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Water-Resources Research in the Federal Government

Physical, biological, engineering, and social sciences can help solve a problem of growing dimensions.

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Water is the most abundant substance in the part of our planet that is accessible to man. Nearly all our planet's water is salty, and this is perfectly satisfactory for the creatures that live in the sea. But land plants and animals must have fresh water. They can live only because the sun continually distills pure water from the ocean and some of this distillate is carried in the air as vapor until it condenses and drops on the land. The flux of water from the ocean into the air, onto the land, and back to the sea, is called the hydrologic cycle.

Although the hydrologic cycle is exceedingly complex in detail, in general we can think of the water particles as following one of three paths. (i) The larger part of the water that falls on the land surface passes back to the air, either directly by evaporation or through the bodies of plants in transpiration. It may recondense and fall again on the land, or it may fall in the ocean. (ii) A smaller part of the water that reaches the land surface remains in liquid form and either sinks into the ground or stays on the surface. This liquid water runs downhill or flows underground until it is gathered by rivers that carry it back to the sea. (iii) A very small fraction is taken up in the bodies of plants and animals. Some of this fraction is broken down by plants, which use its hydrogen in forming their tissues. The hydrogen is later recombined with oxygen in animal and plant respiration, and the water thus produced is returned to the air.

The time required for water particles to travel through the hydrologic cycle varies widely. A particle evaporated from the ocean near shore may fall as rain in a coastal region, evaporate again almost immediately, and return to the ocean as rain within a few hours. Water falling as snow in the mountains may remain for months (or, in glaciers, for centuries) before it melts and runs off. Water that sinks into the ground may remain there a few years or many millennia before reappearing on the surface to complete its journey to the sea. Thus, enormous quantities of fresh water are stored underground. In the United States the volume of underground fresh water is probably at least 10 times the average annual precipitation of 30 inches.

The amount of water evaporated each year from the oceans would be sufficient, if it were carried to the continents and uniformly distributed, to cover all the land with more than 100 inches of rain and snow. This is three times the potential annual evaporation from land surfaces. The fact is, however, that the average depth of rainfall over the oceans is much greater than the average over the continents. On about a third of the land areas of the earth the annual precipitation is less than the potential evaporation. Life is possible in these arid regions only because water is carried to them from nearby mountains, where rain and snow exceed evaporation, and because precipitation in the arid lands occurs sporadically, so that some of the water can be caught and stored by plants, or in the ground, before it can evaporate. Even in humid regions the hydrologic cycle slows down and speeds up from time to time, causing periods of drought to alternate with floods. If we can think of the hydrologic cycle as nature's plumbing system, it must be admitted that from man's point of view the pipes are erratically arranged and the valves capriciously managed. Man is slowly becoming more skillful at forecasting fluctuations in this system; someday he may be able to improve the arrangements.

Water Supply of the United States

The United States, exclusive of Alaska and Hawaii, has a surface area of about 2 billion acres. On the average, nearly 5 billion acre-feet of water per year falls on this area (*1*). Seventy-one percent of this water evaporates or is transpired back to the air near the place where it falls. The remaining 29 percent runs off or sinks into the ground and is eventually gathered by streams. A quantity equivalent to about one-fourth the streamflow (345 million acre-feet, 7 percent of the total annual precipitation) is diverted from rivers or pumped from wells for human use. Something less than half the water with-

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drawn from rivers and from the ground is used for irrigation; an equal quantity is used for industrial cooling, washing, and waste removal; and the remainder, less than a tenth, is used for municipal and domestic purposes. Between one-third and one-fourth of the amount withdrawn (2 percent of the total precipitation) is "consumptively used"—that is, returned as vapor to the atmosphere. The rest of the amount withdrawn is returned to streams directly, or is allowed to sink into the ground, whence eventually it flows back to the rivers.

Forty percent of the total precipitation returns to the air by evaporation and transpiration from crop and grazing lands and from forests and is thus "consumptively used" in the sense that it sustains most of our national production of food, fiber, wood, and paper. With our population doubling every 40 to 50 years, and with the corresponding increase in the demand for agricultural and forest products, one might suppose that in the near future the need for water for agriculture would exceed the total annual supply. However, the present efficiency of use of the water that falls on croplands and forest lands is low. Part of it falls at seasons other than the growing season and descends into the water table, because there are no plants to take it up. During the spring and summer, precipitation exceeds potential evapotranspiration over a large part of the cultivated land. Hence, even if the intensity of cultivation were greatly increased, the water supply would still be adequate. In cultivated areas where potential evapotranspiration exceeds precipitation, advances in agricultural technology are making it possible to grow more productive crops with the same amount of water.

The portion of the total precipitation that returns directly to the air is highly variable, both in time and in space. Per unit volume, its contribution to man's requirements is far less than that of the fraction that runs off or sinks into the ground, because to a considerable extent this latter fraction can be controlled by man and distributed in accordance with his needs. It can, moreover, be used to generate hydroelectric power. The energy dissipated by the 1400 million acre-feet of water flowing in United States rivers each year is about 2.5 trillion kilowatt-hours, equivalent to a fifth of the total energy consumed in our industrial society. About 13 percent of this 2.5 trillion kilowatt-hours is now used to generate power. One of the objectives of water-resources research is to find ways of reducing the proportion of water that evaporates or is transpired near the place where it has fallen and to increase the proportion that descends into the water table or is gathered into controllable streams.

Costs of Water Structures

At present, only about 27 percent of the total precipitation is carried to the sea by streams. But this is still an enormous quantity, a thousand times greater than the quantity of any other material used by man, with the exception of air (*2*). Consequently, it is not surprising that the structures required to capture, regulate, transport, treat, and distribute water, though low in unit cost, are very expensive overall. In large modern systems water can be transported for about 0.1 mil per ton-mile, 1/100 the cost of transporting coal or natural gas. Nevertheless, the annual capital expenditure for water structures in the United States currently is of the order of $10 billion.

A committee chaired by Abel Wolman (*3*) has estimated that, in the absence of technological or economic changes, by the year 2000 it may be necessary to withdraw from streams and from the ground 1 billion acre-feet per year, equivalent to about 75 percent of the total streamflow, in contrast to the 25 percent that is withdrawn at present. To obtain, as an assured supply, such a large fraction of the total runoff would require disproportionately more expensive structures for storage, regulation, transportation, distribution, and drainage. If surface storage were used, the required storage sites would intrude on areas already intensively occupied or needed for urban and industrial development. The total capital cost would be several hundred billion dollars, and annual charges would be of the order of tens of billions. Clearly, we need technological and economic developments that will lead to marked reduction in requirements for water withdrawal, to lowering of the unit costs of water structures, and to greater utilization of underground storage. Otherwise, both the economic and the social costs of meeting future water needs will be painfully high.

Regional Needs

Because of the great differences in precipitation and in present and future demand in different regions, and of the high costs of transporting water over long distances, the water problems of the United States are essentially regional ones. In parts of the arid Southwest, water stored underground is now being mined at an alarmingly high rate, and new sources must soon be found to supply even the present population. In several humid regions of the country the volume of water required to dilute sewage approaches, and in some places already exceeds, the amount of water in the rivers during times of low flow. Requirements for controllable water may exceed average river and underground flows by the year 2000 in Southern California and the Great Basin; in the Delaware-Hudson, Upper Arkansas-White-Red River, Great Lakes, and Western Gulf regions; and in the Upper Missouri, Rio Grande-Pecos, and Colorado River basins (*4*). The total deficit in dry years may be 100 million acre-feet per year (*5*). Unless significant improvements in the efficiency of water use can be made, expensive water-transportation systems will be required to meet the needs of these regions.

Needs for Research

The problems involved in developing water resources can be grouped in five categories: (i) regional water-resources planning for optimum development and beneficial use of controllable supplies; (ii) increasing the supply of water for beneficial use; (iii) increasing the efficiency of use; (iv) maintaining and improving the quality of water; and (v) preventing damage by water.

To attack these problems we need more information than we now possess, greater understanding of natural processes in the hydrologic cycle and of the relations between human beings and water, and more powerful methods for analyzing existing information.

Regional water-resources planning. The central problems in regional water-resources planning are those of distributing controllable water supplies in ways that will be economically and socially most beneficial, and of choosing from among different alternatives the most satisfactory means of providing the needed supplies. Solution of these problems requires (i) *appraisal* of the quantity, quality, and variability of all the water moving in the hydrologic cycle, and of the possibility of achieving different degrees of water control; (ii) *projection* of changes in demand and of the effects of various possible uses on quantity and quality; (iii) economic and social *evaluation* of the benefits of various possible uses; (iv) *estimation* of the costs of alternative methods for augmenting, regulating, transporting, and distributing controllable water supplies; and (v) *design* of compatible systems for use and reuse of the available water.

Appraisal requires a long series of measurements of precipitation and streamflow at a network of points throughout the region, together with knowledge of rates of evaporation from different surfaces, rates of transpiration from natural and farm plants, and the relation of streamflow to time, rate, and duration of precipitation. It also requires accurate descriptions of the location, storage capacity, transmissibility, and rates of recharge of the underground reservoirs (including the accelerated rates that might be achieved artificially) and data on the salt content of existing underground waters. The effect on downstream river flows of pumping ground water must be estimated, as well as the rates at which ground-water levels will be lowered by given rates of pumping.

Useful projections of future demand and of changes in quantity and quality of supply are difficult to make because development of water resources sets in motion a chain of events that will itself change both demand and supply. Irrigation, urbanization, industrial expansion, and road construction will alter the pre-exsting relationships between precipitation, runoff, and underground flow. Technological advances in the use and reuse of water will affect future demand, as well as future quantity and quality. Broad-scale investigations of these interactions are needed.

Methods for evaluating benefits and estimating costs can be greatly improved through combined engineering and economic research and the application of modern methods of analyzing highly complex systems.

Improvement in the design of compatible systems requires more knowledge than we now possess of the needs of different water users.

Increasing water supplies. Our concern is to increase the supply of fresh water that is controlled and distributed. This can be done in three ways: by constructing works that will make it possible to use more of the now-controllable water; by increasing the fraction of the total precipitation that can be controlled; and by increasing the total supply of water.

More of the controllable water can be used if it is stored until it is needed. This can be accomplished by construction of dams and conveyance channels for surface storage and distribution or by installation of wells and artificial-recharge facilities to utilize underground storage. Surface storage has some advantages: hydroelectric power as well as water can usually be obtained, gravitational energy can often be employed to convey the water to the point of use, and lakes back of the dams can be used for recreation and other purposes. In many circumstances, however, surface storage has disadvantages. Valuable lands may be flooded, some of the stored water is lost by evaporation, and the costs of construction are high.

There are also serious obstacles to the utilization of underground storage. The water may be degraded through mixing with saline waters or through the dissolving of soil and rock salts. It is hard to increase the rate of recharge of many underground reservoirs because of the limited size of recharge areas or the difficulty of increasing flow through the unsaturated zone above the water table. Pumping costs may be high if the water table is deep. Suitable aquifers may not exist where they are needed. Pumping from underground storage may seriously reduce the river flows available to downstream users. Where underground storage can be utilized, however, evaporation losses are negligible, very little land need be withdrawn from other uses, and capital costs are comparatively low. Because of the advantages of underground storage, particularly in combination with surface reservoirs, vigorous research is needed to overcome the obstacles. The prospect of obtaining valuable results from such investigation is good.

The use of controllable water can often be increased through construction of canals and aqueducts to transport water from surplus to deficit areas. Engineering research on design, materials, and construction methods, aimed at reducing the costs of storage and transportation works, could result in large savings.

In some cases, the use of controllable supplies can be augmented by protecting the fresh water from mixing with saline or otherwise degraded waters, such as acid mine waters. Methods for accomplishing this need to be improved.

In arid regions the runoff from a large area must be concentrated to provide water for a relatively small fraction of the land, and techniques are needed to increase the proportion of total precipitation that can be controlled. Development of such techniques requires research on means of reducing the evaporation from reservoirs and snowfields, on means of increasing the runoff from mountain areas (for example, by modifying the plant cover so as to reduce evapotranspiration), and on methods for increasing the recharge of valley aquifers.

In the long run, it will be necessary to increase the total supplies of fresh water over large areas of the United States. For the near future, however, attempts to increase total supplies must be judged, economically, in competition with the transportation of water from surplus to deficit regions. Research and development on increasing total supplies are of two kinds: attempts to modify precipitation patterns by exerting control over weather and climate, and development of more economical methods of converting seawater or brackish water to fresh water. The ability to control weather and climate, even to a small degree, would be of the very greatest importance to human beings everywhere. Whether a measure of control can be obtained will remain uncertain until we understand the natural processes in the atmosphere much better than we do now. As for desalination, this could be accomplished more economically than at present if the amount of energy required to separate water and salt could be reduced or the cost of energy could be lowered. Research on the properties of water, salt solutions, surfaces, and membranes is fundamental to the desalination problem. So is research aimed at a great lowering of energy costs.

Increasing the efficiency of use. Through research and development, ways are being found to increase the efficiency with which water is used in agriculture, particularly in irrigation farming. For example, new mulching methods are already being applied to reduce evaporation from soil surfaces, thereby making more water available to crops. Through research on the physiology of water uptake and transport in plants, and on plant genetics, evapotranspiration from crop plants could probably be lowered without a proportional reduction in growth rates. Through development of salt-tolerant crops, the amount of irrigation water required to maintain low soil-salt concentrations could be reduced. Seepage losses from irrigation canals and percolation from farm fields could be lowered through the development of better canal lining and through improved irrigation practices. Losses from canals would also be reduced if we could learn how to control useless water-loving plants that suck water through the canal banks and transpire it to the air. For both irrigated and nonirrigated agriculture, improvements in the forecasting of precipitation, snowmelt, and streamflow would help farmers adjust times of field preparation, planting, and cultivation, so as to take maximum advantage of the available water supplies. Reliable river forecasts are necessary, also, for efficient operation of most water-control structures.

Equally pressing problems exist for industrial and municipal users. As the costs of high-quality water go up with increases in the cost of waterworks, methods for reusing water and for using water of lower quality for cooling and other special purposes will have to be improved. Especially important, because of the large quantities of water involved, is the development of methods of waste treatment that require less water for dilution of treated effluents and oxidation of organic residues. Otherwise, expensive structures for river regulation will be needed to provide water for waste disposal during low-flow periods. Complete treatment of waste water to make it reusable for all purposes is also a significant research goal.

Maintaining and improving quality. All naturally occurring water contains some dissolved and suspended materials, though ground water contains little of the latter. The concentration of dissolved impurities is increased as water flows over the surface and underground, both because it picks up materials in solution and because, when it flows on the surface, some of the water evaporates. When a major part of the water is used consumptively, as in irrigation agriculture, the return flows may be highly saline, and downstream uses may be seriously curtailed.

In our industrial civilization, nearly all wastes are eventually committed to flowing water. As a result, various noxious substances are being dumped into our rivers, lakes, and estuaries. The long-term effects of many of these on human health and welfare are unknown.

Every housewife is aware of some properties of water—its color, odor, transparency, taste, hardness, saltiness, foaming qualities, and temperature. Farmers, engineers, and public-health workers are concerned with the dissolved-oxygen content; the acidity; the composition and concentration of dissolved salts, plant nutrients, and potentially toxic substances; and the amounts of suspended matter, especially disease-producing bacteria and viruses and abrasive particles.

In attempting to maintain and improve the quality of water, we must first determine the quality requirements for different kinds of uses. We know, of course, that the water which comes in contact with human beings should not carry disease organisms or dissolved substances that will be injurious. Water used for recreation must not be esthetically unpleasant. Water that serves as the habitat of fish and other creatures must be suitable for them. Water used for industrial purposes must be relatively free of damaging chemicals and abrasive particles. Water for agriculture must not contain dissolved salts or toxic substances that will damage crops or livestock. But these general statements can be made specific only through careful analysis of the needs of users and through studies of the biological and other effects of the great variety of substances that are now being added to our water supplies—detergents, pesticides, chemical fertilizers, synthetic plant hormones, wastes from chemical processing, and others.

Because these substances are so varied and because some of them are potentially harmful even in very low concentrations, we must develop sensitive and rapid methods of analysis and biological assay in order to find out just what substances are present in our water supplies, where they come from, how they interact, and what happens to them as the water moves on the surface and underground. We must, in addition, develop means of removing injurious materials from water, or of preventing them from entering our water supplies.

Prevention of water-caused damage. Before man intervenes, moving water is usually in a state of near-equilibrium with its environment. But this equilibrium is radically altered by human action, and our American landscape is scarred with the results. Clearing of forests, improper cultivation of farmlands, or overgrazing of rangelands may produce a gullied and deeply eroded landscape in a few decades. Road construction and reshaping of the natural surface in building suburbs may spread a torrent of mud over once-green fields. The building of breakwaters may destroy beaches and form unnavigable bars. Waste dumped into a stream may turn a clear, fish-filled reach of water into a stinking, algae-choked desert. Works designed to regulate the movement of water may themselves have marked and unpredicted effects. Construction of a dam may produce drastic downstream erosion or, alternatively, a river channel choked with sediment. Rapid headward erosion may result from the draining of marshes. Structures for flood protection may actually increase the damage from occasional very severe floods, even though they eliminate the dangers from frequent smaller floods.

Damage from storm surges and floods could be greatly lessened through improved forecasting of their occurrence, extent, and intensity. Improvement of forecasts requires greater theoretical understanding of the meteorologic, hydrologic, and physiographic conditions that produce floods and surges. This understanding is essential also to improvement in the design of protective works. In planning for flood protection the engineer has many alternatives —for example, upstream control of the runoff from small watersheds; construction of large downstream reservoirs; building of levees and protective embankments; improvement of river channels; construction of diversion and drainage channels; and restriction of the use of areas likely to be flooded. Choice of the best and least expensive combination of these alternatives depends on adequate knowledge both of the particular situation and of the general principles of flood behavior. Physiographic, meteorologic, and hydrologic research to gain this knowledge can be expected to pay for itself many times over in lowered construction costs and reduced damage.

The development of economical methods of reducing erosion in small upstream watersheds must be based on research into the relationships of precipitation, topography, kinds of soil, plant cover, and runoff, and on the mechanisms of suspension and transport of soil particles by running water. Similarly, the lives of storage reservoirs could be lengthened, and the number of unwanted changes in river channels reduced, if we had greater understanding of sediment transport in rivers. Comparative studies of river ecology and of the sequence of biological changes produced by different pollutants are needed to establish realistic standards for pollution control and to lessen pollution damage.

Role of the Federal Government

Under the Constitution, by tradition, and because of the national interest, the federal government has many kinds of responsibility for water resources. As manager of the national forests and all other federal and Indian lands, it conserves and develops the water resources of these lands for livestock grazing, timber production, outdoor recreation, fish and wildlife conservation, hydroelectric power, and irrigation agriculture, and maintains them as the principal watersheds for adjoining regions. It protects these lands, which cover about a quarter of the entire area of the country, from erosion, floods, and other water damage.

The federal government has responsibilities for all navigable coastal and inland waters, including related nonnavigable river reaches and tributaries. It has joint control, through treaties with Canada and Mexico, over the development and use of international streams. Public works for the development of these waters are large items in the federal budget. They include projects for flood control, navigational improvements in rivers and coastal waterways, and watershed and shoreline protection, as well as hydroelectric power, drainage, conservation storage of industrial and domestic water supplies, pollution abatement, maintenance of recreation areas, and other aspects of river-basin development.

The government delivers much of the water for irrigation agriculture in the 17 western states. Federal water investments in this largely arid region include projects for storage, transportation, distribution, and drainage of agricultural waters, for hydroelectric power generation, for flood control, and for other purposes.

Because many river basins cross state lines, the government has had to assume growing responsibility, as water supplies have become scarcer, for participation in river-basin planning. The pollution of interstate river waters is becoming increasingly serious in many regions, and the government has begun to take vigorous control measures.

In cooperation with the states, the federal government surveys the nation's water resources, including the water carried in rivers and available from underground. It measures and forecasts precipitation, snowmelt, evaporation, runoff, river flows, floods, and storm surges.

To conserve and augment the nation's fish and wildlife population the government acquires wetlands, establishes refuges, maintains hatcheries, and constructs waterways for fish migration. It attempts to keep the effects of water pollutants on fishes, birds, and mammals to a minimum.

The government is virtually the sole producer of one of the most potentially dangerous of water pollutants—radioactive wastes—and it maintains a careful surveillance over the behavior of these materials in rivers, aquifers, and coastal waters.

To carry out these responsibilities efficiently and economically, the federal government must undertake a wide range of investigations and research. Nearly all aspects of this research ultimately provide results of broad applicability throughout the country. Consequently, the government has long supported and conducted water-resources investigations for the benefit of all levels of government, and of private industry in many sectors of the economy. A Task Group on Coordinated Water-Resources Research was established in 1962 by the Federal Council for Science and Technology, to find ways of improving this research program (*6*). The following is a condensation of its conclusions and recommendations.

Task Group Conclusions and Recommendations

In the short period of its existence, the task group was not able to develop a satisfactory basis for evaluating or comparing research projects in different fields, or even in the same field. For the present, we must depend on the judgment of the responsible agencies. With adequate staff resources, a future water-resources research coordinating committee should, in time, be able to develop criteria for evaluating the components of the national program.

The task group did arrive at general conclusions in four areas: program deficiencies and opportunities; manpower needs; coordinating mechanisms; and legislation.

Program deficiencies and opportunities. Deficiencies in intramural and extramural education and training, in research on ground water (including the infiltration processes and soil-plant-water relationships), and in socioeconomic research are so evident that we can immediately recognize the need for increased effort in these fields. Similarly, the opportunities for water-quality research are so great, and the demand for results so pressing, that the level of sustained effort should be sharply raised.

Manpower needs. Shortages of qualified personnel now exist in many areas of water-resources research. Steps will have to be taken to increase the number of people qualified to carry on the research programs. The scientific fields involved are much broader than physical hydrology and include many of the physical and biological sciences as well as social sciences and engineering. The universities need help in attracting graduate students to research and training bearing on water resources. To accomplish this, the federal agencies should make grants to, or contracts with, universities so that they can strengthen their graduate research and training programs. The following steps should be taken.

1) The federal agencies engaged in water-resources research should be authorized and given funds to use a variety of educational-assistance measures to strengthen the training and research capabilities of the universities in the disciplines bearing on water resources, and to attract increasing numbers of graduate students. Such measures to promote training at the graduate level include training grants, facilities grants, research fellowships, and institutional grants. For example, the Department of Agriculture does not have specific statutory authority to award fellowships, training grants, or grants for educational facilities, except

for a small number of postdoctoral associateships. In certain other agencies, the authority may exist, but programs have not been initiated. In others, one or another of these measures is being utilized on a modest basis. There is need for a government-wide concerted effort, in which all these measures are fully utilized.

2) Institutional grants to strengthen and encourage interdisciplinary water research programs should be made on a selective basis to those educational institutions where sufficient competence is available in the physical and biological sciences, engineering, and the social sciences.

3) To improve the skills of government employees already engaged in water research, the Government Employees Training Act and other procedures for in-service training should be more fully utilized by the federal agencies, and adequate funds should be provided for this purpose. Centers should be established at universities in different regions of the country to provide interdisciplinary training in water-resources research both for young graduate students and for selected federal career employees. This effort should be coordinated with the grant programs referred to above.

4) Increased support of research at the universities is needed to further research in water resources as well as to attract needed manpower. It will be necessary to strengthen the extramural research efforts of federal agencies along the lines already initiated by the Public Health Service. Adequate authority and direction should be provided for this purpose. The restraints that now prevent the Department of Agriculture from using its research-grant authority should be removed; the Weather Bureau should be given sufficient funds to launch a significant extramural research program in cooperating universities; the Department of the Interior needs authority and appropriations, broadly applicable to its water-research responsibilities, to make grants and contracts for a wide range of extramural research in support of its missions; and there should be clarification, where needed, of the authorizations in this area held by other agencies, such as the Corps of Engineers.

5) Cooperative arrangements between federal research establishments and the universities should be strengthened and extended so that the outstanding scientific competence of men and women in the government agencies may contribute to the training of new scientists. Needed measures include arrangements for government scientists to teach and engage in research at educational institutions and increased opportunity for graduate-thesis work at government laboratories under arrangements with the universities.

6) In establishing a balance and relationship between in-house and extramural research, it must be kept in mind that the government agencies have an indispensable place in basic research on water. There is a need to strengthen their research, to upgrade the quality of their scientific efforts, and to insure effective guidance of their overall research programs. Accordingly, funds should be provided to strengthen the in-house research competence of the federal agencies, particularly their basic-research programs.

Coordinating mechanisms. The water-resources problem facing the nation is one of growing dimensions. An accelerating research effort spanning the physical, biological, engineering, and social sciences is required if we are to gain the knowledge necessary to direct a very expensive, continuing investment in public works. The number of scientists, engineers, and other specialists who are able and willing to do creative research in water resources is dwarfed by the research needs, and the fiscal resources that can be applied are strained by other priority needs of our society. The diversity of the technical problems and the limits on human and material resources call for a carefully planned and executed research effort that is scientifically sound and properly balanced to meet both short-term and long-term needs.

Some three dozen bureaus or equivalent units in seven major departments and independent agencies of the government are engaged in water-resources research. Their responsibilities and missions overlap, in part because of the pervasive nature of water resources problems. The situation calls for concerted efforts to achieve effective coordination and for such clarification of responsibilities as may be necessary to make the most effective use of public and private resources.

Some coordination of agency research activities in water resources has already been accomplished at laboratory and management levels. To meet the demands for future research progress, coordination must be effective at all levels. The task group recommends consideration of the following.

1) Measures to improve communication among scientists, engineers, and other specialists engaged in water-resources research, including interdisciplinary conferences in fields related to water resources; support of scientific journals and meetings aimed at furthering and facilitating the rapid exchange of information among water scientists; and the preparation of technical reviews and bibliographies. Consideration should be given to the establishment of specialized information clearinghouses. The Science Information Exchange of the Smithsonian Institution may be able to make an important contribution here.

2) Measures to improve communication among technical directors and program managers, including the circulation of comprehensive and timely information on water-resources research efforts currently under way throughout the government. There is need, also, for regular coordination of technical activities on a more systematic basis, through meetings of scientists and engineers from the various water-resources agencies.

3) Clarification of agency responsibilities for water-resources research should be approached on the basis of a division of technical effort among the agencies, in the light of their principal operating and research responsibilities. Recognition of technical leadership in different research areas by different agencies should be given on this basis through the Federal Council for Science and Technology. The agency (or agencies) so identified would be technically responsible for the adequacy of coverage of the work in a particular research category, would keep itself informed of related work and competence in other organizations, and would draw upon such competence to the maximum extent possible.

4) The responsibility for encouraging interagency planning and coordination of research should be assigned to the Office of Science and Technology and the Federal Council for Science and Technology. Coordination should be accomplished through a coordinating committee on water-resources research, which would identify technical needs in various research categories;

devise programs and measures to meet these needs; review the overall program; look for desirable allocations of technical effort among the agencies; review the technical-manpower base of the program; recommend management policies; and generally facilitate interagency communication at management levels. Provision should be made for involving in the committee's deliberations both technical personnel and managerial personnel conversant with the operational problems and needs. The committee should be assisted by technical panels having competence in the various research categories.

5) The coordinating committee should have a chairman of senior standing, of rank comparable to that of an Assistant Secretary.

6) A small full-time analytical staff should be established in support of the work of the coordinating committee. The staff should be responsible for systematic analyses in water resources which will be of aid in planning the federal water-resources research program, and for the development of criteria for evaluating research projects. Funds should also be provided, where necessary, to draw on analytical competence outside the federal government (*7*).

7) There is need for a continuing independent mechanism, representative of the views of the scientific and engineering community, to advise the Federal Council in identifying longer-range objectives and needs in water-resources research and education. The National Academy of Sciences should be requested to consider means whereby overall government planning in this field could be aided, and exchange of views between the government and the academic community could be provided.

Legislative aspects. New legislation is needed to strengthen the contributions that the universities can make to research and graduate education in water resources.

1) All agencies concerned with water resources should be able to contract with, and make grants to, any universities, whether or not they contain water-research centers, for research projects in support of agency missions.

2) It is desirable to develop new centers for water-resources research in many universities and to strengthen existing centers and programs.

3) To develop new centers and strengthen existing ones, some federal support to each such center on a continuing basis is necessary, in addition to the support provided under recommendation 1. Responsibility for deciding how this supplementary support would be used should be left to the universities.

4) Support to centers should be (i) in part on the basis of a relatively small formula amount to one or more designated research institutions in each state (*8*) to establish or strengthen their capacity for water-resources research and (ii) in part on a matching-fund basis, consideration being given to the research potential of the institution.

5) New legislation should give one agency the administrative responsibilities for carrying out recommendation 4(i) without superseding authorities presently vested in the several agencies.

6) Similar authority is needed for carrying out recommendation 4(ii). The administrative responsibility should be vested in one agency, which should seek appropriations for this purpose, but the grants should be made in consultation with the other agencies having interests in the field of water resources, and these agencies should participate in the drawing up of rules, regulations, and criteria for evaluation. Such consultation and coordination could be accomplished through the proposed coordinating committee on water-resources research.

7) All agencies concerned with water resources should be able to make arrangements with educational institutions to permit government scientists and engineers to teach and engage in water-resources research at those institutions.

References and Notes

1. In considering water as a resource we are concerned with the volume of flow through the hydrologic cycle; hence, the most meaningful engineering units are in terms of volume per unit time—for example, acre-feet per year, gallons per day, or cubic feet per second (1100 acre-ft/yr is approximately equal to 10^6 gal/day or 1.5 ft^3/sec). A million gallons per day fills the needs of 5000 to 10,000 people in a city; 1000 acre-ft/yr is sufficient to irrigate 250 to 300 acres of farmland. The average flow of the Colorado River is on the order of 20,000 ft^3/sec.
2. The largest use of air is in the burning of fossil fuels; the weight of air used in this way in the United States is about 1/100 the weight of water carried to the sea by rivers.
3. A. Wolman, *Water Resources: A Report to the Committee on Natural Resources of the National Academy of Sciences–National Research Council* (Washington, D.C., 1962).
4. N. Wollman, "Economics of water production and use—projections to 1980 and 2000," paper presented at the Desalination Research Conference of the National Academy of Sciences, Woods Hole, Mass., 1961.
5. With the present patterns of water utilization, by A.D. 2000 consumptive uses of controllable water alone will probably exceed supplies in the Upper Missouri, Rio Grande-Pecos, Colorado, Great Basin, and Southern California regions and may exceed supplies in the Western Gulf. Water required under present methods for waste dilution plus that required for consumptive uses may exceed supplies in the Delaware-Hudson, Great Lakes, and Upper Arkansas-White-Red River regions.
6. The Task Group on Coordinated Water-Resources Research was established to study problems in water management and control that require research by the federal government and to make recommendations for an expanded research program as a framework for new legislation and interagency coordination. The members of the group are listed on page 1027. Observers and consultants to the task group were Joseph A. Liebermann, U.S. Atomic Energy Commission; Michael Brewer, Council of Economic Advisors; Thomas C. O'Brien, Bureau of the Budget; David Z. Beckler, Office of Science and Technology, Executive Office of the President; Abel Wolman, Johns Hopkins University; Rolf Eliasson, Stanford University; Irving K. Fox, Resources for the Future; and Theodore M. Schad, Library of Congress. Staff members who assisted in the preparation of the report were E. C. Elting, H. Steele, and C. H. Wadleigh, Department of Agriculture; W. E. Hiatt and M. A. Kohler, Department of Commerce; E. W. Weber and H. A. Schwartz, Department of the Army; B. B. Berger, Department of Health, Education and Welfare; and C. L. McGuinness and M. D. Dubrow, Department of the Interior. Mr. Schad had overall responsibility for supervising the study. The complete report was published as a Committee Print of 213 pages, entitled "Federal Water Resources Research Activities," by the Committee on Interior and Insular Affairs, U.S. Senate, 88th Congress, 25 March 1963.
7. Action by the Federal Council for Science and Technology on this recommendation was deferred pending a study by its Natural Resources Committee of the needs for analytical support in all areas of natural-resources research.
8. The Federal Council for Science and Technology qualified its acceptance of this recommendation, agreeing that at least one water-resources research or analysis center could be established with federal grants on a permissive basis in each state, under explicit qualification standards.