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Role of Water in Economic Development

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Water, said the Greek philosopher Pindar, some 2500 years ago, is the best of all things. It may perhaps be an overstatement, but it is certainly not surprising, especially when it is considered that it has been one of the most important and prized resources throughout recorded history. Water makes life in the biosphere—human, animal, or plant—possible, and without it life and civilization can neither develop nor survive. Wars have been fought in the past over the availability of water, and even now relations between several nations are strained because of disputes over management of water bodies shared between two or more countries.

Because of the important role water plays in human survival, it has always been a subject of great interest, and the entire history of humankind can be written in terms of our need for water. From the very beginning, it was realized that water is essential for the satisfaction of basic human needs, and hence early civilizations flourished on lands made fertile by the major rivers: The Tigris and Euphrates in Mesopotamia, the Nile in Egypt, the Indus in India, and the Huang-He and Chang Jiang in China. As early as 3000 BC, the Egyptians had already developed complicated water resource networks, especially irrigation systems. The historian Herodotus, provided a vivid description of these early Egyptian water development works. He was so impressed by the role of the River Nile in the country's development and survival that he called Egypt "the gift of the Nile."

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The importance of water can be further exemplified by the fact that the Greek philosopher Empedocles of Agrigentum (490–430 BC), considered water to be one of the four primary elements or roots (*rhizomata*) from which all the materials of the world were constituted. The other three basic elements were air, fire, and earth; the last two in the present day can be interpreted as energy and land. One can thus argue that such a concept was the forerunner of the molecular theory of materials, and water was considered to be so important that it was accepted as one of the fundamental building blocks of nature. Even such great philosophers as Plato and Aristotle accepted this concept of water as a fundamental element, with only minor modifications.

The magnitude and complexity of water resources development and management problems in the early days were not great. Population pressure, both in terms of numbers and concentrations, was not high; per capita demand was low and water was plentiful. When there were water related problems such as droughts or floods, people simply migrated to a better location. Pollution loads were low, and were primarily of an organic nature. Accordingly, water courses assimilated whatever load that entered without any serious deterioration of quality. Thus, right from the beginning we tended to treat water as gift from God—a "free" resource—and our birthright to use and squander as we saw fit. This freewheeling concept, until recent times, did not pose serious management problems. Hence, until the early twentieth century, the demand for water, its efficiency of use, and its quality were generally secondary issues for most parts of the world.

This scenario started to change in the presently developed countries with the advent of the Industrial Revolution. Workers from agricultural sectors in rural areas started to migrate to urban centers, attracted by the burgeoning industrial employment opportunities. One of the undesirable side effects was the development of centers of dense population. As the industries in the cities developed, more workers migrated to them from rural areas; this in turn attracted more industries, creating a vicious circle.

Industries were often unfortunately located in close proximity to water bodies because of the ease with which waste products could be discharged to the receiving waters at no direct economic cost. Furthermore, cities discharged their sewage into the water bodies without much treatment, thus compounding the problem. Even today, some major cities, such as Montreal, Canada, discharge sewage to nearby watercourses without even primary treatment. Such developments contributed to growing water pollution near centers of dense population. In medieval Paris, the streets were often like open sewers, but the River Seine was clean, and one could see fish swimming in the clear water. Times have now changed. Today the streets of Paris are clean, but the Seine is murky and gray, and one would indeed be fortunate to see any fish.

GLOBAL DISTRIBUTION OF WATER

Water is considered to be a renewable natural resource since it is continuously being renewed through nature's hydrologic cycle. However, it is a unique natural resource in the sense that the total amount of water available on a global basis is constant, and compared to other renewable resources, like biota, its total stock can neither be increased nor decreased by changing management practices. This, however, does not mean that local or regional sources of water cannot be exhausted by shortsighted use or rendered unusable due to large-scale contamination.

Approximately 71% of the earth's surface is covered with water, and nearly all of this water is saline. Current estimates indicate that the total volume of water on the earth is about 1.4×10^9 km^3, of which 97.3% is ocean water. The balance, 2.7%, is fresh water. At any given time, 77.2% of the fresh water is frozen in the polar ice caps and in glaciers in various parts of the world, and thus, for all practical purposes, is unavailable for human consumption or for vegetation. Ninety percent of this ice is in Antarctica, and the remainder, for the most part, is contained in the Greenland ice cap. Distribution of the world's fresh water resources is as follows:

Location	Percentage of global fresh water
Ice cap and glaciers	77.2
Groundwater and soil moisture	22.4
Lakes and swamps	.35
Atmosphere	.04
Stream channels	.01

Source: UN Water Conference, 1977. (Biswas, 1978).

Groundwater and soil moisture constitute 22.4% of global fresh water, but nearly two-thirds of this lies deeper than 750 below ground level. About .1% of this reserve (13,000 km^3) participates in the hydrologic cycle in an average year, mostly through contribution to stream flow. Nearly 30% of total stream flow is contributed to by groundwater. Lakes contain about 200,000 km^3 of fresh water, which is about four times the average annual runoff from all land areas. In contrast, artificial lakes store about 11% of the yearly runoff (about 5000 km^3). Lakes, the atmosphere, and streams contain only .4% of fresh water, or .01% of the total volume of water. This tiny fraction is vitally important in sustaining life on this planet.

The tremendously dynamic nature of the hydrologic cycle can be demonstrated by two simple facts. First, even though the mean annual precipitation of the earth is about 973 mm, the water content of the atmosphere at any given instant is only .001% of the total water of the earth, and if by some means all this vapor can be precipitated, it would cover the earth's surface to a depth of only about 25 mm. Second, notwithstanding large discharges of the major rivers, the amount of water contained in the world's rivers at any instant is relatively small. Thus, the important factor to consider in water resources planning and management is not the actual quantity of water in a channel at any time but rather its flow through the channel over time.

Although we do not yet have precise figures for the world water balance, all recent estimates have been relatively consistent, even though different methods were used for the estimates. Table 6.1 shows such an estimate for the average annual water balances of the world (Baumgartner and Reichel, 1975). The major uncertainty in such analyses comes from the difficulty of estimating precipitation on and evaporation from the oceans due to lack of observed data.

Such a global picture, however, does not give a correct impression of the tremendous variability of the distribution of water, both with regard to space and time. This can be easily shown by considering distribution in any

TABLE 6.1
Average Annual Water Balance of World[a]

	Volume (thousands km^3)		
Regions	Precipitation	Evaporation	Runoff
Africa	20.7	17.3	3.4
Asia	30.7	18.5	12.2
Australia	7.1	4.7	2.4
Europe	6.6	3.8	2.8
North America	15.6	9.7	5.9
Latin America	28.0	16.9	11.1
Antarctica	2.4	.4	2.0
Total, land areas	111	71	40
Oceans	385	425	−40
Total, world	496	496	0

[a]Source: UN Water Conference, 1977. (Biswas, 1978).

continent. In the first continent of Table 6.1, Africa, nearly 50% of the total surface water resources are in one single river basin, that of the Congo. Nearly 75% of Africa's total water resources are in eight major river basins—Congo, Niger, Ogooué (Gabon), Zambezi, Nile, Sanaga (Cameroon), Chari-Logone (Lake Chad basin), and Volta. This relative abundance of water in the river basins of the equatorial zone of Africa is in sharp contrast to the total lack of water in the world's largest desert, the Sahara, to the north of the equator, and in another major desert, the Kalahari, to the south, with varying degrees of water sufficiency or insufficiency in the intervening areas. The savannah area, between the humid equatorial belt and the deserts in the north and south, is most vulnerable to periodic and severe drought, permitting bare survival for humans and livestock. Thus, the development of water resources of Africa is an essential prerequisite for the development of its agricultural and industrial potential, besides being a fundamental necessity to long-term survival of humans.

WATER QUANTITY AND QUALITY

Whereas much of the discussion in the area of water development in the past has been primarily concerned with quantity, the quality of water has been an increasingly important issue during the past 2 decades. Quantity and quality of water are related. For example, if a given amount of pollutant is to be dispersed in a certain body of water, the overall quality of that water will depend on its quantity: the larger the quantity, the less will be the water quality deterioration and vice versa.

The quality of water often determines its use. Naturally, water for human consumption must be of the cleanest quality. Water of lower quality can be used for other purposes such as agricultural or industrial uses, but even then the uses are often case specific. A certain quality of water can be used for industrial purposes but may not be suitable for agricultural uses and vice versa, depending on the industrial products being manufactured and the crops being grown. Water quality is of less importance for hydropower generation but is a primary consideration for recreational uses.

When environmental concerns became an important public policy issue in the late 1960s and early 1970s, primarily in the industrialized countries, water pollution became one of the major societal concerns. Highly visible polluted sources of water attracted much media attention. The general public not only became aware of the dangers posed to human health by water pollution but also became seriously concerned with continually deteriorating quality.

Dispersal of toxic chemicals and heavy metals to the ecosystem through the medium of water became a serious cause for concern. Complex dispersal mechanisms meant that evidence of toxic substances appeared in areas far away from the points of application. Thus, significant quantities of pesticides, including DDT and its derivatives, were found in animals in Antarctica, such as penguins and their eggs, skua, and fish, even though there is no agriculture, no insect life, and no use of pesticides there.

It was further generally recognized that water played an important part as a medium through which toxic chemicals were being dispersed to the ecosystems by selective concentration, as they passed relatively unchanged through successive levels of food chains and food webs. For example, in Lake Michigan, the concentration of DDT in lake sediments was .0085 ppm. Invertebrate primary consumers concentrated this to .41 ppm, their fish predators concentrated it to 3–8 ppm, and the herring gulls, predatory on the fish, had levels no less than 3.180 ppm. This meant the level of concentration increased by nearly 374,000 times between the lake sediments and the gulls.

The effect of such selective concentration is that the toxic effects of chemicals are more readily noticeable in top carnivores. Thus, discharge of mercury in Minimata Bay, Japan, increased the mercury content of fish to dangerous levels, so much so that the people who depended on that fish as a major source of food suffered heavily from mercury poisoning. Currently, this form of disease is often known as Minimata, and mercury poisoning, under similar circumstances, has also been noted in Canada, especially among Indians having fish as their staple diet.

One of the direct results of our past preoccupation with water quantity has been that as a rule significantly more information is available at present on quantity of water than on quality, both at global and national levels. With very few exceptions, even approximate continental or global assessments of the different water quality parameters are not known. Nor is much known about the magnitude and type of organic and inorganic wastes entering water courses, from municipalities and industry, although they are rapidly constituting a growing hazard to human health and environment. There are serious problems even in a major advanced industrialized country such as the United States. According to the 1976 report of the U.S. National Commission on Water Quality, 92% of suspended solids, 37% of biochemical oxygen demand, and 98% of the coliform bacteria will remain uncontrolled in natural surface water, *even* when all discharges from point sources have been eliminated. This is largely due to agricultural activities. Currently there no general measurements of volumes of synthetic organic compounds and heavy metals reaching water courses and, eventually, the oceans. In general, the water quality information available in most developing countries leaves much to be desired and is often nonexistent.

ROLE OF WATER IN DEVELOPMENT

Water has always been an important prerequisite for development, but its role became even more important during the last decade due to a combination of several events, some natural others artificial. Undoubtedly the most important factor stemmed from the fact that overall global food production is still very much dependent on availability of water. During the early 1970s, climatic anomalies contributed to drastic reductions in food production in most parts of the world due to incidences of floods and droughts. Since the quantity of grain available for export in the world market was limited, and many countries were attempting to import grain, prices increased sharply. The situation was most serious for those developing countries that needed the grain but not have adequate funds to purchase it in the open market, especially in the Sudano-Sahelian region of Africa. Faced with this critical situation, the United Nations convened a World Food Conference in October 1974 in Rome, at the highest decision-making level, in order to resolve the immediate food crisis confronting the world and to seek long-term solutions (Biswas and Biswas, 1975). One of the direct results of the deliberations at Rome was the clear understanding and realization of the fact that proper water control and management is absolutely essential not only for further horizontal expansion of agriculture but also for increasing the overall yield from existing cultivated land. The urgency and essentiality of the need for water control for agricultural development was later further endorsed by the United Nations Water Conference held in March 1977 in Mar del Plata, Argentina (A. K. Biswas, 1978; M. R. Biswas, 1977) and by the United Nations Desertification Conference held at Nairobi, Kenya, in August 1977 (M. R. Biswas, 1978c).

The second event, which occurred during the 1970s and had a major impact on the role of water in economic development of nations, is the energy crisis of September 1973. The oil embargo of that period not only sharply increased the prices of fossil fuels but also raised the serious question of the long-term reliability of energy supply. As the energy prices continued to escalate during the 1970s, all oil-importing countries started to search for other energy alternatives that could significantly reduce their energy import bill, and thus their overall balance of payments problem. The situation was specially critical for oil-importing developing countries.

The only immediately available major alternative to large-scale generation of electricity turned out to be hydroelectric power. This radically changed the perceptions of planners in those countries that had potentially good sites for hydropower development. During the 1950s and 1960s, fossil-fueled plants were preferred for electricity generation due to their cost advantage over hydroelectric developments. This scenario started to change in the 1970s. As the decade advanced, so did the oil prices, which further contributed to the attractiveness of hydropower development. Since hydroelectric generation does not consume any water, the water can subsequently be used for other purposes such as irrigation and industrial development.

The third reason the role of water became very important is that water requirements for industry have been increasing. For example, one of the principal recommendations of the Lima Declaration of the United Nations Industrial Development Organization (UNIDO) is that by the year 2000, 25% of global industrial production should take place in developing countries. If the Lima target is to be achieved, more water will be required for further industrial development.

Fourth, the United Nations Conference on Human Settlements, held in Vancouver, Canada, in 1976 (M. R. Biswas, 1978b) and on Water (M. R. Biswas, 1977), firmly put on the global agenda the plight of people in developing countries, especially in rural areas, who do not have access to safe drinking water. At the recommendation of the Water Conference, the decade 1981–1990 has been officially designated to be the International Drinking Water Supply and Sanitation Decade by the General Assembly of the United Nations (A. K. Biswas, 1981).

Finally, pollution of inland and coastal water bodies and the oceans became an increasing focus of national and international concern, partly through the activities of the United Nations Environment Programme, which itself was created in the early 1970s by the United Nations Conference on the Human Environment held at Stockholm in 1972 (Biswas and Biswas, 1982).

All these factors, individually and cumulatively, heightened policymakers' awareness of the importance of the role of water in the development process of nations. Furthermore, the factors clearly indicated the urgent necessity of sustainable water development which would ensure optimal utilization of available water as well as maintenance of its quality.

Water is used for many purposes, chief among which are domestic, irrigation, hydropower, industrial, navigation, recreation, wildlife habitat, and waste disposal. In addition, water resources management plans often consider flood control and low flow augmentation requirements. The quality and quantity of water required to satisfy each of these demands vary considerably, depending on types of demands, geographical locations, cultural traditions, standard of living, climatic characteristics, and other individual factors. Conditions vary from one country to another. For example, navigation is an essential form of transportation in Bangladesh and thus it is of paramount importance for that nations development, but its importance is significantly less for countries like Kenya.

Of all the various water uses, the four most important ones on a global basis at present are domestic, agricultural, and industrial uses and hydropower generation. Since domestic use of water is discussed in great detail in other chapters of this book, it will not be discussed here. The emphasis in this chapter is on the other three major water uses: agriculture, industry, and electricity generation.

AGRICULTURAL USE

For most developing countries, agricultural development is an essential ingredient for further economic development: in fact it can be argued that it is a prerequisite for their economic development. This is being increasingly recognized by decision makers in developing countries.

The world food crisis can only be resolved by increasing food production. This can be accomplished two ways: by bringing new land under cultivation and by increasing cropping intensities and yields of existing cultivated areas. It is expected that approximately one-fourth of the increase will be accounted for by new lands; the balance has to come from increasing yields and cropping intensities. Although many items are necessary to increase yields and cropping intensities (e.g., water, fertilizer, pesticides, improved seed, agricultural machineries, better management practices), undoubtedly the most important input required is water. With the exception of soil, water is the only indispensable factor for plant growth. The potential benefits to crop production under various degrees of water control, combined with additional material inputs and consistent with cultural practices, are shown in Table 6.2. It clearly indicates that increase in output is primarily dependent on the degree of overall control.

Cropping intensity is a key element in determining the value of irrigation and benefits to be accrued from such developments. These indices are especially important where arable land is scarce, and thus limits to agricultural production will be determined by crop yield and intensity of cropping. Table 6.3 shows irrigated areas and cropping intensities for developing market economy countries for 1965 and 1975, and projected values for 1990. The cropping intensity for 1975 ranged from 89 in Latin America to 129 for Asia, and the 1975 values for all four regions are higher than the corresponding figures for 1965.

Agriculture is the largest user of water, and accounts for some 80% of global consumption (comparable figure for the United States is slightly over 40%). Much of this water is used through irrigation, even though vast areas of the world still continue to depend on rainfall as the primary source of water for agricultural production.

TABLE 6.2
Yields of Paddy Rice with Different Degrees of Water Control

Degrees of water control	Material inputs	Location	Average yield 1971–1974 (tons/ha)
No water control (rain fed, uncontrolled flooding)	Nil	Laos	1.3
Successive introduction of water control			
Elimination of floods	Nil	Kampuchea	1.5
Elimination of drought	Low fertilizer application	Burma India Thailand	2.0
Improved water control (irrigation and drainage)	Low to medium fertilizer application	Pakistan Vietnam Republic Sri Lanka Western Malaysia	3.0
Sophisticated management practices (mid season drying)	High fertilizer use	Republic of Korea	5.0
	High fertilizer use, improved seeds and pest control, and diversification mechanization	Japan	6.0
Experimental conditions			10.0

TABLE 6.3
Irrigated Land (IL, in Thousands of Hectares) and Cropping Intensities (CI, in Percentage Utilization of Cultivated Area) for Developing Countries, 1965–1990

	1965		1975		1990	
Region	IL	CI	IL	CI	IL	CI
Africa	1,882	104	2,610	107	3,570	121
Latin America	9,623	77	11,749	89	14,850	95
Near East	13,329	80	17,105	95	21,400	106
Asia	45,691	119	60,552	129	74,370	142

If the total agricultural production in developing countries is to be doubled between 1980 and 2000, the total irrigated area has to be expanded by more than 40% from 105.3 million ha in 1980 to 148 million ha by the year 2000 (FAO, 1981). Even then, however, the total irrigated area, as a percentage of all arable area, will only increase moderately, from about 14% in 1980 to only 16% 2 decades later. The average rate of expansion will be 1.7% per annum, a rate that is slightly lower than developments in the recent past. The importance of irrigation can be further indicated by the fact that even though this target is achieved, 84% of the area will still be nonirrigated, but irrigated areas will account for 41% of total crop production.

Two aspects of recent developments in irrigation are worth noting. The first is cost, which has been constantly increasing. Currently, costs of the magnitude of about $7000 per hectare for exclusively-gravity systems are not uncommon. Provision of irrigation alone is not enough. If soil salinity and waterlogging are to be prevented, drainage systems have to be constructed. Costs of drainage systems range from $300 to $1500 per hectare. Thus, overall investment costs of providing irrigation and drainage could be quite high.

The second aspect is the general inefficiency of the water delivery systems in most irrigation projects. Loss of water in the section where water is transferred from canal outlets to farms is often the worst. Not much research has been carried out in this area. But studies carried out on 40 such sections in the Indus Basin during 1975 and 1976 indicated losses ranging from 33 to 65%, with an average of 47%. Another investigation on 60 sections carried out in 1977 and 1978 by the Water and Power Development Authority (WAPDA) of Pakistan indicated similar losses. The magnitude of this problem can be best realized by considering the case of good lined canals, which are expensive to construct and have operating efficiencies of 70–80%. When the efficiency of the total system, that is, lined canals in conjunction with the inefficient section from canal outlets to farms, is considered, the total efficiency is of the order of 20–50% which means that even for expensive, lined, and well-maintained canal systems, in many cases less than one-quarter of water released from a reservoir reaches the crops being irrigated (A. K. Biswas, 1983b).

A major consequence of this sad state of affairs is that engineers have accepted this inefficient system, at least implicitly. During planning of irrigation projects, total water requirements are generally calculated by multiplying the extent of total area to be irrigated by the amount of water required per hectare. The water requirement per hectare is generally estimated on the basis of existing systems, where major portions of water released from reservoirs are lost. Accordingly, overall estimates of irrigation water requirements are invariably high—certainly significantly higher than necessary—and the inefficient system is condoned and perpetuated. In other words, most of the irrigation systems designed thus far are generally inefficient and use far more water than necessary. Unfortunately, instead of attempting to make irrigation systems more efficient and then maintaining them, engineers are continually looking for new sources of water for irrigation. They often look for costly alternatives, such as interbasin water transfer, when such major and expensive projects are not essential (A. K. Biswas, 1983a) and cheaper alternatives are available—which can be implemented within a significantly smaller amount of time with indigenous labor and expertise by simply improving the existing systems. Furthermore, when new projects are developed, unless special efforts are made to maintain their efficiencies at high levels, their effectiveness will decline with time and the vicious circle continues to be perpetuated.

Viewed from a different standpoint, present irrigation systems are highly efficient in recharging groundwater!

INDUSTRIAL USE

Industry requires a large amount of water. In the United States industrial demand accounts for nearly 40% of the total water requirement, and five major industrial groups—food and kindred products, pulp and paper, chemicals, petroleum, and coal products and primary metals—account for slightly more than 85% of total withdrawals. Approximately 60–80% of water required for industrial processing is for cooling and need not be of high quality. However, such an enormous discharge of heated water has intensified the problem of thermal pollution, and some studies indicate that the quantity of heat to be dissipated to the aquatic environment will increase tenfold in the United States during the last 3 decades of this century. The possibility of using thermal discharges for beneficial purposes is not very significant at the present time.

There are basically two major issues regarding industrial use of water: (1) use of river systems to dispose of industrial wastes; and (2) the striking difference between the gross amount of water needed for various industrial processes to manufacture the same product. Besides discharging heated water, industry is responsible for the disposal of a whole variety of waste products, depending on the stringency of local pollution control measures. Thus, discharges of mercury to the aquatic environment have created the serious problems in Japan and Canada resulting in Minimata disease. Similar problems have been observed with cadmium, arsenic, and PCB, as a result of which new rules and regulations are being drafted or updated in different parts of the world.

The second set of policy issues is on the actual use of water by industry. The amount of water required depends on the type of industry, the processes being used, the availability of water, and legal requirements. The cost of water is rarely a major issue, since it represents .005–2.58% of total manufacturing costs for the five most intensive water-using industries mentioned earlier. Seldom does this cost exceed 1%. Within these limits, water

TABLE 6.4
Water Requirements and Waste Loads for Selected Industries[a]

Industrial product	Unit	Range of water requirements per unit of product	Pounds of 5-day BOD per 1000 gallons of process water discharge (United States)
Steel	Ton	8,000–61,000	—
Soap	Ton	960–37,000	16.70
Gasoline	Kiloliter	7,000–34,000	2.50
Paperboard	Ton	62,000–376,000	2.21
Sugar beets	Ton	1,800–20,000	9.16

[a]Source: UN Water Conference, 1977. (Biswas, 1978).

requirements vary tremendously for the same industrial group, as shown in Table 6.4. It is quite common to find some industrial plants requiring 5–40 times more water than other plants manufacturing the same product. The example of soap, given in Table 6.4, indicates the higher range to be 38 times that of the lower. Such drastic differences in net amounts of water required are due to the use of extensive in-plant recirculation and treatment technologies rather than simple once-through flow processes. Whereas water requirement for industrial purposes is high, a small fraction of the water used is actually "consumed," that is incorporated into the product, or lost through evaporation or seepage.

As in agricultural water use, the potential for water conservation in the industrial sector is quite significant.

HYDROELECTRIC DEVELOPMENTS

Hydroelectric power is an important by-product of water development and currently accounts for 70–90% of all electricity generated in countries as diverse as Brazil, Canada, Morocco, Norway, and Sri Lanka. With the current energy situation, hydroelectric power makes a great deal of sense in many countries, especially in terms of achieving self-reliance and reducing the balance of payments problems due to the importing of energy-producing materials. Although capital costs for hydropower developments are quite high, the running costs are minimal. Recent World Bank (1980) estimates, shown in Table 6.5, confirm this. Investment costs indicated in Table 6.5 include transmission and distribution costs.

The potential for hydropower has been exploited to a great extent in North America and Europe, including the USSR, as shown in Table 6.6.

TABLE 6.5
Comparative Cost of Power Generation in 1980 U.S. Dollars for Oil-Importing Developing Countries[a]

Generator type	Investment cost per kW installed	Fuel cost (cents/kWh)	Power cost (cents/kWh)
Hydro			
Large high head	1100	—	2.4
Low head, mini	3500	—	12.7
Steam			
Large, gas fired	800	10.9	13.2
Large, coal fired	1000	2.7	5.2
Large, oil fired	800	5.5	7.6
Nuclear			
Large, multiple units	1600	1.0	5.1
Single, small unit	2200	1.0	7.4

[a]Source: World Bank.

However, a vast potential can be exploited in Africa, Asia, and Latin America. Africa is the most underdeveloped, the current annual production being only about 5% of the potential usable output. In sharp contrast to North America, where the share of hydropower in total electricity generated has been steadily declining, and is expected to continue to decline in the future, the situation in Africa—even with the current very low level of development—has been quite the opposite. Thus, the share of hydropower has increased from 22.9% in 1962 to 28.4% in 1974. This trend toward increased emphasis on hydropower generation, in preference to other forms of energy development, is expected to continue in the foreseeable future.

There is a major misconception with regard to hydropower. Many people tend to think that because of economics of scale, all recent developments must be large scale, like the Aswan in Egypt, the Volta in Ghana, or James Bay in Canada. In fact, mini-hydro-developments have significant international potential.

ENVIRONMENTAL IMPACTS OF WATER DEVELOPMENT

All water resources development projects have social and environmental effects. Whether such effects are acceptable depends very much on the individuals concerned, their personal interests, views, and biases. It is quite common to find that a new development project is unacceptable to a certain

TABLE 6.6
Annual Hydroelectric Potentials of Different Regions[a]

Regions	Theoretical potential (10^{12} kWh)	Technical usable potential (10^{12} kWh)	Operating potential (10^{12} kWh)	Potential under construction (10^{12} kWh)	Planned potential (10^{12} kWh)
Africa	10.118	3.14	.151	.047	.201
North America	6.15	3.12	1.129	.303	.342
Latin America	5.67	3.78	.299	.355	.809
Asia (excluding USSR)[b]	16.486	5.34	.465	.080	.368
Oceania	1.5	.39	.059	.020	.032
Europe	4.36	1.43	.842	.094	.197
USSR	3.94	2.19	.265	.191	.017 (estimated)
Total	44.28	19.39	3.207	1.090	2.12

[a] Source: El-Hinnawi, Biswas, and Biswas, 1984.

[b] The figure may not include data from China, theoretical potential of which is 6×10^{12} kWh, and technically usable potential is 1.9×10^{12} kWh. At the end of 1979, total operating potential was $.05 \times 10^{12}$ kWh and potential under construction was $.0517 \times 10^{12}$ kWh.

segment of society, whereas another segment lobbies hard for its implementation.

The many social and environmental effects of water development often extend much further than the river basin unit itself. The interactions of diverse forces are often so complex that ecologists and environmentalists are hard put to predict them with any degree of certainty.

The social and environmental impacts of water development can best be considered by dividing them into three categories of subsystems: physical, biological, and human.

Physical Subsystem

Development projects invariably change river and ecosystem regimes, and thus the real question is not whether a dam will affect the environment, but how much change is acceptable to the society as a whole, and what countermeasures should be taken to keep the adverse changes to a minimum and within that acceptable range. The Aswan Dam in Egypt, one of the major dams of the world, has received its share of criticism for contributing to environmental disruptions. The scheme, built primarily for generating hydropower, has reduced the fish population of the Mediterranean by abruptly breaking the aquatic food chain in the eastern Mediterranean. Planktons and organic carbons have been reduced by about 67% because of the lack of Nile sediments, which are now trapped in the reservoir created by the dam. This has, in turn, substantially reduced the sardine, scombroid, and crustacean population of the area. Erosion has become a major problem, and the fertility of the Nile valley has been lowered by the lack of sediments. Already a proportion of Egypt's 2.4 million hectares of cultivated land need artificial fertilizer, and it is anticipated that the rest will need it in the near future. Salinity in Middle and Upper Egypt is increasing rapidly, and it will be a very expensive process to rectify the situation. This, however, does not mean that the Aswan Dam should never have been built, since it is absolutely essential for Egypt's economic development, but rather secondary and tertiary effects should have been foreseen, to the extent possible, and appropriate measures should have been taken during the planning phase to reduce them to an absolute minimum.

Water development projects to increase irrigated agriculture have also contributed to problems that eventually reduced total food production. Among such problems are deterioration of soil fertility and eventual loss of good agricultural land, due to progressive development of salinity or alkalinity. At one time Pakistan alone was losing 24,280 hectares of fertile cropland every year, and currently, nearly 10% of Peruvian agriculture is affected by land degradation due to salinization. Among other major areas affected by salinization are Helmud Valley in Afghanistan, the Punjab and Indus Valleys in the Indian subcontinent, Mexcali Valley in Northern Mexico, Imperial Valley in California, and the Euphrates and Tigris basins in Syria and Iraq. A study of major modern irrigation schemes in the Punjab shows that seepage from unlined canals has, in the first 10 years of operation, raised the water table 7 m, 9 m above the long-term levels recorded since 1835 (M. R. Biswas, 1978a).

Biological Subsystem

One of the most serious impacts of irrigation developments in the tropical and semitropical regions is the secondary effect of spreading water-borne diseases, and the consequent suffering of millions of human beings and animals. Irrigation schemes have often enhanced and created favorable ecological environments for parasitic and water-borne diseases such as schistosomiasis, liver fluke infections, filariasis, and malaria to flourish. These diseases are not new; for example, schistosomiasis was known during the Pharaonic times. But unprecedented expansion of perennial irrigation systems has introduced such diseases into previously uncontaminated areas.

Such developments have been conclusively demonstrated in several countries of the world. In Egypt, the replacement of simply primitive irrigation with perennial irrigation has caused a high incidence of both *Schistosome mansoni* and *Schistosome haematobium*; where basin irrigation is still practiced, the incidence is much less. Infection rates in four selected areas, within 3 years of introduction of perennial irrigation, rose 10–44%, 7–50%, 11–64%, and 2–75%. The life expectancy of males and females in heavily infected areas is estimated to be 27 years and 25 years, respectively. In Sudan, with the introduction of perennial irrigation to 900,000 acres under the Gezira Scheme, the incidence of blood fluke rose greatly. It also increased the incidence of flukes in cattle and sheep. In Kenya, Lake Victoria is hyperendemic for schistosomiasis. *S. mansoni* infection in schoolchildren is up to 100% in areas associated with irrigation schemes. In Transvaal, South Africa, the *S. mansoni* infection rate in European farms was 68.5% compared with only 33.5% in the reserves, because the former had irrigation. Similarly, in some countries in the Far East, irrigation has not only increased schistosomiasis, but also liver fluke infections, eosinophilic meningitis, and bancroft filariasis (A. K. Biswas, 1982).

Human Subsystem

Many of the large dams have contributed to large displacement of local inhabitants, as shown in Table 6.7, which in certain cases has resulted in

TABLE 6.7
Resettlement of People Due to Various Dams

Dams (dates reservoirs filled)	Number relocated (approximate)	Countries involved
Aswan (1968)	120,000	Egypt and Sudan
Bhima	57,000	India
Bkakra (1963)	36,000	India
Brokopondo (1971)	5,000	Surinam
Damodar (4 projects, 1959)	93,000	India
Gandhi Sagar	52,000	India
Kainji (1969)	42,000-50,000	Nigeria
Kariba (1963)	50,000-57,000	Zambia and Zimbabwe
Keban	30,000	Turkey
Kossou (1971)	75,000	Ivory Coast
Lam Pao	30,000	Thailand
11 projects (1963-1971)	130,000	Thailand
Nam Ngum (1971)	3,000	Laos
Nam Pong (1965)	25,000-30,000	Thailand
Nanela (1967)	90,000	Pakistan
Netzahualcóyotl (1964)	3,000	Mexico
Sanmenxia (1960)	870,000	China
Pa Mong (projected)	310,000-480,000	Thailand-Laos
Tarbela (1974)	86,000	Pakistan
TVA (ca. 20 dams 1930s-present)	60,000	United States
Upper Pampanga (1973)	14,000	Philippines
Volta (1965)	80,000-84,000	Ghana

serious problems. Thus, the Kariba dam on the Zambezi displaced approximately 57,000 Tonga tribespeople, who had to pay a great price for this progress. What the planners, often from outside Africa, did not realize was the enormously complex relationship between the African tribes and their land. The resettlement program for the Tonga tribespeople left much to be desired; not only did they suffer great cultural shocks when thrust into communities as different from their own as theirs are from those in Great Britain, but also it took 2 years to clear sufficient land to meet their subsistence needs. The government had to step in to avert famine and very serious hardships and, ironically, this good-intentioned step was probably the most destructive. The food distribution centers also became transmission sites for the dreaded sleeping sickness disease.

This, however, has not been a unique occurrence. Approximately 100,000 people had to be relocated for the Aswan High dam without adequate planning, and the World Food Program had to rush in famine relief for the Nubians. Similarly 80,000 people had to be relocated because of the Volta dam in Ghana, and the World Food Program had to step in again to avoid a major catastrophe.

CONCLUSION

The role of water in the economic development of nations is an extremely important one. An analysis of the development patterns of the last 3 decades, especially the experiences in developing countries, clearly indicates that for the majority of such nations proper water control and management is an essential prerequisite for economic development. The two most pressing crises facing humankind—food and energy—will never be solved on a global basis without sustainable water development.

Herein lies one of the potential major crises of the future. Because of the importance of water development, all nations are trying to use their available water sources to the maximum extent possible. Many of the countries, especially those in arid and semiarid regions, have already developed, or are in the process of developing, the best sites available. But there are not enough new water sources available that can be economically or technologically developed in the near future. This is highly likely to create serious problems. Thus, all the signs point to a future global water crisis, and for some select countries the crisis has already arrived.

In the past, the primary solution for a water crisis has been to develop new water sources. Politically, such solutions have been expedient. However, as countries run out of new sources of water to develop, the principal solution will have to be more efficient use of water. This would mean better management practices and institutional arrangements which have not been easy in the past to implement. Undoubtedly this will be the major challenge that will confront water planners and managers for the rest of the twentieth century and beyond.

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