Water as a Resource

K. C. Wilson

INTRODUCTION

With the possible competitor, air, water occupies a position as the resource most utilized by modern technology. It is used in vast quantities in almost all fields of production, as that can be seen from the representative figures presented on Table 1. In general, such large amounts of process water are not physically necessary, and the typical figures shown in the table have come about because of the traditionally low price paid for water supplies. In zones where water is expensive, there are instances of plants with water input less than one-tenth that of the figures given.

TABLE 1

Representative Values for
Industrial Water Demand

Commodity	Tons of Water to Produce one ton of commodity
Oil	20
Alcohol	120
Sulphate Pulp	250
Steel	300
Synthetic Fibres	3000

Despite the profligate water demand of the manufacturing industries, the industrial sector is not the largest water user in the world today. Even in such a heavily industrialized country as the United States, industrial use accounts for only some 20% of the total water demand, whereas irrigation, the largest single user, accounts for almost 40%. Although figures for the world as a whole are necessarily inaccurate, it has been estimated that on a global basis approximately 80% of the total fresh water supply to all users is presently devoted to agricultural irrigation. There can be no doubt as to the primary importance of this agricultural use. Although irrigated cropland comprises only about one-sixth of the world's total, it is now providing almost half the food crops. In view of the rate of population growth, particularly in the poorer countries, the requirement for an expansion in irrigated agriculture is vital.

HISTORICAL SETTING OF WATER RESOURCE DEVELOPMENT

Agriculture is not only the leading water user at present, but also has occupied this position for thousands of years, and it may be appropriate here to deal with the various types of water use in an historical setting in order to provide the background for later consideration of present and projected water use. Naturally, humans, like all mammals, are dependent on drinking water for their existence. In the distant past this merely implied that primitive tribes stayed close to water supplies, and the first conscious use of water as a resource arose with the discovery of agriculture. As greater and greater areas were irrigated from water-bearing canals, the development of large population centres became both possible and necessary-- possible because of the high productivity of irrigated land, and necessary in order to co-ordinate the effort required to build and maintain the irrigation systems. Before 3000B.C., massive irrigation systems covered much of Egypt and Mesopotamia, and these were later followed by similar systems in India and China. The growth of early civilizations along with irrigation is remarkable, but not really surprising. The construction of irrigation works gave rise both to technical innovations and to the managerial know-how required to co-ordinate the work of the vast numbers of manual labourers involved. These in turn provided the basis for the building of cities and temples and also for the organization of armies which expanded and unified the agricultural nations. The need to keep records and measure valuable land likewise led to great developments in writing and mathematics.

However the results were not uniformly positive-- even at this early time the consequences of resource mismanagement could become acute. A serious problem arose because of the relatively small quantities of salts which occur in river water (even although it is classified as fresh).

If for decades or centuries such water is applied to fields without drainage, the salts will tend to accumulate as the water is evaporated by the plants, and in time the land will no longer be capable of producing. In antiquity very sizeable areas of both Egypt and Mesopotamia were destroyed by this salting process, and much of this land is still unproductive today.

An additional effect of the population concentrations associated with irrigation was that the river water became unsuitable for drinking, and the solution of this problem led to the next major water resource development-- municipal water supply. As we all know, this reached a peak of sophistication with the Romans. Some of their aqueducts supplied water from sources more than 50 km. from the capital, and it has been estimated that with all aqueducts flowing, the quantity of water entering Rome would have been at least one million cubic metres per day, giving a per capita supply fully comparable to that used by modern western cities.

No doubt the use of industrial process water increased because of this convenient supply and, in addition, power for milling grain could be produced by water wheels which used the head from the elevated aqueducts. The Roman Vitruvius is credited with the invention of the classic type of water-wheel mill (a rather poor example can be seen today outside Aunt Lucy's Restaurant on Highway 2). The development of this early application of hydro power can be traced by the numerous regulations restraining mill operators from taking an unfair share of the water from the aqueducts.

However, with the plentiful supply of slave labour in the Roman empire, the full development of hydro power was delayed. Later, in the middle ages, the water mill became common in Western Europe. The Domesday Book listed, for tax purposes, more than 5000 water mills in England at the time of the Norman conquest. The technology of water mills was later extended to windmills in areas centering on Holland, and the existence of sizeable numbers of millwrights in the Low Countries and England was very significant to the later technical innovations leading to the Industrial Revolution. With the progressive use of water mills for more and more industrial activities, the practice of siting industries by rivers and diverting process water into industrial plants also became common. It should be noted here that even the later developments in thermal energy generation did not impede the development of hydro power so long as suitable sites were available. Specifically, in the early history of Ontario, villages and small industries typically were located at sites suitable for water mills, and the remains of such mills can be seen throughout the countryside. Later, the first major industrialization in Canada resulted from the cheap hydro-electric power developed at Niagara Falls.

We have now traced the origin of several of the major water users--irrigation, municipal supply, hydro power and industrial process water. Another use that may be mentioned in passing is water for navigation canals. Because of the low cost of water transportation there was a great canal-building boom in the early phases of the Industrial Revolution (the Rideau Canal is typical of the works of this period), while more recently there have been developments like the St. Lawrence Seaway. However, although such canals are important transport links they are relatively small users of water.

The remaining use of water that must be considered has come into prominence more recently. We already saw that water power has been the favoured method of electric generation where suitable sites are available and even now is being developed at such sites -- for example those near James Bay. In the more industrially developed areas, however, almost all suitable water power sites have already been exploited, and here the bulk of new power is produced by thermal generation using either fossil fuels or nuclear reactors. Because of the need to maintain a low sink temperature for thermal generating units, large quantities of cooling water are required. In the United States and also for the world as a whole, this demand for cooling water now ranks above both municipal supply and industrial process water.

This completes the list of major users of water as a resource, but in addition it should be noted that very large and rapidly growing sums of money are also expended for the amelioration of two categories of undesirable effects associated with water. The first of these, which has been a problem since the days of the Pharaohs, is flood control. The second is pollution abatement.

The need for flood control arises because the hydrologic cycle is a natural process of extreme variability, and sudden snowmelt or storm rainfall can cause river flows much greater than normal -- often by an order of magnitude or more. As a result engineers must provide storm sewers, highway culverts, river embankments, spillways at dams and so forth.

The pollution abatement aspect has been necessitated both by the large quantities of industrial process water noted at the beginning of the lecture and by the municipal water supply which typically amounts to about half a ton of water per person per day. The combination of these factors accounts for about 30% of water use in the U.S. and about 10% for the world as a whole. However, this water is returned to rivers and lakes in highly polluted form, and by mixing, there will be produced a total quantity of polluted water larger by at least an order of magnitude. The total volume contaminated by industrial and municipal effluent now exceeds the volume of water actually used for all purposes including irrigation.

INTERACTION BETWEEN RESOURCE DEVELOPMENT AND THE HYDROLOGIC CYCLE

In discussing water resource development it is necessary to relate water use and misuse to the physical background of the world in which we live. No doubt everyone haere has been exposed, at some time in his or her early schooling, to a description of the hydrologic cycle. The concept is simple -- water is evaporated from the oceans, travels as vapour through the atmosphere, falls as rain or snow, seeps through the soil or flows through channels, and finally returns via the rivers to the sea (refer to Figure 1).

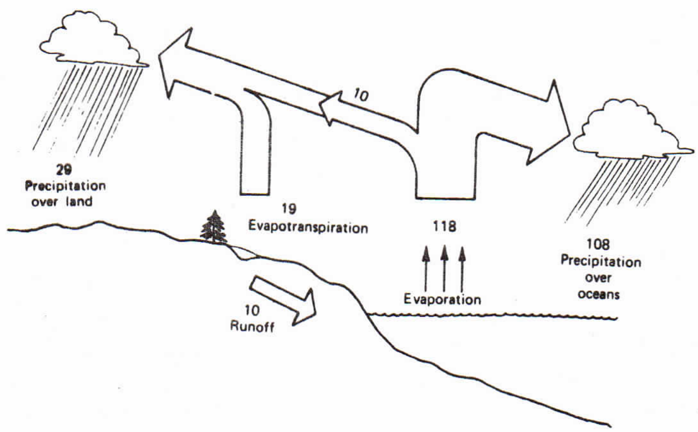
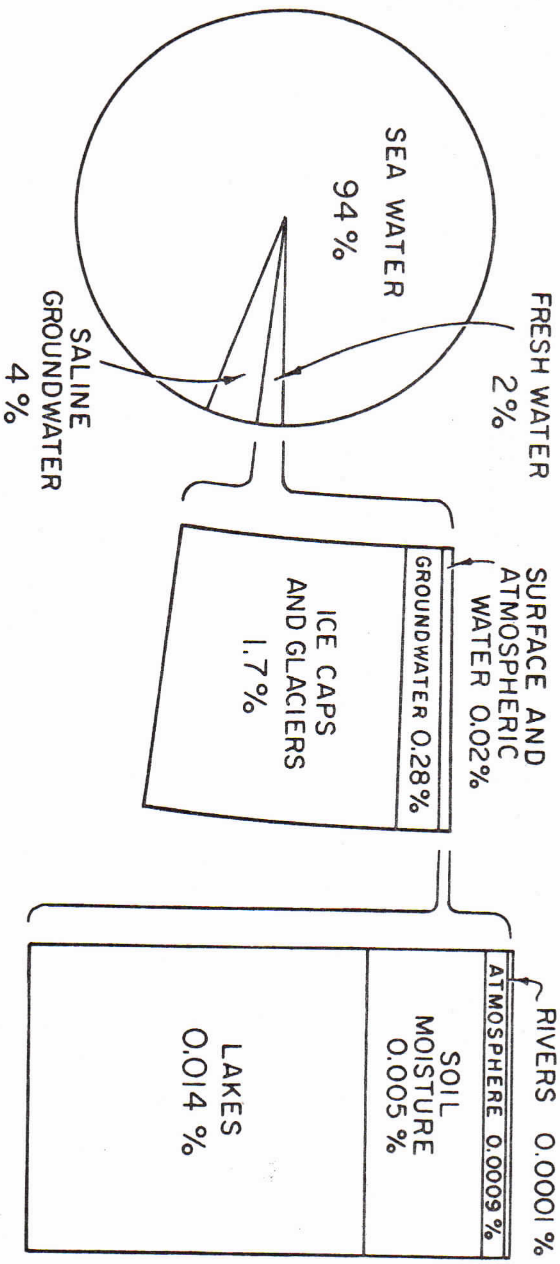


FIGURE 1: The World Hydrologic Cycle, units are 10^{15} gallons/year. (after Lvovitch 1972)

What is less well known is the distribution of water within this system. The oceans account for the vast majority -- some 94% of the total. On including the volume of salt or brackish water buried deep underground, it is found that virtually 98% of the world's water is saline (see Figure 2). The remaining 2% of fresh water is comprised principally of polar ice and ground water which are not significantly active in the hydrologic cycle. At any time only 0.02% of the world's water inventory is included in the active components of surface water, atmospheric water and soil moisture. The division among these components is shown on the figure. It is worth thinking about the fact that such a small fraction of the water inventory serves both as the source of useful water and the sink for the great bulk of pollutants.



<u>FIGURE 2</u>: World Water Inventory

The interaction between the development of water resources and the hydrologic cycle can be illustrated by considering a representative river system. Figure 3a shows such a system prior to development. As the vapour evaporated from the sea moves inland it will tend to be cooled by rising over the mountains, and thus the precipitation will be highest in the upland areas. Here the terrain and soil may not be suitable for intensive agriculture. On the other hand, the agricultural areas of the lowlands may suffer from inadequate water. It seems logical to use some of the river water originating from the highlands to irrigate the lowlands. However, if the river is a typical one a great deal of the flow will come down in destructive floods at a time when irrigation water is not required, and conversely there may be insufficient water in the river

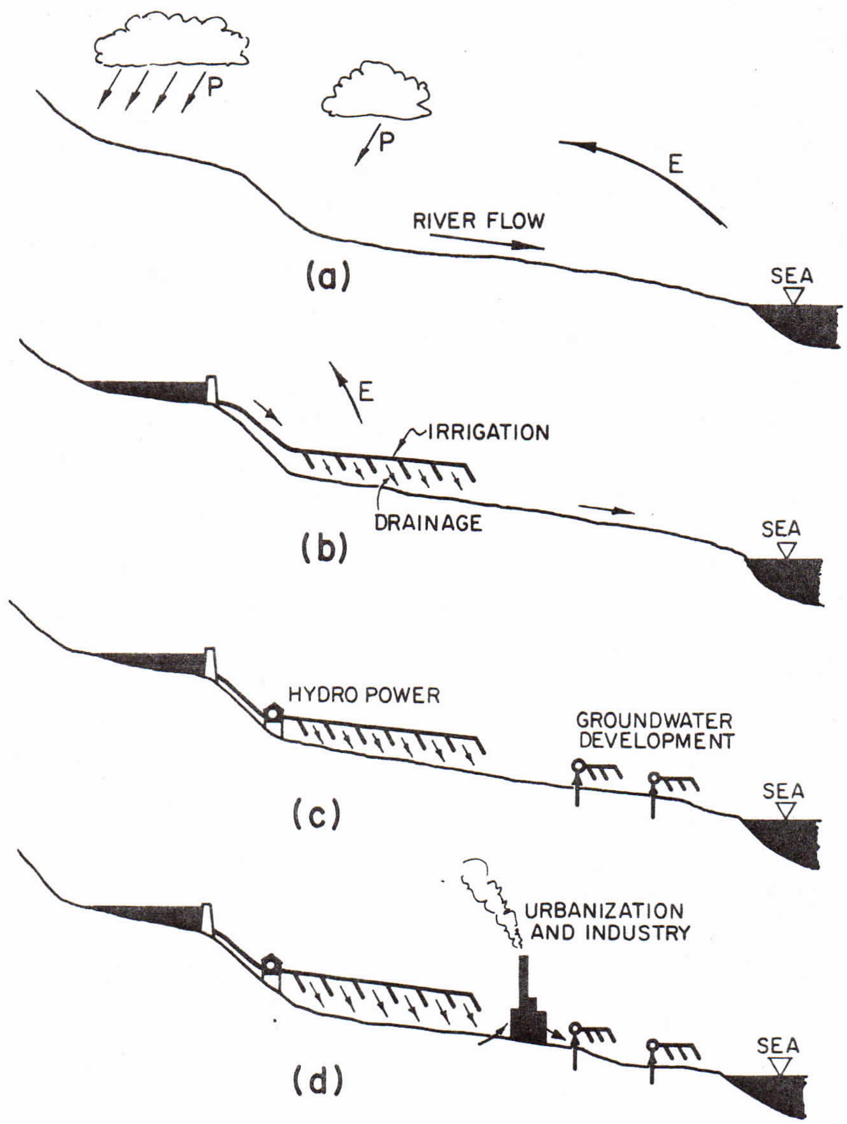


FIGURE 3: Representative Water Utilization Schemes

when it is needed for irrigation. In this case it is possible to kill two birds with one stone by putting in a storage reservoir as shown on Figure 3b. Such a reservoir impounds the unwanted and possibly destructive flood waters and later releases them gradually to provide a dependable supply for irrigation. Most of this irrigation water will be evaporated by the crops, but, as seen previously, it is wise to let some water drain back to the river in order to prevent salting. Figure 3b shows a development of this type. The evaporation by the crops is normally described as consumptive use, although of course the water is not consumed in the physical sense. Some of it may actually increase the precipitation at the headwaters; however, the average flow of the downstream portion of the river will certainly decrease. Moreover, the drainage water from the irrigated area will carry with it a higher than average concentration of salts, fertilizer and other possibly undesirable substances. This could be a source of difficulty, but it should be recalled that the previous state-of-nature river flows varied greatly from seasonto season, with the reduced flows of the dry season carrying a larger-than-average dissolved load. In general, it can be ensured that the new conditions resulting from the irrigation development are no worse than the natural conditions which existed at low water periods. For example, not all of the stored water need be used for irrigation, and the remainder can be released directly to the river when it is required to maintain an adequate quantity or quality of water. The net result is a system which is in balance, considerably more productive of food than the state of nature, with water quality better than that of dry-season natural flows, and with reduced flood peaks. This represents good resource management.

In practice, not all the irrigable land can be serviced from reservoirs. However, as noted previously in connection with the water inventory of the hydrologic cycle, there is a vast amount of groundwater which is potentially available. This water can be extracted by pumping, with the provision that the quantity pumped out of the aquifer should not exceed the natural recharge. Otherwise, the water level in the wells will drop, and in the case of wells near the coast such as those shown on Figure 3c, this will cause salt water to seep inland -- contaminating the wells and destroying the agricultural productivity of the soil. Such deleterious effects can be avoided by adequate planning of the extraction system, but it is worth drawing attention to another aspect of groundwater use -- the need for a source of power to pump the wells. In the particular case shown in the figure there is an ideal answer at hand. The water coming down the pipes from the highland reservoir will be under considerable pressure, and the combination of pressure and discharge can be used to generate hydro-electric power, both from the irrigation water and from the compensation water used to maintain the river flow. Note that the power output, which can be used to operate the pumps or for other purposes, has been obtained without any "consumptive" use of water. All that has been extracted from the water is potential energy, and the water leaves the turbines virtually unchanged in quality and temperature. The same could be said about navigation use, and it would be quite possible to add navigation locks to the river shown on the figure, enabling the farmers to transport their increased agricultural production to market. This addition of groundwater extraction, hydro power and navigation to the basin shown on the figure results in a balanced multi-purpose scheme which provides great benefits in agricultural production, power, flood control and transportation, and if well managed has small or negligible deleterious effects.

However, in considering the river basin, we have so far omitted the features that cause the greatest problems -- cities and industries. It has already been noted that the water used for hydro power and industrial uses are much more invidious since the bulk of the water extracted is returned to the river in such a polluted form that vastly greater amounts of water are contaminated on mixing with it. Even the cooling water for thermal power generation, while not polluted in a chemical sense, is returned to the river at an elevated temperature which causes a thermal pollution effect on the river life.

PRESENT SITUATION AND FUTURE PROSPECTS

At this point it is appropriate to consider the present status of water use and some of the predictions which have been made for the future. Since some major water-use problems occur in the populous underdeveloped countries and others in the countries with advanced industrial development, it is preferable to deal with these areas separately.

In the populous underdeveloped countries, the vital water-resource problem is asscoiated with raising agricultural productivity. In these countries traditional dry-farming methods are extremely inefficient, although the climate often would permit the growing of three crops per year if adequate water can be supplied. At present some 160 million hectares of land is under irrigation. This represents about one percent of the total land surface of the earth, and the water used to irrigate it is roughly four percent of the annual discharge of all the world's rivers. The total potentially aerable land has been estimated at about 20 times the present irrigated areas, so that in theory, land, rather than water, is the limiting resource for food production. In practice, however, the uneven distribution of water over the continents makes the availability of water the crucial factor. Despite this, estimates show that with full development of available water resources the irrigated area of the world could increase by a factor of six, and this, together with improved agricultural techniques, would suffice to support more than 10 times the present world population.

Even if this long term forecast appears to be encouraging, the short term problems are formidable. The underdeveloped countries generally have insufficient capital to construct the required irrigation works, and in addition the changes from traditional to modern farming practices involve a social upheaval that many nations seem unwilling to contemplate.

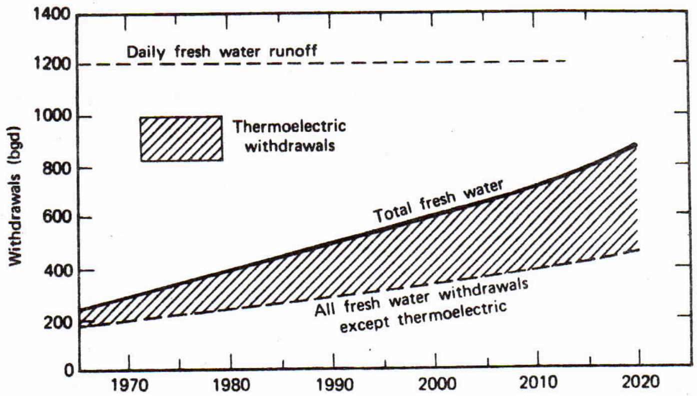


FIGURE 4: Estimated future U.S. water withdrawals. Cross hatched area indicated withdrawals for cooling thermoelectric power plants. (after Masters 1974)

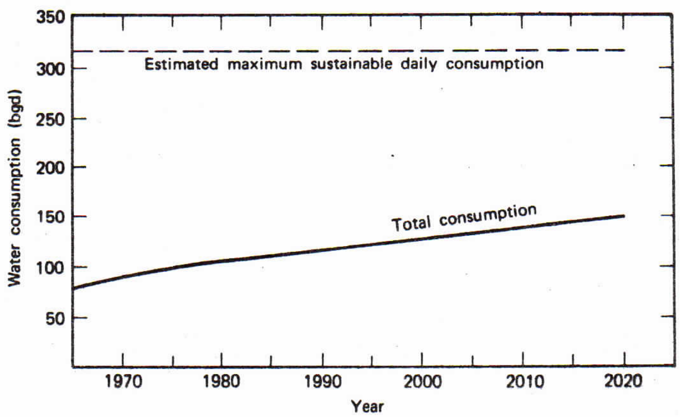


FIGURE 5: Estimated total freshwater consumption for U.S. is considerably lower than maximum sustainable level. (after U.S. Water Resources Council 1968, Kruse 1969)

For the advanced industrial countries, on the other hand, the problems are different, but also very severe. Data from the United States can be used to illustrate conditions in industrialized regions. Figures 4 and 5 show trends of fresh water withdrawal and consumption in the U.S. projected to the year 2020 (Note that "consumption" refers to the water returned to the atmosphere by evaporation). It can be seen that within the period of projection the total withdrawals will be well below the fresh water runoff, and that consumption will be less than half that which can be sustained. These figures show that the quantity of water per se is not a crucial problem in the United States, and studies of other industrialized areas suggest the same conclusion.

On the other hand, the problem of water quality is now becoming acute. As mentioned previously, this results from the practice of diluting pollutants with fresh water and allowing the resulting effluent to contaminate the water bodies to which it is returned. This dilution approach was a tolerable strategy when the quantity of polluting substances was relatively small and the water quality would be restored by natural processes. In areas of industrial concentration this is no longer possible, and an alternate strategy must be employed -- that of removing the pollutants near the source. However, it is difficult and expensive to remove pollutants from the large volumes of urban and industrial water which have been associated with the traditional dilution approach. In order to obtain the concentrated effluents that are most suitable for reprocessing, industrial and urban supply patterns must be changed to give less water per capita and less process water per ton of product. The resulting concentrated pollutants can then be removed before returning the water to the natural river systems.

The need is clear, but the accomplishment will not be easy. As with the expansion of irrigation in the underdeveloped countries, the control of pollution in industrial regions will require both massive quantities of capital and significant changes in social attitudes.

<u>REFERENCES</u>

Introduction to Environmental Science and Technology, Masters,G.,Wiley and Sons, 1974.

The World's Water, Lvovich, M., Mir, Moscow,1973.

Water,Morris, W., Inland Waters Branch, Dept. of Energy, Mines and Resources, Queen's Printer, Ottawa, 1968.

Water Resources Engineering, Linsley, R. and Franzini, J., 2nd ed., McGraw-Hill, 1972.

Water in the Service of Man, Vallentine, H., Pelican A852, Penguin, 1967.

"Food and Population", Revelle, R., *Scientific American*, Sept. 1974.

Environmental Quality and Water Development, ed. Goldman, C., McEvoy, J., Richerson, P., W.H. Freeman and Co., San Franciso, 1973.