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WATER FOR THE UNITED STATES

An Analysis of the Report of the Senate Select Committee on National Water Resources¹

C. L. MCGUINNESS²

For a free nation to survive and prosper at this point in history involves some very stringent requirements. The nation must have a viable, stable yet flexible political system. It must have the means and the will to defend itself from external aggression and internal subversion without sacrificing essential personal and political freedom. It must have, and exploit, a combination of resources adequate to provide for itself, or to provide for the purchase of, the food and other things necessary to a high and rising standard of living.

Among the basic resources essential to the exploitation of other resources, as well as to life itself, is water. Being only one of the essentials, water, no matter how abundant, can neither insure survival nor create prosperity, but a shortage of water can threaten both. It is well, therefore, that the United States is pausing to take stock of its water supply, as well as of its other physical and spiritual resources, in these fateful days.

The United States has a water supply the size and extent of development of which are the envy of many another nation. Our water has contributed immeasurably to our strength and prosperity, and it can and must keep on doing so. Nevertheless, we have reached the point where growing water problems and rising water costs have created a need for us to take a careful, comprehensive look at ourselves to see where we stand. In response to this need, the United States Senate in 1959 created the Select Committee on National Water Resources and instructed it to make a survey and report that would outline the fundamental requirements of our national water policy during the next 40 years. The Committee's report, together with the 23 volumes of hearings and 32 Committee Prints on which it is based, represents the most comprehensive effort of this kind yet made, and we will ignore its principal conclusions and recommendations at our peril.

THE BASIC WATER SUPPLY

The total water supply of any area adds up to the precipitation on, plus the water that flows into, the area. The supply that is available for ordinary uses is indicated in a general way by the runoff—the portion of the total supply that reaches the streams after flowing over or under the surface of the ground.

1. Publication authorized by the Director, U.S. Geological Survey.

2. Geologist, U.S. Geological Survey, Washington, D.C.

The indication is general rather than exact because, on the one hand, the runoff within a given area may not represent all the water that might be made available, and on the other hand it may represent more water than can feasibly be captured. Thus the runoff that occurs within an area (1) does not include water that flows into the area in streams; (2) may not include all the water that flows into the area underground; (3) does not include water that gets into the ground within the area and leaves the area without getting into the streams; (4) does not reflect the possibility of re-use; and (5) under natural conditions is smaller than the potentially available supply to the extent of its possible increase through salvage of water naturally discharged by evaporation and transpiration. On the other hand, the available supply is smaller than the runoff to the extent that floodwater cannot feasibly be retained and that water must be allowed to leave the area to carry off salt and other wastes and meet needs in downstream areas.

The conterminous United States is so situated geographically that it does not depend to any great extent on inflow of water from outside, and so constructed geologically that the equation "precipitation equals runoff plus evapotranspiration" applies with an accuracy of 99+ percent. The only substantial departure from the equation for the country, as a whole, occurs where water flows out beneath the coastline instead of entering the streams. The amount of such underflow is greatest in the Atlantic and Gulf Coastal Plain and especially in Florida, and for the whole coastline it totals some hundreds of millions and perhaps as much as a few billion gallons per day—but it is equivalent to only a fraction of 1% of the total runoff.

The precipitation in the conterminous States averages about 30 inches per year—the beginning of the humid range in one classification of climate in which "desert" means 10 inches or less, "semiarid" means 10 to 20 inches, "subhumid" means 20 to 30 inches, and "humid" is anything above 30. For an area as large as 3 million square miles to have an average climate than can be classified as humid means that the area has a very large water supply, and ours is certainly one of the largest. It totals about 4,400 bgd (billion gallons per day).³

Of the 30 inches, about $21\frac{1}{2}$ is evaporated from natural and dry-farmed vegetation and from soil and water surfaces. The other $8\frac{1}{2}$ inches represents, virtually, our manageable water supply—about 1,250 bgd.⁴ Of it we used in 1960 the equivalent of a little less than 2 inches, or about 270 bgd.⁵ About half an inch of the water we use evaporates; the rest joins the unused flow to make a total of about 8 inches flowing into the oceans under present conditions—about 1,150 bgd.

3. U.S. Weather Bureau, *Water Resources Activities in the United States—River Forecasting and Hydrometeorological Analysis*, Senate Select Comm. on Nat'l Water Resources 25 (Comm. Print. 1959).

4. U.S. Geological Survey Circ. No. 52, *Annual Runoff in the United States* 5 (1949).

5. U.S. Geological Survey Circ. No. 456, *Estimated Use of Water in the United States, 1960* (1961).

The term "use" needs to be defined. It represents "withdrawal" use—water that is physically removed from a surface-water body or an aquifer, used and discharged, or used up (evaporated or incorporated into a product). As defined it includes water used in generating electric power by thermal means—"steam power." It does not include water used in hydroelectric-power generation, the total amount of which in 1960 was equivalent to about 2,000 bgd, or three-fifths again as much as the total streamflow.⁶

That the use of water for hydropower can exceed the total streamflow illustrates an important point—the effect of re-use. We are not actually "withdrawing" as much as 2 inches of our 8½ inches of runoff, because in substantial part our withdrawal as well as our hydropower use represents the same water used over again. Re-use is the key to the whole water situation. A large proportion of the 8½ inches of runoff either is not available where or when it is needed or, under current economic conditions, cannot feasibly be prevented from escaping in floods. Hence, in each area we must capture as much as we can, and use it over again several times when to do so is cheaper than importing or storing "new" water in needed quantities.

GROUND WATER

It is important to remember that ground water is a part of the total supply and not a resource that is independent of the runoff. Ground water is simply the part of the precipitation that, after penetrating the soil and bringing the moisture content up to "field capacity," has percolated to the water table. After it reaches the water table it moves slowly to the streams to form a part of the surface runoff—an important part because it makes up the bulk of the dry-weather flow. Except for the fraction of an inch of the precipitation that flows out as ground water beneath the coastline—negligible in comparison to the amount that flows out in streams—all the water that reaches the water table either flows into a stream or is discharged by evapotranspiration. Ground-water reservoirs, or aquifers, provide a means of making use of a part of the total supply under conditions locally more advantageous than those which apply to surface water. Also, they offer a means for storing runoff that locally may be preferable to a surface reservoir. Except as their use results in salvage of water previously evaporated and transpired, however, they do not add to the total net supply.

REGIONAL WATER SUPPLY AND DEMAND

To the Southwesterners who make up most of the readers of this Journal it is laboring the obvious to point out that the availability of and the need for water differ from place to place in the United States. Obvious or not, the point must be emphasized because the distribution of water resources and needs is

6. Ibid.

a guide to how the nation must divide up its effort in coming decades to make its water supply secure.

The U.S. Senate Select Committee on National Water Resources has divided the conterminous states into 22 water-resource regions. The regions are shown in tables 1-3. The boundaries, partly natural and partly political, enclose regions which include or form major parts of major drainage basins and in which the hydrologic, economic, and political situation gives a degree of uniformity making each region a logical unit for discussion of water supply and prospects.

The Committee in 1959 and 1960 held public hearings in 25 cities and in the latter year published the hearings in 23 parts. It obtained reports on all aspects of water resources from Federal agencies concerned with water resources and development, from the 50 States, from such private institutions as Resources for the Future, the Edison Electric Institute, and the American Public Power Association, and from several distinguished consultants. These reports are published in the first 30 of the 32 Committee Prints. The whole picture is pulled together in the last 2 prints, No. 31, "The Impact of New Techniques on Integrated Multiple-Purpose Water Development," by E. A. Ackerman and others, and No. 32, "A Preliminary Report on the Supply of and Demand for Water in the United States as Estimated for 1980 and 2000," prepared for Resources for the Future, Inc., by the University of New Mexico's Nathaniel Wollman; and in the Committee's own report.⁷

The following four tables are adapted from the summary of Committee Print 32 included in the main report of the Committee.⁸ They show by regions the withdrawal, consumptive use, and storage of water as estimated for 1954 and predicted for 1980 and 2000, and water use by categories.

The tables are nearly self-explanatory, but attention should be called to one or two points. The total withdrawal shown for 1954, 300.3 bgd, is an artificial figure based on the assumption that a full supply of water was available for all uses existing in 1954. The middle 1950's were years of drought in large parts of the United States, and there were substantial shortages of water to meet existing uses. The actual total withdrawal was about 240 bgd in 1955 and was probably about the same in 1954.

The consumptive uses subtotaled in Table 4 include only the uses listed in footnote 2 of Table 1. The consumptive uses resulting from watershed-treatment measures and the losses from swamps and wetlands inhabited by wildlife as of 1954 were already reflected in the figures for streamflow remaining as of that year. The supplemental figures for these uses included in Table 4 for 1980 and 2000 are additional losses which, according to the best estimates that could be made, will occur because of additional watershed-treatment measures that

7. Senate Select Committee Report, National Water Resources, S. Rep. No. 29, 87th Cong., 1st Sess. 1-147 (1961), hereinafter referred to as "Report."

8. *Id.*, tables 15-17 at 128-30.

TABLE 1.—*Water withdrawals, consumptive uses, and storage, 1954*

| Water-resource region | Withdrawal in 1954 ¹ (bgd) | Consumptive use in 1954 ^{1,2} (bgd) | Average remaining runoff (bgd) | Existing storage for all purposes (million acre-feet) |
|--|---|--|---|---|
| New England | 6.3 | 0.37 | 67.0 | 9.0 |
| Delaware and Hudson | 14.8 | .63 | 32.0 | 3.1 |
| Chesapeake Bay | 7.2 | .29 | 52.0 | .9 |
| Southeast | 11.2 | 1.91 | 212.0 | 16.4 |
| Eastern Great Lakes | 11.2 | .40 | ³ 40.0 | .5 |
| Western Great Lakes | 12.9 | .59 | ³ 42.0 | 1.2 |
| Ohio River | 22.0 | .72 | 110.0 | 5.7 |
| Cumberland | .1 | .03 | 17.0 | 6.4 |
| Tennessee | 3.6 | .13 | 43.0 | 15.0 |
| Upper Mississippi | 8.5 | .56 | 62.0 | 4.3 |
| Lower Mississippi | 4.4 | 1.40 | 49.0 | 4.5 |
| Upper Missouri | 28.0 | 13.97 | 19.0 | 74.8 |
| Lower Missouri | 1.3 | .13 | 23.0 | 1.2 |
| Upper Arkansas-White River.. | 8.4 | 3.96 | 11.0 | 7.3 |
| Lower Arkansas-White River.. | 3.8 | 1.38 | 77.0 | 26.8 |
| Western Gulf | 22.8 | 10.00 | 46.0 | 11.2 |
| Upper Rio Grande and Pecos.. | 8.9 | 5.10 | ⁴ | 3.3 |
| Colorado | 26.7 | 15.70 | 3.2 | 35.1 |
| Great Basin | 12.6 | 7.35 | 3.7 | 4.1 |
| Pacific Northwest | 24.8 | 12.70 | 143.0 | 28.9 |
| Central Pacific | 50.0 | 27.90 | 47.0 | 16.4 |
| South Pacific | 10.8 | 4.19 | .36 | 1.8 |
| Total United States except Alaska and Hawaii. | 300.3 | 109.5 | 1,100.0 | 278.0 |

1. Based on assumption that a full water supply was available to meet all needs. There were substantial shortages of water in 1954, and the actual total withdrawal was close to the 240 bgd estimated for 1955 by MacKichan. See U.S. Geological Survey Circ. No. 398, p. 13 (1957).

2. Consumptive uses or losses for agriculture, mining, manufacturing, steam-power cooling, and municipal use.

3. Runoff from United States portion only.

4. Present appropriations exceed supply.

TABLE 2.—*Water withdrawals, consumptive uses, flow, and storage, 1980*

| Water-resource region | With- drawal (bgd) | Consumptive uses and additional losses ¹ (bgd) | Flow needed for pollution abatement ² (bgd) | Total water required (bgd) | Additional storage required (million acre-feet) |
|---|--------------------------|---|---|-------------------------------------|---|
| New England | 18.0 | 1.5 | 12.7 | 14.2 | 3.4 |
| Delaware and Hudson | 35.8 | 2.1 | 11.7 | 13.8 | 6.1 |
| Chesapeake Bay | 20.8 | 1.5 | 22.5 | 24.0 | 11.2 |
| Southeast | 39.2 | 19.4 | 56.0 | 75.3 | 28.0 |
| Eastern Great Lakes | 32.5 | 1.8 | 14.0 | 15.8 | 8.5 |
| Western Great Lakes | 38.0 | 4.3 | 31.9 | 36.2 | 34.0 |
| Ohio River | 67.2 | 2.2 | 17.2 | 19.4 | 10.1 |
| Cumberland | .5 | .2 | 7.5 | 7.7 | 3.3 |
| Tennessee | 11.7 | .5 | 23.9 | 24.4 | 6.4 |
| Upper Mississippi | 22.5 | 5.1 | 25.3 | 30.4 | 14.0 |
| Lower Mississippi | 8.7 | 9.5 | 12.7 | 22.2 | 15.8 |
| Upper Missouri | 33.9 | 29.2 | 4.4 | 33.6 | ³ 30.0 |
| Lower Missouri | 2.6 | .4 | 3.2 | 3.6 | 3.6 |
| Upper Arkansas-White River | 12.1 | 5.3 | 2.6 | 7.9 | 8.0 |
| Lower Arkansas-White River | 7.1 | 4.0 | 12.9 | 16.9 | 20.0 |
| Western Gulf | 43.0 | 20.5 | 20.4 | 40.9 | 34.0 |
| Upper Rio Grande and Pecos | 10.3 | 6.3 | 1.0 | 7.3 | ³ 7.4 |
| Colorado | 27.6 | 17.1 | 2.2 | 19.3 | ³ 14.5 |
| Great Basin | 13.0 | 10.9 | 1.2 | 12.1 | ³ 6.5 |
| Pacific Northwest | 35.0 | 13.9 | 28.9 | 42.8 | 19.2 |
| Central Pacific | 60.2 | 30.7 | 13.8 | 44.5 | 31.0 |
| South Pacific | 19.4 | 4.0 | 6.3 | 10.9 | ³ .6 |
| Total United States except Alaska and Hawaii . . . | 559.0 | 190.4 | 332.2 | 523.2 | 315.6 |

1. Projection of items listed in footnote 2 of Table 1 plus increase over 1954 in losses from land treatment and structures, and from swamps and wetlands for wildlife.

2. Streamflow required to maintain 4 milligrams of dissolved oxygen per liter under minimum-cost program except in regions of water shortage, where minimum-storage program is used.

3. Storage required to develop runoff fully.

TABLE 3.—*Water withdrawals, consumptive uses, flow, and storage, 2000*

| Water-resource region | With- drawal (bgd) | Consumptive uses and additional losses ¹ (bgd) | Flow needed for pollution abatement ² (bgd) | Total water required (bgd) | Additional storage required (million acre-feet) |
|---|--------------------------|---|---|-------------------------------------|---|
| New England | 31.2 | 2.5 | 16.9 | 19.4 | 6.1 |
| Delaware and Hudson | 58.7 | 3.1 | 16.7 | 19.8 | 12.0 |
| Chesapeake Bay | 36.0 | 3.1 | 23.8 | 26.9 | 14.5 |
| Southeast | 73.2 | 32.6 | 66.8 | 99.4 | 49.0 |
| Eastern Great Lakes | 58.3 | 2.9 | 26.0 | 28.9 | 22.8 |
| Western Great Lakes | 65.4 | 7.9 | 51.2 | 59.1 | ³ 50.0 |
| Ohio River | 110.7 | 4.9 | 29.4 | 34.3 | 20.3 |
| Cumberland | 2.0 | .4 | 12.3 | 12.7 | 7.8 |
| Tennessee | 24.3 | 1.1 | 28.6 | 29.7 | 12.0 |
| Upper Mississippi | 40.0 | 11.0 | 21.8 | 32.8 | 17.0 |
| Lower Mississippi | 16.0 | 13.5 | 22.6 | 36.1 | 29.0 |
| Upper Missouri | 47.3 | 40.1 | 11.0 | 51.1 | ³ 13.0 |
| Lower Missouri | 6.4 | 1.8 | 5.3 | 7.1 | 6.7 |
| Upper Arkansas-White River | 16.6 | 7.1 | 4.6 | 11.7 | ³ 30.0 |
| Lower Arkansas-White River | 11.5 | 6.4 | 20.9 | 27.3 | 32.0 |
| Western Gulf | 79.0 | 28.7 | 14.8 | 43.5 | ³ 34.0 |
| Upper Rio Grande and Pecos | 10.8 | 6.7 | 3.6 | 10.3 | ³ 7.4 |
| Colorado | 30.0 | 17.1 | 4.5 | 21.7 | ³ 14.5 |
| Great Basin | 13.3 | 11.8 | 1.7 | 13.5 | ³ 6.5 |
| Pacific Northwest | 60.5 | 16.3 | 28.0 | 44.3 | 20.3 |
| Central Pacific | 69.1 | 29.9 | 24.6 | 54.5 | 36.5 |
| South Pacific | 28.5 | 4.3 | 11.4 | 15.7 | ³ .6 |
| Total United States except Alaska and Hawaii . . . | 888.4 | 253.1 | 446.5 | 699.6 | 442.2 |

1. Projection of items listed in footnote 2 of Table 1 plus increase over 1954 in losses from land treatment and structures, and from swamps and wetlands for wildlife.

2. Streamflow required to maintain 4 milligrams of dissolved oxygen per liter under minimum-cost program except in regions of water shortage, where minimum-storage program is used.

3. Storage required to develop runoff fully.

TABLE 4.—*Summary by uses*
[Billion gallons per day]

| | 1954 | | 1980 | | 2000 | |
|--|-----------------|----------------------|-----------------|----------------------|-----------------|----------------------|
| | With- drawal | Consump- tive use | With- drawal | Consump- tive use | With- drawal | Consump- tive use |
| Municipal | 16.7 | 2.1 | 28.6 | 3.7 | 42.2 | 5.5 |
| Agricultural | 176.1 | 103.9 | 167.2 | 104.5 | 184.2 | 126.3 |
| Manufacturing . . . | 31.9 | 2.8 | 101.6 | 8.7 | 229.2 | 20.8 |
| Steam-electric . . . | 74.1 | .4 | 258.9 | 1.7 | 429.4 | 2.9 |
| Mining | 1.5 | .3 | 2.7 | .6 | 3.4 | .7 |
| Subtotal | — | 109.5 | — | 119.2 | — | 156.2 |
| Watershed improvement | | | | ¹ 4.0 | | ¹ 7.0 |
| Swamps and wetlands for wildlife | | | | ¹ 66.7 | | ¹ 89.9 |
| Total | 300.3 | | 559.0 | 189.9 | 888.4 | 253.1 |

1. Increase over similar consumptive uses in 1954, which were already reflected in the streamflow remaining as of that year.

will be undertaken, and additional swamps and wetlands that will be created for wildlife, by 1980 and 2000.

The figures for streamflow required for pollution abatement are based on estimates made by G. W. Reid (1960) in Committee Print 29, and indicate the amount of water required to maintain a dissolved-oxygen content of 4 milligrams per liter, the minimum considered necessary to maintain the streams in acceptable condition for fish and wildlife and recreational uses. The flows shown are those required for waste dilution and dissolved-oxygen maintenance after the wastes receive a certain specified minimum degree of treatment before being discharged. Where flows are expected to be adequate, the treatment specified is such as to result in an overall minimum cost for treatment. In regions of expected water shortage, the treatment specified is such as to require minimum storage (and thus minimum loss of water by evaporation from reservoirs), even at the expense of increased cost of treatment.

That we used about 240 bgd of water in 1954 when we could have used 300 bgd to supply fully the demands existing as of that time, and that we used about 270 bgd in 1960 when we could have used perhaps 330 to 350, shows that we are a long way from having caught up with even the existing demands. Are we going to be able to increase our total supply to the 559 and 888 bgd predicted as needed by 1980 and 2000—to double our present supply in less than 20 years and triple it in less than 40? Judging from experience, when those dates roll around we very likely will find ourselves in something

like our present position—water supplies greatly increased over those of the past, but still short of what they should be. We dare not let ourselves fall any farther behind in relation to our minimum real needs, however, for if we do we may find our economy and our standard of living slipping instead of advancing steadily.

The projections of demands to 1980 and 2000 are based on the following assumptions:⁹ that the national economy will continue to grow at past rates (the Committee would like to see it grow even faster, which would mean even larger water demands); that adequate water supplies will be made available under present pricing policies; that there will be little change in presently known technical methods of water use; and that present inefficient methods of water use will continue except that, hopefully, irrigation efficiency will improve substantially. The Committee expects irrigation acreage to increase by 1980 by 7 million acres over the figure for 1954, but expects that increases in water cost and absolute shortages of water will necessitate improvements in efficiency. Alternatively, a part of the current irrigation use will be converted to economically more productive uses, as is already happening in the vicinities of some Southwestern cities. In any event, it is expected that by 1980 there will be an actual decrease in irrigation withdrawal and only a slight increase in consumptive use. (See Table 4.)

No such assumption of increased efficiency is made for industrial use, but increasing costs and water shortages could necessitate more intensive water-conservation and waste-treatment measures and could reduce the growth in manufacturing and steam-electric withdrawals predicted in Table 4.

Whether we develop more water or re-use the same water to a greater extent, we will be spending great sums of money on water, and our task is to find the most effective and least costly means of satisfying our needs.

ALASKA, HAWAII, AND OTHER OVERSEAS AREAS

Alaska, Hawaii, Puerto Rico and the Virgin Islands, and other possessions and trust territories of the United States are not discussed in detail in the report of the Senate Select Committee and are not covered by the predictions and estimates described above. Like all other areas anywhere, our newest two States and other overseas areas which are a part of the United States or for which the United States is responsible have their water problems, but they make a separate story.

The water resources of Alaska and Hawaii are described in Committee Prints 19 and 20.¹⁰ Both States have water supplies ranging from very large to very

9. Report, p. 4.

10. U.S. Dep't of Interior, *Water Resources Activities in the United States—Water Resources of Alaska*. Senate Select Comm. on Nat'l Water Resources 19 (Comm. Print 1960); U.S. Dep't of Interior, *Water Resources Activities in the United States—Water Resources of Hawaii*, Senate Select Comm. on Nat'l Water Resources 20 (Comm. Print 1960).

small, and both have special problems—in Alaska, those related to perennially frozen ground (permafrost) and in Hawaii, those related to salt-water encroachment.

Puerto Rico also has water supplies ranging from abundant to meager.¹¹ The Virgin Islands are similar geologically but only half-similar hydrologically—their water supply is meager, period.¹² Other islands, including Guam and American Samoa, have locally abundant supplies but are mostly problem areas because of the possibility of salt-water encroachment.

PROBLEMS

The Senate Select Committee lists^{12a} our major water problems under six categories: (1) supply in relation to demand, (2) distribution, (3) natural quality, (4) man-made pollution, (5) variability, and (6) floods.

SUPPLY AND DEMAND

Projected withdrawals of 559 and 888 bgd by 1980 and 2000 will be equivalent to something like one-half and four-fifths of the average streamflow remaining as of 1954. Because of re-use, the actual demand on streamflow will not be so high as the figures might suggest, and the problem boils down in large part to maintenance of quality to permit reuse. A better idea of how much streamflow will actually be needed can be obtained by adding the expected consumptive use to the minimum quantity needed to supply withdrawal uses. Consumptive uses for the purposes listed in footnote 2 of Table 1, plus increases over 1954 consumptive uses for watershed treatment and swamps and wetlands, are expected to total 190 and 253 bgd by 1980 and 2000 (Table 4). Projected streamflow requirements for pollution abatement are larger than for any other single need except hydropower generation. Because there are other ways of generating power, the Committee made its assumptions of required minimum flows on the basis that pollution abatement rather than hydropower generation would be the controlling factor. The projected needs for flows to dilute wastes are 332 and 447 bgd for 1980 and 2000. Adding the figures for consumptive use given previously, we obtain 522 and 700 bgd as the required minimum flows in 1980 and 2000. If enough storage is provided to assure these flows, and if the assumed degree of treatment of waste is achieved, other needs will be largely satisfied: water of acceptable quality for municipal, industrial, and irrigation uses, for recreation, and for fish and wildlife, as well as for navigation. In addition to providing increased low flows for these purposes, the storage will go a long way toward meeting flood-protection needs.

11. See McGuinness, *Ground-Water Resources of Puerto Rico: Puerto Rico Aqueduct and Sewer Service* (1948).

12. McGuinness, *Summary of the Water Resources of the Virgin Islands* (1953).

12a. Report, pp. 4-14.

DISTRIBUTION

So far we have been dealing in totals. We all know that water is not uniformly distributed over the country. There are already substantial areas of water shortage in many of our western river basins. According to the Committee¹³ full development of all the available water resources will be necessary by 1980 in 5 of the 22 water-resource regions, if the projected increases in demand are to be met. These are the South Pacific, Colorado River, Great Basin, Upper Rio Grande-Pecos River, and Upper Missouri River regions. The Committee points out that the South Pacific region has already run out of water so far as its natural supply is concerned; it is already importing a substantial part of its water and is planning to import more.

By 2000, if the projected demands are to be met, 3 more regions will be added to those in which full development will be needed: Upper Arkansas-Red River, Western Great Lakes, and Western Gulf regions.

The Committee points out that these eight regions will not necessarily have reached their economic ceilings by those dates. They are, however, the regions where the most vigorous steps will have to be taken to construct dams and reservoirs, water-salvage projects, and flood-control facilities; to develop techniques for conversion of saline water, control of evaporation, and improved waste disposal; to manage watersheds for increased water yield; to make more intensive use of aquifers as storage reservoirs; to work out interbasin transfers of water within and between regions; and to revise water uses for maximum economic productivity.

NATURAL WATER QUALITY

Water varies greatly from place to place, and surface water from time to time, in the content of dissolved and suspended materials that inhibit use, and in the cost of treatment to reduce or remove the impurities to meet specific needs. As demand increases in relation to supply, it will become progressively more necessary to use water of poorer quality than is now considered desirable for particular uses, and to accelerate research on saline-water conversion and on methods of water-quality improvement such as the brine-control project now underway at Malaga Bend on the Pecos River.¹⁴

MANMADE POLLUTION

Major polluting substances now discharged to streams in excessive quantities include sewage and other organic wastes, which consume oxygen; phosphorus and nitrogen, derived largely from sewage, which serve as plant nutrients and promote the growth of algae and other undesirable organisms; and chemical

13. Id. at 9-11.

14. Pecos River Comm., New Mexico and Texas, *Possible Improvement of Quality of Water of the Pecos River by Diversion of Brine at Malaga Bend, Eddy County, New Mexico* (1954).

wastes, largely industrial and including radioactive substances, which may make water unsuitable for ordinary uses. To these can be added man-generated sediment, which like that resulting from natural erosion must be removed to make the water suitable for ordinary uses; and heat, which can be considered a polluting "substance" because it makes water less usable for cooling (one of the principal withdrawal uses of water) and it reduces the ability of the water to dissolve oxygen from the air and so inhibits decomposition of organic wastes and affects fish life adversely. The projections of streamflow required to meet future water demands assume that used water, before being discharged, will be treated to remove oxygen-consuming substances in percentages ranging from a general minimum of 70% in 1980 and 80% in 2000 in regions of relatively plentiful water supply to 95% or even more in regions where water is short or costs of reservoir storage are high. These stringent requirements for treatment, which in nearly every drainage basin in every region are far higher than the standards met today, will call for vastly increased research in waste treatment and expenditures for treatment facilities.

VARIABILITY

The supply of water varies from time to time at the same place as well as from place to place. The average runoff in the country as a whole in 1895-1955 varied from as little as 50% of the long-term average in some years to as much as 140% in others.¹⁵ What this means in terms of storage needs in the country as a whole can be visualized by comparing 50% of about 1,100 bgd with the estimate of 700 bgd for the minimum required streamflow in 2000.

The variation from year to year in individual regions of course may be, and generally is, considerably greater than that from the 50 to 140% recorded for the country as a whole; in individual areas within the regions it may be even greater; and from season to season within a given year it is greater still. And, characteristically, it is in the driest areas, where the need for water is greatest, that the variations are most extreme and the low flow in dry weather in dry years is least. Thus, a stream that has a very respectable average flow, measured in hundreds of cubic feet per second, may have no flow at all in dry weather in some years, or even in most years. Much larger streams, whose average flow is measured in thousands of cubic feet per second, may decline to a trickle in droughts—for example, the Red River of the North, which in 1912-57 flowed an average of 2,755 cfs (cubic feet per second) at the Canadian border but which has a recorded minimum flow of 0.9 cfs.¹⁶

15. Geological Survey, U.S. Dep't of Interior, *A Primer on Water* 1-50 (1960).

16. Geological Survey, U.S. Dep't of Interior, *Water Resources Activities in the United States—Surface Water Resources of the United States*, Senate Select Comm. on Nat'l Water Resources 4 (Comm. Print 1960).

The same drainage basins that produce very low dry-weather flows are likely to yield high flows in wet weather, for such reasons as rugged topography, erratic heavy precipitation, or poor infiltration facilities as shown by low base flow. These flood flows build up the figure for average flow, but unless they can be captured they do no one much good and may do much harm. To take an extreme example, the Neosho (Grand) River as measured at Iola, Kansas, during a period of record including 1895-1903 and 1917-57 had an average flow of 1,550 cfs, a maximum of 436,000, and a minimum of 0.¹⁷

Furthermore, streamflow records are made only to be broken. Records on most gaged streams are only a few decades long, and there is no reason to suppose that they indicate the extremes that ultimately will be recorded. Even where a low flow of 0 has already been observed, and it might be thought that the worst was already known, future records very likely will extend the period of zero flow beyond the longest recorded in the past.

If variable streams are to meet demands which themselves are variable and are likely to be greatest when natural flow is least, there is only one answer—storage. What immediately comes to mind is dams and surface reservoirs, and these are bound to continue to be the chief means of providing needed storage. However, storage in aquifers having unused capacity also must be considered, especially in dry areas where the best sites for surface reservoirs are already occupied and where building additional reservoirs on the remaining sites may not be worth the cost in terms of money and in loss of water by evaporation.¹⁸ Unfortunately, many areas where additional surface storage is undesirable or impractical for some reason, whether it is excessive evaporation loss or excessive money or social costs involved in the flooding of valuable land, have no aquifers suitable for large-scale storage of water in times of surplus and withdrawal in times of deficiency. Much research and many area studies will be needed to outline the possibilities of using ground-water storage to supplement surface reservoirs.

FLOODS

Floods are one of the earliest problems to come to attention in a country having a large but variable water supply and few problems of obtaining water to meet ordinary needs. Thus, flood control has been on the country's mind for a long time, and a great deal of money has been spent in building numerous valuable projects to control floods. Nevertheless, flood damage as expressed in dollars keeps on rising, both because new record flood peaks are reached and because the structures and activities of man that are damaged by floods are constantly increasing in value. Increasing encroachment by man on flood plains, which by their very name and definition are bound to be flooded from time to time, is the chief cause of increasing damages.

17. *Id.* at 31.

18. U.S. Geological Survey Circ. No. 409, *Water Yield and Reservoir Storage in the United States* (1959).

Flood-plain zoning to reduce or prevent additional encroachment is one of the tools that will have to be used increasingly to reduce flood damages. The most important reduction of floods in the future, however, will be that incidental to the construction of storage facilities to provide the minimum stream-flows needed for waste dilution and other water uses. Nevertheless, many additional flood-protection works will still be needed, along with the flood-plain zoning mentioned above and with better systems for predicting floods and issuing timely warnings. Storage capacity for flood control in addition to that needed for other purposes will be provided mostly in multipurpose reservoirs, but locally reservoirs will need to be constructed for flood protection alone.

WHAT DO WE DO NOW?

The Senate Select Committee in its report¹⁹ after pointing out the abundance of our water resources, sets forth in one sentence the basic water problem confronting the Nation: "There is work to be done, work to develop and use the abundant resources placed in our custody by a Munificent Providence, work to develop the practices and techniques *which will permit ever-increasing needs to be filled within the finite limits of the resources we have*" [Emphasis supplied.] We have, and will continue to have, about as much water as we have had in the past, and with it we must meet withdrawal needs which, after having actually increased from about 170 bgd in 1950 to 240 bgd in 1955 and 270 bgd in 1960, are expected to increase to 559 bgd by 1980 and 888 bgd in 2000. Hopefully, the world will not come to an end for us in 2000, or by 2100, or by 3000, and we presumably will continue to increase in number and in need for water.

In the more or less distant future, perhaps within the next 100 years, the time may come when our water needs will be such that no conceivable combination of presently known techniques will be able to satisfy them with our present supply. By such a time it is to be hoped that there will have been a major breakthrough in reducing energy costs, making them so low that sea water can be desalted and piped wherever it is needed. If and when such a situation develops, most of our water problems as we see them today will have vanished.

Meanwhile, we must do the best we can with what we have. We dare not allow hopes for the "big breakthrough" to delay us for one minute in our current efforts to catch up with and keep ahead of our existing and emerging water shortages. We must learn more about our hydrologic environment and how to control it than we have ever known. As we press on, we will find that we can do a lot more with what we have than might now seem to be possible.

And, we must remember that the "big breakthrough" may never come. It is mentioned more as a hope than as an expectation. Nevertheless, we must

19. Report, p. 2.

leave no stone of research unturned in our efforts to achieve it, as we edge ever closer to the limits of our recoverable fresh-water supply.

The Committee²⁰ summarizes the immediate task confronting the nation as "one of meeting the growing demands on water resources in the most efficient manner consistent with accepted public aims. It is important that plans be made to meet demands before they arise so as to avoid any retardation of economic activity in particular localities because of a deficiency in water development. The problem is a dynamic one because the rapid advances of science continually stimulate new demands while at the same time opening up new opportunities for meeting them."

Five major categories of effort are outlined:

1. Regulating streamflow by constructing surface reservoirs and through watershed management.
2. Improving the quality of water through more adequate pollution abatement.
3. Making better use of underground storage.
4. Increasing the efficiency of water use through elimination of wasteful practices, improved sewage treatment, recirculation of water instead of "once-through" use, increased irrigation efficiency, and substitution of air for water cooling.
5. Increasing natural fresh-water yield by desalting, weather modification, and other artificial means.

Not one major phase of any one of these categories can be pursued fully on the basis of existing hydroeconomic knowledge. Some of them, such as building surface reservoirs, can be tackled on the basis of existing knowledge of principles, but at the very least it will be necessary to make intensive site studies and hydrologic and economic analyses to make sure that a given project is the one that should be undertaken at the particular time and on the particular scale that is proposed. Some of the phases, such as weather modification, are somewhat speculative at best as now known, and intensive research into principles will be needed to determine whether they are even practicable, to say nothing of practical. Of all the tasks facing the nation, the first and foremost is that of obtaining the knowledge essential to making the best possible decision on how to meet each new water problem. Not only is it the first, it is one of the most difficult because there is so much to do, so few trained people to do it, and so little time in which to get it done.

Before listing its specific recommendations for action, the Committee concludes that our national water supply is adequate to meet the needs as of 1980 and 2000, if we take positive, forward-looking steps to develop and use the water we have.²¹ It then summarizes the capital investments required to meet the needs, in part as envisioned by the principal agencies concerned and in part

20. *Id.* at 15.

21. *Id.* at 31.

as modified by the Committee. The following table is based on the information given on pages 32-40 of the Committee's report.

| Purpose | Needed by | Needed between | Total ¹ |
|---|-----------|----------------|--------------------|
| | 1980 | 1980 and 2000 | |
| [Billions of 1959 dollars] | | | |
| Waste-collection and -treatment facilities for pollution abatement ² | 42.2 | 39.4 | 81.6 |
| Water-storage facilities ³ | 12.1 | 5.9 | 18.0 |
| Navigation ⁴ | — | — | 7.9 |
| Flood control ⁵ | 11.5 | — | — |
| Watershed improvement | 4.6 | 4.5 | 9.1 |
| Irrigation ⁶ | — | — | 22.0 |
| Fish and wildlife ⁷ | — | — | — |
| Water-based recreation ⁸ | — | — | — |
| Municipal water supply ⁹ | 29.0 | — | — |
| Industrial water supply ¹⁰ | — | — | — |
| Hydroelectric power ¹¹ | — | — | — |

1. Total of sums shown separately for 1954-80 and 1980-2000, or total for needs whether met before 1980 or stretched out to 2000.

2. Minimum-cost program to achieve level of 4 milligrams of oxygen per liter in streams.

3. Minimum-cost program. Covers storage for pollution abatement only, but would provide a substantial part of the flow regulation needed for flood control and municipal, industrial, and agricultural water supply.

4. \$2.5 billion for authorized projects and \$5.4 billion for possible additional projects. Feasibility and desirability of substantial part of program challenged by other transportation interests.

5. \$5 billion for authorized projects, \$6 billion for additional needed projects along streams, and \$0.5 billion for coastal protection works. Overlaps in part with cost for water-storage facilities, as those facilities would do a part of the flood-control job. On the other hand, the estimates for water-storage facilities include no provision for flood and sediment storage or for consumptive use involved in withdrawal uses.

6. Estimate by the Bureau of Reclamation covering 17 million acres of new land by 2000. Cost overlaps to some extent with those for water-storage facilities and flood control.

7. No estimate available. Much of need would be met by streamflow regulation for pollution abatement and flood control. Additional expenditures would be required for acquisition and development of wetlands and for fish hatcheries.

8. Needs would be met largely by reservoir construction and streamflow regulation for other purposes. Relatively slight additional expenditures required for recreational facilities on reservoirs, etc.

9. Overlaps with previous costs to the extent that streamflow regulation for pollution abatement and other purposes listed previously would obviate the need for specific storage projects for municipal supply.

10. No estimate available, but cost assumed to be only a small fraction of annual plant and equipment expenditure, about \$35 billion as of 1960. Cost will be reduced to the extent that streamflow regulation for other purposes will obviate the need for specific storage projects.

11. No estimate available. It is assumed that costs of generating facilities will be met by users of the power.

Owing to overlapping as described in the footnotes and to the absence of estimates of costs for certain purposes, the figures in the table cannot be added to give meaningful totals. The Business and Defense Services Administration of the Department of Commerce prepared an estimate, included on page 41 in the Committee's report, of capital investments, in 1958 dollars, needed during the period 1958-80. The table shows a total investment in existing facilities as of 1958 of \$179 billion, an estimated deficiency of \$26.2 billion to bring 1958 facilities up to 1958 needs, a new investment of \$114.4 billion needed for growth in 1958-80, and a figure of \$87.6 billion for replacement of obsolete facilities in 1958-80. The total cost of facilities needed in addition to those existing in 1958 thus was \$228.2 billion. The "new investment" figure of \$114.4 billion was based on an increase of 2.7% per year in gross national product, a rate substantially smaller than the 3.75% used by the Committee in estimating water demands and in reaching figures of \$1,060 and \$2,200 billion for the gross national product in 1980 and 2000. Thus even the \$228 billion would not be enough if the higher rate of growth prevailed and the other basic assumptions held.

At any rate, it looks as if adequate provision for the Nation's water future will require a capital expenditure of several billion dollars per year at first and an average of \$10 billion or more per year in the next 20 years. These are very impressive figures, but they amount to no more than 1 to 2% of the gross national product, greater but not a great deal greater than the actual percentage in recent years.²² There is no question of the ability of the Nation's people to spend 1 to 2% of their income on water facilities without serious effect on other activities, but their willingness to do so can be guaranteed only through a comprehensive program of public education leading to general realization of the consequences of *not* making the effort, in terms of economic stagnation and a lowered standard of living.

ACTION AREAS AND ROADBLOCKS

In its report²³ the Committee sets forth its ideas on areas of action required to meet national goals. In the following paragraphs these, numbered and lettered as in the Committee's report, are both summarized briefly and commented on from the present writer's point of view.

1. IMPROVING PUBLIC UNDERSTANDING OF WATER PROBLEMS

Adequate public understanding is essential to the support of any desirable public program. The Committee believes that development of informed public opinion would do more toward realization of a sound water policy than would

22. Wollman, *Water Resources Activities in the United States—Water Supply and Demand* 71, Senate Select Comm. on Nat'l Water Resources 32 (Comm. Print 1960).

23. Report, pp. 43-71.

implementation of any other single recommendation it might make. Committee Print 2, "Reviews of National Water Resources During the Past Fifty Years," by Barbara Jibrin, describes the more than twenty major studies and reports on various aspects of national water-resources policy undertaken by presidentially or congressionally established groups since the days of Theodore Roosevelt, no less than seven of which had been completed since 1950. These studies and reports unquestionably have done much to inform the public about its water problems, but the very fact that there have been so many of them proves that the job is far from done. That the studies have been undertaken demonstrates public interest or anxiety, but more than this is needed. There must be public recognition of the dimensions of the problems and their variations from place to place, and of the range of possible solutions. Major water problems are by no means all understood, or even identified. Therefore the first requirement is continued and accelerated investigation to identify and analyze problems and discuss them fully and publicly, so that the people in each area and region may know what they are faced with and what their choices are. The Committee believes that information on water problems, and especially on water supply-demand relationships, should be kept up to date and should be made available to all interested authorities, with a view to publication and public hearings.

2. COMPREHENSIVE PLANNING

Comprehensive planning for river-basin development has been recommended, and undertaken, from time to time since the administration of President Theodore Roosevelt. In view of changing conditions, the term "comprehensive planning" must be defined much more broadly than in the past, when it envisioned mainly the development and management of surface water. The Committee says: "In view of the prospective growth in demand for water and in the problems associated with meeting demands, there is urgent need in almost every region to adopt an orderly procedure for development of water resources. Our prosperity and our very survival are at stake."

Throughout the nation in the long run, and in some of the western regions by 1980, water resources must be developed fully if anticipated economic growth is to be realized. This means that, before long, virtually all the water in whole regions must be developed, and must be developed in accordance with a comprehensive plan that is internally consistent in spite of the administrative difficulties involved in applying the plan to areas in two or more states in which water laws, economy, and political climate may differ radically.

Full development means full regulation of streams "so as to provide from a given stream the maximum amount of water which can be made available to meet all purposes." Among the first needs here is a comprehensive survey of potential reservoir sites throughout the United States, along with develop-

ment of a rational scheme for deciding in each case when and how to purchase or reserve a site, and what conflicting uses of the site might be permitted between the date of reservation and that of construction.

"Full regulation," if it is to be economical, implies full use of ground-water reservoirs as media for cyclic storage of water. The knowledge of both principles and local geohydrology needed to implement such use of ground-water reservoirs is hopelessly inadequate at the present time. Unless the advantages of making use of these reservoirs are to be lost, at least for the next decade or two, an accelerated program of research and areal investigation is needed immediately. As in all situations involving a need for information relating to ground water, the investigations will be hampered by a shortage of trained, competent geohydrologists to undertake the thousand and one studies that are needed.

3. IMPROVEMENT OF STATE AND LOCAL PLANNING AND DECISION MAKING

Most specific water problems are local or regional. Their national significance results from the fact that there are so many of them that, in bulk, they seriously threaten the national welfare. It is only common sense to look at them from a national viewpoint and to provide at the national level such assistance in the form of research, planning, and financing as will meet national needs most economically and rationally. Nevertheless, the bulk of the decisions and of the financing must be at the local and state level. (Of the \$228.2 billion estimated by the Department of Commerce as needed by 1980, three-quarters is expected to come from non-Federal sources.) Therefore, comprehensive plans for river-basin development must be worked out within the framework of local, state, and regional needs.

It is now firm national policy that the states must be kept informed on and must participate in the planning of developments for which federal funds are sought. Considerable progress has been made in setting up regional planning bodies, such as the Missouri and Columbia Basin Interagency Committees, the Arkansas-White-Red Basin Interagency Committee, the New England-New York Interagency Committee, the Delaware River Basin Advisory Committee, and the Southeast and Texas Basin Study Commissions. Nevertheless, much remains to be done. Many states are poorly organized for long-range planning and their water-resources agencies lack adequate financial support. Inevitably, such situations create vacuums into which the federal government must move if problems become critical. A few states have made outstanding progress—for example, California with its State Water Plan and Kansas with its series of river-basin plans. Most other Western states are intensely aware of the need and are striving to improve their planning procedures. New Mexico, which has the distinction of leading the nation in per capita expenditure for hydro-

logic studies, is one of those in which the prospects for rational water development with full participation by the state are most reassuring. Eastern states are beginning to join the parade—some of them having large water resources and few critical problems to date, but having a keen realization of the benefits of investigating water resources and planning water development as a means of nurturing economic growth.

The Committee believes that federal assistance in financing planning activities in the States would be worthwhile, and since its report was released legislation to this effect has been introduced in the Congress.

The Committee believes that, where a state contribution is required as a condition of approval of a federal project, advance instead of year-to-year federal appropriations would simplify the task of the states in providing their share of the financing.

4. NEW TECHNICAL METHODS

There is hope that new techniques in finding, developing, using, or even creating water supplies will make available at reasonable cost the vast new quantities that will be needed to meet the nation's increasing demands. At least for some techniques, the relation of the degree of hope to the hope's familiarity with the hydrologic principles and economic facts of life involved in a particular suggested process tends to be inverse rather than direct—a kind of familiarity-breeds-contempt situation. In the writer's opinion, most of the techniques described here will have only limited application, but the application will be especially important in dry areas, where some of the techniques are already proving helpful. A few others, because of the breadth of their scope, undoubtedly will prove to be among the principal tools employed in increasing water supplies; these mostly involve principles that are already recognized, and what is lacking now is perfection of economical techniques—for example, salvage of waste water for reuse.

No matter how intense the effort to find or develop new techniques, major breakthroughs leading to cheap new supplies of billions of gallons per day—short of the breakthrough in energy-cost reduction mentioned previously—are likely to be few and far between. One of them might be in the field of waste treatment—though perhaps here the writer is illustrating his own familiarity-breeds-contempt principle because he knows very little about waste treatment.

In the one field with which the writer can claim some familiarity, that of ground water, it is his opinion that expectations of ground-water development described in the Committee's report and in Committee Print 31²⁴ are unlikely

24. Ackerman, *Water Resources Activities in the United States—The Impact of New Techniques on Integrated Multiple-Purpose Water Development* 21-22, Senate Select Comm. on Nat'l Water Resources 31 (Comm. Print 1960).

to be realized on anything like the desired scale, important as ground water already is and increasingly important as it seems destined to be.

(a) REDUCTION OF EVAPORATION FROM RESERVOIRS

Application of a film one molecule thick of certain substances such as hexadecanol, or cetyl alcohol, to the water in surface reservoirs has the effect of reducing the rate of evaporation of the water. Materials investigated to date have no known toxic effects. Because of dispersion of the film by wind, the method has been much less successful on large open bodies of water than it has in the laboratory. Also, the material seems to be decomposed by biologic action, and for both this reason and dispersion by the wind it must be renewed periodically. Another effect that has not been evaluated fully is that of the reduction in evaporation in increasing the temperature of the water. The temperature of water reflects a balance between heat energy received and that discharged, and natural evaporation plays an important part in the balance because of the large amount of heat energy required to evaporate water—the “heat of vaporization” of water is more than 575 calories per gram at temperatures below 100°F. If evaporation is reduced, the heat formerly used in evaporation stays in the water and raises its temperature until the excess heat can be discharged, by an increase in the rate of heat discharge to the atmosphere or the ground—and by increased evaporation from the warmer water through the monomolecular film itself. If the temperature simply rises until most of the initial saving is offset by increased evaporation through the film, use of the process might not make much sense. Also, the effect of increased temperature on aquatic life and on use of the reservoir for recreational and other purposes must be considered.

The U.S. Bureau of Reclamation²⁵ estimates that under certain conditions water can now be saved at an average cost of about \$40 per acre-foot (12 cents per thousand gallons). This is far higher than the cost of most irrigation water and much industrial water, but some high-cost irrigation projects being planned even now will have comparable water costs. The Bureau estimates that as much as 2 million acre-feet per year might be saved in this way in the seventeen Western states by 1980, and that costs ultimately might be lowered to about \$10 per acre-foot. The evaporation loss from present reservoirs in those states is estimated at more than 10 million acre-feet per year.²⁶

The writer doubts that evaporation suppression will prove to be one of the really major methods of extending water supplies, but it may be locally important and certainly should be investigated thoroughly to determine all its advan-

25. Water Resources Activities in the United States—Evaporation Reduction and Seepage Control 3, Senate Select Comm. on Nat'l Water Resources 23 (Comm. Print 1960).

26. Ackerman, *supra* note 24, at 23.

tages and limitations. It is especially promising for use on small farm and stock ponds.

(b) REDUCTION OF EVAPOTRANSPIRATION FROM AREAS OF PHREATOPHYTES

According to Robinson,²⁷ water-loving plants, or phreatophytes, of low economic value occupy something like 16 million acres in the seventeen Western states and annually discharge perhaps as much as 25 million acre-feet of ground water. The discharge is greatest where the climate is warmest and driest and water is most in demand, and the worst of the plants, saltcedar, is still spreading. The water thus discharged may be termed "consumptive waste"²⁸ as opposed to "consumptive use," and it is an obvious and important target for efforts at salvage for beneficial use. Estimates of total salvage that might be realized in the Western states range from 1 to 6 million acre-feet per year, at costs of about \$40 to \$100 per acre for the first clearing and something like \$7 per acre per year for maintenance.²⁹ Quantities of water that might be saved range from an acre-foot or less to several acre-feet per acre per year. Obviously, the economic practicability of the method depends on the cost of clearing and maintenance, the amount of water saved, and the cost of obtaining water by other means. To save 1 acre-foot per year at a cost of \$100 for clearing and \$7 a year for maintenance would cost too much in many areas, but if 3 or 4 feet of water could be saved at a cost of \$40 for clearing plus \$7 a year, the effort might well be worthwhile. Intensive study is being given to the possibilities in many areas in the West, and salvage operations are already underway in a few, such as the middle Rio Grande valley. The Pecos Valley is another important target area in New Mexico.

Obviously, something has to be done with the water that is saved; otherwise it will simply run to waste. The water may percolate into a stream and flow to an area of need without any fuss or undue loss; on the other hand, it may have to be pumped from wells either to save it from being evaporated locally as a result of a rise of the water table or to prevent it from flowing to a downslope area of discharge such as a playa lake. One way to make use of the water locally without having to pump it is to substitute useful plants, such as alfalfa, that will use up the water, once the low-value phreatophytes are removed.

Water discharged by evapotranspiration can be salvaged by lowering the water table rapidly by means of drains or wells, and thus denying the water to the phreatophytes rather than eradicating them. The water is then transported for use elsewhere.

Salvage of ground water transpired in the humid East is not likely to be

27. Geological Survey, U.S. Dep't of Interior, Water-Supply Paper No. 1423, *Phreatophytes* 25 (1958).

28. Thomas, *The Conservation of Ground Water* 217 (1951).

29. Report, p. 53.

attempted on a large scale, but locally some reduction of vegetal growth may be worthwhile as a means of increasing streamflow or maintaining pond levels.

A complication is introduced by legal factors. Under existing law in many states that follow the doctrine of prior appropriation, use of water salvaged by evapotranspiration reduction would be regarded as a new use and would have a low priority. Indeed, in areas closed to further development the law might be interpreted to the effect that a person salvaging water would not be permitted to use it at all. Modification of some state water laws therefore may be necessary if attempts to salvage evapotranspiration losses are to be encouraged.

(c) VEGETATION MANAGEMENT TO INCREASE WATERSHED YIELD

The idea that forests create water and that every tree must be saved if we are to have enough water has become thoroughly discredited. It is now realized that trees use water, and that a part of the water they use can be salvaged for other uses by selective cutting of vegetation that will not have adverse effects such as an increase in flood runoff or erosion. The U.S. Department of Agriculture has taken the leadership in this field. In a report to the Senate Select Committee³⁰ it sums up the possibilities in the seventeen Western states. Increased yields of as much as 4 inches of runoff per year could be obtained from forests in the snowpack zone. To realize these yields, it would be necessary to develop markets for the forest products that would be taken out and to build access roads. Though quantitatively very promising in terms of acre-inches of increased yield per acre, the snowpack zone covers a rather small total area; also, a substantial part of it is likely to be included in wilderness areas set up by congressional action, and that part of course—and properly so—could not be treated in this way.

Douglas fir, hemlock, and redwood forests of the north Pacific slope total some 25 million acres from which a substantial increased yield could be realized by forest management. This area is one of abundant runoff and of relatively small water needs at present, and no estimates were made of specific savings, in inches of water, that might be realized. As local needs or needs of water for export increase, the area will offer important possibilities.

Interior ponderosa pine and Douglas fir areas total 43 million acres. The average water yield is about 4 inches, from an average of 20 inches of precipitation, and the yield might be increased by half an inch to an inch by careful management. This area is potentially one of the most important for such salvage.

Chaparral and related woodlands yield runoff ranging from 7 inches in central and 5 inches in southern California to 1.5 inches in Arizona. Conversion of such areas to grass might result in an average increase in yield of 0.5 to 1.0 inch; about half the area of these brushlands might be subject to treatment.

30. U.S. Dep't of Agriculture, *Vegetation Management and Water Yield in the 17 Western States—Evapo-transpiration Reduction 17-18*, Senate Select Comm. on Nat'l Water Resources 21 (Comm. Print 1960).

Areas of piñon and juniper receive an average of only 15 inches of precipitation and yield an average of only half an inch of runoff per year. Control of juniper and conversion to grass might increase the runoff by an average of a quarter of an inch per year, but only in the most favorable tenth of the total area.

Grass and shrub areas receiving an average of 12 inches of precipitation yield an average of only 0.4 inch of runoff per year, and the prospects for increasing the useful yield substantially are nil.

It appears that a good many million acre-feet per year could be obtained by forest management in the Western states. Only a part of the total salvage that could be physically achieved will prove to be economically and politically feasible, but this part might well amount to several million acre-feet per year, of the same order of magnitude as the quantity salvageable by phreatophyte control.

If and when necessary, forest management in the East also could increase runoff substantially where conditions are favorable.

(d) SEEPAGE CONTROL AND INCREASED IRRIGATION EFFICIENCY

Much of the water diverted for irrigation never reaches the irrigated fields, owing to seepage from canals and ditches. These "conveyance losses" are estimated to have totaled 23 bgd, or 26 million acre-feet, in the conterminous States in 1960.³¹ The water is "lost" for useful purposes only to the extent that it moves to areas where it cannot be recovered—for example, areas where it is evaporated in playa lakes or transpired by low-value vegetation. Nevertheless, it is lost so far as the local project is concerned and its loss increases project costs, and enough of it is lost permanently to warrant substantial efforts to recover a part of it. The U.S. Bureau of Reclamation estimates that as much as 1.5 million acre-feet per year could be salvaged by 1980 by such means as lining canals and using closed conduits.³²

Excessive conveyance losses go hand in hand with excessive irrigation applications, which not only are unnecessary but may cause waterlogging which may both damage soil and result in increased "consumptive waste." In part the excessive applications are due to a fear of reduction in water rights, or to a desire to perfect a larger right than is actually needed for the land to which the right applies. Substantial modifications in state water laws, or in their enforcement, may be needed to make irrigation practices conform more realistically to the concept of beneficial use embodied in nearly all existing statutes. Locally, seepage losses may have gone on so long as to have become the basis for either surface- or ground-water rights that depend on their continuation. This complication in some areas may prevent full application of techniques to control seepage losses,

31. U.S. Geological Survey Circ. No. 456, *Estimated Use of Water in the United States, 1960* (1961).

32. *Supra* note 25 at 3.

but it should not be allowed to deter increased efforts to tighten up existing practices where to do so is feasible and reasonable.

(e) REDUCTION IN WATER REQUIREMENTS FOR WASTE DILUTION

As has been stated previously, the principal purpose for which minimum flows of streams must be increased is dilution of wastes.³³ Techniques that could reduce the requirement for water for waste dilution might enable reducing total streamflow requirements by many billion gallons per day and at the same time would result in improving the condition of the streams for recreational uses and fish and wildlife. Among techniques now being tried are "lagooning" of wastes and "rapid oxidation" methods, both of which have the effect of oxidizing much of the organic wastes locally instead of depending on the dissolved oxygen in the streams to do it. Research in the field of reducing waste-dilution requirements should be greatly expanded and aggressively pursued, for the potential savings in water are at least as great as those which might be achieved by any other technique now in sight.

(f) SALVAGE OF WASTE WATER

Used water treated to an extent adequate to make it acceptable for discharge into a stream might prove to be useful for purposes for which the untreated water might be unsuitable. Thus, instead of being discharged to waste after one use and treatment, it might be reused one or more times before final treatment and discharge. In such a case, partial rather than complete treatment might suffice for the intermediate stages, the highest degree of treatment being given only before final discharge. The possibility of reclamation and re-use instead of once-through use should be considered under as many different situations as possible. Some tens of millions of gallons per day of treated sewage from the Baltimore municipal system is now sold to a steel mill. Treated sewage is being used in some places for irrigating golf courses and other tracts where food is not grown. With proper precautions, treated sewage could even be used on crops, but rigid public regulation of such practices would be essential to safeguard health. Use of reclaimed sewage for recharging depleted aquifers is being considered in California. The prospects, in general, are best in industry. The largest single industrial use of water is for cooling, and even partially treated waste water may be suitable for that purpose.³⁴

(g) ECONOMIES IN INDUSTRIAL USE

Industrial re-use of water that has not reached the stage where it might be considered "waste" water, as described in the previous section, is another highly

33. Senate Select Comm. on Nat'l Water Resources 9 and 24 (Comm. Prints 1960).

34. Gloyna, Wolff, Geyer & Wolman, *Water Resources Activities in the United States—Present and Prospective Means for Improved Re-Use of Water* 8-12, Senate Select Comm. on Nat'l Water Resources 30 (Comm. Print 1960).

promising technique.³⁵ The bulk of industrial water is used for cooling and washing and may be contaminated only slightly by such use. Recirculation and re-use may offer economies that will offset the cost of the required recirculation and treatment facilities. There is nothing new about this, and many industries re-use water as a matter of course where to do so may be less costly than purchasing or developing new water. Even so, great additional savings in water can be made by industries that do not now recirculate any water and by all industries in reducing uses to the minimum needed to achieve a particular result. As the cost of developing water increases, and as more and more communities establish water rates that reflect the true overall cost of obtaining, treating, and distributing water and of maintaining and expanding their systems, water will be re-used on a progressively increasing scale as a matter of economic necessity.

(h) SALINE-WATER CONVERSION

Saline water has been converted to fresh on a small scale for many years, such as on ocean liners. Since 1952 the federal government has been investigating various techniques for conversion, at first on a very small scale and since 1958 on a more adequate scale. Five pilot plants using different processes have been authorized, one of which will be at Roswell, New Mexico. Two are already in operation, one a distillation plant for converting sea water at Freeport, Texas, and the other an "electric membrane" plant for converting brackish water at Webster, South Dakota. Several small independently built plants are already in use, including one at Coalinga, California, which is now converting brackish water by the electric membrane process for its public supply at a cost of \$1.50 per thousand gallons, as compared to the \$7 per thousand and formerly paid for water hauled in.³⁶ The pilot plant at Freeport is reportedly producing water at a cost of about \$1 per thousand gallons, not counting the cost of distribution.

No matter how efficient a saline-conversion process may be in recovering and reusing heat or other energy, an inescapable minimum amount of energy is required to separate salt from water molecules—2.6 kilowatt-hours per thousand gallons for sea water.³⁷ In the absence of the breakthrough in energy costs that has been mentioned previously, which would be reflected not only in the cost of energy used in a conversion process but in vastly reduced costs for manufacturing the equipment and building the plant and distribution system, it is unlikely that any conversion process will bring the cost of water below a few tens of cents per thousand gallons—and this only for large plants producing several million gallons per day. This cost would be in the range feasible for domestic use. Under

35. *Id.* at 23-26.

36. Aandahl, U.S. Office of Saline Water vii (1959).

37. Ellis, *Fresh Water from the Ocean for Cities, Industry and Irrigation* 25 (1954).

current and expected economic conditions, however, it would not be low enough for large-scale irrigation and industrial uses, where even now costs are as little as a few cents, and in a few places less than one cent, per thousand gallons. Hence, saline-water conversion, useful as it will undoubtedly be for municipal supplies in areas of high water costs, under current conditions is not a promising means for producing large quantities of low-cost water.

(i) WEATHER MODIFICATION

Weather modification as a technique for increasing water supplies received tremendous publicity and a great deal of support in the years after 1946, when Langmuir and Schaefer made their "cloud seeding" experiments with dry ice. Extensive experiments and large-scale commercial endeavors have added much to existing knowledge of the possibilities, but there is still a great need for research and experimentation to determine what can be done to increase precipitation, as well as in other aspects of weather modification, and what the effects on other areas will be.³⁸ In Committee Print 31, Ackerman and others conclude on the basis of the 1957 report of the Advisory Committee on Weather Control that the water supply of the Western states might eventually be increased by 15 million acre-feet per year by weather modification.³⁹ Though this quantity would not be large enough to be a major factor in the design and operation of multiple-purpose water projects in the West, the additional water would be the cheapest that could be obtained by any means now in sight.

The U.S. Weather Bureau's report in Committee Print 22 concludes that weather modification "is unlikely ever to be a universal solution to shortage of natural water supply. It is unlikely to be a means of relieving general drought or providing water artificially for converting deserts to regions with adequate rainfall."⁴⁰ Summarizing the whole subject in its report, the Senate Select Committee points out that rainmaking efforts to date have been most successful in coastal and mountainous regions and that techniques used there may not be applicable to inland nonmountainous areas.⁴¹ Furthermore, there is as yet no assurance that an artificially induced increase in precipitation in one area will not be offset by a decrease in another area.

If large-scale rainmaking in the Western states proves to be practical, but if increases in precipitation in one area prove to be offset by decreases in another, some states may be in trouble. An example that comes to mind is Colorado, which serves as a source of runoff to adjacent states and is committed by com-

38. Eberle, *Weather Modification as a New Technique to Increase Water Supplies* 44-45, Senate Select Comm. on Nat'l Water Resources 22 (Comm. Print 1960).

39. *Supra* note 24, at 19-21.

40. U.S. Weather Bureau, *Progress and Possibilities in Weather Modification* 1-26, Senate Select Comm. on Nat'l Water Resources 22 (Comm. Print 1960).

41. Report, p. 57.

pacts to let about half its average runoff of 16 million acre-feet per year flow into other states. If rainmaking in upwind areas proved to reduce Colorado's precipitation significantly, the state would be in a most unfortunate position. Obviously, in situations such as this there may be a need for federal legislation to enable satisfactory adjustment for the interstate effects of artificial changes in the natural hydrologic regimen. On the other hand, areas in which rainmaking might be practical are small enough that the overall effect on the moisture content of huge air masses may be negligible, even in the West. This is simply one of the unknowns that needs evaluating.

(j) HYDROMETEOROLOGIC FORECASTING

Variations in natural water supply put a high premium on forecasting, as accurately as possible, how much runoff is likely to be received at a given time, in order that plans can be made for best use of the water. The very size of a reservoir which is to have a given average and minimum yield is determined by analyzing past records of precipitation, runoff, and evaporation and predicting what is to be expected in the future. If the prediction is too optimistic and the reservoir is designed too small, it will not yield the desired supply in dry years, and it will have relatively little value for flood control. If the prediction is too conservative, the reservoir will be larger and costlier than it need be. A prime example is the San Carlos Reservoir formed by Coolidge Dam on the Gila River in Arizona, which has never been filled to capacity.⁴²

Flood forecasting is another important phase, as a means of saving lives and protecting property.⁴³

Probability analysis is a principal tool in hydrologic design.⁴⁴ It is a method in which the precipitation or runoff in a given period is regarded as a random quantity which can be expected to recur at intervals determined from the normal-distribution curve used in statistical analysis. The method indicates the statistical probability that a given amount of precipitation or runoff may occur in any future year, but it cannot indicate whether *next* year is the one in which the given amount is to be expected. So far success has eluded those who have attempted to predict that, from past trends, next year's precipitation will be so much—that is, to predict on the basis of trends and cycles rather than on the assumption of randomness. As records lengthen, this situation may change, and someday it may be possible to predict next year's events more confidently than can now be done. That day should be hastened by means of an intensive program of research; the task is likely to be one of the most difficult in the whole field of

42. Langbein & Hoyt, *Water Facts for the Nation's Future—Uses and Benefits of Hydrologic Data Programs* 228-29 (1959).

43. *Supra* note 3 at 4-7.

44. U.S. Geological Survey Circ. No. 410, *Probability Analysis Applied to a Water-Supply Problem* (1959).

hydrology,⁴⁵ but the possible rewards in terms of lives and money saved and water supplies assured are tremendous.

(k) EFFECTS OF NUCLEAR ENERGY

Generation of electricity by nuclear plants offers no particular problems, barring major accidents resulting in the release of dangerous quantities of radioactive substances. The water requirements for cooling are about the same as for conventional steam plants.⁴⁶ Again barring accidents, disposal of radioactive wastes without substantial damage to water and other resources—and to people—can be achieved by known techniques.

Radioactive substances and nuclear energy have been hailed as having potentially tremendous contributions to make to the finding and development of water. With one exception, discussed in the last paragraph of this section, these possibilities seem to the writer to have been greatly exaggerated. Radioactive substances have a number of uses in hydrologic studies.⁴⁷ They can be used as tracers to indicate direction of movement and possible sources of water. They can be used to a limited extent to indicate the age of water, which may be of significance in relation to occurrence and amount of replenishment. They are useful in logging cased wells in which ordinary electrical loggers cannot be used, and in determining soil-moisture content.

Even if nuclear devices were able to find water, which they are not, finding water is a very small part of the job, and not even an important one in comparison to the task of evaluating the quantity.

The subject is put in proper perspective by A. R. Luedecke, General Manager of the Atomic Energy Commission: "Nuclear energy techniques that may also be useful in water resources development are of considerable interest to the AEC and other specialized Federal agencies, particularly the U.S. Geological Survey, directly concerned with water resources. Although the development and application of such techniques should be encouraged to the fullest possible extent, it is apparent that they are tools for use by the hydrologist, geologist, and other water resource specialists and not new methods nor avenues for water resources development."⁴⁸

Nuclear explosions have been suggested as a means of shattering rocks to create aquifers out of impermeable rocks, to increase the permeability of aquifers of low productivity, or to increase the rate of recharge. For example, see part 23 of the hearings before the Senate Select Committee, Washington, D.C., May 26, 1960, pages 3683-3686. In the writer's opinion, the possibilities along this line

45. *Supra* note 3, at 36.

46. U.S. Atomic Energy, *Water Resources Activities in the United States—Application and Effects of Nuclear Energy* 1, 2, Senate Select Comm. on Nat'l Water Resources 27 (Comm. Print 1959).

47. *Id.* at 9-13.

48. *Id.* at v.

are small and relatively insignificant. To create an aquifer of really substantial storage capacity or to increase the permeability of a large existing one would be beyond the practical capabilities of even nuclear explosions. Hydrologic situations in which impermeable brittle rocks overlie highly productive aquifers and in which, also, the natural rate of recharge of the aquifer as a whole could be increased substantially percentagewise by shattering the impermeable rocks are not common. There will be local applications where the shattering effect of an explosion could be used to divert a stream into an aquifer or to divert ground water from one outlet to another, but in total these applications will not be significant to the water economy of the nation as a whole. Application of nuclear energy to earth-moving jobs is a much more promising field. According to Dr. Edward Teller,⁴⁹ in some cases "we can move earth for only 1 percent as much [cost] as we did by old-fashioned methods."

Developments in nuclear-energy generation conceivably could lead to the great reduction in energy costs that will have to come at some time in the future. Energy from the hydrogen (fusion) process used in the H-bomb, now available only in explosive form and only when a fallout-producing A-bomb is used for a trigger, would seem on the basis of present knowledge to be the logical target.

(1) IMPROVED USE AND CONTROL OF GROUND WATER

Ground water has a very important contribution to make to the future water economy of the nation. Productive aquifers that are unpumped or only lightly pumped underlie many thousands of square miles and offer an opportunity for diverting a part of the water supply that is free of sediment and uniform in temperature and chemical quality. Diversion of ground water, like that of surface water, depletes the total supply only to the extent that the water is evaporated, discharged at a point beyond recovery for other uses, or made less useful or unusable by addition of heat or contaminants. Thus, even though development of ground water will not increase the nation's total supply of some 1,200 bgd, it can add appreciably to the total usable supply.

At the same time, the potentialities of ground-water development must be kept in perspective.⁵⁰ There is a tendency, based in part on unfamiliarity with the resource, to impute to ground water a degree of promise in meeting future water needs that is not likely to be realized. For example, it has been predicted⁵¹ that the ratio of ground-water to surface-water withdrawal might increase from the present ratio, stated to be about 1 to 4, to something between 1 to 2 and 1 to 1

49. Hearings before the Senate Select Committee on Nat'l Water Resources, 86th Cong., 1st Sess. 3683 (1960).

50. Report to 21st International Geological Congress, Copenhagen 1960, by McGuinness, *Ground Water—A Mixed Blessing*, pt. 20, 7-16.

51. See Ackerman, *supra* note 24 at 22.

in the next 20 to 50 years. Nothing of the sort is likely to occur; the ratio probably will go down rather than up.

The ratios indicated by the U.S. Geological Survey's data for 1950, 1955, and 1960,⁵² use of saline water included, were about 1 to 4.8, 1 to 4.2, and 1 to 4.4, respectively. The data for the three years are based on estimates, many of which are very crude, and are not strictly comparable. They indicate an increase in ground-water withdrawal of nearly three-fifths from 1950 to 1955, but almost no increase from 1955 to 1960. The 1950 figure for ground-water irrigation was probably low and the 1955 figure for industrial use of ground water was probably high. Even though the 1950 figure for irrigation may have been low, there was a substantial increase in ground-water irrigation by 1955, owing in large part to a shortage of surface water in the middle 1950's. The shortages persisted through much of the late 1950's, so that the total for ground-water irrigation remained at about 30 bgd in 1960. The increase in irrigation withdrawal was responsible to a considerable extent for the actual increase in total ground-water withdrawal, whatever it was, from 1950 to 1960, and the rate of increase is not likely to persist through the 1960's.

Thus the increase in total ground-water withdrawal from 1950 to 1960 was probably less than the nearly three-fifths indicated by the figures—possibly no more than one-third. If the rate of increase in coming decades is one-third each decade, the totals will be only 82 bgd in 1980 and 147 bgd in 2000. Even if it is as much as one-half, the totals will be only 105 and 235 bgd. In the writer's opinion, the actual rate of increase may prove to be even less than one-third each decade. And, even if it is that or more, it obviously cannot be kept up indefinitely after 2000.

A large part of the future increase in ground-water development will, or at least should, result from the use of ground-water reservoirs as media for storing surface water in time of surplus and withdrawing it in time of shortage. The aquifers of the nation have an enormous total storage capacity, a substantial part of which, amounting to many millions of acre-feet, would be usable for cyclic storage. Unfortunately, a large part of the surplus storage capacity is in Western desert basins where surface water simply is not available, and cannot be made available except by long-distance diversion from wetter areas. Also, recovery of the stored water is complicated by the presence of saline water at depth or in the inner parts of most basins. Nevertheless, the advantage of ground storage is so great, especially in dry areas where the stored water is relatively immune from evaporation losses, that it should be kept in mind wherever provision of storage to achieve desired streamflow regulation is a problem. Intensive research and areal studies and much practical experience with artificial recharge will be required before ground-water reservoirs can begin to come anywhere near their potential as storage media.

52. U.S. Geological Survey Circs. No. 115, 398, and 456.

Hydrologically incorrect concepts embodied in much of existing water law, and failure to recognize ground water and surface water as the single resource they are, will be stumbling blocks in future development of ground water and in multipurpose development of water as a whole.⁵³ Much remains to be done in his field, and it is a pleasure to see New Mexico among the leaders, as marked both by the way in which water rights are administered by the State Engineer and by establishment of the Journal in which this paper appears.

5. RESEARCH IN ECONOMICS AND THE SOCIAL SCIENCES

Even when improved and more efficient methods of water use and treatment are developed, users are slow to adopt them. To understand how adoption of such methods can be promoted, research in water management is needed, not only to guide improvements in use but to enable predicting the impact of changes in use on the water regimen and water projects.

Several areas have some promise:

(a) ECONOMIC INCENTIVES

Publicly supplied water is rather commonly a subsidized commodity; charges for water do not fully reflect the costs of water supply, treatment, and distribution, the deficit being made up by taxes. If the price of water fully reflected all costs, water rates in many if not most places would be higher, and economy in water use would be encouraged.

Often there is not much incentive to adopt, and considerable resistance against adopting, realistic water rates. The writer recalls a proposal to *increase* the charge per unit of water after a specified minimum quantity was used, to discourage heavy uses by individuals in an area of extremely scarce fresh-water supplies. Though the proposal made hydrologic sense, it ran contrary to the general philosophy of charging less per unit the greater the quantity used, and it was not adopted.

(b) ALTERNATIVE USES OF WATER

As water demands grow and remaining supplies shrink, many decisions will have to be made as to the use of water to be favored when there is not enough water for all proposed uses. Studies are needed to develop guidelines that could be used in making such decisions so as to realize the greatest economic and social return from use of limited supplies of water.

(c) SYSTEM PLANNING

The major water project of the future is a multiple-purpose project. Better methods are needed for planning the design, construction, and operation of such projects—in other words, better informed planners using better tools. The need

53. U.S. Geological Survey Circ. No. 117, *Water Law, With Special Reference to Ground Water* 4-8 (1951).

for high-speed computers, and, even more important, for development of systems of programming computations to avoid unnecessary effort, are made evident by the fact that comparison of all possible alternatives in allocating water from x sources to y uses involves x^y comparisons. If the number of sources and the number of different potential uses are substantial, as they would be in large multiple-purpose projects, the number of computations required may be fantastic unless schemes can be developed for eliminating some unpromising types of choices without precluding the comparison of all promising ones. Such a scheme is presented in a paper by Hall and Buras.⁵⁴

(d) ECONOMIC EFFECTS OF EXISTING PROJECTS

Studies of the past and current effects of existing projects on the local, regional, and national economy are needed in order to develop guides for analyzing the effects of future projects. The studies should compare the actual effects of the projects, good and bad, economic and hydrologic, with those predicted during the planning stage. Such studies, in addition to leading to improvements in the planning of future projects, might lead to modification of existing projects for greater efficiency or productivity—for example, to enable greater use of a reservoir, originally constructed for flood control, for water supply or recreation.

6. IMPORTANCE OF INCREASED BASIC AND APPLIED RESEARCH

A greater proportion of the money devoted to water projects should be spent on research, now accounting for federal expenditures equivalent to less than a tenth of 1% per year of a total federal investment of more than \$40 billion in the water-resources field. The Committee in its report refers to one industry that has a total investment of about \$1 billion and spends about \$90 million each year on research.⁵⁵

(a) DEFICIENCIES

Fundamental research in water resources is gravely deficient in comparison to that in fields such as health, agriculture, and defense. Basic information is needed on the physical chemistry and molecular structure of water in relation to desalinization; on atmospheric physics, photosynthesis, and solar radiation in relation to weather modification, hydrometeorologic forecasting, and evapotranspiration; and so on.

Applied research is needed urgently in such fields as treatment of sewage and industrial wastes, one of the most promising fields for effecting savings in water use. Similar research is needed on agricultural and industrial uses of water.

There is need for improved coordination of water-related research in federal and other governmental agencies, universities, and private companies and insti-

54. Hall & Buras, *The Dynamic Programming Approach to Water-Resources Development*, 66 J. Geophysical Research 517-20 (1961).

55. Report, p. 60.

tutions, to avoid unnecessary duplication of effort at a time when the total effort is so inadequate in comparison to the total needs.

(b) PERSONNEL LIMITATIONS

Research in water has attracted less attention, and fewer well-qualified candidates, than that in such fields as electronics, aeronautics and astronautics, and nuclear energy. Unless universities expand their training programs in hydrology and water agencies needing researchers publicize and make more attractive the opportunities to be found in their programs, the needs are not likely to be met. In the writer's own field of ground water, there is even now no such thing as a college graduate who has sufficient training to begin producing useful results immediately upon his entrance into an agency making hydrologic studies.

7. COLLECTION, ANALYSIS, AND INTERPRETATION OF BASIC DATA

Nearly all studies of needs related to water resources have concluded that we need more "basic data" on water, and this conclusion is true. Yet, even now, we have large collections of data which have not been analyzed, and the study of which would pay dividends in making future data-collection programs more effective and economical. New analytical and computing methods are needed both to make better use of the data and to show what kinds of data should be collected in preference to others. Among the fields in which many more data, and more analysis, are needed are local and regional occurrence and quality of ground water; effects of disposal of low-level radioactive wastes; climate-induced fluctuations in water supply; soil erosion and movement and deposition of sediment; topographic, geologic, and soil mapping; effects of land-management practices; and so on. Deficiencies and needs in the field of basic hydrologic data are the subject of a whole book by Langbein and Hoyt (1959), entitled appropriately "Water Facts for the Nation's Future."

8. FEDERAL WATER-RESOURCES ACTIVITIES

Lack of consistency among federal agencies in the way they operate in the water-resources field has been charged by many observers. The Committee believes that, on the whole, there are no important difficulties that will not be resolved if efforts are made by the federal agencies to improve public understanding of water problems, to renew emphasis on comprehensive planning, to strengthen state and local participation in planning, and to beef up the research effort. The Committee points out several fields in which additional effort may be required.

(a) BETTER USE OF FLOOD PLAINS

Flood damage can be and in some areas has been reduced substantially by land management, reservoirs, levees and channel improvements, and flood forecasting. So long as continued encroachment on flood plains is permitted, however, the

means listed cannot be entirely effective. Inasmuch as flood control is largely a federal responsibility, the federal government can improve the situation by insisting on state and local control of unwise encroachment, by means of zoning regulations, as a condition of approval of a federal project. Flood maps prepared by the Geological Survey, such as the one for Topeka,⁵⁶ will be of substantial help in the devising of proper controls.

(b) DISPOSAL OF RADIOACTIVE MATERIALS

The Committee, though praising the efforts of the Atomic Energy Commission to date in controlling the disposal of radioactive materials, recommends that an outside agency participate in the setting of standards for radioactive-waste disposal, in order that public confidence in the adequacy of the control measures may be maintained.

(c) CLARIFICATION OF THE FEDERAL POSITION ON WATER RIGHTS

The Committee points out the extent to which the rate at which states and localities undertake or contribute to water-resources developments—and their contribution is the largest part of the whole job—may be adversely affected by uncertainties concerning the federal position on water rights, particularly rights to the use of water originating on the public domain and reserved and withdrawn lands. Such uncertainties have become widespread since 1954, when the Supreme Court in the so-called *Pelton Dam Case*⁵⁷ decided in favor of the Federal Power Commission a case involving a license to build a power dam on the Deschutes River. Legislation introduced in subsequent Congresses and “memorials” by nineteen state legislatures have sought to bring the matter to a head. (See hearings on Federal-State water rights before the Committee on Interior and Insular Affairs, United States Senate, June 15-16, 1961.) The Senate Select Committee on page 67 of its report states: “The problem of Federal-State water rights is one that calls for broad objective inquiry, and for statesmanship of the highest caliber on the part of both the Congress and the States in its solution. A solution must be worked out, and worked out promptly, for the preservation of the historic pattern under which our people have grown great.”

(d) FURTHER STUDY AND CONTINUING APPRAISAL

The Senate Select Committee hopes that “its efforts have opened the door to a new type of analysis of water resources.” It recommends two further types of study: (1) appraisal by federal agencies and the states of emerging water problems in the areas where water shortages will be most acute by 1980, with a view

56. Atlas HA-14, available from the U.S. Geological Survey.

57. *Federal Power Comm'n v. Oregon*, 349 U.S. 435 (1954).

to finding solutions that will minimize adverse effects on the economy; and (2) periodic reassessment of the water supply-demand relationship in the different water-resource regions, as done for the current period in Committee Print 32.⁵⁸

(e) IMPROVEMENTS IN BUDGETARY PROCEDURES

The Committee recommends improvements in procedures for (1) keeping the states fully informed and up to date on plans for federal-project construction, in order to facilitate state action in appropriating necessary matching funds; and (2) financing federal projects in advance or on a continuous basis, which would result in substantial economies in construction and would provide a firmer basis for required action by states and localities.

(f) OUTDOOR RECREATION

There is a growing tendency to recognize the necessity of providing adequately for recreational interests, and for fish and wildlife, in planning multipurpose water projects.⁵⁹ Broad authority in the development of recreational facilities at flood-control reservoirs is provided in the Flood Control Act of 1944, but there is no similar provision in federal reclamation or watershed-development laws. The need for adequate provision for recreation and fish and wildlife would be demonstrated and the justification for such provision would be strengthened if criteria for realistic, and if possible quantitative, evaluation of benefits could be devised.

9. OTHER SUBJECTS CONSIDERED BY THE COMMITTEE

(a) IMPROVING CONGRESSIONAL PROCEDURES AND ACTIONS

Numerous suggestions have been made that permanent committees be set up in the Senate and House and charged with responsibility for all legislation related to water resources. In view of the very wide scope of such legislation, of the fact that to establish such committees would require modification of the Legislative Reorganization Act of 1946, and of the fact that the existing Senate Committee on Interior and Insular Affairs and Committee on Public Works have operated well together in joint sessions, the Senate Select Committee believes that establishment of new committees on water would not be justified at this time.

(b) IMPROVING FEDERAL ADMINISTRATIVE PROCEDURES

It has been suggested that a new agency be created and made responsible for coordination of federal water-resources policies and programs. The Committee would be inclined to favor fewer rather than more federal agencies operating in the water-resources field, but believes that creating an agency that merely com-

58. *Supra* note 22.

59. Senate Select Comm. on Nat'l Water Resources 18 and 17 (Comm. Prints 1960).

bined all existing water agencies would not necessarily improve the situation. In view of this possibility, and of the many conflicting interests of different segments of the public supporting the programs of existing agencies, the Committee doubts that widespread public support could be generated for merging any of the water-resources agencies. It believes that existing agencies can, and should, accommodate themselves to carrying out the improvements in procedures suggested previously under the heading "Federal Water-Resources Activities."

CONCLUSION

From the report of the Senate Select Committee and from other available information, the writer draws the following conclusions:

1. Water use is going up, but it is not going up as rapidly as predicted in the Committee's report. Water demands have increased more rapidly than the population, and the population growth has rarely failed to exceed predictions made even a few years in advance. Nevertheless, it cannot be assumed that per capita use of water will continue to increase indefinitely. Rising costs of obtaining water, and the inexorable fact that the supply is fixed, will combine to force greater economy and efficiency in water use. The factors of increasing costs and increasing water shortages that the Committee—realistically, in the writer's opinion—assumes will lead to increased efficiency in irrigation cannot help but operate in the other principal withdrawal uses, municipal supply and industrial use. As taxpayers discover that an increasing share of rising income and property taxes is used to subsidize water systems in order to keep their water bills low, they will insist on realistic water rates that will reflect true costs of exploration, development, treatment, distribution, and maintenance, and they will economize on water use. As industries find their water costs increasing, from the fraction of a percent of total operating costs that many of them still pay to 1 percent or more, they too will find ways to economize.

2. Ground water will be developed on an increasing scale to meet water demands where surface supplies are inadequate or of unsuitable quality or temperature. Ground-water reservoirs will be used to a much greater extent for storage of surplus surface water. Important as these uses will be, they are not likely to be undertaken on the scale envisioned in some of the supporting documents of the Committee's report. Ground-water development costs money, in many cases enough to make conservation and re-use of existing supplies, or development of ground water on a limited scale, more attractive economically than the initially contemplated development.

One of the greatest costs of ground-water development is that involved in locating and evaluating the resources. In general, it costs more per gallon to find and evaluate a supply of ground water than to find and evaluate a corresponding supply of surface water. Whether it costs more to develop a ground-water supply depends on circumstances—often, on the quantity desired. Where the demand

is small, as for domestic supply, ground water may be the only choice; surface water may be entirely impractical for reasons of cost in obtaining, storing, and treating the water. As the desired quantity increases, however, this situation commonly is reversed.

3. Research and investigation are the prime need. One can do only what he knows how to do. By a long shot, we do not yet know enough about how to increase our water supplies, even on the assumption that time and money are no problem. To obtain the scientific and technical knowledge required to do the job will call for greatly increased efforts in education and research, and these will take time that can ill be spared in view of the rapidly increasing demands which are already on us.

4. If time and money are made available to acquire the basic education, do the research, make the correct choices among alternative proposals, and design and construct the projects, we can meet our water needs for some decades to come by use of principles and techniques that are already known or can be seen to be emerging. But our population and water demands will continue to increase indefinitely. Eventually, the needs will be such that our existing fresh-water supply will not be able to meet them. It is then that fundamental technical breakthroughs will be necessary to enable conversion and distribution of saline water. As stated previously, the writer believes that the most fundamental breakthrough of all will have to be in energy costs.

5. The key to the whole situation is public education and support. There are two principal goals: (a) public willingness to meet the increasing costs of supplying tomorrow's water, and (b) public adjustment to the increasingly centralized control of water developments that will be essential to rational water management.

We have the highest standard of living in the world, but no one can deny that we still have too much poverty in our nation. Our ability to produce and overproduce everything from food to automobiles to airline seat-miles proves that we have the capacity to provide a comfortable standard of living for all our people. But we have yet to demonstrate the intellectual and political maturity needed to accomplish the necessary distribution of these goods, short of adoption of a more centralized form of government and surrender of more of our individual political freedom than most of us would be willing to accept.

In the same way, we have yet to demonstrate that, without surrendering the ultimate control which must remain in the hands of the people, we can provide the financial support, and can achieve the proper balance between retention and delegation of authority, to enable efficient planning, construction, and operation of the vast water projects of the future—projects that will cross state lines and will involve coordinated control of watershed management and of collection, treatment, and distribution of water for water supply, flood control, navigation, and power generation.

The writer is optimist enough to believe that we can do all these things, but

realist enough to believe that to do them we will have to work and think harder than we ever have before in peacetime. We had better get on with the job.

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