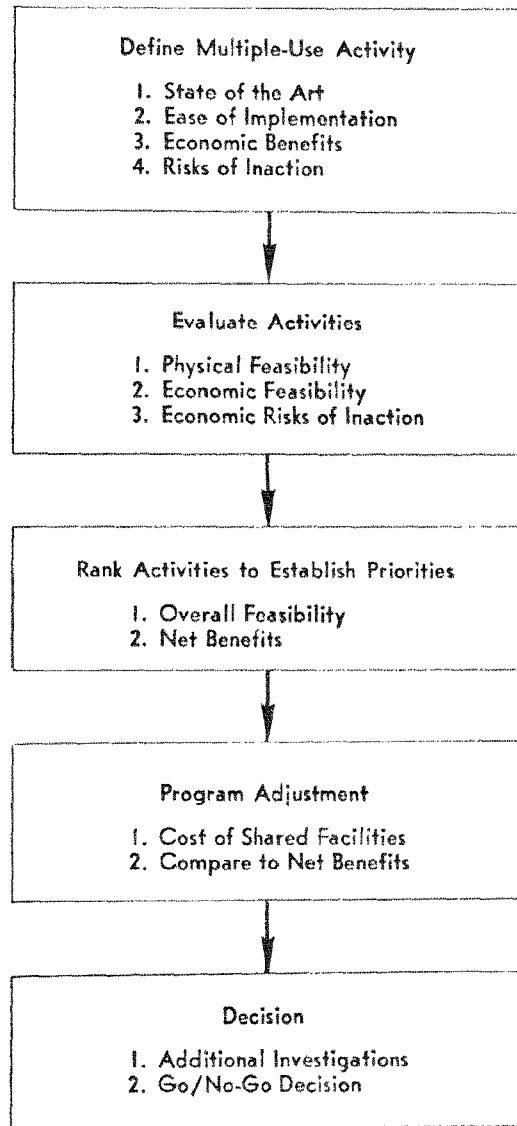
The first step is to describe each multiple-use activity as a discrete package. A description statement includes a name for the activity followed by a description that should answer the relevant who, what, when, why, and where questions. Then estimates of feasibility elements for the activity that will be used in evaluation are posted. Table 1 shows a format for displaying this information. The timber-management sample featured will be followed through the whole procedure.

An assessment of *state of the art* requires judgments about the technical problems that may be encountered, as well as the availability of technical skills and the market context in which this multiple use will have to operate successfully. In this case, state of the art was judged high because ample research and precedent indicate that such a program can be undertaken without jeopardizing watershed objectives, is within the state of the art, and that arrangements can be made readily for technical help and markets.

Ease of implementation requires a certain amount of introspection. How much trouble will our company have getting there from here? Compatibility with existing philosophies and procedures is important, together with the amount of effort to do an effective job and its appropriateness as to use of company land. Our example contains a low rating for ease of implementation mainly because this will be a radical departure in historical patterns and operating philosophy.

Economic benefits must be estimated according to company planning criteria. The suggestion in our example is that identifiable benefits be estimated for a 10-year period and discounted to the present at 6 percent. As part of the economic-benefit analysis, costs are dis-

Figure 1.—Steps for deciding about multiple use.



The system illustrated in figure 1 was adapted and expanded from an article by Logan M. Cheek, (Cost effectiveness comes to the personal function, Harvard Bus. Rev. 51 [3] : 96-105, 1973.)

Table 1.—Multiple-use activity description

Multiple use name: Timber management

Description: Manage timber to promote timber production and other uses on the 10,000 acres of the watershed away from hazard areas. Begin 1974 and continue.¹

Feasibility:				
State of art	High		Moderate	Low
Ease of implementing	High		Moderate	Low
Economic benefits	High		Moderate	Low
Identifiable benefits	Potential impact	Probability of occurrence	Probable impact	Probable net benefits ³
1. Potential timber returns ²	\$40,000/yr.	0.80	\$32,000/yr.	\$235,000
Total				\$235,000
Identifiable costs				
1. Timber mgt. costs ⁴	\$10,000/yr.	1.00	\$10,000/yr.	\$ 73,600
2. Water quality monitor ⁵	5,000/yr.	0.50	\$ 2,500/yr.	18,400
Total				\$ 92,000
Probable present net benefits	B/C ratio 2.5		Net	\$143,000

Intangible benefits: 1. possible minor increase in water yield.

2. possible reduced chance of catastrophe, i.e. fire, insects, diseases.

3. possible increase in vegetation management flexibility for future.⁶

Economic risks of not acting:

Tree cutting and planting necessary for any other use. Probability of sustaining other uses without a systematic timber overstory management program is low.

Assumptions: Make assumptions, sideboards, calculations explicit.

¹200 feet from lakes and stream channels to minimize water quality hazards.

²Timber returns abstracted from research literature and precedents on other lands. Variety of local markets exist. Amount of returns depends on careful marketing.

³6% discounted costs and values for 10 year period.

⁴Based on engaging forestry agent for planning and implementing.

⁵Expect to monitor water quality till timber management side effects are known then to record quality for other departments.

⁶Research results in other fields suggest these are possible but they aren't quantified or altogether firm.

counted in a similar fashion. Allowances are made for probability of occurrence. In the example, some of the land might be located so that the potential impact might not be realized. Water-quality monitoring costs might not need to be incurred over the whole period at the intensity suggested, but engaging a forestry agent is a 100-percent requirement. Identifiable benefits and costs are treated to produce a benefit/cost ratio and an estimate of present net value. The magnitude of the latter is a basis for estimating economic benefits and judging the desirability of spending money for this activity.

A place is left on this form for recording intangible benefits. This is intended to give the executive a feel for the qualitative side effects of a favorable decision. Whether this statement becomes any more than rhetoric depends upon both the care with which it is recorded and the attention the executive pays to such items. These two attitudes are likely to go hand in hand. Later on we will make more use of the intangible-benefit item. The intangible-benefit statement is not intended to be a springboard for the last evaluated item, *Risks of inaction*, which needs to stand by itself.

The point made in our example about risks of inaction is that only through a systematic program of timber overstory management can we expect to sustain the vegetation requirements for a variety of uses. The risk of not acting in this regard was rated high.

Finally, there is a section on the form called *Assumptions*. It is included for making explicit the key assumptions that underlie the description. Though it is filled out in abbreviated fashion in table 1, the abbreviations point to the intent. Without careful and explicit treatment of the assumptions, the description elements become mere assertions. But when filled out appropriately, assumptions indicate to the executive the length of thought given to each consideration. An executive can decide if the presented depth of thought is adequate for the particular planning stage for which the form was submitted.

Our example is brief; the assumptions are general. Such depth may be appropriate at an early stage of planning, but certainly not at a stage of planning when final go/no-go decisions are imminent. It is envisioned that the system be implemented at each of the different stages of planning from a general initial proposal to the comprehensive background needed for the final decision. Table formats may be similar for all stages, the main difference between stages being the depth of information developed, which is described in the assumptions section.

Standards are needed to help guide the rating of these feasibility elements and as a focal point for assumptions relating to them. Though standards need to be written, they should be considered flexible guidelines to orient the thinking of the person actually making the appraisal and as a basis for feedback from those who actually make the decision. Table 2 presents a set of general guidelines or standards for rating the elements. Of

course, every company has its own requirements, so it is hoped that the guidelines in table 2 will help individual companies draw up their own guidelines.

Evaluate Activities

The second step is designed to form an estimate of how good a bet this particular activity is for the municipal water company. Table 3 shows that we draw heavily on the information developed in the first step and use it to judge (1) physical feasibility, (2) economic feasibility, and (3) the risks of inaction. The table is in the form of a decision table so that the activity can be characterized at each step as to whether it is an (1) excellent, (2) good, (3) fair, or (4) poor activity for the particular watershed.

Table 3 is structured so that it is tested for physical feasibility first. The results of this test enter into the test for economic feasibility etc. Activities judged poor at any stage of the process are withdrawn from further consideration. They won't disappear from sight because we will record them later to account for them.

It is clear from the table that it really takes a high-class proposal to have a final rating of *excellent*. Though the first feasibility test is a little generous with the excellent rating, by the time we get through the drill, everything has to be superior for a proposal to rate excellent. Conversely, combinations of moderate and low in the first feasibility test lead to many *fair* feasibility ratings, but only one *good* rating. By the time we complete the whole rating schedule, there are more *goods* occupying the body of the table than *fairs*.

As we trace our timber-management example through the form, we find that our two high ratings and one low rating from table 1 lead us to judge this as a good alternative, not an excellent one. If both the physical feasibility elements

Table 2.—Standards for multiple-use activity statement

Descriptive grade	Feasibility		Criteria	
	State of the art	Ease of implementation	Economic benefits	Economic risks
High	1. Can be conducted without jeopardizing primary watershed objectives. 2. Appears simple. 3. Adequate research, precedent and/or arrangements make outcome highly probable. 4. Expertise available in-house or easily contracted. 5. Market (demand) appropriate to potential scale of supply. 6. New technology not likely to render obsolete in near future.	1. Little or no extra effort required. 2. Compatible with existing in-house equipment procedures and operating philosophy. 3. An in-house cost competitive job is feasible. 4. Annual maintenance procedures likely small and to come at a convenient time. 5. Spatial efficiency easy to achieve.	1. Present net estimated benefits over year period at percent exceed \$	1. Political risks of inaction likely to be costly. 2. Physical risks of inaction likely to alter costs of fulfilling water quantity and/or quality. 3. High costs of outside alternatives to achieve demands.
Moderate	1. Minor risks of compromising watershed objectives involved but can be overcome easily. 2. Appears complex but can be visualized to conclusion. 3. Some research or precedent or arrangements make predicted outcome credible. 4. Specialists required are available. 5. Market relations unclear, perhaps difficult to control. 6. Changing technology unlikely to make investment obsolete but may affect operations.	1. A modest new effort will be required. 2. Some operating changes foreseen, but not disruptive in nature. 3. Getting a cost-competitive job likely to be possible with present contacts. 4. Annual maintenance and management procedures may require extra effort but not a serious inconvenience.	1. Present net estimated benefits over years at percent between \$ and \$	1. Political, physical, or economic risks of inaction present but not imminent or substantial. 2. Other outside alternatives to achieve needs available at comparable cost.

1. Major risks to watershed objectives envisioned, which may be difficult to correct. 2. Appears complex; unfamiliar effort involved. 3. Little to go on, so low probability that outcome as predicted. 4. Competent technical advice scarce and expensive. 5. Scale of potential supply too large or too small for market, with attendant problems. 6. New technology likely to require major changes in current feasible efforts.	1. Substantial new procedures required. 2. Radical departures from historical practices require major changes in equipment, procedures, or operating philosophy. 3. Outside contracts required to get cost-competitive job are difficult to negotiate. 4. Annual maintenance procedures likely to be source of considerable inconvenience. 5. Spatially possible but inefficient.	1. Present net estimated benefits over . . . years at . . . percent less than \$	1. Political, economic, or physical risks of inaction inconsequential. 2. Other outside alternatives to satisfy demands available at lower cost.
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Low

Table 3.—Multiple-use activity evaluation form

Alternative name: Timber management

Description summary:

State of art	high
Ease of implementing	low
Economic benefits	high
Economic risks	high

1. PHYSICAL FEASIBILITY		Ease of implementation		
State of art		High	Moderate	Low
High		Excellent	Excellent	Fair
Moderate		Excellent	Good	Fair
Low		Fair	Fair	Poor
2. ECONOMIC FEASIBILITY		Probable net economic benefits		
Physical feasibility		High	Moderate	Low
Excellent		Excellent	Good	Fair
Good		Excellent	Good	Fair
Fair		Fair	Fair	Poor
3. ECONOMIC RISKS OF INACTION		Economic risks of inaction		
Economic feasibility		High	Moderate	Low
Excellent		Excellent	Good	Good
Good		Good	Good	Fair
Fair		Good	Fair	Poor
4. OTHER NOTES BROUGHT FORWARD				
Net economic benefit—dollars		\$143,000		
Economic risks. Other uses require systematic timber mgt. to be effectively sustained.				
Benefit-cost ratio		2.5		

had been rated low, our rating at that stage would have been poor and we would go no farther in our rating.

The importance of doing an effective, objective, and thorough job at each step is becoming apparent at this early stage. Each step builds on the previous step, and any errors are compounded as we go along. It is becoming apparent too that each watershed will have a tailor-made evaluation for each activity. An activity that might rate excellent on some watersheds may fall out of serious contention on others.

Finally, other items are brought forward from the first form for later use in ranking the activities.

Rank the Activities

After each activity has been evaluated on its own merits, it needs to be classified with others to generate alternative multiple-use packages. A convenient way of doing this is shown in table 4. First the activities are ranked according to their overall feasibility. The net benefits and benefit-cost ratios are posted, and priorities are assigned. In our example the priorities don't exactly follow the feasibility ratings. Potential net benefits influence the priorities. Here, for example, if the water company wants to generate any land-based multiple-use program, it must recognize timber management early in the game because it

Table 4.—Multiple-use activities ranked for program development

Alternative ranking; overall feasibility	\$ Net benefits	Benefit-cost ratio	Priority
Excellent			
Fishing and boating	25,000	1.3	1
Organization camping and picnicking	7,300	1.1	3
Good			
Timber management	110,000 ¹	2.1	2
Public camp and picnic area	(15,000) ²	—	4
Fair			
Wildlife management and hunting	34,000	3.2	5
Nature trails	1,100	1.1	6
Poor			
Public trail camp	(500)	—	7
Total	161,900		

¹Requirements for wildlife management and nature trails induce timber opportunity costs of \$33,000 which is accounted for here. For packages not using these activities net benefits are \$143,000 and the benefit/cost is 2.5.

²Benefits in brackets are negative.

will provide a dollar base for shared facilities. Those activities ranked poor in feasibility are shown. They can be included if the intangible benefits or the risks of inaction are high enough and if the package net benefits are large enough to afford them.

Conversely, if the water company is in an austerity period, or if budget limits the package, other additional activities can be cut. The activity ranking becomes the basis for allocating resources. For example, here we have estimated the lowest net benefits to accrue from a package of these multiple uses. By cutting negative benefit activities we could generate a highest figure of \$177,500. Other combinations could be evaluated for potential net benefits as well. This information becomes a basis for adjusting the multiple-use program so that a match can be achieved with the costs of shared facilities.

Adjust the Program to Fit

In this step we seek to match the estimated net benefits with the costs of

shared facilities. For our purposes, only access costs will be considered, and it is assumed that all other costs have been figured into the net benefits for each activity. Access requirements involve a permanent road network connecting the various activity sites. Entrance provisions are needed for some activities such as camping and picnicking. Area is needed for dispersed activities such as timber and wildlife management.

For the 20,000-acre example area, these may be specified as in table 5. The cost calculations in table 5 proceed in a straightforward manner from left to right. Costs of the special facilities that depend on the road network for the package can be plowed back into the activity costs if this is likely to cause a change in the multiple-use package. A new net benefit and benefit-cost ratio can be calculated, resulting in a new estimate of total net benefits to be matched with only the permanent road-network costs.

The general costs used here may be appropriate in the early phases of deciding whether to go into certain uses

Table 5.—Costs of shared facilities

Cost item	Multiple-use activity	Miles or units	Cost/unit ^a	Total cost
Permanent road network	All	10	\$8,000	\$ 80,000
Special roads and trails	Fishing and boating entrance	0.2	8,000	1,600
dependent on permanent road network	Timber-management truck trails	3	2,000	6,000
	skid trails	6	1,000	6,000
	loading areas	3	500	1,500
	Organization camp entrance	0.5	8,000	4,000
	Public camp entrance	0.8	8,000	6,400
Total estimated construction costs		—	—	105,500
Road location and engineering planning @ 15%		—	—	15,825
Total		—	—	\$121,325

^aIncludes discounted allowances for maintenance for a decade.

at all. If a decision is made to investigate in more detail, then engineering planning costs must be undertaken to get a better construction-cost figure. This parallels the philosophy used in activity specification that, when the actual investment decision is close, sound technical information is required to zero in on the problems encountered. Planning costs enter into the total here as they did in the timber-management example.

Decision

Will the water company spend \$120,000 for an estimated \$160,000 of present net benefits? This depends largely on the company and whether it will accept a 1.33 benefit-cost ratio as an adequate margin for investment under these circumstances. An affirmative answer at the early stage of decision-making in our example will probably indicate management's willingness to make the next planning investment to tighten up the information in the system so top management feels they are on firm ground rather than in dreamville. A succession of these rounds will eventually lead to a decision one way or another. In the meantime the watershed

manager and executive management have a common ground for communication. The system may need to be altered in the consecutive rounds of investigation so that the executives have the specific local information they need and can feed back in a fashion that reflects their concerns about the place of watershed management in the total enterprise.

CONCLUSION

Multiple-use management is inevitable on many of our municipal watersheds in the Northeast. At first glance it seems incredibly complex to a watershed manager who is used to managing for a single use. But these complexities fall apart when the multiple uses are subjected one by one to a systematic evaluation and recommendation. The one described here is one of many that can be found in textbooks on decision theory. Any general system found in textbooks or articles needs to be adapted to fit the problem and local circumstances as Logan M. Cheek's system used here was adapted and expanded from his original. It is hoped that this acts as a point of departure for your own search for and recognition of a systematic approach to multiple use on municipal watersheds.

STATE TECHNICAL ASSISTANCE PROGRAMS

by ALFRED DARRACH, *Hydrologist, Northeastern Area, State and Private Forestry, U.S. Forest Service, Upper Darby, Pennsylvania.*

ABSTRACT. Discussions with representatives of the 12 Northeastern States showed that each State provides some technical assistance for municipal watershed management. The State Forester supplies technical help on forested land. Other State agencies concentrate on public health, fish and wildlife, ground water, and law enforcement. It was also found that few State Foresters feel that an intensive municipal watershed program is needed. The present response-type program now used by most State Foresters to assist municipal watershed management seems destined to continue at present levels, unless more funds are made available for an intensified effort. Few States are attempting to handle municipal watershed problems beyond the limits of the municipal watershed ownership. Almost none of the States have set up goals and their corresponding objectives for a municipal watershed program.

IN THIS SYMPOSIUM we have made an effort to identify the elements of management that affect water quality. In addition, we have explored current practices and operational procedures presently in use on municipal watersheds. Various management considerations of potable water quality, recreation, herbicides, and multiple use on these ownerships have been reviewed. Now consider the help that is provided to municipal watershed managers through state technical assistance programs.

STATE FORESTERS INTERVIEWED

I consulted with the offices of 12 state foresters from Maine to Delaware and westward to West Virginia to evaluate these assistance programs. In the course of our discussions, several interesting facts came to light.

- All twelve states provide some technical assistance, usually for municipal watersheds that do not have the service of a forester.
- Considerable assistance is available to the municipal watersheds from state institutions other than the state forester. Much of this assistance, however, is not oriented to management of vegetation. The institutions most often mentioned were those that were concerned with public health, fish and wildlife, groundwater, geology, and enforcement of law.
- Of the state foresters interviewed, over 70 percent could not envision a need for an intensive municipal watershed program.
- There is a general intent to continue the type of service now offered. A more direct and specialized program

will not be undertaken by most state foresters.

Discussions about technical assistance yielded some general but useful bits of knowledge.

For instance, only 25 percent of the states considered that their technical assistance is specially geared to watershed needs. Generally the assistance given is of the CFM (Cooperative Forest Management) type, and only upon request. Ownerships visited were predominantly public, but some private property is serviced. Many types of help are provided, ranging from management plans to cruising and marketing forest products. In all cases, the blanket service of fire and insect and disease protection is available. Unfortunately, limited assistance or no assistance at all is offered in hydrology. The time allotted to each cooperator for services varies, but generally ranges from 2 to 5 days per year. The length of service time appears to be under re-evaluation in some states to spread the assistance available and still stay within increasingly limited budget and manpower constraints.

In a broader outlook, only one state mentioned giving special attention to watershed-management problems associated with private forest lands within the physical limits of a municipal watershed. More encouraging, 25 percent of the states have set or are setting goals for municipal watershed management. Fewer than 17 percent have set objectives for such a program. It was also found that about half of the states have lists of municipal watersheds; the remainder have partial information or none at all.

Two and possibly three states may expand their municipal watershed programs, but only on a request basis. If financial help, training, and technical assistance are provided by the state or federal government, increased manage-

ment effort could be expected on municipal watersheds.

DISCUSSION

At present, most of the technical assistance for municipal watersheds is provided to municipalities that are not able to provide this for themselves. The effort to date has been largely on a request basis and appears to be continuing on this basis. The assistance provided is really little more than general forest management with a watershed flavor. Possibly this is all that is needed today. Things could change, however, if increased use of these lands is wanted by the public. Better technology may become a necessity. There is little indication that the present general program will become specialized and aimed specifically at municipal watersheds, unless the public demands this service. In either the absence or presence of public demand, funds would be needed to expand and concentrate the technical-assistance.

A recent example of a state response to a municipal watershed need serves to emphasize what may be coming. Technical assistance given on the Thurmont Municipal Watershed, north of Frederick, Maryland, illustrates one type of service a state forester may be called upon to provide. In this case, a watershed specialist and the district forester worked together to produce a multiple-use management plan for the property and guidelines for intended logging.

Information about timber value, recreation potential, and water yield and quality was provided to the town fathers. Logging took place, and no lowering of water quality was experienced, even though the site of the timber sale was along the main watercourse and terminated within a few feet of the town's water intake. Great care was exercised during the operation to prevent erosion and sediment. In addition, trees were

left along the stream to shade the water and hold the banks. Finally, there was a return of \$32,000 for the wood sold. This single sale paid half of the original cost of the entire property. Good technical advice and assistance from a qualified team provided by the state forester paid off for Thurmont, Md.

There are some elements of a municipal watershed program that appear to have been neglected by the state foresters. Two of the key items involved are goals and objectives. To date, few states have seen a need for these, probably because no real municipal watershed program exists. Much confusion and wasted effort associated with existing programs and municipal watershed assistance can be alleviated by setting program goals and objectives. Some of the advantages to setting these are a better apportionment of technically trained manpower to help reduce or remove existing workloads, and the coordination of the state foresters' efforts with those of other state and federal agencies. In addition, properly selected objectives can serve as a measure of success or failure of any effort made.

In my discussions with the several state foresters, I have noticed a concern for the finite and little evaluation of the broad picture. Planning is fast becoming a real and usable science over vast land areas. We can no longer proceed down various paths without coordination and mutual cooperation of many agencies and technologies. Land-use planning will have a profound effect on the type of assistance given by watershed foresters of the future.

For instance, there could be an operational plan to protect aquifer recharge zones critical to municipal water supply in a distant city. Forests may be encouraged along streams to stabilize banks, reduce temperatures, and improve oxygen levels of the state's water. Buffer zones could be set aside to pre-

vent sediment from entering and polluting the water supply.

These problems are usually associated with property owners. They are broad public problems that are getting more attention each day. It is for these compelling reasons, among others, that a set of goals and objectives should be developed for municipal-watershed management. Whenever a forester makes a set of recommendations or assists a landowner, he would do a better job for both his customer and his state if he knew in advance what the landowner's management goals and objectives are for the area involved.

Another point worth pondering is that laws about how land can be used or what constitutes a public area of concern have shifted sharply in the last few years. A well-thought-out set of goals and objectives would assist a state forester in constructive response to any given legislative effort.

AN EXAMPLE

You may be interested in a New England city's recent predicament and the service rendered to help alleviate the problem.

Adjacent to the municipal watershed, a builder proposed constructing a series of condominiums. A septic system was to have provided sewage treatment. Naturally, the city was concerned with its water supply and possible contamination. A new state law provided the municipality with a means of protecting its interest in clean water, but technical help was needed to evaluate the problem and state the city's case.

The State Forester responded to the city needs and request for help. Unable to supply a forest hydrologist of its own, the state asked for federal help. On-the-ground inspections were made and reported. An expert witness was provided at a hearing to assist the city during litigation.

This action resulted in a precedent-setting decision for the city. A potentially dangerous land use was successfully prevented before damage was done. A team effort protected the public interest. This time it was a city, state, and federal response.

RECOMMENDATIONS

In conclusion, I feel that state technical assistance on municipal watersheds as it exists now is passive. There is reaction to a call rather than action for a cause. To improve this condition and hasten an effective municipal watershed program, I suggest the following:

- Each state forester should have a set of coordinated goals and objectives for municipal watersheds in his state.
 - There should be federal and state cooperation in developing needed watershed programs and the necessary financial support.
 - Forest Service hydrologists and other available technologists should be made available to train state personnel upon request.
 - The Forest Service, the universities, and state agencies must help provide suitable guidelines and management procedures for use in watershed management.
 - Symposiums to exchange ideas and procedures need to be continued by the state universities.
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SUMMARY OF MUNICIPAL WATERSHED MANAGEMENT SURVEYS IN THE EASTERN UNITED STATES

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ABSTRACT. The U.S. Forest Service conducted two municipal watershed management surveys in the eastern United States, using mailed questionnaires, to (1) determine the importance of surface water supplies, (2) inventory the land uses allowed in these watersheds, (3) inventory the nature and extent of various land-management problems related to water supplies, and (4) determine what information and management practices are needed to improve watershed management and water supplies.

THE U.S. FOREST SERVICE, through its Northeastern and Southeastern Forest Experiment Stations and the Southeastern Area Office for State and Private Forestry, conducted two municipal-watershed-management surveys in the eastern United States, in the Northeast in 1968 and in the Southeast in 1972 (fig. 1). The Southeastern study also included Arkansas, Louisiana, Oklahoma, and Texas; but for the purposes of this summary only those states east of the Mississippi River are included.

Both studies had basically the same objectives: (1) to inventory the land uses allowed in municipal watersheds; (2) to inventory the nature and extent of various land-management problems in these watersheds; and (3) to determine what information, research, and types

of management practices are needed to improve the management of municipal watersheds.

Different definitions of a municipal watershed were used in the two surveys, and this influenced some of the results. In the Southeast, a municipal watershed was defined as *any* watershed that supplied surface water to a community, whether or not any portion of the watershed was owned or controlled by a water-supply agency (fig. 2). In the Northeast, a municipal watershed was defined as one in which a water-supply agency owned land and "the primary function is to provide domestic water supplies, whether in public or private ownership, including protection land surrounding reservoirs and forest land managed for the protection of well fields and their

Figure 1.—The areas for which municipal watershed management was surveyed and summarized.

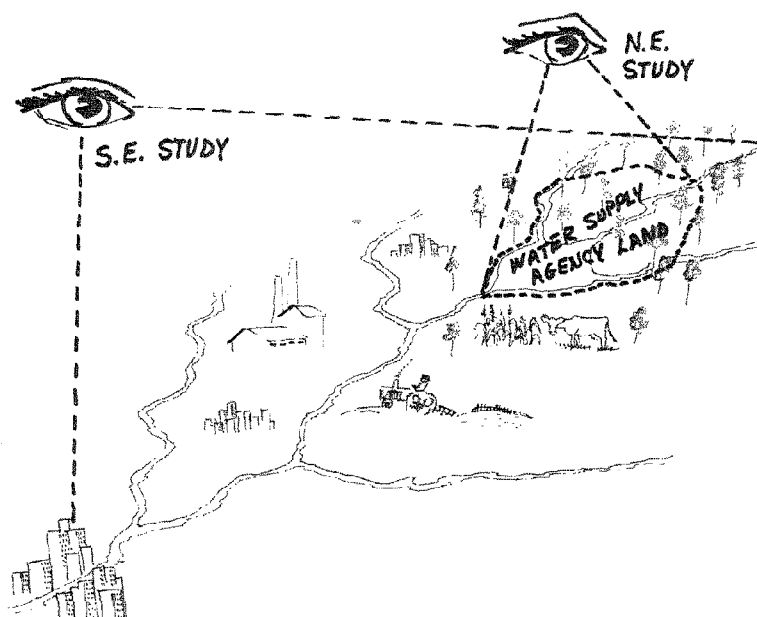
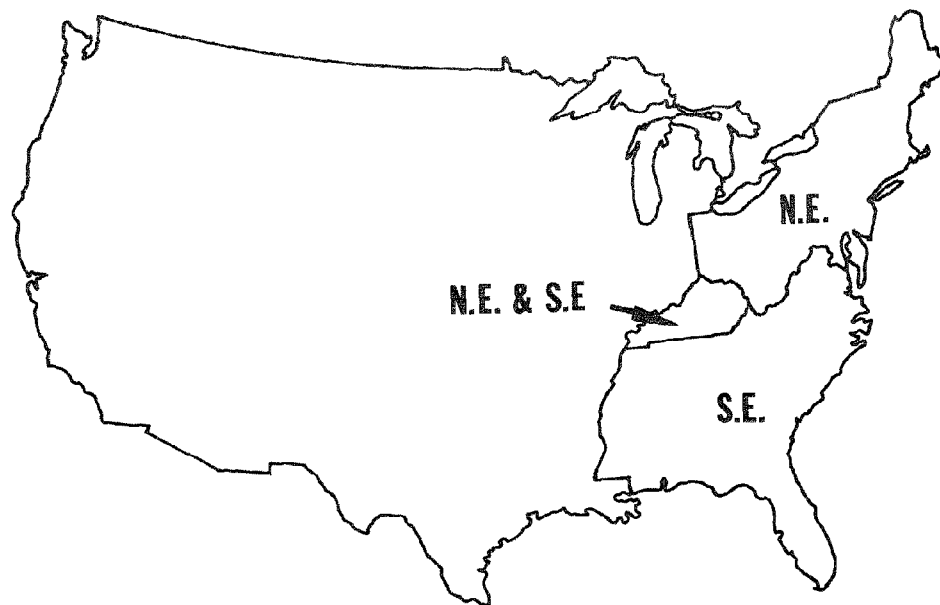


Figure 2.—The types of watershed surveyed.

recharge areas". A municipal watershed manager, therefore, is an individual whose responsibility is the care and management of such lands (*Corbett 1969*). The Southeastern study did not include well fields or recharge areas. The Northeastern watersheds sampled were predominantly forested, whereas the Southeastern watersheds contained a mixture of land uses.

SURVEY PROCEDURES

In both studies, questionnaires were sent to municipalities and water-supply companies. In addition, in the Northeast, questionnaires were sent also to state and federal agencies. Mailing lists were compiled from available records of state and federal agencies, publications, and a previous survey. 1,332 questionnaires were mailed in the Northeastern survey and 631 in the Southeastern survey. Two months after the questionnaires were mailed, a follow-up mail contact was made with the nonrespondents. In the Northeastern study, the nonrespondents who were known to own part of a watershed were asked by phone for data on the acreage of ownership. In the Southeast, no phone contacts were made except in Georgia (*Shaw 1973*). Respondents to the Southeastern survey ranged from mayors and water-supply managers to clerks who used available data and personal knowledge to complete the questionnaires. The Northeastern survey had 78 percent response, the Southeastern survey 53 percent.

EXTENT AND OWNERSHIP

In the states surveyed (fig. 1), at least 1,930 watersheds are used as sources of water. In the Southeast, the 337 water-supply agencies and companies that responded to the survey tapped at least 244 streams and 142 lakes and reservoirs to provide water for approximately 10,400,000 people — ap-

proximately 1,640 million gallons per day.

Several large rivers are tapped for municipal water; for example, the Chattahoochee, Tennessee, and Mississippi. In the Southeastern survey, 20 percent of the streams used had watersheds greater in area than 1,000 square miles (table 1).

Table 1.—Watershed size-class distribution in the Southeast and Northeast, in percent

Watershed size class (square miles)	Southeast	Northeast
<5	18	54
5-9	11	13
10-49	23	18
50-99	10	7
100-499	14	7
500-999	4	0
1000+	20	1

However, when one contemplates management of municipal water-supply watersheds, one must limit consideration to relatively small watersheds, where land management can be influenced by a community or a water-supply agency. The practical limit to the size of such a watershed is probably 100 square miles. In our surveys we found that most of the watersheds used were of less than 100 square miles, (62 percent in the Southeast and 92 percent in the Northeast: table 1).

The ownership mixture varies between the Southeast and Northeast. Because the Northeast watersheds all had ownership by a water-supply agency, there is a difference in the interpretations that can be made from the data. In the Northeast, approximately 29 percent or 2,000,000 acres of the total watershed areas was owned or control-

led by 750 municipalities, private water companies, and state and federal agencies. These agencies manage these areas primarily for water supply. Of this acreage, 41 percent is owned by municipalities and 13 percent by private water companies; 36 percent is under state control and 10 percent federal control. The average size of such holdings is 4.2 square miles.

However, the remaining 71 percent of the total area is managed for other purposes. This consists of private, federal, state, and local government ownerships, the mix of which is unknown.

In the Southeast, the total watershed acreage is 15 percent in municipal ownership, 1 percent state, 11 percent federal, and 73 percent private and industry. The 15 percent of municipal ownership is spread over 46 percent of the watersheds.

LAND MANAGEMENT

Land uses and management varied between the two regions, and this is reflected in the water problems identified. Though the Northeastern watersheds were predominantly forested, the respondents to the survey in the Southeast

estimated that forest occupied 53 percent of the watershed areas. A significant difference is that 68 percent of the Southeastern respondents estimated that 24 percent of the area was used for agriculture and 9 percent for range. This creates significant agriculture- and livestock-related water problems. For those watersheds in the Southeast with municipal ownership, the forest occurrence and area increased to 93 and 58 percent, respectively. The area of brush is 11 percent with agriculture and range lands reduced in area.

The Northeast watersheds all have forest lands which occupies 71 percent of the area (table 2). Twenty-six percent of the watersheds are 100 percent forested. An additional 25 percent are 90 to 99 percent forested.

Control of activities on land owned by water-supply agencies in the Northeast is strict: 41 percent of these ownerships are closed to use; 59 percent allow some type of recreation. The restriction of uses on other lands in these watersheds were not evaluated. In the Southeast, only 11 percent of the respondents reported all or any portion of the watershed as closed. Seventy percent of the respondents reported no restrictions on

Table 2.—Percent occurrence and area of different vegetation types on watersheds supplying municipal water in Southeast and Northeast

Vegetation type	Southeast				Northeast	
	All watersheds		Watersheds with municipal ownership ¹		Occurrence ²	Area
	Occurrence ²	Area	Occurrence ²	Area		
Forest	89	53	93	58	100	³ 71
Brush	49	12	56	11	—	—
Agriculture	68	24	66	19	⁴ 13	—
Range	32	9	30	7	—	—
Other	9	2	10	5	—	—

¹Watersheds that contain some municipal ownership.

²Percent of responses indicating occurrence of a vegetation type within the watershed.

³Total area of non-forest conditions: 29 percent.

⁴Estimate based upon voluntary comments from Pennsylvania responses.

uses. Nineteen percent reported partial restrictions.

The permissiveness of activities is generally much greater in the Southeast (table 3). This is related in part to the types of watersheds surveyed. In the Northeastern study, activities were surveyed only on watershed land owned or controlled by the water-supply agency, while in the Southeastern study the activities were related to the total drainage area, most of which is not under management for water-supply purposes.

Special attention was given to recreation activities. The Northeastern watersheds allow little boating, swimming, and water skiing. Pressures on opening these watersheds for water sports is great, and there are requests for research to determine the recreational carrying capacities of watersheds without degrading water quality. Water-supply managers are seeking informa-

tion for planning and managing recreation.

In the Southeast, a question asked was: Do you have watershed management agreements with outside landowners or other agencies? Negative answers were received from 78 percent of the respondents. However, 4 percent indicated that they had agreements with private landowners and 5 percent with the U.S. Forest Service. The remaining agreements were with industry and other federal and state agencies and were probably for water-supply or water-quality analysis.

HYDROLOGIC AND WATER-QUALITY DATA

The type and quantity of hydrologic data collected were similar in both studies (table 4). In the Southeast, the emphasis on water-quality data was apparent: 79 percent of the watersheds collected raw-water quality data. Sixty-nine percent reported the parameters analyzed, including temperature, pH, turbidity, color, bacteria, suspended matter, and chemical constituents. The quantity of hydrologic data is limited for both regions.

Table 3.—Percent of watersheds on which various activities are allowed in the Southeast and Northeast

Activity	Southeast ¹	Northeast ²
Fishing	87	39
Hunting	71	40
Agriculture	60	³ 13
Camping	50	9
Grazing	49	(⁴)
Boating	48	11
Swimming	44	4
Timber production	44	54
Horseback riding & hiking	39	14 & 35
Water skiing	27	4
Mining	16	(⁴)
Snow skiing	7	7
Ice skating	(⁴)	8
Other	3	1

¹Activities occurring somewhere in the total watershed, whether or not land was owned and managed for water-supply purposes.

²Activities only on land owned by water-supply agencies.

³Pennsylvania only.

⁴Not asked in survey.

Table 4.—Percent of watersheds on which different types of climatic and hydrologic data are collected

Type of data	Southeast	Northeast
Raw water quality	79	(¹)
Water temperature	53	(¹)
Precipitation	32	39
Air temperature	21	29
Streamflow	22	18
Evaporation	6	4
Humidity	4	3

¹Not asked in survey.

MAJOR PROBLEM AREAS

Municipal watersheds in the East are experiencing a variety of water problems. Corbett (1969) reported that 72 percent were concerned with water quality or water yield. In the Southeast, water quality is the biggest problem, followed by seasonal distribution of flow and total water yield (table 5). Although the Southeast is generally considered a water-abundant area, survey results indicated that 50 percent of the municipalities are concerned with seasonal distribution and yield problems. The seasonal distribution problem was reported primarily by communities that drew water from streams and lacked reservoirs.

Where water quality was a problem, the respondent was asked to indicate the sources of contamination (table 6). The leading source in the Southeast was agriculture and livestock, and in the Northeast municipal and recreation sources were of about equal importance. Municipal sources were also important in the Southeast, followed by recreation and industry. Pollution from farms in the Northeast was lumped with other sources and was not as common a problem as in the Southeast, but where it did occur it presented an important water-quality problem. Other than recreation, forest-related activities were a small percentage of the source of water-quality problems.

Table 5.—Percent of watersheds that indicate broad water-supply problems

Problem	Southeast	Northeast
Water quality	42	59
Seasonal distribution	29	53
Total yield	21	

¹The Northeastern survey did not differentiate between seasonal distribution and total yield.

Table 6.—Pollution sources within municipal watersheds, in percent of watersheds reporting a source of pollution

Pollution source	Southeast	Rank	Northeast
	Percent	No.	Percent
Agriculture & livestock	39	1	13
Municipal	30	2	38
Recreation	22	4	36
Industry	22	3	13
Mining	10	7	—
Logging	9	6	9
Wildlife	7	8	—
Roads	7	9	—
Woodland grazing	1	11	—
Fire	1	10	—
Other	30	5	30

¹Based upon voluntary comments from Pennsylvania respondents.

²Industry included mining in Northeast.

³Other causes included color, odor, and taste from algae, swamp drainage, and urbanization.

⁴Other causes dealt primarily with water color, odor, and taste from algae, drainage from swamps and runoff from farms, road salting, and wildlife.

Water supply problems are not exclusively related to forest management, but forest practices and forest uses do have a role in accentuating or alleviating these problems.

INFORMATION NEEDS

In the Southeastern survey, respondents were asked what types of forest-related information would be useful in making future decisions about their watersheds. The impact of forest management on the chemical composition of water was ranked highest (table 7).

They were also asked what land management information and methods would help them meet their water needs. Water quality again came to the forefront, water yield second (table 8). About 25 percent of the respondents were interested in technical assistance to improve land management.

Comparisons were made between Southeastern watersheds with and with-

Table 7.—Information thought useful for all Southeastern watersheds

Impact of forest management on —	Rank: Sum of frequency an information need was ranked first, second, or third in importance	Responses indicating an information need
	<i>No.</i>	<i>Percent</i>
Chemical composition	71	31
Turbidity	59	34
Biological	54	27
Water yield	51	24
Recreation — bacteria	44	33
Recreation — chemical composition	32	22
Water yield timing	24	15
Temperature	6	8
Other	1	1

Table 8.—Management information needed for future decisions in Southeast
[Percent of responses indicating need for land-management information
or technical assistance.]

Information needed	All watersheds	Watersheds without municipal ownership	Watersheds with municipal ownership
Land management for water quality	33	28	38
Land management to increase water yields	26	22	31
Technical assistance	25	18	33
Land management for water yield timing	10	9	12

Table 9.—Publications received, by percentage respondents

Publication	Southeast	Northeast
Water & Wastes Engineering	70	49
J. American Water Works Assoc.	64	65
Public Works	53	(¹)
J. Water Pollution Control Fed.	29	(¹)
Industrial Water Engineering	20	(¹)
Farm Journal	7	(¹)
J. Soil & Water Conservation	1	19
Southern Lumberman	1	(¹)
Journal of Forestry	1	17
U.S. Forest Service Research Papers	1	15
J. New England Water Works Assoc.	(¹)	24
Other	6	5

¹Not asked in questionnaire.

out municipal ownership. The only comparison that appeared to show a significant difference was in land-management information and methods (table 8). Managers of watersheds with municipal ownership appear to have a significantly higher interest in land management (80 percent level of confidence). The biggest difference was in technical assistance: 33 percent of those with municipal ownership showed interest.

PUBLICATIONS RECEIVED

In the Southeastern survey, respondents were asked to list the journals and publications they receive that help them in managing their watersheds. The top five publications were trade journals that concentrate on water-supply management (table 9). Few respondents received publications that concentrate on land management. This indicates that land-management information is not reaching these people.

They were asked if they wanted to be put on a mailing list for publications relevant to land management on municipal watersheds. Sixty percent of the respondents requested being put on such a list.

CONCLUSIONS

Municipal watersheds pose some challenging problems and opportunities in land management. Water-supply managers recognize the relationship between

land management and water supply. Most watersheds are small enough that towns could influence the management of land within these watersheds. Consistently, water quality was the first concern, followed by water yield and recreational impacts. The leading causes of water-quality degradation were agriculture and livestock grazing, municipal, industrial, and recreational sources.

Interest in the impact of land use and management on the water resource is strong. Information is needed about the impact of forestry on chemical composition of water, turbidity, biological quality, and water yield. There is an interest in technical assistance in helping alleviate some of the problems.

The land management story may not be reaching the water-supply manager, and this may be preventing the improvement of management on these watersheds. More articles should be aimed at this audience through the trade magazines.

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RESEARCH NEEDS RELATED TO MANAGEMENT OF MUNICIPAL WATERSHEDS

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ABSTRACT. Major research needs in municipal-watershed management now center around the quality of water supplies, particularly the interactions between human activities on municipal watershed lands and water quality. We need to know the impacts of various intensive and extensive recreational activities and pressures on a number of water-quality factors. Knowledge is also needed on the effects of urbanization, on-site reservoir use, and other human activities. Prediction schemes and management recommendations need to be formulated. Foresters and resource management specialists should also extend their concerns to management of undeveloped parcels of land such as green belts, flood plains, and park land.

THIS SYMPOSIUM has brought us up to date on physical, biological, and hydrologic processes and how we can manage municipal watersheds. In the last 10 to 15 years, long-term watershed experiments have produced results confirming earlier theories about land-water relationships and have extended our knowledge greatly, particularly in water-yield relations. We now know more about water-yield relationships in the forested mountains of the eastern United States than probably in any other region in the world. Although gaps certainly exist, we are not practicing all that we presently know, and various constraints may well prevent many types of watershed treatments. Building on this knowledge base, we now must consider where we should direct our present and future research efforts to

meet the needs of planners and resource managers.

Some research needs have been identified. Our purpose is to suggest some ideas for thought and future discussion. I hope we can all extend our thinking to look at not only near-term problems, but also to research planning, longer-term problems, and needs. We can't discuss every research need; some of the obvious we will skip over.

We think of municipal-watershed management in terms of two broad categories: management of the area immediately draining into a water-supply system; and the broader concept of managing the land surface in the generalized urban-suburban complex, even though the area may not contribute to a municipal watershed as a supplier of water.

THE MUNICIPAL WATERSHED

In any discussion of research needs for municipal watersheds, concern over water quality has to be first on the list. By water quality we mean impairment of water that may prevent or restrict particular uses. Water for human consumption is most important. Lower on the scale might be quality levels that limit swimming, fishing, and boating. Of course, we're concerned with esthetics and excessive algal blooms, suspended sediment, and accelerated weed growth that may lower the quality of recreational experiences for users. What management practices contribute to bringing about water quality changes? Can we suggest alternative management practices that may enhance water quality?

RECREATIONAL USE

Information is needed about the impacts of a variety of recreation-associated land uses on water quality. This need is not limited to municipal watersheds, but answers obtained in other research disciplines, as well as studies of basic hydrologic processes on any watershed area, will be helpful. Land uses of primary concern are those most likely to occur on or within municipal watersheds, particularly recreational-use impacts. These can vary from extensive use such as hiking, horseback riding, and hunting to very intensive uses such as well-developed picnic and camping sites, boating, swimming, and summer-home development.

Research should be aimed not only at assessing impacts, but also at providing information for the proper planning and management of activities to prevent particular adverse impacts from recreational uses.

Relationships between management of intensive and extensive uses and the basic resources of soil, geology, and

vegetation need to be quantified. Pressure to use underdeveloped areas for recreation seem destined to expand in the future, but our basic resources and their capacity to assimilate man's activities are limited.

FORESTRY AND AGRICULTURE

The use and management of forest and agricultural land within municipal watersheds will have impact on water quality and yield. But intensive management practices, such as the use of fertilizers, other chemicals, and land disturbance, are research topics. Intensive management practices will likely be applied where vegetation, soils, and other factors are favorable. However, intensive management will not be practiced everywhere, and researchers must be aware of the views and plans of foresters and agriculturists to avoid expending resources on low-priority problems. For example, studies of fertilization in low-value hardwoods would not have high priority.

Research is presently directed towards intensive forestry practices in various sections of the United States, and these studies will apply to municipal watershed management. More information is needed on the integration of uses within a complex watershed and the effect of a variety of activities on water-quality parameters further downstream.

Watershed research should be concerned with problems of managing reservoirs and areas in and around streams. What types of in-stream water activities will adversely affect water-quality values? What type of vegetation cover is best on the immediate shoreline of a reservoir, particularly one that fluctuates widely? Do certain reservoir management practices encourage adverse impacts? Identification of potential research problems such as these is also part of municipal watershed manage-

ment. Our thinking must extend beyond the land area.

URBAN SOIL AND WATER PROBLEMS

Planners, resource managers, and researchers should also be addressing soil and water problems in the broad urban-suburban complex. A number of hydrologists have studied the effect of urbanization on runoff and water quality.¹ Generally, these studies have concentrated on effects on the hydrograph, including peak flows, flow duration, and total water yield. Less effort has been applied to developing low-cost effective means of reducing excessive erosion and soil loss during the active construction phase of highways, shopping centers, or homes.

We don't know many of the impacts of the tremendous amounts of chemicals applied to urban areas — lawns, streets, and parking lots. Nor even the impacts of highway contaminants on surface and ground-water resources. In addition, we should consider the water-resource problems resulting from road design, location, and construction.

As watershed scientists, we could also turn our attention to the placement, design, and use of greenbelts, parkways, and other open areas for soil and water protection purposes. Can we help planners select greenbelts along stream courses to protect water quality and input to a reservoir? Can we offer guidelines on the width or size of streamside protection zones based on soils, rainfall, and channel characteristics? Should certain uses or activities be prohibited in such areas because of potential damage to soil and vegetation? A whole host of researchable questions might be posed concerning the selection and man-

agement of land and vegetation surrounding streams and reservoirs in and around urban areas. And what people are better qualified to consider such questions (and perhaps to pose new ones) than those concerned with soil and water management?

RELATED ACTIVITIES

Research performed in other geographic areas and in related disciplines will have application to municipal watershed and urban hydrology problems. Most useful will be studies of basic processes involving soil-water and plant-water relationships. Understanding the dynamics of soil-water movement and identifying critical water-source areas will lead to improved watershed management.

Studies concerned with waste recycling have high priority because of the potential use of wooded and open lands near urban centers for this purpose. Under the right conditions, liquid wastes could be recycled on watershed lands where the potential recharge water may be highly valuable. In effect, we could be recycling the water back through a municipal watershed system.

Other studies dealing with water quality, such as methods of effectively monitoring (how, when, and where to monitor) sensitive water-quality parameters, would be helpful to various resource managers. Research on chemical transport processes and subsequently the modeling of such processes are needed in both urban and wildland situations.

We have tried to point out some of the broad research needs in watershed management. To do an effective job, managers need information about the related economic and social benefits and costs associated with the various land-management practices.

Finally, although not a research topic, we do see a real need for planners and managers to keep research scientists in-

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formed of their research problems in this complex field. And, since communication is a two-way street, researchers must keep in close touch with management concerns and continually strive to place the latest information and research results into the manager's hands.



Caution about Pesticides

This publication reports research involving pesticides. It does not contain recommendations for their use, nor does it imply that the uses discussed here have been registered. All uses of pesticides must be registered by appropriate State and/or Federal agencies before they can be recommended.

CAUTION: Pesticides can be injurious to humans, domestic animals, desirable plants, and fish or other wildlife—if they are not handled or applied properly. Use all pesticides selectively and carefully. Follow recommended practices for the disposal of surplus pesticides and pesticide containers.
