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SOME PHYSICAL, TECHNOLOGICAL, AND ECONOMIC CHARACTERISTICS OF WATER AND WATER RESOURCES SYSTEMS: IMPLICATIONS FOR ADMINISTRATION

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In attempting to indicate the interrelations among physical, technological, economic, and administrative facets of water resources, it seems useful to start with a premise, two definitions, and a postulate. The premise is: the United States is now entering a period in which water resources administration rather than water development as such will be the major task.[1] Water development means regulation of flow by means of reseroirs, the degree of development being measured by the amount of reservoir storage capacity in relation to mean annual discharge.[2] This premise is substantiated by some of the studies made for the Senate Select Committee on National Water Resources. These studies indicate, for example, that alternative ways of meeting needs for water and water-related products—such as flood plain zoning, waste treatment plants, in-plant recirculation, and changing uses of existing supplies—will become increasingly important. To put it another way, administrative activity with respect to water resources in the future will be weighted more toward manipulation of developed supplies than toward development of new supplies. This does not mean that the latter activity will not be important, particularly in certain regions of the country, but rather that other activities of water resources administration will become relatively more important.

The definitions are of (1) water resources administration and (2) water resources system. Water resources administration comprises a collectivity of functions or activities: collection of basic data; research; planning; design and construction of reservoirs, related works, and other facilities and measures; operation of reservoirs, treatment plants, power plants, well fields, and ground

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1. This is essentially the same statement as contained in Leopold, *Water Resource Development and Management,* 51 J. Am. Water Works Ass'n 824 (Pt. 2, July, 1959).

2. Where ground water is involved, the degree of development is more difficult to measure. One measure might be the annual pumping capacity in relation to the mean annual recharge of the ground water basin.

water recharge facilities; establishing, promulgating, and enforcing water quality standards; water quality monitoring; controlling water withdrawals and waste discharges when and where necessary; operating flood warning networks; establishing, promulgating, and enforcing ordinances for the zoning of flood plains; managing vegetation for water yield; and so on. This listing is not all inclusive. Nor are all of these functions necessarily relevant in any one area at any point in time. Succinctly, these functions might be grouped into three broad categories: one, making the investment decision, *i.e.,* what magnitudes of facilities and related measures are to be constructed and put into operation when and where to meet the needs for water and water-related products; two, constructing structural facilities and organizing the nonstructural measures; and three, operating the system, generally including the wholesale distribution of the outputs.[3] The various activities from data collection and research to review and evaluation of operations are component parts of, and contribute to, these three generalized functions.

A water resources system is defined as a complex configuration of structural and nonstructural measures and operating procedures which transforms the raw material, water, into outputs of water and water-related products and services. Such a system is illustrated in Figure 1, in which examples of system components are indicated. It is the structures and the nonstructural measures and the procedure for operating these components which comprise a water resources system and which produce water and water-related products.

Finally, the postulate: The physical nature of the inputs to and the outputs from the production process and the technology available set limits on the organizational structure for administration.[4] Expressed another way, if political pressures and traditions were not operative and social factors were not considered, then the structure of a governmental or private organization to accomplish given tasks would be essentially determined by physical and technological factors (where technological and economic factors are undifferentiated). This is, of course, stating the proposition deterministically. In any real situation the optimal or ideal administrative structure on the basis of physical and technological considerations is likely to be modified by the socio-political milieu.[5] But the postulate as stated serves to focus attention on the question of concern here, namely, what characteristics of water and water resources

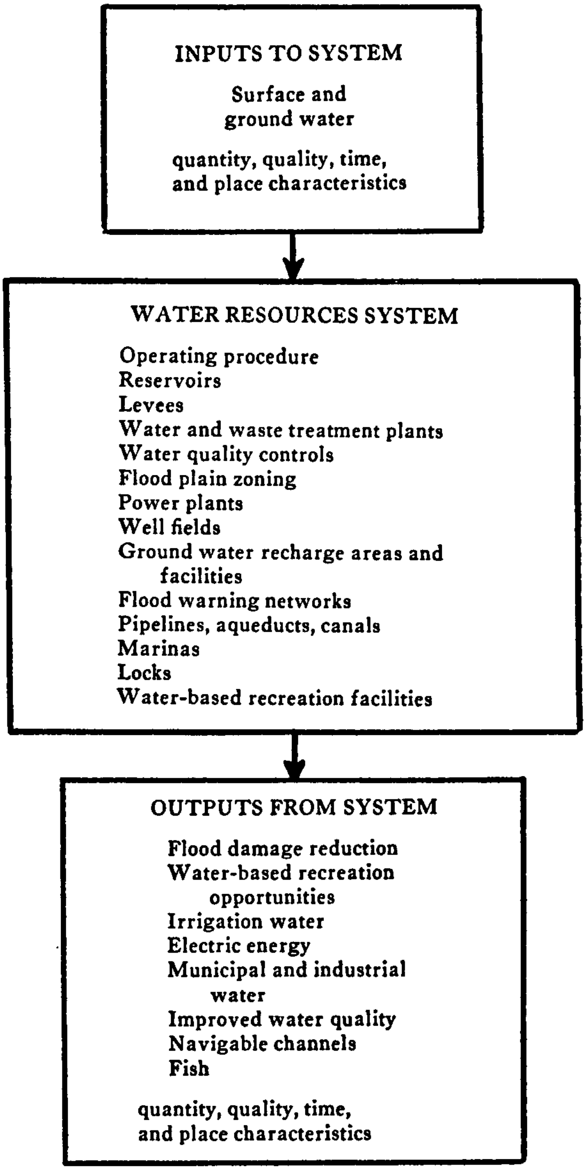
3. This tripartite division is used in Ackerman and Löf, Technology in American Water Development 465-66 (1959).

4. See Thompson and Bates, *Technology, Organization, and Administration,* 2 Ad. Sci. Q. 325-27 (1957).

5. For a lucid statement of other factors affecting organizational structure for water resources administration in the United States, see Fox and Crane, *Organizational Arrangements for Water Development,* 2 Natural Resources J. 1 (1962).

Figure 1

WATER RESOURCES DISTRICT



systems influence, or should influence, organizational structure for water resources administration?

SOME CHARACTERISTICS OF WATER AND WATER RESOURCES SYSTEMS

Three types of characteristics are suggested: physical, technological, and economic. The boundaries among these three types are not clearly defined. They are, in and of themselves, interrelated. Nor can characteristics be neatly classified by type. Therefore, rather than attempting to classify each characteristic more or less arbitrarily, the characteristic will simply be described, and its implication for water resources administration will be suggested. The purpose in noting the three broad types of characteristics is to suggest the "roots" of the characteristics—in the physical environment, in technology, and in economic behavior.

These characteristics relating to the production process for water and water-related products and services are analogous to the characteristics of any production process, such as that used in steel manufacturing. They should be considered in thinking about organizational structure for water resources administration just as the corresponding characteristics of the steel production process should be considered in establishing an administrative structure for a steel plant.

No connotation of priority for, or relative impact on, water resources administration should be attached to the order of the characteristics mentioned herein.

A. Surface Water and Ground Water Are Integrally Related Physically

This relationship has been amply documented by hydrologists, geologists, and engineers, despite all attempts by lawyers and judges to rule otherwise. Impoundment of water in a reservoir may increase ground water flow in areas adjacent to the reservoir. Withdrawals from ground water reduce the base flow of a stream normally fed by such water, thus making less surface water available for use. Ground water withdrawals may reduce the natural discharge which would have wasted to an ocean in the absence of such withdrawals. Reservoir regulation of surface flows may either increase or decrease ground water recharge downstream from such regulation. In many small watersheds in the East, where irrigation is increasing, ground water withdrawals for irrigation are made upstream from surface water withdrawals by municipal and industrial users. In some of these areas, if only a fraction of the total irrigable land were eventually to be irrigated, the surface flow would be completely depleted, leaving no supply for the downstream users.[6]

One of many excellent examples of the surface-ground water relationship exists in the Delaware Basin. It is a particularly interesting example because it transcends surface-river-basin boundaries. Along the Delaware River between Trenton and Philadelphia, the southeasterly dipping Magothy and Raritan formations outcrop. These ground water aquifers receive recharge from the river in this reach, and are, or can be, tapped by wells in the coastal plain of New Jersey outside of the Delaware Basin. The magnitude and quality of recharge are affected by regulation and use of the surface water upstream from Trenton and in the Trenton-Philadelphia reach.

The implication for water resources administration is that both surface and ground water should come under the jurisdiction of the same agency, by ownership, regulation, and/or responsibility for operation.

B. Quality of Water Is Inseparable From Quantity of Water

This is a well proved relationship physically, despite typical governmental dissection, of adminstratve jursdiction on both state and federal levels. In meeting the needs for water the problem is one of the proper quantity of water of the proper quality—physical, chemical, biological and radiological—at the right time and place. The quantity of water affects the quality as illustrated, for example, by the relations between quantity and temperature, quantity and hardness concentration, and quantity and dissolved solids concentration. The quality of water can affect the quantity of water required. For example, the amount of irrigation water required is generally higher when water high in dissolved solids concentration is used than when water low in dissolved solids is used. Water high in hardness might be used only for once-through cooling; whereas water of low hardness could be recirculated, thereby reducing the total quantity of water needed. The quantity of water and its time pattern of distribution affect the quantity, quality, and time pattern of wastes which can be discharged into the receiving waters, surface and/or ground.

With respect to the quality-quantity relationship, the time dimension can be of crucial importance. Some of the effects of changes in water quality—stemming from quantity and time pattern of quantity changes and/or from waste discharges—become evident only after a considerable time period. These delayed effects are particularly relevant with respect to sediment processes in stream channels (aggradation and degradation), changing composition of fish and plant life in water bodies, the movement of contaminants in ground water bodies and ground water overdraft.

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6. Wiseman, *Potential Conflicts between Supplemental Irrigation and Pollution Abatement Programs,* 27 Sewage and Industrial Wastes 1284-87 (1955).

The implication for water resources administration is that jurisdiction over both quantity and quality of water should be lodged in one agency.

C. The Areal Focus Varies Among the Different Outputs From a Water Resources System

For flood damage reduction, water quality improvement and navigation, the relevant area generally is the drainage basin. Flood flows do not flow over basin boundaries.[7] The physical effects of waste discharges on water quality do not extend beyond the given basin. The improvement of water navigation involves water courses within the basin. On the other hand, demands for power and for water-based recreation opportunities are rarely confined to the given drainage basin. Power generated within a basin is often transmitted and used outside the basin, as in the Tennessee and Colorado Basins. The relevant area for analysis of power production and marketing, from a technological standpoint, is the economic transmission distance for power, which in itself changes over time.[8] People from outside basin boundaries take advantage of water-based recreation opportunities at reservoirs and streams within a given basin. Increasingly even municipal, industrial, and irrigation water demands are met from outside the basin in which the demands are located, as exemplified by the transfer of water from the Colorado River Basin to the Los Angeles area, primarily for municipal and industrial use, and to the Platte and Big Thompson basins, primarily for irrigation, and from the Delaware Basin to the New York City and northeastern New Jersey areas for municipal and industrial uses.

Thus a water resources system does not encompass a single geographic area, but rather a set of overlapping, but not necessarily coincident, areas. Each area corresponds to the demand area of one of the outputs from the system. These overlapping areas are centered on, but are not necessarily coincident with, the drainage basin. Further, the areal boundaries for some of the outputs are subject to change over time as economic and technological conditions and hence demands for water and water-related products change. An area adjacent to a given basin may have adequate water for the present, but at some future time, when its local supples have been developed as fully as is economically possible, it may become part of the demand area for one or more outputs from the given basin. Technological changes in the method of transmitting an output, such as power, may increase the area which can be served economically.

7. There can be exceptions even for flood damage reduction, for example, where the method utilized to reduce flood flows involves diversion of flood waters outside of a given basin. Such a proposal was advanced by Arthur E. Morgan as an alternative to the Kinzua Dam project on the upper Allegheny River in Pennsylvania. One of the reservoirs in the Mahoning Basin in Ohio involves transfer of flood waters to an adjacent basin.

8. See Kilgore, *Longer Transmission Interties Are Within Reach,* 158 Electrical World 38 (No. 3, 1962).

The implications for water resources administration are that the areal unit for administration should not necessarily or arbitrarily be restricted to a drainage basin, and that the areal jurisdiction should be amenable to change over time with changing conditions.

D. Water Resources Development on the Local Level Affects Planning and Development on the Basin or Regional Level

With respect to pollution, conditions in a sub-basin considered alone may be such as to permit certain waste discharges. While not adversely affecting the sub-basin, such discharges may result in water quality problems in the larger basin or region. Discharge of chlorides on tributaries of the Ohio River is an example.[9] With respect to flood damage reduction, unless reservoirs on tributaries and in small watersheds are properly planned and operated, such reservoirs can actually increase flood crests on the main stem of a river. The needs for municipal and industrial water in a sub-basin are often met from reservoir storage located outside the particular sub-basin. The demand for water, and hence the amount of surface and/or ground water reservoir storage required in the basin as a whole, depend upon the efficiency with which water is used in the local area or sub-basin.

Similar effects stem from the manner in which water is transported from the place of storage, *i.e.,* reservoir, to the local place of use, such as a municipality. A different, and probably more expensive water resources system for the entire basin, will be required if water is transported from a reservoir to a local area by pipeline than if it is transported via a river channel to a location near the local area. Obviously, water moving in a pipeline between two points cannot be used for recreation and/or navigation and/or water quality improvement en route to the place of use for water supply. Thus the places at which water is withdrawn for use in, and the means of transport to, local areas affect planning and development basin-wide.

In a like manner, if there is a multiplicity of local water agencies distributing water in an area, without interconnections among them, more water will usually be required to meet the total water needs of the area than if the operations in the various local areas were integrated. Each local system, when operated independently, must have its own reserve capacity. Each system may have separate transmission lines to a common source of supply. Without integration no advantage can be taken of diversities in demand and/or supply patterns of the

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9. See *Your Most Important Raw Material* 25, Address by Everitt P. Partridge, 60th Annual Meeting of the Amer. Soc'y for Testing Materials (Issued by Amer. Soc'y for Testing Materials, 1957).

individual systems. The effect is to increase the total amount of water development required in the basin to meet the same outputs.[10]

The implication for water resources administration is that local water resources planning, development, and operation should be integrated with basin-wide or region-wide water resources planning, development and operation.[11]

E. Uncertainty Exists in Both the Supply of and Demand for Water

The inputs to a water resources system are variable over time—in quantity, quality and spatial distribution. They can never be known with certainty but only in terms of probabilities. This is in contrast with the usual production process, such as in an oil refinery, where the specific quantities of inputs are known for a specified process and are used to obtain specific quantities of outputs.

Knowledge of future hydrologic events is limited by the past record, which represents a sample of the possible variability of future events. However, the past record cannot indicate the exact sequence of future hydrologic events, which sequence of course will affect the outputs and benefits to be obtained from the water resources system. The only certainty is that the probability of recurrence of the past sequence, for example of yearly or monthly runoffs, is virtually nil. Thus planning must be done and operations carried on within the context of a range of possible future system inputs. Edward J. Cleary has phrased the problem succinctly: "One might reflect that purveyors of river water are probably the only 'manufacturers' who are expected to take out a raw material that varies from day to day and yet be prepared to turn out a uniform product regardless of what they must start with."[12]

Uncertainty on the demand[13] side is considerably greater than hydrologic or supply uncertainty. Because hydrologic events are basically random, the extent of variability to be expected can be defined.[14] However, future demands for

10. An analogous situation exists with respect to the provision of power and energy, as indicated by the evolution of interconnected utility systems and pooling arrangements.

11. The reverse is also true of course. Basin-wide planning should not disregard local areas. Facilities to provide basin-wide outputs are often incapable of providing desired outputs in small headwater basins.

12. 161 Engineering News-Record 55 (No. 14, 1958).

13. The term demand is not used here in the strict economic sense, *i.e.*, where there is a defined relationship between quantity of a product and price. Rather, it is used in what might be termed the physical or engineering sense, traditional in water resources planning. For example, based on historical use data on industrial water intake per unit of product output, and estimated trends in both product output and technology, total required intake is the product of estimated product output and esimated unit intake. However, to make realistic estimates of future water demands, the cost of water must be included as a factor.

14. Where streamflows, for example, are not completely random, account can be taken of the nonrandom component. For one illustration of this and for one approach to

water and water-related products are not random; they depend on estimates of future population, industrial production, technological changes, uses of leisure time, political decisions and so on. The farther ahead the demands are estimated, and the smaller the area for which such estimates are made, the more uncertain the estimates become. For example, with respect to time, Wollman has indicated a range between the low and high estimates of water withdrawals for the United States in 1980 of 200 per cent; in 2000, 300 per cent.[15] With respect to area, Resources for the Future has stated: "The range of error increases geometrically as the national economy is subdivided."[16]

Uncertainty has at least three major implications for water resources administration. First, because of unpredicted and unpredictable changes in future conditions with the consequent deviation of actual demands from the estimated demands on which plans for water resources development were based, water resources planning must be a continuous process. An estimate in 1960 that Reservoir *X* will be needed by 1980 may be incorrect when re-examined in 1965 or 1970. Second, flexibility must be designed into the various structures and operations of a water resources system, so that the mix of outputs from the system can be changed if conditions change over time. Third, the organizational structure for water resources administration itself must be flexible, so that its functions and areal jurisdiction can be adapted to changing conditions.

F. There Are Economies of Scale in the Production of Water and Water-Related Products

This means, for surface water reservoirs as an example, that as the size of a reservoir is increased the capital costs of equal increments of storage capacity decrease up to a point. This is illustrated in Figure 2a. The characteristics of the reservoir site, including possible existing facilities that may be inundated,

handling hydrologic uncertainty in water resources planning, see Mass, Hufschmidt, Dorfman, Thomas, Marglin, and Fair, Design of Water-Resource Systems, ch. XII, *Mathematical Synthesis of Streamflow Sequences for the Analysis of River Basins by Simulation* (1962).

It seems useful to define three types of uncertainty. First, uncertainty for which the parameters of the distribution of events, expected value and variance, can be estimated, represented by hydrologic events. Second, uncertainty for which the parameters of the distribution of events cannot be estimated explicitly, but for which a range of events or states at future time points can be estimated, exemplified by low, medium, and high estimates of future water demands—where the medium estimate does not necessarily have the connotation of the most likely event or the expected value. Third, uncertainty for which neither the parameters nor range of states can be estimated, exemplified by the uncertainty associated with war and disarmament, with political decisions on interest rates to be used by governmental agencies, and with major changes in recreation patterns.

15. Senate Select Comm. on Nat'l Water Resources, 86th Cong., 2d Sess., *Water Supply and Demand* 6 (Comm. Print No. 32, 1960).

16. Resources for the Future Annual Rep. 17 (1960).

determine the shape of the curve and the limit of decreasing incremental costs. A decreasing unit cost relationship also pertains to the operation and maintenance costs of a reservoir. Economies of scale likewise exist for power plants, both hydro and steam, as shown in Figure 2b, again for both capital and operation and maintenance costs. Pipelines, water treatment plants and waste treatment plants, in general, exhibit similar economies.

The implication for water resources administration is that the larger the market area for the administrative organization, and hence the larger the demands, the greater are the possibilities for taking advantage of economies of scale.

G. Outputs From Water Resources Systems Are Complementary to Some Degree

One form of complementarity is the use of the same water for more than one purpose. Economies can be obtained by taking advantage of such complementarity. For example, water released from a reservoir to meet municipal water or irrigation demands could develop power. Water released for navigation might also develop power, provide water for fish life, and enhance the desirability of the stream for recreation. On its journey from headwater to ocean, the same acre-foot of water may be used for a variety of purposes. This is a unique characteristic of water resources systems. In other production processes, each input becomes part of only one output. The same piece of steel cannot be part of the body of a car and of the motor.

One hundred per cent complementarity of this type among any two outputs or uses is highly unlikely. The more the time-patterns of the uses differ, the less complementary they are. The effect of complementarity in outputs from water resources systems is illustrated in Figure 3. With a reservoir of a given capacity, the straight line in Figure 3 illustrates the total output with no complementarity between the two outputs; the curved line illustrates the situation with some degree of complementarity. The total output from the reservoir, the sum of outputs 1 and 2, is 200,000 acre-feet larger with complementarity than without.

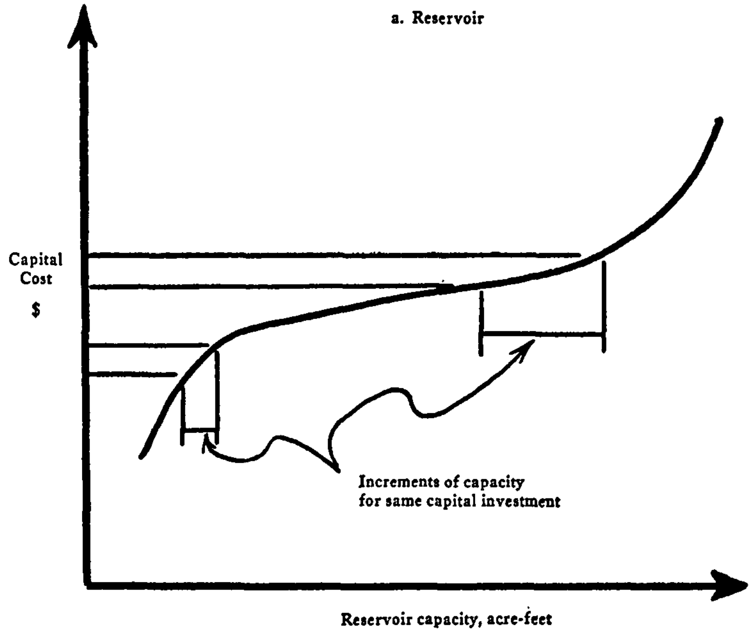
Another form of complementarity is the joint use of the same reservoir space for more than one purpose. During certain portions of the year storage capacity may be used to store flood water; in other seasons the same capacity may be used for water supply or power. Recreational activity on a reservoir used for water supply, irrigation, flood damage reduction and/or power is another example of joint use of reservoir capacity. The degree of complementarity in joint use of reservoir capacity depends on such factors as the seasonality of the demands for outputs and the impact on water quality of the various uses.

The implication for administration is that the more varied the outputs from

Figure 2

ECONOMIES OF SCALE

a. Reservoir



b. Power Plant

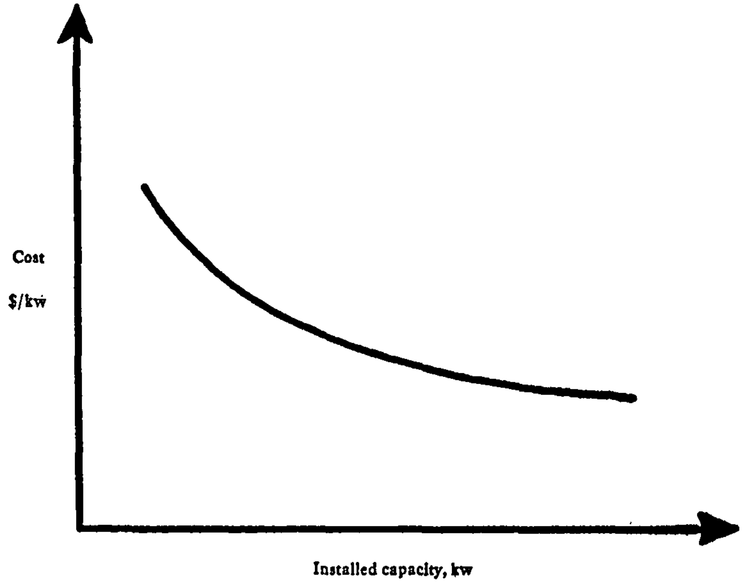
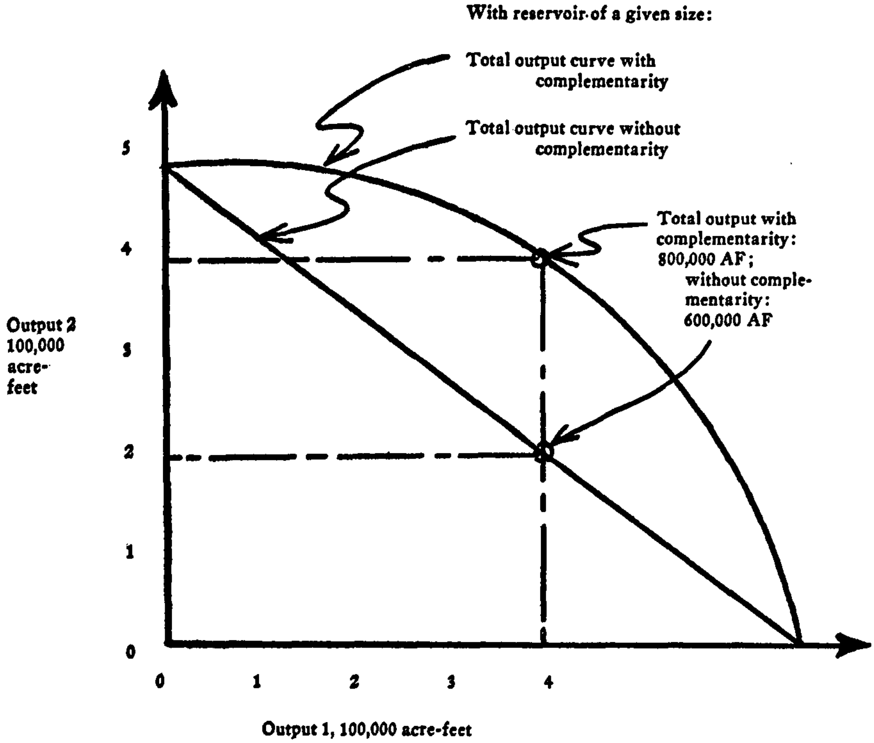


Figure 3
COMPLEMENTARITY



a water resources system, for whose production the administrative agency is responsible, the greater are the possibilities of taking advantage of complementarity. Conversely, if administrative responsibility is limited to only one or two outputs, possibilities for deriving economies from complementarity are limited.

H. There Are Economies in Integrated Operation of a Number of Reservoirs

Operation of a number of surface and/or ground water reservoirs as an integrated system will produce, in general, more output than operation of the same reservoirs independently. This is true for one output and is more true for a number of different outputs, *i.e.*, multiple purpose operation.[17]

To understand how economies can be derived from integrated-system-operation, an understanding of the behavior of reservoirs is essential.[18] Figure 4

17. See Ackerman and Löf, *supra* note 3 at 192-94.

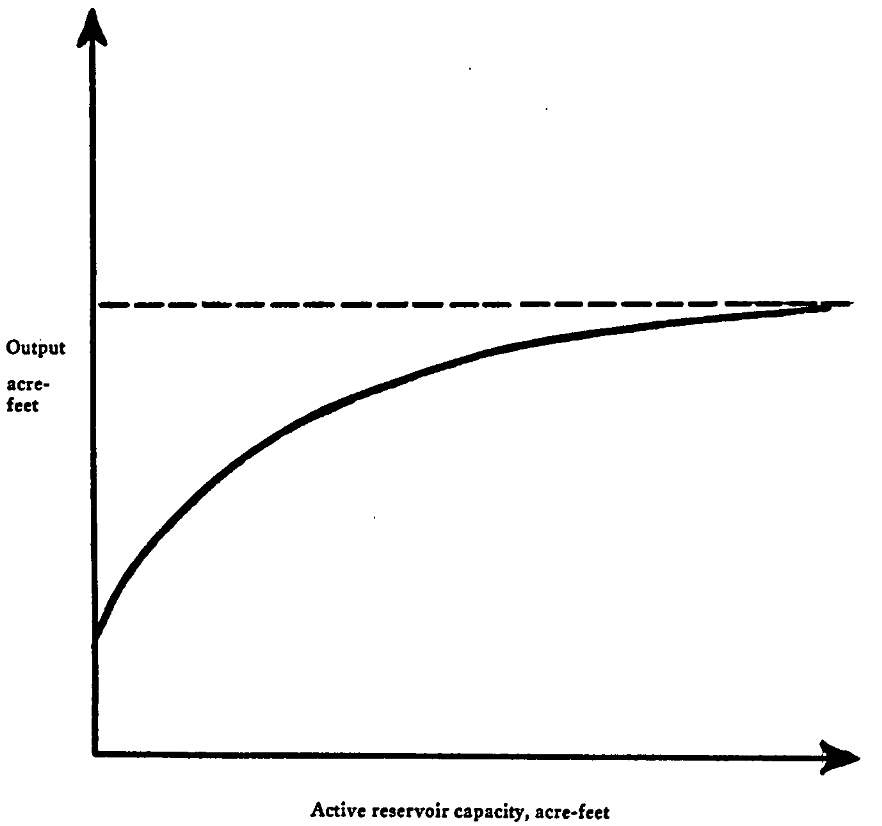
18. This and the following two paragraphs draw on material prepared by William W. Reedy of the Bureau of Reclamation.

shows a typical capacity-output function for a surface water reservoir. Output is defined as the amount of water required for some use, such as municipal water supply or irrigation, for which there is a particular time pattern of demand throughout the year. It should be noted that some output is possible without any storage of water. This means that use can be made of the available streamflow without storage. Figure 4 shows that the early increments of capacity yield the largest increments in output. As the magnitude of the output approaches the mean annual runoff, the curve approaches a horizontal line. The mean annual runoff is, of course, the maximum output theoretically possible from a stream at a given point.

The shape of the capacity-output function depends on the stream hydrology and on the specified time pattern of the output. For a given time pattern of out-

Figure 4

RESERVOIR CAPACITY-OUTPUT FUNCTION



put, the capacity-output function differs for (1) streams with different mean annual runoffs, and (2) for streams with different seasonal and annual distributions of runoff. Thus if the variation in runoff from year to year (or month to month) is large, relatively more storage is required to obtain the *same* output than if annual (or monthly) runoff variation were smaller. This is illustrated in Figure 5a, where the required output is assumed constant and the different stream flow regimes are as shown. Further, with a *given* stream flow regime, the reservoir capacity required to provide an output with a specified time pattern of use, such as irrigation, differs from the reservoir capacity required to provide the same quantative, *e.g.*, volume, output but with a different time pattern of use, such as water supply. This is illustrated in Figure 5b.

The above relationships indicate why outputs, and hence benefits, can be increased through integrated system operation. By operating two or more reservoirs as a system, advantage can be taken of: (1) the diversity of stream flows at the various reservoirs; (2) the diversity in time patterns of the desired outputs; and (3) the most efficient capacity of each reservoir, that is, the portion of the reservoir capacity which provides the greatest output for a given capacity. Thus, for any given output, two reservoirs in combination (usually) are more effective than either reservoir by itself, because less *total* capacity within the two reservoirs is required to produce the given output.[19] This is illustrated in Figure 6, where the active capacity of reservoir 1 to produce the required output is 6 units, of reservoir 2 about 4.5 units, and of the two together 3 units. In addition, with integrated operation of a number of reservoirs, maximum advantage can be taken of complementarity. As the number of reservoirs increases, the complexity of operating the system increases—in some sort of geometric ratio—but the alternative ways of meeting demands for water and water-related products also increase.[20]

Integrated system operation is not limited to surface water reservoirs. Maximum economic utilization of ground water to meet water needs is desirable for several reasons. First, evaporation from water stored in ground water reservoirs usually is virtually negligible, in contrast to the significant amounts of water which are often lost from surface water reservoirs. This is particularly important in arid and semi-arid areas. Second, ground water is often available close to the places of use, thus reducing water transmission costs. Third, the quality

19. The exceptions to this generalization occur when the total output required is so small that the total capacity required to produce the output is within the steep portion of the output-capacity curves of both reservoirs. Cost also is a factor. In an actual analysis, output-cost relationships rather than output-capacity relationships would be used. Since cost is a function of capacity, output-cost relationships can be readily obtained.

20. The same factors leading to integrated reservoir operation have led to interconnections among power systems—economics of scale, load diversities, varying system components, and technology. Benefits from integration accrue in the same manner as with reservoirs.

Figure 5a

STREAM FLOW-STORAGE RELATIONSHIPS

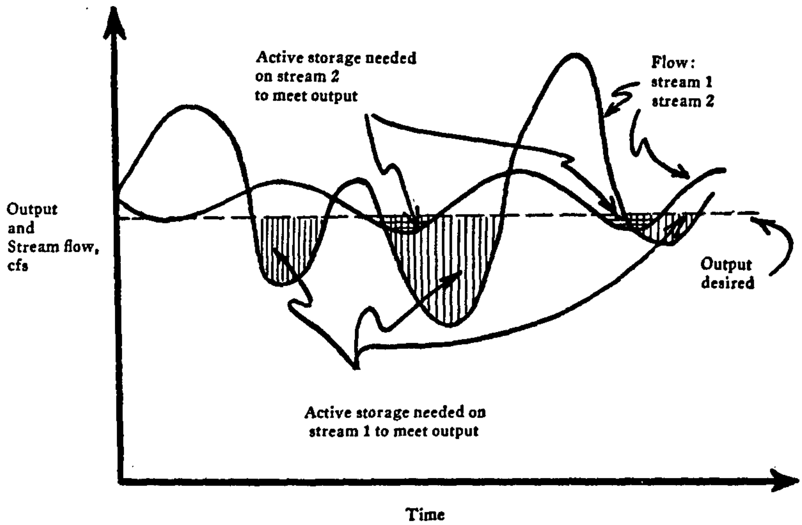


Figure 5b

OUTPUT-STORAGE RELATIONSHIPS

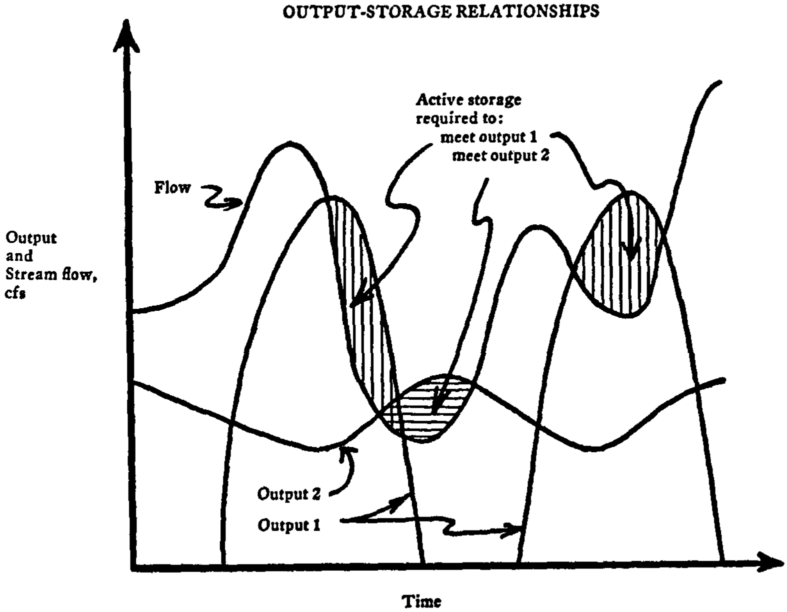
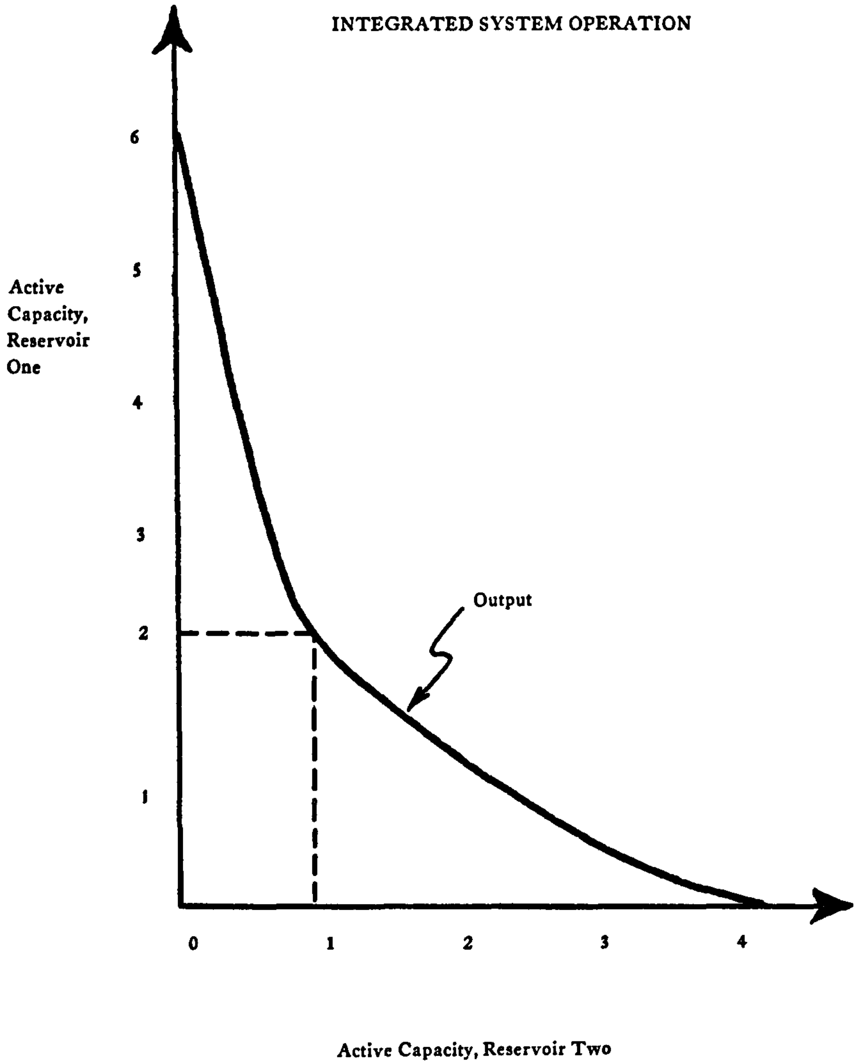


Figure 6

INTEGRATED SYSTEM OPERATION



of ground water often varies much less over time than the quality of surface water. This relative constancy of water quality is of economic importance in many uses.

The integrated operation of surface and ground water reservoirs can increase the amount of usable water from an area. Because stream flow varies both seasonally and annually, ground water reservoirs can be used in some areas for long-term storage of water and related surface water reservoirs for short-term storage. For example, water retained in a surface water reservoir during a flood period must be released to provide storage space for the next flood. Often such releases must occur before the water is needed for downstream uses such as irrigation and industry. By using the temporarily stored flood waters to recharge ground water basins downstream, water that otherwise would be wasted can be made available for use. In months or years of low stream flow during longer time periods of stream flow fluctuations, water can be withdrawn from the ground water basins as needed. Such withdrawals make storage space available in the ground water reservoirs for recharge during periods of above average stream flow. For the optimum use of ground water storage, ground water reservoirs must be drawn down in dry periods and filled in wet periods. Thus, the operation of ground water reservoirs should be planned in the same manner as the operation of surface water reservoirs.[21]

The implication for water resources administration is that the administrative agency should have sufficient areal coverage and output diversity and control by one means or another over both surface and ground water to be able to capitalize on the economies inherent in integrated operation of a number of surface and ground water reservoirs. As demands for water and water-related products increase in an area, and water is used more intensively, the greater are the total benefits which can be derived from multiple-purpose, integrated system operation.[22]

I. There Are Economies From Integrated Operation of Reservoirs and Related Nonstructural Measures and Facilities

Although explicit in the definition of a water resources system, and similar in concept to the integrated operation of a number of reservoirs, the integration of nonstructural measures and facilities other than reservoirs into a system merits separate mention because of the complexities involved. Related measures and facilities include flood plain zoning, flood warning networks, water and waste treatment plants, in-plant process changes, and water quality controls. Not all of these will be covered herein.

Flood damage reduction is one output of a water resources system. It can be produced by a variety of means: storing flood waters in reservoirs, building levees, zoning flood plains, straightening and clearing stream channels, removing people from areas susceptible to flooding, operating flood warning networks, establishing and enforcing standards of design and construction for buildings on

21. For one description of integrated operation of surface and ground water reservoirs, see Clendenen, *The Outlook for the Future*, Proceedings of Conference on the California Ground Water Situation—Berkeley, Calif. (Dec. 3-4, 1956) 49-55 (Issued by Comm. on Research in Water Resources—Univ. of Calif., 1956).

22. See Ackerman and Löf, *supra* note 3, at 536.

the flood plain, and combinations of these. In any given situation some combination of methods is likely to be the most efficient. In many cases structural methods for flood damage reduction cannot be economically justified.[23] Hence, utilization of other methods instead of and in conjunction with reservoir storage of flood waters is essential. In addition, the design and operation of any reservoir to reduce flood damage is based on the capacity of the stream channel below the reservoir, including perhaps a portion of the flood plain. If encroachment of buildings and other uses is permitted inside the flow boundaries assumed in the planning, flood damage will occur despite the existence of the reservoir. As White put it, "In carrying out its assigned duties the Corps of Engineers is put in the position of exercising high skill in design of protection works while further encroachment is fostered by other activities. It is an army resolutely pushing back an enemy on one frontier while he infiltrates the territory from other frontiers over which it exercises no control."[24]

The implications in relation to such measures are first, that the agency for water resources administration must consider alternative ways of producing outputs if efficient development is to be achieved, and second, that the agency must be able to prevent negation of the effects of one segment of the system, *i.e.*, reservoirs, by deficiencies in another segment, *i.e.*, failure to prevent encroachment on the flood plains.

Internal water utilization patterns—industrial, municipal and agricultural—comprise another facet of integrated system operation in this context. The required water output from a water resources system, and hence the required reservoir storage, are based on the amount of water needed for the intakes of various users. The less efficiently a plant or city uses water, defined in terms of amount of intake water per unit of product or per person, the greater will be the required output from, and storage in, the system. The extent to which water is re-circulated or re-cycled within the plant (or municipality or farm), determines the intake water required. Once-through water utilization, no recirculation, and utilization with recirculation are shown in Figures 7a and 7b, respectively. The assumed data in the figures are illustrative of the difference recirculation can make in the quantity of intake required.[25]

At the other and of the water utilization process of a plant or a municipality is the outlet, from which wastes are discharged, with the related potential problems of pollution. Water is a traditional, and often economic, means for disposal of wastes. To reduce pollution and improve the quality of water receiving

23. See Senate Select Comm. on Nat'l Water Resources, 86th Cong., 1st Sess., *Flood Problems and Management in the Tennessee River Basin* 18 (Comm. Print No. 16, 1959).

24. White, Calef, Hudson, Mayer, Sheaffer, and Volk, *Changes in Urban Occupance of Flood Plains in the United States* 228 (U. Chi., Dep't of Geography Research Paper No. 57, 1958).

25. Consumptive use is assumed to be the same in both cases.

Figure 7a

ONCE-THROUGH WATER UTILIZATION

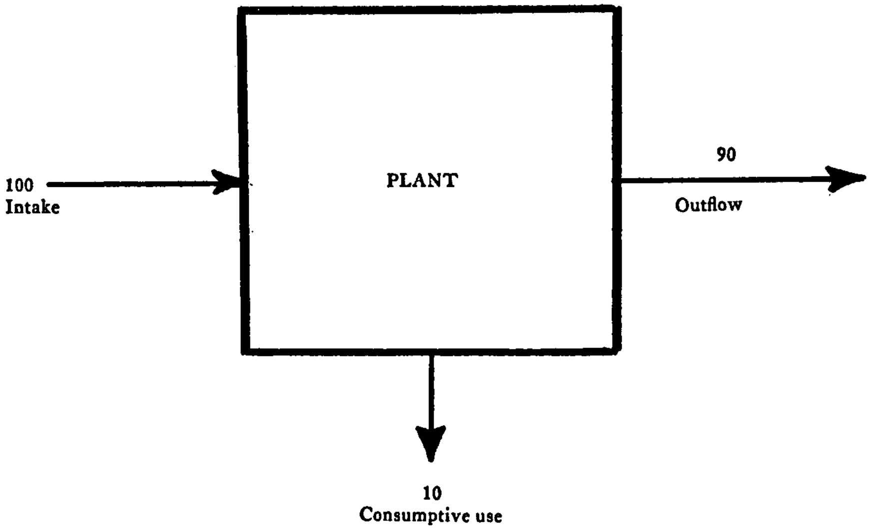
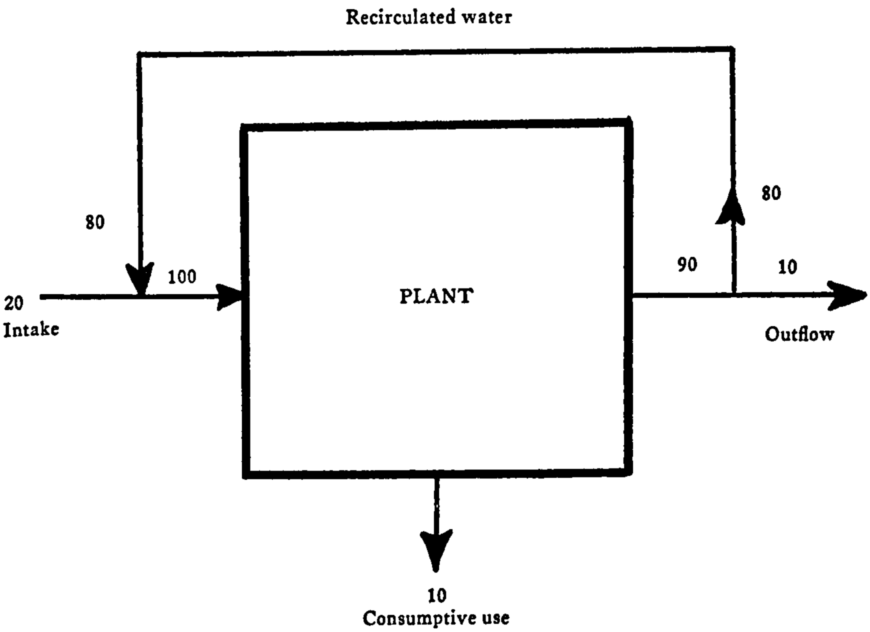


Figure 7b

WATER UTILIZATION WITH RECIRCULATION



Note: Both plants have same product output. The data on water quantities are illustrative only.

wastes, the traditional method has been to provide water for dilution of wastes. But there are alternative ways of reducing pollution. For example, Velz suggests that wastes can be temporarily stored for later release during higher stream flows, thus reducing the concentration of wastes and concomitant pollution.[26] Another alternative is to increase the degree of waste treatment. The costs of preventing wastes from entering streams often may be less than the cost of constructing reservoirs to provide dilution water to achieve the same water quality. In many cases some combination of waste treatment and dilution water is the least expensive.[27] Internal plant changes in production processes, resulting in less and/or different wastes, comprise another means of reducing pollution. According to Partridge, "It costs far less to recondition a small amount of water containing a high concentration of pollution than a large amount of water containing a low but still objectionable content."[28]

The major problem of internal water utilization and waste treatment practices with respect to water resources administration is that the decisions whether or not to adopt such practices are generally in the private or other governmental sectors which are outside the domain of the agency responsible for water resources administration. Partial exceptions occur where the agency has control over discharge of waste effluents. At the same time, the decisions of the administrative agency are dependent on the decisions made by individual users—industries, municipalities, irrigators—because internal water utilization patterns and waste treatment practices determine the amount of total water required, and hence the degree of reservoir development necessary. Whether implicit or explicit, the administrative agency, in its planning, makes assumptions about these decisions.

The implication for water resources administration is that the administrative agency should consider, as potential integral parts of a water resources system, the wide range of non-reservoir alternatives for meeting quantitative and qualitative needs for water—temporary storage of wastes, recirculation, in-plant process changes, concentration of wastes, and reclamation of waste water.[29] The agency should not assume that alternatives in the private and local government sectors are outside its purview, at least as far as analysis is concerned. Max-

26. Velz, *Industrial Waste Disposal Tailored to Stream Flow,* 85 J. of the Sanitary Engineering Div. of the ASCE (No. SA6) 95 (Published by the Am. Soc'y Civil Engineers, Nov., 1959). Such a procedure has been proposed for both the Ohio and Arkansas-Red River Basins.

27. See Senate Select Comm. on Nat'l Water Resources, 86th Cong., 2d Sess., *Water Supply and Demand* 6 (Comm. Print No. 32, 1960).

28. See Patridge, *Industrial Water: Use, Reuse, Misuse?* 8, ASME Paper No. 59-SA-60 (Printed by Amer. Soc'y of Mechanical Engineers, 1959).

29. This approach is clearly enunciated in terms of the concept of a basin-wide firm in Kneese, *Water Polution: Economic Aspects and Research Needs,* Resources for the Future, Inc. 21-24 (1962).

imum net benefits to society might well result from some combination of public and private activities, but this cannot be known unless such alternatives are analyzed. To achieve the maximum benefits from integrated operation of related nonstructural measures and facilities with reservoirs, techniques must be devised to induce the requisite private and local government decisons. At the very least, analysis of all alternatives will indicate the benefits foregone by society if the techniques to induce these decisions are not evolved.

J. The Planning of Water Resources Systems Is Integrally Related to the Design and Operation of Such Systems

This is generally accepted as a truism, but often without exploration (or understanding) of the implications. This characteristic merits emphasis here because of the extent of dissection currently existing between the planning of water resources systems and the operation of such systems. Examples are the Southeast and Texas River Basin Commissions, which have responsibility only for planning, and the prevalent separation of water resources planning from pollution control, which is basically an operating activity because it is performed by pollution control agencies.[30]

In planning a water resources system, not only are specific designs of the component facilities assumed, but also a method or procedure for operating the system is assumed. The assumed operating procedure relates not only to such system components as the reservoirs but relates to such components as water treatment plants, waste disposal facilities, flood warning networks, and the zoning of flood plains (whether or not these components are under the jurisdiction of the administrative agency). If the components are not designed, and operated after construction, in accord with the operating procedure assumed in planning, the achieved outputs and benefits from the system will not coincide with the planned outputs and benefits.

Another facet of this integral relationship between planning and operating is the monitoring and "feedback" function or activity. In the manufacture of pharmaceuticals, or of yarns, or of gasoline, for example, there is a quality control function which feeds back information from the production process (operation) to the planners and designers. Such an activity is just as relevant to water resources systems. Evaluation of the operation of a water resources system in relation to outputs produced, costs incurred, benefits obtained, and engineering performance should be carried on continuously, so that the information thus obtained can be fed back into the planning. Unless the operation, monitoring and planning are performed by the same agency, the feedback channel will be inefficient, if not absent. This separation is perhaps a major reason for the grossly

30. The extent of dissection will be increased if recent agitation for the establishment of more river basin commissions responsible only for planning is successful.

inadequate attention which has been accorded this evaluation or monitoring activity in the past, despite the need for the information therefrom for efficient planning.

The implication for water resources administration is that the responsibility for planning, design, and operation—including monitoring—should be in a single agency.

K. The Outputs From Water Resources Systems Have Varying Degrees of Marketability

The relative marketability of various outputs from water resources systems has been discussed at length elsewhere.[31] Marketing of outputs is a function not only of economics but also of political decisions and the degree of commonality of the outputs. Power outputs face a well defined market. On the other hand, municipal water may be sold at less than cost, *i.e.*, subsidized by general muncipal funds, at cost, or at more than cost, depending on the political decision. Flood damage reduction can rarely be provided for a single individual—it is a common good. The beneficiaries of flood damage reduction—individual homes, farms and industrial plants—are not assessed direct charges for the "service," although they and their benefits are specifically identified in the course of computing flood damages in water resources planning.[32] In the case of water-based recreation opportunities at reservoirs, no definitive economic demand curve for such outputs has as yet been established, though conceptually this could be done. Where recreational opportunities and aesthetic enjoyment along a stream are enhanced, by providing a more constant flow, for example, these outputs cannot be directly marketed. Thus the decisions about the outputs to be provided from a water resources system cannot be completely determined by the market and, to a greater or lesser degree in any particular case, must be determined by the political process.

Several implications for water resources administration stem from the above discussion. First, because non-marketable and common goods are often typical outputs from water resources systems, governmental action on one or more levels to produce such goods is necessary. Second, because social values are involved, and different groups in society hold different values, alternative ways of achieving outputs should be proposed by the administrative agency, the alternatives reflecting the different values. Third, the importance of non-market-

31. See, *e.g.*, Fox and Crane, *Organizational Arrangements for Water Development*, 2 Natural Resources J. 1, 9-10 (1962).

32. Economically there appears to be no reason why a "betterment levy" could not be assessed against all flooded land, the value of which would be enhanced by the commonly provided flood damage reduction service. Compare Hart, New India's Rivers 221 (1956).

able outputs emphasizes the need for an administrative structure which will provide for explicit consideration and structuring of values, goals and policies and provide for channels by which decisions can be made whether or not to devote public funds to produce non-marketable outputs. In a democratic society it is a fundamental assumption that decisions involving value judgments should be made openly by the political process rather than be left to those who are responsible for technical decisions.

CONCLUSION

In sum, the type of administrative agency suggested by these physical, economic and technological characteristics of water and water resources systems is an agency which:

is unitary, rather than consisting of several separate agencies;

has jurisdiction, by one means or another, over both quantity and quality of water and over both surface and ground water;

is regional in areal jurisdiction, but with varying boundaries corresponding to different outputs;

is flexible over time, both with respect to areal jurisdiction and outputs to be provided;

is large enough to take advantage of economies of scale and of integrated system operation;

has responsibility for producing the entire range of outputs of water and water-related products and services;

is required to look at the whole range of alternative ways of meeting needs for water and water-related products; and

is responsible for planning, design and operation, including monitoring. Such an agency appears to be essential *if* the demands for water and water-related products and services are to be met efficiently, over time, in the face of continuous changes in an increasingly complex, interrelated and predominantly urban-industrial society.

What have been termed characteristics in the above discussion obviously are not mutually exclusive. For example, the relationship between surface water and ground water may, in a given situation, be simply another way of saying that water resources development at the local level affects development on the regional level. No claim is made that the characteristics included exhaust all of the relevant ones, or that the physical, technological and economic determinants are delineated definitively. Nevertheless, it is hoped that this way of looking at the problem of water resources administration has some utility, and that it provides some basis for assessing, if perhaps only qualitatively, technological and economic losses and hence benefits foregone when inadequate consideration is given to these characteristics in establishing and structuring an agency for water resources administration.