12-2-1971

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A. Alvin Bishop
Utah State University

Recommended Citation

Bishop, A. Alvin, "Conflicts in Water Managment" (1971). *Faculty Honor Lectures.* Paper 17.
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Professor of Agricultural
and Irrigation Engineering
Utah State University

FORTY-SECOND HONOR LECTURE

WINTER 1971

THE FACULTY ASSOCIATION

FORTY-SECOND ANNUAL HONOR LECTURE DELIVERED AT THE UNIVERSITY

A basic objective of The Faculty Association of Utah State University, in the words of its constitution, is:

> to encourage intellectual growth and development of its members by sponsoring and arranging for the publication of two annual faculty research lectures in the fields of (1) the biological and exact sciences, including engineering, called the Annual Faculty Honor Lecture in the Natural Sciences; and (2) the humanities and social sciences, including education and business administration, called the Annual Faculty Honor Lecture in the Humanities.

The administration of the University is sympathetic with these aims and shares, through the Scholarly Publications Committee, the costs of publishing and distributing these lectures.

Lecturers are chosen by a standing committee of the Faculty Association. Among the factors considered by the committee in choosing lecturers are, in the words of the constitution:

> (1) creative activity in the field of the proposed lecture; (2) publication of research through recognized channels in the field of the proposed lecture; (3) outstanding teaching over an extended period of years; (4) personal influence in developing the character of the students.

A. Alvin Bishop was selected by the committee to deliver the Annual Faculty Honor Lecture in the Natural Sciences. On behalf of the members of the Association we are happy to present Dr. Bishop's paper.

Conflicts in Water Management

Committee on Faculty Honor Lecture

Conflicts in Water Managment

Today we hear a lot about the "quality of life" and the "quality of the environment," two terms that everyone understands, but as yet no one has defined. Like others, I will not attempt a definition but introduce my subject by saying that water is intimately tied up with both our life and our environment, and its management has a profound effect for good or bad, depending upon the point of view. Today also, clean water and anti-pollution are popular crusades. Someone or something has to be responsible and engineering and science are convenient scapegoats. Considerable emotionalism is involved and there is need to inject some element of reason so as to approach the water problems of the day in a rational way. As an engineer, I am undoubtedly biased, yet except for engineers I see no one really doing anything constructive about the problems except to make a lot of noise, disregard any responsibility, and suggest that the government should make everything illegal. In the meantime, engineers go about building the necessary flood control works, water treatment plants and control systems as they have done for decades to eliminate or reduce the hazards that nature and the society have imposed on the water resource. In the light of present day knowledge it is apparent that engineers, like everyone else, have made many mistakes in the past. Therefore, my major purpose is not to vindicate the engineers but to outline some of the conflicts in water management and encourage an informed approach to the solution of the many problems.

There are countless facets to the conflicts in water management. The arenas of these conflicts are also countless, and like the conflicts, may be physical, biological, chemical, legal, political, economic, sociological, ecological, emotional, or religious, and they may be private, local, national, international, or global in extent. Thus, I will not be so presumptious as to suggest that I will even attempt to enumerate all the possible conflicts, or for that matter, all of the arenas, but rather, I will attempt to focus on what I think are some of the most important issues in the water management problems of the day.

Before dealing in more detail with the conflicts in water management, it is perhaps appropriate to briefly review the extent and nature of the fresh water resource, keeping in mind that water is the most manageable of the natural resources. It is highly mobile. It can be moved great distances from point of origin to point to use. It can be stored to be used at the most opportune time or the most convenient amount so it can be manipulated with regard to amount, space, and time.

Extent and nature of the Water Resource

Although there have been many statements to the contrary, we are not running out of water. The problem arises from the fact that we do not have the quantity and quality where we want it. Through the ages, the water supply of the world has remained almost constant, most of it in the great oceans of the world, (see Fig. 1). Wolman (1962) estimated that 97 percent of all of the water of the world is contained in the oceans. The remaining 3 percent, amounting to approximately 33 trillion acre-feet, constitutes the fresh water resource and is divided as shown in Table 1 and Fig. 1B.

Table 1. Distribution of World Fresh Water Resource (Wolman, 1962)

Location	Acre-ft. (billions)	Percent
Polar ice caps and glaciers	24,700	75
Ground water:		
depths less than 2500 ft.	3,600	11
depths over 2500 ft.	4,600	14
Lakes	100	0.3
Rivers	10	0.03
Soil moisture	20	0.06
Atmosphere	11	0.035

The figures shown in the table are the static estimates for the distribution of the earth's water supply.

From the stand point of water resource management, our interest is primarily concerned with the dynamic part of the world water resources, that is, the fresh water in the lakes, rivers, soil moisture, and the atmosphere which are subject to constant replacement and exchange due to the nonequilibrium of forces in nature. We are especially concerned with the water in the streams and rivers being driven towards the ocean by gravitational forces. If we use Wolman's estimates, only about 1/100,000 of the world's water resource is in the streams and rivers at any particular time. Yet, according to Wolman, the annual precipitation on land surfaces is almost 8 times as great as the moisture contained in the rivers at any one time. The point is that we are dealing with a highly dynamic system when we consider the fresh water resource of the world.

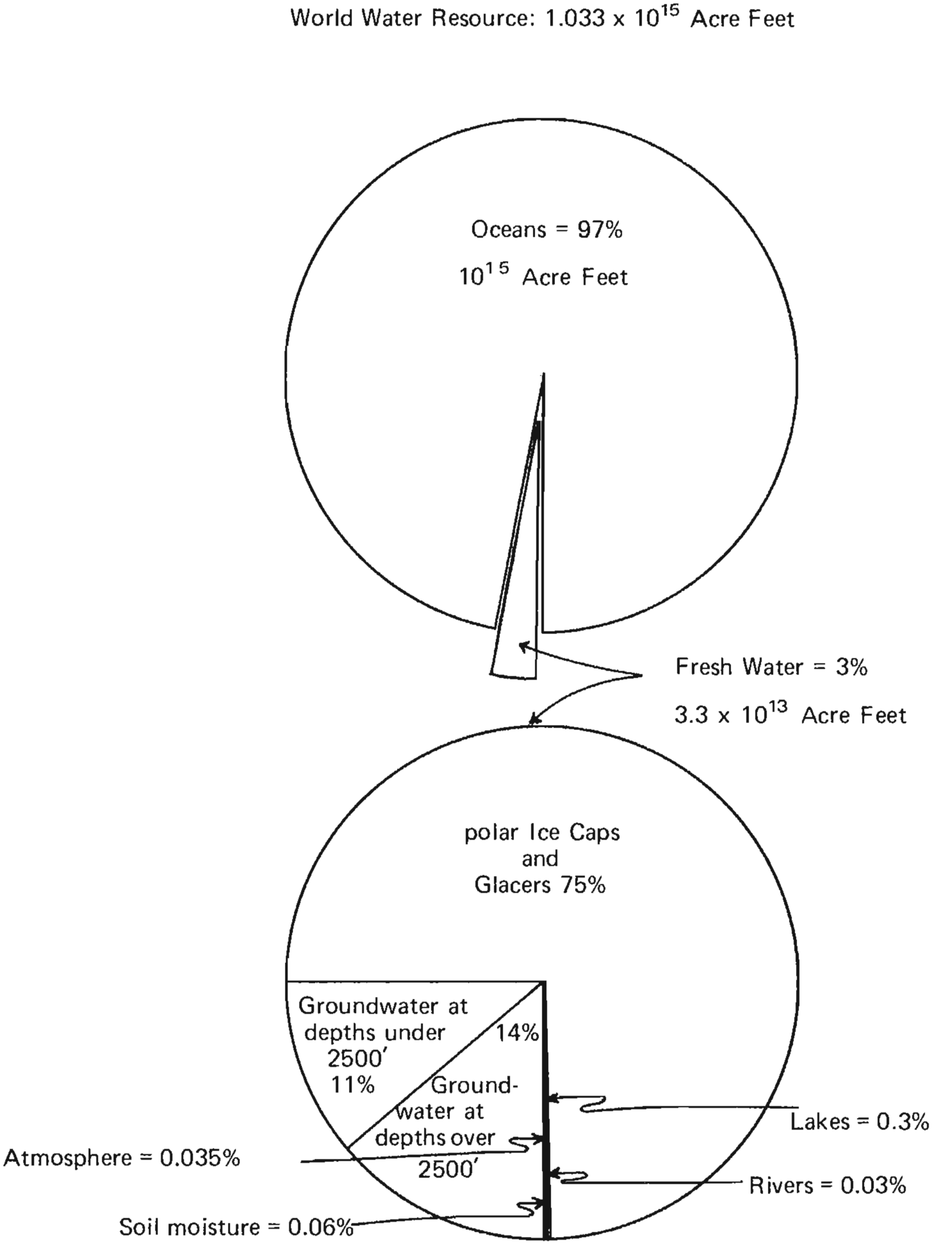

Figure 1. Distribution of World Water Resource.

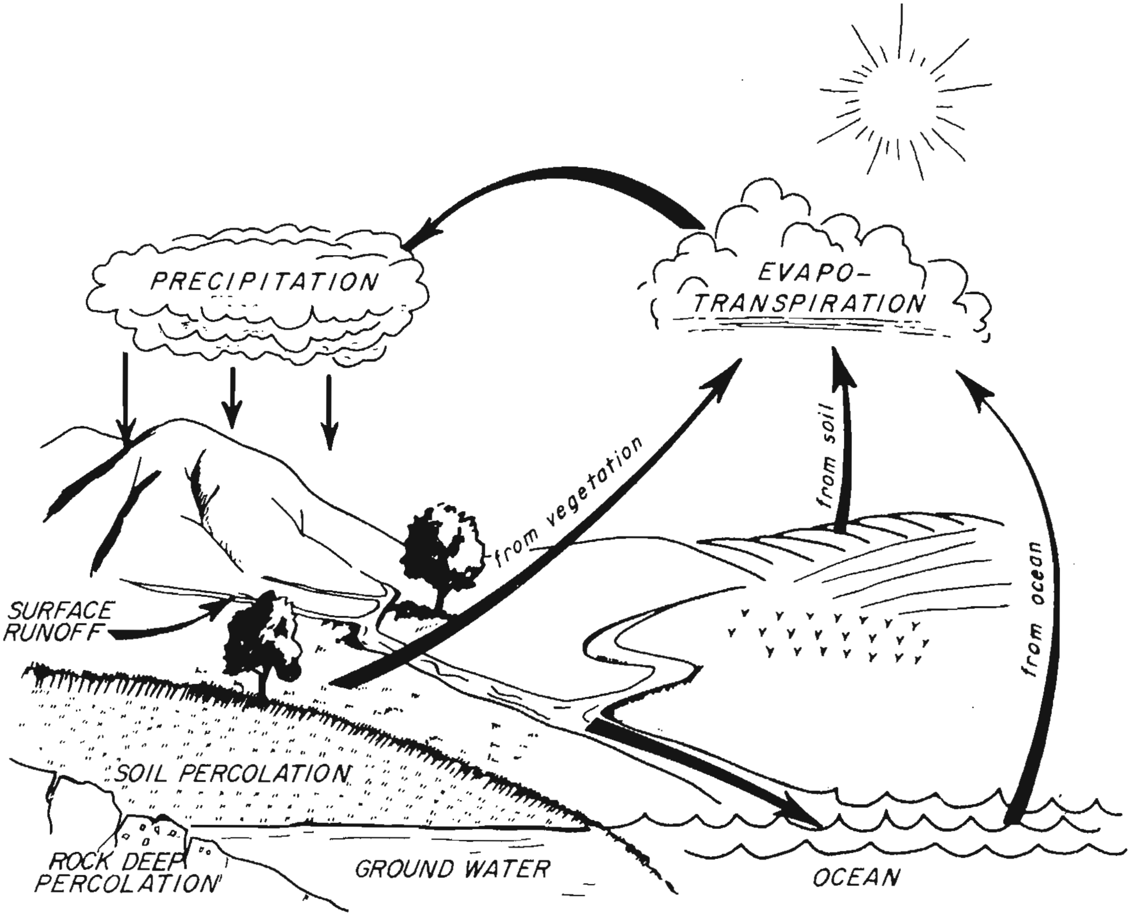

Figure 2. Hydrologic Cycle

We are fairly well informed regarding the nature of the water resource, but we need to be reminded of some of its peculiar characteristics. The fresh water supply of the world is both limited and inexhaustible. Limited, because the amount of fresh water at any given time is almost constant. Inexhaustible, because the dynamics of the hydrologic cycle (see Fig. 2) (Utah Water and Power Board, 1963) is continually feeding new relatively pure water into the system as the old and used water finds its way into an ultimate sink where the renewing process is begun again in the cycle (evaporation-transpiration and precipitation as rain, hail, dew, sleet, or snow).

The hydrologic cycle is beautiful in its purpose, and its functioning is important in providing a continuous inexhaustible supply of fresh water to all life on this planet. It really has no beginning nor any end, although for simplicity, we might think of the beginning as the continuing evaporation process taking place at the oceans. Here, all dissolved solids are left behind and the pure water molecules are lifted into the atmosphere as water vapor. At this point, the renewing process begins.

At the time of condensation, the liquid water exists as pure, distilled water. As it falls to the earth, it brings with it materials absorbed and dissolved from the earth's atmosphere. A major source of nitrogen so essential to plant growth is received in this way. Other important functions are performed during the precipitation process. The elements of atmospheric pollution are to a large extent removed, thus renewing and maintaining the air we breathe.

Precipitation is the source of the manageable fresh water supply. When it reaches the earth it is relatively pure containing only minute amounts of pollutants derived from the atmosphere. However, being the universal solvent that it is, it dissolves the minerals released in the geologic weathering process and begins the important role of transporting these solids to the ocean. It is apparent, therefore, that even in natural water systems which have been untouched by man, the water dissolves solids and minerals as it passes through the soil and over the soil into rivers and down to the ocean where the minerals and solids are deposited and left behind in the renewing process. This provides a rather simple explanation of how the oceans became salty and how the land areas of the earth are purged of elements that might inhibit plant growth.

Normal ocean water contains about 35,000 parts per million total dissolved solids. Applying this concentration to the estimates given by Wolman for the water in the ocean would indicate that approximately 47 quadrillion tons of salt are contained in the ocean at the present time. A reasonable estimate of the salt concentration of the rivers discharging to the ocean is 300 parts per million. If we assume that the river waters are completely exchanged ten times each year, that is to say that the discharge to the oceans amounts to 10 times the instantaneous amount contained in the rivers at the present time, on this basis, it would require a million years to build the salt content of the oceans to their present concentration. This, of course, does not include the large amounts of certain dissolved solids that have precipitated and deposited on the ocean floor in the solid state or those solids required to build up the coral reefs and other large areas of relatively solid residues made up from the oceans' water in the eons that have passed. It does, however, illustrate a very important role that the rivers play in maintaining the quality of the environment that will allow continued vegetative growth on the world's land surfaces. If the salts and minerals released in the geologic weathering process were not dissolved and removed, one might postulate that more of our land would be sterile and non-productive.

This suggests that an important role in water management is to maintain the integrity of the river in moving the dissolved solids from the land surface to the ultimate sink in the ocean, or in the case of inland seas such as Great Salt Lake and others, to a natural inland sink. In this manner, the renewing process of the water supply is also extended to the land areas, whereby, the water and the rivers act as a natural transporting system to transmit the by-products of the weathering processes into the ocean sinks. In simple terms, one might say that the rivers are the sewers of nature and the ocean is the repository. In this way, the land is renewed and maintained in its productive capacity.

In addition to dissolving solids and minerals, oxygen is also dissolved by the water, and, thus, the essential element so necessary to all aquatic life is provided. The dissolved oxygen is consumed both by the aquatic life and by the organic compounds that find their way into the streams and rivers either naturally or artificially. If the biochemical oxygen demand (BOD) does not exceed the oxygen replacement rate, usually there is no problem. If a heavy loading of organic materials is introduced into the water, reducing the dissolved oxygen below the level required for fish and other aquatic life, a problem is created. Such a BOD loading may come from many sources. Sewage and industrial wastes are well known and publicized, but migratory waterfowl, fish, and wildlife may impose heavy BOD loadings as well. Here again, it is essential that the complex interactions are fully understood in order to maintain the desired ecological system.

As yet, man has not improved on the natural functions performed by water in transporting the residues of nature to the ocean sink. On the other hand, he has learned of the great transporting power of flowing water, he has increased the consumptive use and has greatly added to the loadings imposed by nature so as to change or endanger the natural system. This brings into focus the need to look carefully at all phases of water management in order to make wise decisions when conflicts arise. The conflicts are with us, and the challenge is to resolve them for the maximum good of all, now and in the future.

Major Arenas of Conflict in Water Management

The arenas of conflict in water management are directly related to its many uses along with the social, political, and legal forces related to these uses. Water use may be broadly classified into those uses which are consumptive and uses which are nonconsumptive. For simplicity, therefore, we will classify the arenas of water management into those dealing with consumptive use and those which do not.

Consumptive Use Arena. – Consumptive use, as considered here, means that the body of the water is used up; or in other words, it has escaped into the atmosphere in the vapor phase and is, therefore, beyond the reach of further manipulation by man within the physical framework of existing water resource systems. Examples of consumptive use may be found in agriculture, industry, municipalities, human uses, recreation, nature, fish and wildlife, and flood control. Basically, there are no compatible consumptive uses. That is to say that insofar as consumptive use is concerned, once the water has been withdrawn and consumed by one of the uses mentioned, it is not physically available for any other use within the system.

The management problem in the consumptive use arena concerns meeting the demands with regard to quantity, time and space and establishing the priorities to meet social and economic goals as well as determining the priority of use between users. The demands made by each use upon the water supply with regard to amount, time, and location become important considerations. The demands are seldom in harmony with the occurrence of the supply, therefore, storage regulation and manipulation become important in the management mix. The conflicts intensify when the supply is insufficient to meet the demands. In the 17 Western States at the present time the rights to the use of water far exceed the supply in many streams. The situation is further complicated by the fact that most of the water in the west is used for irrigation and irrigation is the major consumptive use of water.

The Select Committee on National Water Resources (1959) estimated that the water use of the United States was 46 percent irrigation, 46 percent industrial, and 8 percent public, with the total consumptive use being 94.2 percent irrigation, 3.1 percent industrial, and 2.7 percent public (see Fig. 3). Although withdrawals for water use for industry and irrigation were almost equal in 1959, according to the Select Committee Reports, 60 percent of the water used for irrigation was consumed compared with only 2 percent of the withdrawals for industry. It is generally considered that agriculture and specifically irrigation is and will continue to be the largest consumer of the manageable water in the United States.

Legal right to the use of water in the Western United States is based upon the Doctrine of Appropriation which recognizes consumptive use in the principle that "first in time is first in right." The priorities of use established under the doctrine of appropriation depend only upon the time sequence in putting the water to use and do not differentiate between the various uses. Now that the waters are fully appropriated on many streams, the change in nature of use, i.e., agricultural to industrial, further complicate the management problems.

Withdrawals from the water supply for consumptive use purposes can be either man-made diversions into canals, pipelines, aqueducts, and reservoirs, or they can be natural withdrawals of considerable extent by means of evaporation and/or transpiration as indicated in the following discussion of consumptive uses.

Agriculture. – In the evapotranspiration process, agricultural crops consume large volumes of water averaging about 7,000 gallons per acre per day (0.20 inches) with extremes exceeding 15,000 gallons per acre per day (0.50 inches). When the water is provided by irrigation, it must be withdrawn from the water resource pool. The management of water for agriculture is primarily concerned with providing agricultural crops with the right amount of water at the right place at the right time, and this has led to the introduction of irrigation in many parts of the world where formerly crops were grown with only natural precipitation. The reliability of meeting the agricultural demands by irrigation not only makes it possible to fertilize, plant, and manage all production factors for maximum returns, but it also allows a change in the type of agriculture from those crops which must be capable of withstanding short periods of drought to those which may have a much higher economic value.

For example, in Japan irrigation was recently introduced to include many crops that were previously grown only under conditions of natural

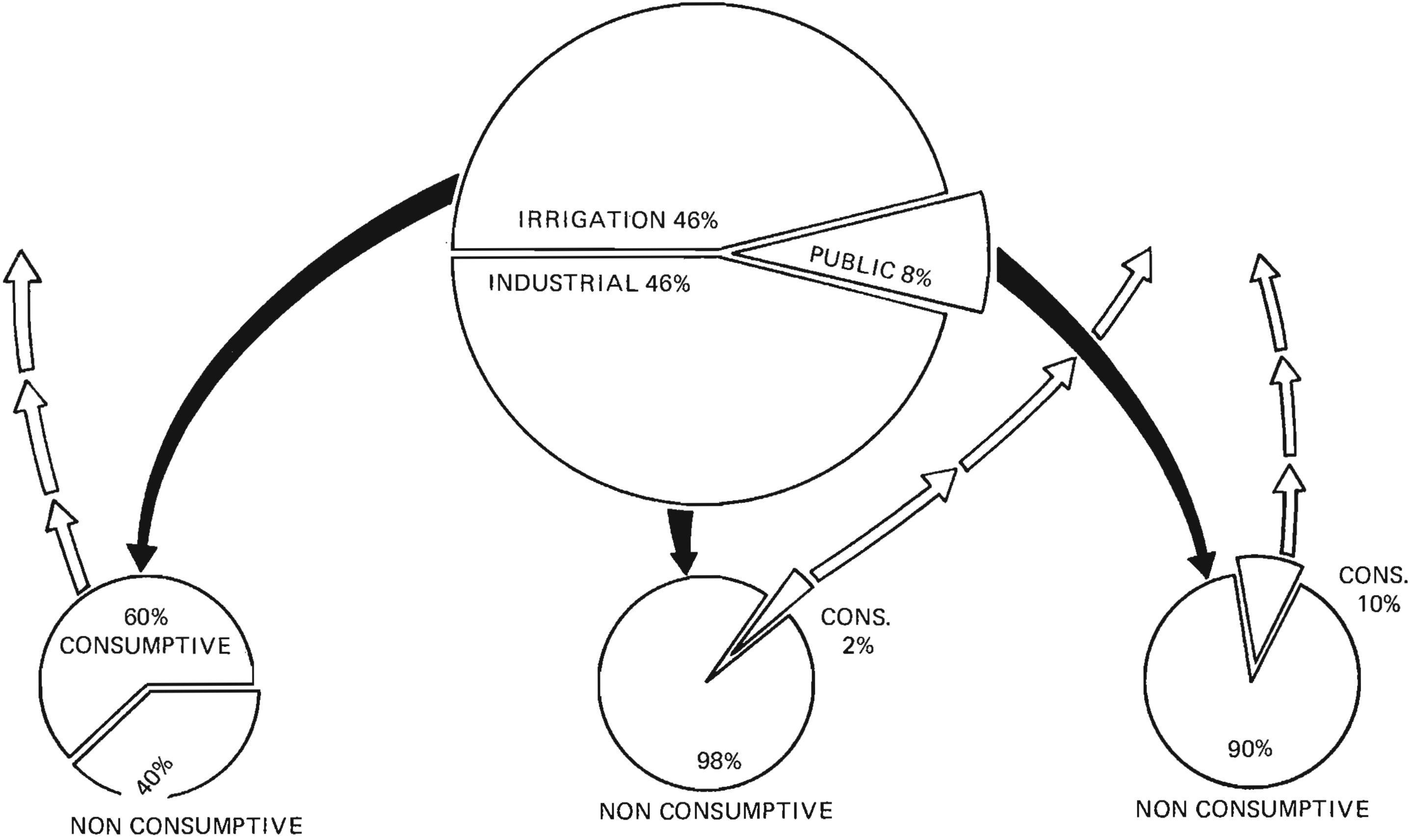

Figure 3. Water Use in United States

precipitation. In one area of Japan near Nagoya, it was reported that yields increased from two to three times with irrigation. Furthermore, a change was made in the agricultural practices from the cultivation of sweet potato, which is of relatively low value but highly drought resistant, to vegetables such as cucumber, tomato, melon, radish, cabbage, and other crops having a much higher economic value. In this area of Japan, which has a relatively high annual precipitation, droughts of from two to six weeks are experienced each year, and this essentially eliminates the possibility of raising high value crops without supplemental irrigation.

The management of the water supply to increase agricultural production is the one means of maximizing the conversion of solar energy into forms that can be used by man.

Plant growth and the process of photosynthesis converts and stores the energy from the sun in the form of grains, plant tissue, oils, fruits and fuel. Cultivated agriculture is one of the oldest and perhaps one of the most important discoveries of mankind. Agricultural development has created the ability to force or control the environment to cause it to produce those products, cheifly food, required to satisfy the energy requirements for our daily life. Agricultural crops, where agriculture is practiced, form a canopy over the soil surface to intercept the sun's rays and absorb and convert the solar energy.

Since the solar energy of the world falls almost equally on all unit areas, the use of large land areas in productive agriculture seems to be a very efficient way of capturing solar energy and making it available to mankind in the form of food, clothing, and fuel. In agriculture, solar radiation also provides the energy required for transforming water from the liquid to the vapor phase (539.55 calories per gram).

Industry. – Consumptive use of water by industry varies greatly from industry to industry. A modern steam electric plant consumes about 3/4 gallon of water per kilowatt hour of power produced, and to quench one carload of coke from a coking furnace, about 5,000 gallons of water are almost instantly transformed into vapor. McGauhey (McGauhey 1968) estimates that approximately 66 percent of the water used by industry is for cooling purposes and about half of this is lost to the atmosphere. Other consumptive uses by industry include evaporation from holding ponds and reservoirs, and make up water for boilers and process water. Energy consumed in the consumptive use processes in industry is generally derived from the heating required in the processes, whereas in most consumptive uses, especially agriculture, solar energy is the direct source.

Municipalities. – Although many municipal uses of water are not consumptive, relatively large quantities of water are consumed in maintaining lawns, gardens, parks, and ornamental vegetation. A large shade tree, for example, may transpire as much as 1,000 gallons per day. Lawns, parks and gardens consume about the same quantity of water per unit area as agricultural crops (7,000 gallons to 15,000 gallons per acre per day). Some water is also evaporated in cooking, washing, and most all household uses. As in agriculture, the sun provides most of the energy for the water consumed in urban use.

Human Uses. – You and I, if we are moderately active, require from five to six pints of water a day to maintain our physical body processes, (USDA 1955). More than half of the water that we take into our body is consumed in perspiration and exhalation. The source of the energy for the vaporization comes from our body.

Water for human consumption is generally considered the highest use of water and other uses of the resource seem unimportant until the body requirements are met. Yet at the present time we pay very little for our drinking water compared with other liquids. In Logan City, drinking water costs about 2-1/2 cents per ton, compared with about $200 per ton for milk which is more than 80 percent water.

Fish and Wildlife. – Although generally not considered to be in the arena of consumptive use, fish and wildlife do require large quantities of water. Christiansen and Lowe (Christiansen 1970) estimated that for Utah conditions, evapotranspiration from the marshlands of Utah amounted to 41 inches during the April-October season. This is an average of 5,200 gallons per acre per day for the 214 day season with no estimate for the other five months. Evaporation from fish ponds, reservoirs, and recreation areas would approximate this amount. Here again, solar energy is the source of the heat of vaporization.

Flood Control. – Flood control projects are generally considered to be regulatory in nature and nonconsumptive. However, as in the case of all manipulation of water, the increased surface area required for leveling off the flood peaks behind flood control dams increases the area exposed to evaporation, and consumptive use will occur. The extent and magnitude of this source of water used has not been estimated.

Recreation – Use of water for recreation is generally considered to be non-consumptive. Boating, fishing, water sports, etc., do not consume water in the use process. However, to be available for such sports the water must exist in the liquid state and is, therefore, exposed to the evaporation process. Likewise, vegetation growing in areas set aside for recreation purposes will transpire water and consequently deplete the supply. The consumptive use charged to recreation will, therefore, be proportional to the surface area of the lake, stream, or land area designated as a recreational area. Estimates vary, but if, for example, Lake Mead were considered a recreational lake, the consumptive use charged to recreation would be from 1.5 million to 2 million gallons per acre per year (about 1,000,000 acre feet per year from Lake Mead). (US Geological Survey, 1964)

Nature. – Along all water courses, natural rivers, lakes, and streams, the water surface areas are exposed to the evaporation process. In addition, the vegetation within the phreatic zone of the stream or lake transpires large quantities, and the water transpired or evaporated is taken from the stream either directly or indirectly. It has been estimated (Utah Water and Power Board, 1963) that the use of water by phreatophytic vegetation in Utah amounts to 2,376,900 acre feet annually. This same report estimates that the annual consumptive use of water by irrigated land in Utah amounts to 2,308,000 acre feet.

The challenge in water management for consumptive use is to see that the allocations are just and correct and in the interest of the best use of the water resource. Now, as competition for the water becomes greater and greater, some of the existing uses, for example, for agriculture, are giving way to water use for other purposes, such as industry or for municipalities. The re-allocation is usually achieved on an economic basis since the economic value of water may be higher for uses other than agriculture. In other words, if the water supply for industry or for a municipality has a higher unit value, then agricultural land can be retired, and the water use changed from agricultural to industrial or municipal because of the higher unit value. The pressure on the water resource is forcing agriculture to eliminate unnecessary wastes and to encourage those practices which will use water for agriculture more efficiently.

On the other hand, there is a tendency for irrigation and the use of water by agriculture to increase because of the increased production possible with a full water supply. In commenting on this point, the

President's Science Advisory Committee concluded, "An inadequate water supply places inherent limitations on the productivity of all other agricultural inputs. Once a full water supply is provided, production increases resulting from the interaction of other inputs can be dramatic. Consequently, the development of additional supplies of water by the construction of dams and canals by drilling large capacity wells can provide the basis for a general increased agricultural production." (The Presidents Science Advisory Committee, 1967)

Non-Consumptive Use Arena

From the definition of consumptive use, it can be easily seen that the non-consumptive use arena must involve those uses of water in which the water is used for some purpose and the used water is then returned to the water supply pool. The use almost always changes or pollutes the water in some way. However, use does not reduce the water to the vapor phase and the water does remain as a resource subject to further manipulation and management within the realm of the water resource system. The management problem in the non-consumptive use arena concerns the quantity and priority of use as indicated for the consumptive use arena and in addition involves the problem of quality and pollution to a much higher degree. Since reuse is possible within the non-consumptive use arena, the quality of the water becomes an important consideration for its acceptability to reuse.

Two types of reuse have been indicated (Hendricks, 1969): 1) Recycle Reuse is the reuse of the effluent water by the using sector itself; and 2) Sequential Reuse is the reuse of the effluent water from one sector by another. These definitions of reuse bring into focus some very important elements in the management of the water within the non-consumptive use arena. For example, a primary user may be able to recycle the water using it over and over again so long as the control can be maintained and the quality of the water is suitable for the purpose of use. When the quality deteriorates to a point of non-acceptability, the usual practice is to discard the water into the natural stream or river system and pass the problem on to a sequential user downstream.

At the present stage of water development for non-consumptive use, recycling is generally the exception, and the primary user simply uses the water and discards it, passing the problem of deteriorated quality to the users on downstream. The quality deterioration will develop naturally even though there is no withdrawal and use by man. Downstream users, therefore, must accept the fact that the quality of the water at the downstream position will almost always be inferior in quality to the water within the same river system at the point near the headwaters.

Natural ecosystems must be considered as water users within a river basin. Water will deteriorate in quality between the headwaters and a point downstream, due entirely to use of water in nature. In other words, if the natural ecosystems are the only users of water on a particular stream, and if the stream system is considered to be the use area, waters originating in the headwaters are naturally recycled within the river system. In the recycling process the stream or river is picking up sediments and transporting them, dissolving solids and transporting them, continually dissolving oxygen and having the oxygen consumed by the BOD of the natural loadings. In addition, the water is being used by fish, waterfowl and aquatic life as a habitat until the water arrives at the ocean or other sink to deposit its load of dissolved solids and sediments.

As withdrawals are made from the water resource pool to satisfy any use or requirements imposed by society, it seems evident that some additional quality deterioration will result from the use of water. The extent to which renovation or treatment is required in order to maintain the integrity of the natural system is a problem that must be decided by society so as to manage the water within the framework of acceptable social and economic goals.

Many more challenging and complex management opportunities exist in the non-consumptive use arena because of the myriad of possibilities for varied combinations of reuse by recycling and/or reallocation. Within the consumptive use arena once the water is consumed, these recycling and reallocation alternatives are not possible.

Description of Non-consumptive Uses. – Some of the following described non-consumptive uses will require withdrawals from the water resource pool whereas others will simply use the water where it exists. The non-consumptive uses are:

Agriculture. – As pointed out earlier, 40 percent of the water withdrawn by agriculture for irrigation is returned to the receiving waters in the form of irrigation return flow. The complexity of the irrigation return flow system is discussed in a recent report by the Federal Water Pollution Control Administration (1969) and a model showing irrigation use and the return flow system was presented as shown in Fig. 4.

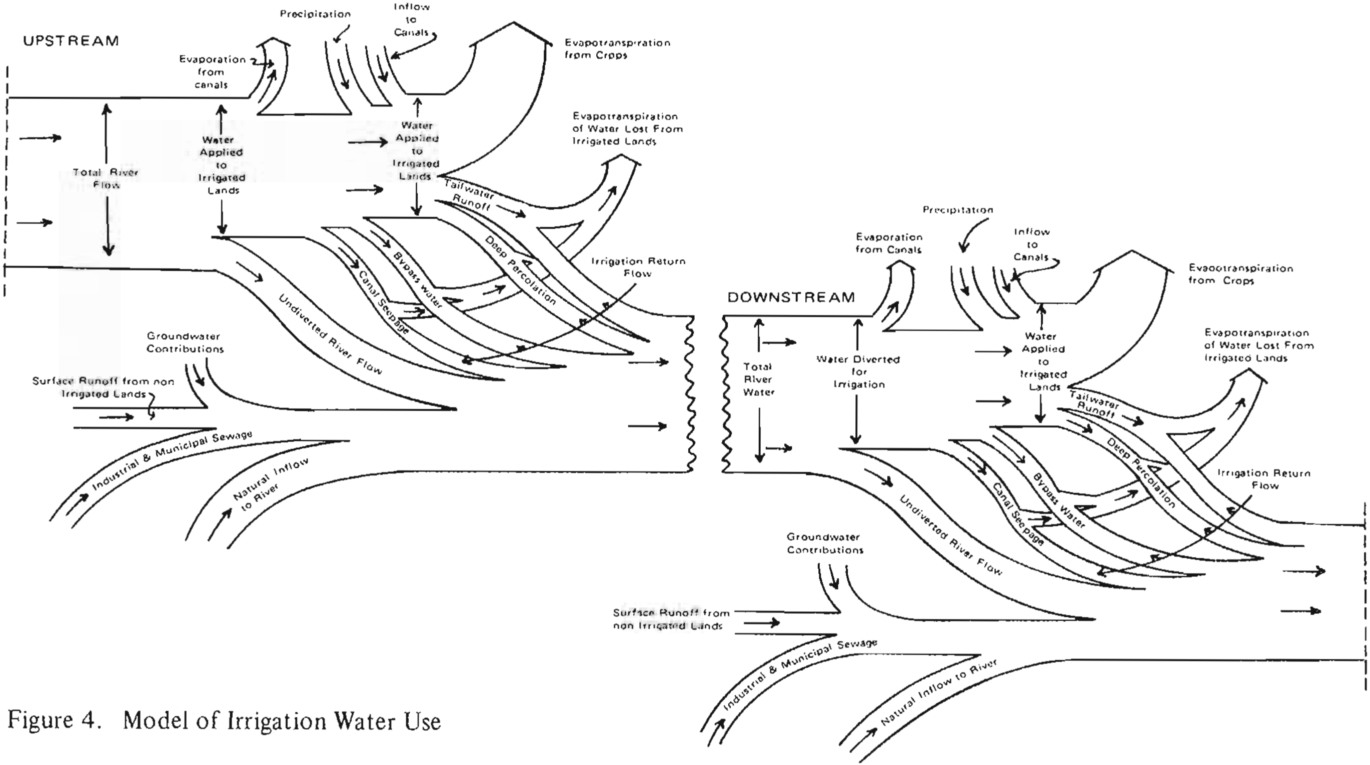

Figure 4. Model of Irrigation Water Use

Fig. 4 shows that irrigation return flow is derived from the following sources: (1) *seepage,* water seeping from canals, ditches, and other structures comprising the conveyance and distribution system: (2) *bypass water,* water which is returned directly to the river or source of supply without being applied to the irrigated land; (3) *deep percolation,* applied irrigation water which finds its way to the drainage system or contributes to the groundwater recharge; (4) *tailwater runoff* (wastewater), that portion of the applied water that runs off the land surface.

Irrigation return flow itself is a complex mechanism as shown in Figure 4 and becomes even more complicated when the water quality and pollution vectors are added as shown in Figure 5 taken from a recent paper (Peterson etal, 1970). As stated in this paper, "The pollution effects of irrigation are different for each specific area or condition and depend on the concentration in the irrigation water, the proportion of the water leaching through the soils to that applied, the number of times the water is reused, and the amount of leaching from areas having residual salts."

Three of these sources of irrigation return flow (seepage, bypass water, and tail water runoff) although unavoidable in many existing systems, are not essential to maintaining a perpetual agriculture under irrigation. Therefore, they may be reduced by physical structures or by management to reduce the primary flow requirements. In other words, seepage control by canal lining, reduction of bypass requirements with regulatory reservoirs, and better management and recycling of tailwater runoff will reduce the withdrawal requirements for irrigation and, consequently, reduce the irrigation return flow. However, deep percolation and drainage from irrigated land is essential in maintaining the salt balance in the crop producing area. Waters diverted for irrigation normally contain from one-half ton of salt to as much as five tons of salt in each acre foot of water. Waters of the Lower Colorado at the present time contain about 1.3 tons of salt in each acre foot (1000 ppm.) The dissolved solids (salt) contained in the water diverted for irrigation must be returned back to the river system where they can be disposed of in the natural way. This water used for irrigation but not consumed plays a very important role to maintain the high productivity of agricultural land. Other beneficial non-consumptive uses of irrigation water include frost protection, seed bed cooling, germination improvement, control of pests, application of fertilizers or dissolving them, loosening of soil for the formation of tubers on root crops and perhaps others. Agriculture may use water for other purposes besides irrigation, including farmstead

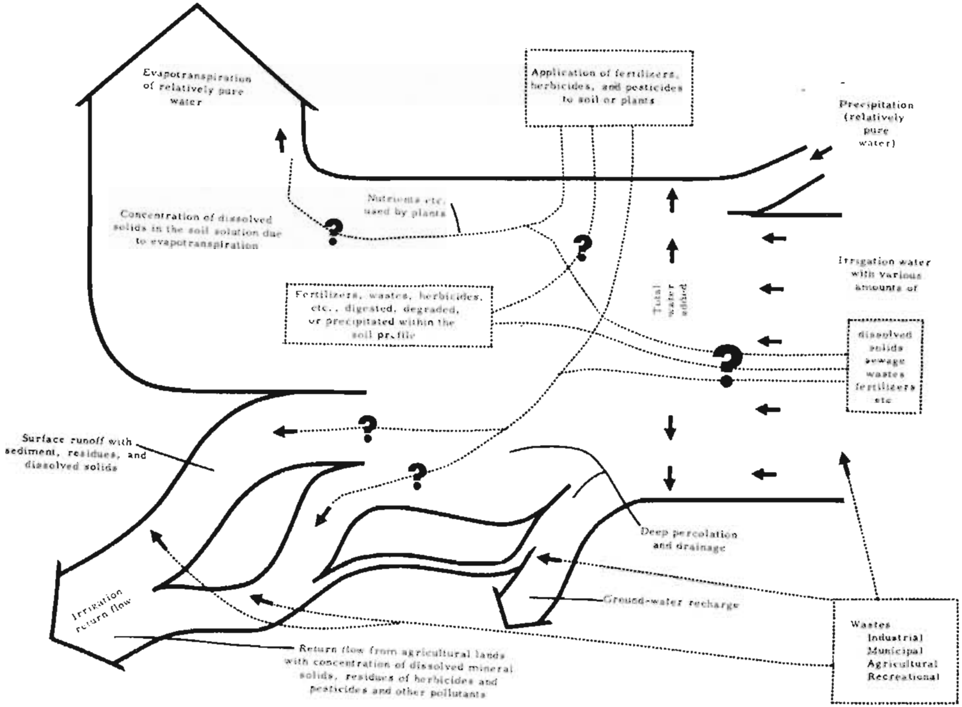

Figure 5. Effect of the water-plant-soil complex on the quantity and quality of irrigation return flows. (USDI 1969)

requirements, washing of dairy barns and milk handling equipment, cooling of dairy and farm products, and agricultural buildings, and for fish ponds and wildlife areas. These uses are largely non-consumptive but each use may have the potential of pollution or quality degradation.

Industry. – Although nearly half of the water withdrawn from the water resource pool at the present time is for industrial purposes, only a small percentage of this water (approximately 2 percent) is consumed. The remaining 98 percent of the water withdrawn for industry is returned to the resource pool and is subject to reuse. Industrial use of the water may drastically change its characteristics adding many pollutants or it may return the water essentially unchanged. For example, a hydroelectric plant diverts water at one point in the resource pool and returns all of it at some point lower in elevation. The return flow from the plant is undiminished in quantity and unpolluted in quality thus leaving the water unimpaired for any sequential use. On the other hand, a steam electric plant using fossil or atomic fuel requires water for cooling purposes. The steam turbines are less than 50 percent efficient in converting the heat energy into electrical energy and huge quantities of heat must be wasted into the atmosphere through the cooling towers or returned with the return flow to the river resulting in a rise in temperature. Other industries use the water to transport and dispose of waste materials generated in the processes. A single plant such as a paper mill, sugar factory, or processing plant may produce as much equivalent BOD loading as a city with a population of more than a million people.

Municipalities. – Generally speaking, more than half of the water diverted for municipal use is returned to the water resource pool carrying with it the sewage and municipal wastes of the city. The non-consumptive uses include washing, cleaning, cooling, cooking and other household uses and transporting the normal municipal wastes. It is hard to visualize not being able to lift the plug on the bathtub or turn the handle to flush the toilet, but these conveniences do require large quantities of water in relation to the material transported. McGauhey (McGauhey, 1968) in commenting on the aspect of water use has the following to say: "It is hard to justify the dedication of some 2,000 tons of water to transport a single ton of solids. Certainly it is without parallel in the history of transporation to send so vast a train to carry so small a load."

Although most modern cities now have treatment facilities primarily designed to reduce the solids and the BOD loadings imposed by the sewage effluents, large quantities of non-reducible sediments and dissolved solids are carried back to the resource pool thus creating a problem in management of the resource. A comparison of tap water and sewage effluent is shown in Table 2. It can be seen that rather large quality changes take place.

Fish, Waterfowl, and Wildlife. – Except for the water evaporated and transpired from the areas supporting fish and wildlife, water used to support fish and waterfowl is largely non-consumptive. The use, however, may impose rather drastic quality changes as a result of the fish or waterfowl being present. Fish life and waterfowl both produce BOD loadings on the water supply, and, though by themselves do not usually degrade the system beyond its recuperative power, do produce a loading that must be dealt with in the overall management of the resource.

Recreation. – Like fishing and wildlife, the use of water for recreation is largely non-consumptive and the water is either left in place or returned immediately to the water resource pool. The use, however, does place some demands on the resource and leaves its mark in various forms of pollution. Swimming, boating and related sports are increasing each year. The November 1970 Newsletter of the Colorado River Association contains the following statement:

> More than 43 million persons participated in recreational boating in this country last year, Donald A. Milton, of Chrysler's marine and industrial products division, told the National Water Resources Association convention in Las Vegas. Other 1969 statistics he provided: there were more than eight million pleasure craft of all types and sizes in U.S.; ten million and more people went water skiing; more than thirty-one and a half million went fishing; three and a half million participated in scuba and skin diving; more than seven million outboard motors were in use; and in excess of $3 billion was spent on boating equipment and services.

More people with more leisure time are imposing greater demands upon the water resource. Vacations seem to be automatically linked to some sort of water-based recreation from skiing and the more recent motorized skidooing on the solid forms of water in the winter to boating, fishing, swimming, and the like, in the summer.

The extent and nature of the water quality change resulting from these uses is yet unknown. The quality change or pollution resulting from ten million people water skiing may be insignificant, the eight

Table 2: Comparison of tap water and sewage effluent[1] (FWPCA, 1969)

Test	Batavia	Dayton	Hamilton	Lebanon	Loveland	Average	Batavia	Dayton	Hamilton	Lebanon	Loveland	Average	Average Increments Added
COD-unfiltered	7.8	5.7	2.3	8.2	5.4	6.0	171	169	165	92	146	149	143
COD-filtered							128	114	92	78	92	101	
COD-filtered, corrected for Cl^-	4.5	1.4	0.3	2.7	1.7	2.0	116	99	79	49	78	84	82
Anionic detergents (ABS)	0.03	0.02	0.03	0.02	0.01	0.02	10.1	7.2	6.2	4.6	9.0	7.4	7.38
Hydroxylated aromatic (tannic acid)	0.04	0.01	0.01	0.07	0.11	0.05	2.9	1.3	2.0	0.6	1.5	1.7	1.65
Carbohydrated (glucose)	0.05	0.06	0.04	0.08	0.03	0.05	2.6	2.2	5.0	1.0	1.5	2.5	2.45
Reducing sugars (glucose)	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	
Organic nitrogen (N)	0.15	0.04	0.02	0.09	0.07	0.07	4.1	1.4	3.5	1.1	1.5	2.3	2.23
Nitrate (N)	0.03	1.41	1.18	0.08	0.62	0.67	3.1	4.9	0.2	7.8	4.6	4.1	3.43
Nitrite (N)	0.008	0.003	0.040	0.095	0.008	0.031	0.59	0.10	0.08	0.34	0.56	0.33	0.33
Ammonia (N)	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	6.8	16.3	22.1	19.4	15.7	16.1	16.1
Total alkalinity ($CaCO_3$)	22	38	40	311	294	141	174	198	257	351	335	263	122
Calcium (Ca^{++})	20	22	12	108	96	52	63	53	54	109	97	75	23
Magnesium (Mg^{++})	5	11	11	30	21	15	14	21	22	33	22	22	7
Potassium (K^+)	2.0	2.1	2.0	1.6	1.8	1.9	13.7	9.3	11.2	9.8	11.8	11.2	9.3
Sodium (Na^+)	8.5	17.5	17.3	13.9	10.5	13.5	50	68	63	112	55	70	26.5
Phosphate ($PO_4^=$)													
Total	0.045	0.051	0.038	0.022	0.58	0.043	34.6	19.4	19.5	18.5	29.5	24.3	24.25
Ortho	0.004	0.009	0.005	0.006	0.032	0.011	33.8	17.9	18.9	15.6	27.5	22.8	22.8
Sulfate ($SO_4^=$)	56	79	56	96	53	68	95	91	108	111	99	101	33
Chloride (Cl^-)	11.5	16.8	9.0	22.5	15.7	15.1	51.8	67.3	49.4	124	62.0	70.9	55.8
Residue 105°C	98	177	140	520	344	256	472	525	597	648	492	547	291
Residue 600°C	78	149	133	368	262	198	359	380	445	526	389	420	222
Loss on ignition	20	28	7	152	82	58	113	145	152	122	103	127	69
pH	9.4	8.4	8.5	7.7	7.4	8.3	7.5	7.3	7.8	7.8	7.4	7.5	
Specific conductance, micromhos/cm	193	307	236	750	622	422	730	864	796	1,185	1,003	916	494

[1] Table values are mg/l except pH and specific conductance.

million pleasure craft and the seven million outboard motors with their underwater exhausts may not be so insignificant. We need to know.

Dividing the resource between more and more people greatly increases the pressures on the resource and complicates its management. At the same time we are being forced to reassess our private attitudes toward water use so as to include more people. For example, we must find a way to share our once considered private fishing holes with others since there are simply not enough to go around on a private basis. I believe this is possible in many areas by changing the management. In fishing, for example, the sport could include many more people if certain areas were designated where all fish caught had to be released. Although I have been fishing most of my life, I have personally received my greatest enjoyment in the last few years when I began releasing almost 100% of the fish that rise to the fly. The catching and playing of the fish produces the thrill and the release creates much more satisfaction than the killing. I must also confess that occasionally I enjoy a meal of fine mountain trout but the eating I would gladly forego to protect the catching. To others, the getting of the fish for the fine meal to follow is the primary objective, so we must strike a balance in order that both objectives might be realized. How to achieve such goals and how to determine and allocate the costs remain to be solved.

Flood Control. – Flood control as a water use regulates the natural supply to eliminate the disasterous flood peaks and usually results in augmentation of the low flow stage of the stream. Although it is almost completely non-consumptive, it leaves its mark on the water resource system in the form of sediment concentration in the reservoir area and concentration of the dissolved solids as a result of the evaporation that takes place in the flood control facility. Flood control by means of diversion, water spreading, and augmentation of the groundwater resource also results in quality changes by dissolving solids from the surface and subsoil before finding its way back to the stream or groundwater reservoir.

Resolution of the Conflicts

In the preceeding paragraphs I have outlined some of the peculiar characteristics associated with the various uses of water and have indicated the nature of the change in quantity or quality resulting from the use. Management of the water resource is almost always concerned with managing its quantity or quality within a space and time reference to achieve certain goals. The major conflicts in managing the water resource arise from the limited concept of water use in the minds of those having responsibility for its allocation or management. Many are inclined to view the system solely from the standpoint of the engineering devices and structures. Man's impact on the water resource is to a large extent due to the engineered system; however, as pointed out above, the natural system must be fully understood and considered in the overall water resource management scheme.

All over the world water is considered to be free and the property of the people (Allah's Gift) and the society must therefore take the leadership and responsibility to allocate the water to those uses which will result in the most good for the most people, now and in the future. Since the resource is dynamic, the uses may also be dynamic and subject to change with time. As social pressures develop, drastic changes may be necessary changing the use from non-consumptive to consumptive, or vice versa. The committment of the water resource to a given use is not necessarily irreversible. For example it is physically possible to open the gates of all dams on the Colorado River and thus return the river to its wild uncontrolled state. The dams left obsolete by such a drastic measure actually cost less in dollars than the Apollo 14 moon landing, the cost of which we are content to write off. I am not suggesting that the Colorado River be returned to a pre-developed state – I think it would be idiotic – but I am saying that such a choice is still possible if we would be willing to forego the advantages provided by the existing development and write off the cost of the existing dams, power plants and related structures. In the future changes may be required to obtain more compatibility between uses or extend the resource by renovating, treatment and sequencing. It is axiomatic that in order to enjoy the desirable benefits from a particular use of the water resource, the objectionable factors resulting from the use must be tolerated. Some examples follow.

Consumptive Use. – The allocation of water for the irrigation of agricultural crops may need to be increased to combine and maximize the production factors required to grow the food necessary to feed the expanding world population. I personally believe that the tremendous energy requirements of the human race must be supplied mainly from agricultural crops. Although we have made some progress in synthetic foods, even these are derived from agricultural products. We have not yet been able to substitute for nature's way of providing for our basic energy requirements, although we have improved the situation and forced the environment to produce more and better food through cultivated agriculture.

Since agricultural crops consume huge quantities of water the increased use of water by agriculture will undoubtedly reduce the water in the natural supply and may require sequencing of existing non-consumptive uses to provide more water for agriculture. The use of sewage effluents from cities and return flows from industrial plants may be an acceptable reuse possibility. Besides providing the necessary source of water, there may be additional side benefits. The soil may have the capacity to absorb many of the major pollution vectors such as heat, organics, and specific elements without permanent damage. We need to know more about this possibility. It has been stated that there are no compatible consumptive uses, but there may be a high degree of compatibility between non-consumptive uses and the use of water for irrigation. Alternatively, increasing consumptive use would require additional developments to augment the natural supply.

Non-Consumptive Use. – The allocation of water to one use versus another within a given space time framework is difficult to resolve. An example came to my attention last year while attending regional research meetings at the California Experiment Station near the city of El Centro in the Imperial Valley. There seemed to be a movement generating to prohibit the salinized irrigation return flows from getting into the Salton Sea. The newspapers contained articles on the increase in salinity in the Salton Sea to the extent that the species introduced for sport fishing there were in danger. (The Salton Sea was formed in 1905-1907 when the Colorado River went wild, jumped its banks during a flood, and flowed into the valley rather than the Gulf of Lower California for almost two years.) The movement naturally lost momentum when it was learned that the salinity level of the irrigation return flows were less than the salinity level of the Sea and that the drainage from the irrigated land was really prolonging the day when the fish life could no longer tolerate the increase in salinity. Obviously, now some other solution to the Salton Sea problem must be found. Incidentally, I think the Salton Sea is a good example of the way the oceans have become salty, except that there the process has taken place in a few short years, whereas millions of years have been required for the salinity build-up in the oceans.

With the building of Hoover Dam and the creation of Lake Mead on the Colorado River, the possibility of floods on the river downstream of the type creating the Salton Sea have been eliminated. The multipurpose Boulder Canyon Project now protects the rich Imperial Valley from flooding, provides a reliable and safe water supply for irrigation, generates huge quantities of hydro-electric energy and has created a water based vacation land enjoyed by millions each year.

Farther upstream on the Colorado River, additional controls by engineered systems have been placed on the river. Glen Canyon Dam and Flaming Gorge Dam, recently completed, have created recreation lakes now enjoyed by thousands for boating, sightseeing, and fishing. The dams have changed the river below them from a muddy silt-laden stream, ecologically suitable only for minnows and trash fish to a bright, clear, rainbow trout stream. The lakes provide storage so necessary to all water management, and at the same time, gives insurance against dangerous and disastrous flooding downstream. Protection of the natural system is provided by stabilizing the flow below the dams. Conservation of soil and water and regulation of the river is provided. These multipurposes developments on the Colorado also produce electrical energy valued at many millions of dollars per year.

The recreation value of the Colorado River development, considered as an incidental benefit before construction, probably exceeds its value for power purposes as viewed through the eyes of our present affluent society. Undoubtedly, I am biased, but I see most river developments as serving mankind in many ways and improving the quality of life and the quality of the environment at the same time. For me, the dams are beautiful and serve many useful purposes. To some others, these structures have converted the Colorado River into an ugly machine and mechanized the river. The differences in the point of view may never be harmonized.

Last summer Utah Power was severly criticized for drying up a section of Provo River. We have a similar example, a few miles from here at the City Dam (Third Dam) in Logan Canyon, where water is diverted for the production of hydroelectric power for Logan City. Except during flood flows, all the river is diverted into the large pipeline serving the power plant leaving the river bed dry. This is the condition generally found in the mile long section of the river between the Third Dam and the power plant and it exists usually from about August to late April the following year, a period of approximately nine months.

As an avid fisherman and a lover of mountain streams, I would like to see this section of Logan River kept alive all year long. Personally, the dry river bed is not acceptable to me. About twenty years ago the Third Dam was not tight and a small stream amounting to a few cubic feet per second passed the dam and maintained a few deep holes in this section of river, and for a few days in June during the flood flows I experienced some fine fishing in this reach of the stream. Since the dam was repaired and made tight, the river bed is now dry each year and I doubt that this section of the river supports any trout life at any time. At least, after a few unsuccessful trials, I have discontinued any fishing of this part of Logan River.

I would like to see a live stream of at least 25 cfs in this section of Logan Canyon at all times and 50 cfs or 100 cfs or the total river flow would be even more to my liking. On the other hand, as a long-time taxpayer in Logan City, I am interested in economy so I have computed the cost of keeping this mile of Logan River alive.

The operating head on the Logan City Hydro-Electric Plant is 98.23 feet and the present plant efficiency is estimated by the Logan City Engineer to be 94 percent. On this basis, 25 cfs would produce 262.32 horsepower or 195.7 kw. Obviously, if the water is in the river, it cannot be in the pipeline; thus, to keep 25 cfs in the river, the generating capacity of the plant would be reduced by 195.7 kw for about nine months each year representing a loss to the city of 4695 kwh per day or 1,268,071 kwh per year. Logan is currently buying power from Flaming Gorge at an average cost of between 0.75 cents and 0.80 cents per kwh. Applying these prices to the kwh produced by 25 cfs shows the cost to be between $35.22 and $37.57 per day or from $9,510.00 to $10,144.00 per year. A flow of 50 cfs in the river at all times would double the cost and to have the entire river flow would cost nearly five times as much or $50,000 per year.

In managing this section of the stream so as to have a minimum of 25 cfs in the river at all times with a choice between non-consumptive uses, Hydro-Electric Power versus Recreation-Fishing and aesthetics, it is clear that we must put some monetary value on the latter. As a resident of Logan City, I would be willing to pay my pro rata share to maintain a minimum flow in the river, although it is questionable that a majority would be in favor of reducing the net income of the City by some $10,000 to $50,000 per year.

These examples of management conflicts point up the need to know more about the resource and the alternative uses and the aims and objectives of management. We must base our decisions on fact rather than emotionalism. Conflicts in water management are increasing with population pressures. The multi-use and multi-objectives currently in vogue (anti-pollution, clean water, protection of health, and the aesthetics) are causing a re-evaluation of the established objectives of maximizing the economic returns from the use of water. Nevertheless, it will be necessary to quantify these new dimensions of water resource management in order to make decisions having a firm foundation.

The type of calculation and comparison made for Logan River can be made for all resources if we learn how to develop the appropriate relationships. It is essential for us to learn to convert human values, which we normally do not think of in terms of money, into such figures. As long as we regard objects of natural beauty, such as Logan River, as priceless, we can not talk about these priceless beauties in the same sentence with the Logan water supply. In the same way that we learned in the second grade that we can not add apples and oranges until we agree to call both objects, we must learn that we can not compare subjective issues which deal with the quality of life with objective items which deal with the quantity of life, such as clean air, clean water, and running streams until we have established a common unit of value for the comparison.

The management decisions of resource allocation and control must be fully justified and supported by the society. Indeed, I believe the decisions must and will reflect the desires of the majority. The challenge to science is to provide the basic truths required for the necessary evaluations and sound management decisions. It is not enough to know all of the facts about one water use. It is essential that we be well informed about all water uses, including those of the natural systems and those of the engineered systems, and how each use relates to all others. We know some of the simple truths and some of the consequences. We know we can not maintain water quantity and use the water consumptively. We know that consumptive use is a concentrator of the impurities. And we know that non-consumptive uses generally degrade or pollute. On the other hand, we know very little about the natural system and we do not have the required information to explain many of the complicated water use interactions. With our improved knowledge and techniques, we have discovered new possible hazards such as mercury, radioactivity, and pesticides. We need to know the serious nature of these hazards and develop new controls or treatments where required.

I have confidence that science can find the answers we need. Some of the answers will concern what we can and cannot do within the complex system to maintain desired levels of management control. We have made many mistakes in the past, but if we consider the past decisions in the light of the knowledge available at the time, we find that we would probably do it again. Our "hindsight" is good because of the increased knowledge and information generated. We can reduce mistakes of the future with scientific information to give us foresight. We will still make mistakes unless we do nothing, as some have advocated, and thus eliminate the possibility. But doing nothing would perhaps be the biggest mistake of all.

I am one of those who believe that the water resource must be used, that its wise use and management holds the key to providing the basic energy requirements of mankind and that the many uses must be coordinated, sequenced, and organized to protect the basic functions of the natural system and still allow the engineered system to operate.

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