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THE HIGH DAM AND THE TRANSFORMATION OF THE NILE

Richard Elliot Benedick

> The Egyptians . . . obtain the fruits of the field with less trouble than any other people in the world . . .
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> Herodotus, *Persian Wars*, II, 14.

VIEWED from a satellite, Egypt resembles the lotus, a recurring symbol, coincidentally, through more than three thousand years of Nilotic art: a long narrow green stem winds from south to north for 1500 kilometers, ending at the blossom-shaped Delta. This is Egypt—a vast desert traversed by a river. The waters are indispensable for life: even when viewed from close up, the boundary between fertile and barren is nearly surgical in its precision. That irrigated green tract comprises only two and a half per cent of the country's total area, yet in or near it are now crammed 96 per cent of Egypt's 39–40 million people in one of the world's highest population densities: 1,000 per square kilometer.*

This was not always so. In Herodotus' time, and for three millenia previously, only a small fraction of this number of people enjoyed a single easy harvest following the annual overflow of the Nile onto the rich alluvial soil, which averages over ten meters in depth. It was the river which gave the valley's early dwellers a precious commodity—time: years to decorate tombs for the eyes of gods rather than men, decades to erect pyramids, centuries to refine a view of life and mode of living which endured longer than any other.

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* In conformity with most source material, all measurements herein are given in metric terms except for acres, which are used because of their equivalence to the Egyptian land measure, the *faddān* (equals 1.038 acres).

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Reprinted from
THE MIDDLE EAST JOURNAL
Volume 33, Number 2, Spring 1979

The Drive to Control the River

Survival in Egypt was inextricably linked with the river, for its vagaries brought bounty or disaster. Early on, priests and scholars learned that incantations and sacrifices were not always sufficient to assure that the annual inundations were neither too much, nor too little. In the twentieth century before Christ, the XIIth Dynasty Pharaoh Amenemhet constructed the earliest recorded dam and irrigation project. The history of Egypt ever since has been one of trying to control the Nile.

The Aswan High Dam, completed approximately four thousand years later, is not some kind of sinister modern break with an Arcadian tradition of accommodation with nature, but rather only the most recent—and surely not the last—manifestation of an historical pattern. Yet the dam has been a nearly irresistible target for sensational "exposés" in newspapers and magazines branding it an ecological nightmare. Less well known to the general public is a growing body of highly specialized studies treating more seriously, and more fairly, the intricacies of river management.

The present study is an attempt to summarize some of this research, examining the High Dam in the context of Egypt's historical efforts to feed and improve living standards for a growing population. Against a background of critiques of the dam, we will explore the often complex interconnections among various facets of the resultant new lake/river ecosystem; indicate the latest, sometimes tentative, conclusions of scientific observers; note questions still being posed, and discuss possible future developments along the Nile.[1] We will examine such varied subjects as water quality, evaporation and seepage, hydropower, river bed and coastal erosion, land reclamation, waterlogging and salinity, schistosomiasis, fisheries and preservation of archeological monuments.

There are no easy answers; data are still often incomplete or contradictory. Nevertheless, from this perspective in time, distant from the political controversies which once inhibited objective analysis, it does seem possible to offer at least some qualitative impressions of the current state of the Nile.

Of Flooding and Farming

The Nile is the longest river in the world, over 6,600 kilometers from obscure origins in the equatorial rainforests above Lake Victoria to its outlets in the Mediterranean. It drains a vast area of 3.3 million square kilometers, about one-tenth of the African continent, and its basin includes parts of nine countries. By way of comparison, the Mississippi is much shorter at approximately 4,000 kilometers, but it has roughly the same drainage area and more than seven times the average annual flow of water: 600 billion cubic meters (bcm) versus 84. The peculiarity of the Nile, which accounts for its unique rôle in the evolution of agriculture and civilization, is the pattern of its discharge throughout the year; 80 per cent of its water courses through the Nile

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Valley between August and October, only 20 per cent during the remaining nine months. Spring rains in the Ethiopian highlands swell the Blue Nile to a muddy rendezvous with the more placid White Nile at Khartoum, and it is this silt-laden flow which has traditionally inundated and irrigated Egypt's farmlands once a year. However, extreme variations in the flow between years—in the last century alone, the annual volume ranged from one-half to twice the 84 bcm average[1]—have portentous implications for a society relying exclusively on the river.

The earliest cultivators in the valley developed a system known as basin irrigation for utilizing the Nile's annual floods. Beginning in August, the rich, silty waters were diverted by canals onto large fields, or basins, surrounded by dikes to achieve a constant level of water averaging one and a half meters. "When the Nile overflows," Herodotus noted, "the country is converted into a sea, and nothing appears but the cities, which look like islands in the Aegean."[2] The water would stand for six to eight weeks in order to saturate the dry soil, after which any excess would be released back into the stream. Water would also filter back into the river through the ground, dissolving and leaching out salts deposited during the previous growing season and thus renewing the soil. The land would be seeded in fall, and the harvest, primarily grains and beans, would take place in spring, after which the land would lie fallow until the cycle recommenced in August flooding. The main disadvantages of this régime were its complete dependence on an optimal flow in any given year—the alternatives were drought or catastrophic overflooding—and its limitation to a single planting of winter crops.

At a very early phase, Egypt attempted to manage its water resources. Thus Amenemhet, mentioned earlier, constructed the works which so astounded Herodotus: a dam and canals to draw excess flood waters to the Fayoum depression southwest of Cairo, thereby creating an artificial lake which served simultaneously for flood control and for release of waters for irrigation during drought years.[3] In addition, in some areas of the valley and delta, groundwater was close enough to the surface to be drawn at any time of year from wells; this permitted at least limited introduction of some summer crops—rice, cotton, indigo, sugar cane—and may explain the wealth of such ancient towns as Thebes and Memphis, strategically situated near groundwater resources. These early irrigation works and techniques clearly evidenced Egypt's drive to break out of the single-crop basin-type agriculture imposed by the unregulated flow of the Nile.

At the beginning of the nineteenth century, Egypt's rulers began a

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1. On the Nile's flows and fluctuations, see Hurst, Black and Samaika, *Nile Basin*, Vol. X (Cairo: Ministry of Public Works, 1965), p. 81, cited in Yusuf A. Shibl, *The Aswan High Dam* (Beirut: Arab Institute for Research and Publishing, 1971), p. 22; John Waterbury, *The Nile Stops at Aswan*, Part I (American Universities Field Staff, 1977), pp. 8–10.

2. Herodotus, *The Persian Wars*, II, 97.

3. *Ibid.*, II, 149.

concerted effort both to expand significantly the total farmed area and to extend the growing season to permit large-scale cultivation of cotton, which grows in the hot summer months when the Nile is at its lowest. This involved erection of barrages: low dams designed not for long-range storage of water, but rather to raise its level so that it could be held through winter and spring and be diverted in the summer into a newly constructed system of delta canals. Over the ensuing decades up to the First World War, Egypt's transition to perennial irrigation was marked by construction of additional barrages in the delta and upstream, by the first Aswan Dam (erected in 1902), and by an expanded network of irrigation canals eventually totalling 23,000 kilometers. The success of these schemes may be measured by a 76 per cent expansion in cultivated area between 1821 and 1907, while the cropped acreage (reflecting multiple planting) showed a two and one-half-fold increase.[4]

With all this, however, Egypt still remained hostage to high and low floods, while even in average years, nearly 40 per cent of the annual flow passed unused into the sea from August to October. The old Aswan Dam, even after being raised in 1912 and 1934, was simply unable to contain the massive volumes of water and accompanying silt at the peak of the Nile flood. In order to avoid rapid silting of the reservoir, its gates could only be closed to begin accumulating water in late October, after the main flood had passed!

Construction of the High Dam

The trend toward ever greater control of the Nile's flood became an imperative in the twentieth century, as Egypt's population doubled from 1897 to the end of the Second World War (and only took 30 years to double again). The menace of flood catastrophe to the increasingly densely packed settlements was becoming unacceptable. At the same time, growing development aspirations meant that the society was more vulnerable to economic setbacks, whether caused by drought or by excessive flood. Finally, the Sudan was beginning to demand a share of scarce summer water as it, too, entered the world economy with cash crops. With the collaboration of both governments, additional storage dams were constructed in Sudan in the 1920s and 30s, but they only marginally increased the supply of spring and summer water to both countries. In Egypt, agricultural output simply could not keep pace with the population explosion, and the uncertainty of water supply was no longer tolerable.

It is against this background that the High Dam must be examined. Even before World War I, engineers began to consider more ambitious schemes in order to achieve multi-year storage of the Nile flood. A new dam at Aswan appealed to Egypt because alternative plans would have involved complicated international negotiations with several upstream countries, some of dubious

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[4] Waterbury, *op. cit.*, Part I, p. 17.

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political stability, whereas the High Dam placed the storage under Egyptian control, could be completed more quickly, and had the added advantage of providing hydroelectric power.

This enormous undertaking was not frivolously conceived: it was studied for years by teams of reputed international scientists and engineers before a plan was finally approved and construction was begun in 1960. That it turned out to be Soviet-engineered and financed rather than an Anglo-American-World Bank project was due to Cold War politics rather than any doubts on the dam's inherent feasibility or economic worth.

By 1964, the river was definitively blocked and the reservoir—which was eventually to stretch nearly 500 kilometers—began to fill. The dam itself was gradually raised and finished by 1968, and the project reached full completion in mid-1970 with the installation of the last turbines in the power plant.

By any standards, the Aswan High Dam is one of the engineering wonders of the world; there is no comparable structure in terms of impact on the life of an entire country. One of the world's largest man-made constructions, it is a veritable artificial mountain of rock and sand: here, at the first cataract of the Nile and the traditional southern outpost of the pharaohs before the sands of Nubia, modern Egypt erected a gargantuan quasi-pyramidal structure 17 times larger in volume than the Great Pyramid of Giza. It is a kilometer broad at its base, 111 meters high, 3.8 kilometers in length at the top. The new reservoir backed up behind this barrier is the second largest in the world, extending over the Sudanese border and containing 168 bcm of water, compared with the old dam's storage capacity of 5 bcm. In effect, Lake Nāṣir becomes the new source of the Nile for Egypt; its vast basin can accumulate the waters of exceptionally high flood years with neither waste nor damage, and from it a regulated flow of water can serve the year-round requirements of downstream agriculture.

The main results expected from the High Dam were:

(1) the assurance of adequate and dependable irrigation water for Egypt's agriculture, even in lean years; specifically, by achieving full storage and subsequent utilization of the annual flood, the dam would foster the extension of year-round multiple cropping throughout the length of the Egyptian Nile;

(2) the provision to Egypt of an additional 7.5 bcm of water from what had formerly flowed into the sea, thus permitting reclamation of approximately 1.3 million acres of new lands previously uncultivated;

(3) protection of lives, crops and property against calamitous floods;

(4) the supply of large quantities of cheap hydroelectric power, hopefully stimulating a wave of industrialization which would liberate Egypt's economy from dependence on cotton earnings abroad.

Accompanying these major benefits would be improved year-round navigation, and the supply to Sudan of additional water, thereby ending controversy over Egypt's needs for summer water.

As will be seen, these hoped-for results have been substantially realized, but some intriguing complications and environmental side-effects fueled a prodigal controversy over the High Dam.

Ecological Implications

It is evident that any major dam will have often far-reaching ecological implications. Nevertheless, it seems that no similar undertaking in modern times has aroused the degree of international concern, criticism and misinformation as the High Dam. Unfortunately, in the early years of the project, there was very little hard data on anything. Thus was spawned a series of extravagant, scientifically unsubstantiated critiques of the dam: the impression spread that an ill-considered project, undertaken chiefly for nationalistic reasons, would wreak environmental havoc up and down the Nile Valley. In retrospect, some of the charges seem absurd. Thus, in 1973, a consultant for the US space program stated that Skylab pictures showed that the delta was drying up due to the High Dam![5] Another foreign expert asserted that water loss would prevent Lake Nāṣir from filling for 200 years;[6] in fact, it filled in ten. It seemed at times as if many observers, in their legitimate concern over possible environmental depredations, blithely assumed the worst possible case in the absence of adequate data.

Briefly summarized, here are the chief horrors commonly attributed to the High Dam during and after its construction:[7]

(1) Because of massive losses of water from Lake Nāṣir through surface evaporation and underground seepage into the substrata, Egypt would actually end up with *less* water than before, leading to loss of millions of acres of cultivated land.

(2) Since the dam would trap the silt that formerly was carried downstream, farmlands would be deprived of essential nutrients, thus leading to diminished yields or reliance on costly fertilizer imports.

(3) By impounding the annual flood, the dam would foster concentration of effluents in the slower moving canals and also spread waterlogging, leading to a rise in soil salinity which would further threaten agricultural output.

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[5] *Washington Post*, Oct. 16, 1973, p. 6.

[6] Claire Sterling, "The Aswan Disaster," *National Parks and Conservation Magazine*, Aug. 1971, p. 12.

[7] The rich literature of disaster is well represented by the above, and also by articles in the *Washington Post* (Jan. 6, 1971, p. 14; Feb. 17, 1971, p. 18; Feb. 20, 1971, p. 14; Feb. 24, 1971, p. 18.); *Los Angeles Times* (March 9, 1975, sec. 6, p. 3; March 28, 1976, sec. 9, p. 2); *New York Times* (May 4, 1975, p. 30); *Christian Science Monitor* (March 7, 1975, p. 7; Aug. 4, 1976, p. 14); *Wall Street Journal* (Sept. 24, 1976, p. 1). More scholarly critiques can be found in M. T. Farvar and J. P. Milton (eds.), *The Careless Technology* (New York: Natural History Press, 1972), articles on schistosomiasis by Henry Van der Schalie (p. 116), on fisheries by Carl J. George (p. 159), and on coastal erosion by M. Kassas (p. 179).

(4) The now silt-free current would erode the river bed and banks, thus undermining every bridge and barrage from Aswan to the Mediterranean.

(5) The absence of new silt deposits at the river mouths would result in coastal erosion and seawater incursions into rich delta farmland.

(6) Similarly, the cessation of this nutrient-laden flow would destroy Egypt's fishing industry by reducing the resident offshore sardine population.

(7) The dam would spread schistosomiasis, a debilitating parasitical disease, to epidemic proportions, as well as facilitate an invasion of Sudanese "killer mosquitoes."

All of these criticisms contain at least some factual element, but there is, as so often, more than meets the eye. In actuality, the Egyptian government gives every evidence of taking the potential dangers quite seriously; as one official stated, "we only have but one river." The government has commissioned or is participating in a wide range of serious research covering not only these charges, but also other Nile-related factors less commonly publicized. Perhaps the most important and comprehensive effort is being carried out by the Egyptian Academy of Scientific Research and Technology, in collaboration with the University of Michigan, the US Environmental Protection Agency, and the Ford Foundation. In what is probably the most ambitious study of a lake and river ecosystem ever undertaken, scores of scientists, using techniques ranging from remote satellite sensing to computerized models of ecosystem interactions, are analyzing in fabulous detail such subjects as the submarine geology of Lake Nāṣir; circulation, thermal and sedimentation patterns; micrometeorology, temperature and turbidity; phytoplankton and zooplankton cycles; concentrations of micropollutants; and the physical, chemical and biological analysis of water from the Sudanese border to the Mediterranean Sea. Other related research projects include UN and National Science Foundation studies of coastal erosion and marine sediments off the delta; USSR research on river bank erosion; West Germany and UN agencies on schistosomiasis; FAO, Britain, the Netherlands, the US, and the World Bank on various aspects of soil quality, water management, and irrigation techniques; Ford Foundation on the displacement of Nubian tribes from the lake area; UNDP and FAO on fisheries.

This brief listing gives some flavor of the scope and extent of subjects related to the dam. New data and observations developed from some of these research efforts invite a re-examination of the catalogue of horrors. In the following sections, therefore, we will accompany the transformed Nile on its downstream journey, pausing at several potential problem areas along the way, from the anaerobic depths of Lake Nāṣir through the tunnels of the High Dam, under barrages, past ancient temples, into irrigation ditches and the roots of crops, with what's left trickling into the Mediterranean against a counter-tide of sardineless, salty waves. The first, obviously fundamental question was: would there be enough water flowing after you entrap the Nile in a vast artificial lake?

Downstream along the New Nile

Lake Nāṣir

Of Lake Nāṣir's total capacity of 168 bcm, 30 bcm represents the deepest levels, so-called "dead-storage" for accumulation of silt; scientists now estimate that it would take at least 500 years for this volume to be filled. The next 90 bcm is the "live storage," regularly accumulated and partially drawn down for irrigation throughout the year. The upper levels of the lake's capacity, 48 bcm, would capture over-average floodwaters.

One of the most serious theoretical objections to the dam was that creation of this artificial receptacle for the Nile would actually lead to a net *loss* of water to Egyptian agriculture, due to the twin perils of surface evaporation and subsurface seepage into rock strata underlying the new lake. A relatively small increase in water levels behind the dam dramatically expands the reservoir's surface area, rendering it more susceptible to high surface evaporation in the arid, windswept climate. A further threat was posed by the evapotranspiration potential of floating aquatic plants, such as the prolific water hyacinth; one observer calculated that if ten per cent of the lake were covered by such plants, the water loss from this source alone could reach 10 bcm *per ann.* Also, the seepage of lake water under hydrostatic pressure into unexplored faults and fissures could theoretically lead to immense water losses. These not-implausible dangers stimulated responsible scientific debate even before construction of the dam commenced, and they are continuing subjects of study and measurement.[8]

The significance of these measurements can be appreciated from examining the calculus of the High Dam storage scheme. Prior to the new dam, the 84 bcm average yearly flow was divided by international agreement, with 48 bcm going to Egypt and 4 bcm to Sudan, while the 32 bcm balance perforce flowed unutilized into the sea during the peak flood season. The dam would capture this latter amount, of which an estimated 10 bcm would then disappear through evaporation and seepage. The remaining 22 bcm—a net addition to availabilities for irrigation—is again divided by international accord, with Sudan gaining 14.5 and Egypt 7.5 bcm. Since Sudan draws its quota upstream of the dam, it can be seen that any serious miscalculation of evaporation/seepage losses from the lake could rather quickly erase Egypt's projected net gain.

In actuality, the original estimates have proven surprisingly accurate.[9] With respect to seepage, recent studies confirmed that the permeability of

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[8] See, e.g., discussion in Waterbury, *op. cit.*, Part III, pp. 4 ff., and Shibl, *op. cit.*, pp. 59 ff. The water hyacinth speculation is by Prof. Kassas in Farvar and Milton, *op. cit.* p. 246.

[9] K. H. Mancy and M. Hafez, *Water Quality Studies on the River Nile and Lake Nasser* (University of Michigan, 1974), pp. 57–76, 98–106. Also Government of Egypt, National Council, *The High Dam and Its Effects* (Cairo, 1975), p. 32.

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the underlying Nubian sandstone is low, and it appears that cracks and fissures were relatively rapidly sealed with riverborne clay sediment. Horizontal losses to the lake banks also appear manageable; bank storage is in fact part of a reservoir system, since much of the water returns to the lake as the water level is drawn down through the dam.

Evaporation also seems to be within acceptable limits at the operating levels of the reservoir. In fact, a rate of evaporation loss higher than the anticipated average would necessarily coincide with excessive floods having raised the lake's level, and would thereby serve the beneficial purpose of modulating this rise. There is, moreover, no evidence of floating plants in the lake to complicate the picture; the lake's surface is not stagnant but in constant motion throughout the annual cycle of flooding and water release.

A somewhat related question concerns the potential for silt build-up at the southern entrance to Lake Nāṣir, creating in time a new upstream "delta" which could disperse and lose the Nile into the deserts of Nubia. This possibility is being monitored by, among other techniques, satellite scanning of the sedimentation profile. Evidence to date is that the current's own force during each flood period gradually pushes accumulated silt deposits northward into the deeper lake, thus inhibiting formation of an obstacle.

Chemical and Biological Side Effects

If it be accepted, then, that the captive Nile does not disappear, but will indeed accumulate and remain ready for use in Lake Nāṣir, one next confronts the fact that the impounding of water and its subsequent release entails physical, chemical and biological changes which can have important repercussions on downstream use. This topic is currently being closely studied under the Egyptian Academy project, and some tentative observations are possible.[10]

Within the reservoir itself, the heretofore little-publicized phenomenon of thermal stratification could have potentially serious effects on water chemistry. A stagnant layer appears to be developing beneath the gigantic water mass, where biological decomposition of organic matter has completely removed dissolved oxygen. In these gloomy depths, anaerobic microorganisms set into motion complex chemical/biological processes and water-sediment interactions which could eventually adversely affect the entire stream. The percolation upward of such noxious gases as hydrogen sulfide could imperil the aquatic life cycle, and thereby the fishery potential, of the lake's upper reaches. The same processes could promote corrosive action in the power turbines if anaerobic water is drawn through. The danger of an

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[10] Mancy and Hafez, *op. cit.*, pp. 88, 112 ff. on thermal stratification; pp. 127–147 and 172–199 on chemical and biological changes.

insidious expansion of the deep stagnant layer can, however, be offset by certain hydrologic and flow/volume control techniques, and Egyptian authorities, aware of the potential problem, are carefully monitoring the lake's depths.

Other chemical changes also have implications for water use hundreds of kilometers downstream. The process of evaporation from the lake has increased the salinity of water passing through the dam, although not to a dangerous degree. Yet unknown factors include possible effects in the lake of increased use of insecticides, pesticides and herbicides in Sudan's upstream agriculture, as well as run-offs from industry, agriculture, and urban centers if the lake shoreline should be developed. All of these effects, including similar developments downstream, will tend to cumulate in the rich delta soils, and therefore are being closely watched.

On the biological side, the new régime on the Nile is generally more conducive to plant life due to a multiplicity of factors: increased nutrients in the water from agricultural and urban effluents, greater light penetration due to upstream silt entrapment, slower average velocity and the absence of annual flushing by the main flood. It has been established that Lake Nāṣir produces a dense crop of bacteria, phytoplankton and zooplankton, important in the food chain for fisheries development. A less auspicious new presence in the Nile is blue-green algae, also apparently originating in the lake. In death and decay, these microorganisms consume oxygen essential for healthy fish life; in addition, they have occasionally clogged municipal filtration plants and, when chlorinated, can turn drinking water murky and odious in taste and smell, which happened for awhile in Cairo in 1974.

The same factors stimulate excessive growth of weeds, particularly in the slow-moving delta canals, where they can impede water flow and navigation, aggravate waterlogging on neighboring farmlands, and harbor disease carriers (of which more below). Since many canals no longer dry out in winter as they did before, weeds can get stubbornly entrenched. Egypt is tackling this problem with a program of mechanical cutting, herbicides (which must be employed with obvious care), and the introduction of voracious new carp species.

Through the Turbines

Leaving the lake, the Nile now drops 60 or more meters through the High Dam's turbines. Hydropower was clearly one of the most important benefits expected from the project. Russian engineers installed twelve giant turbines totalling 2.1 million kilowatts, capable of generating 10 billion kilowatt hours annually. It is apparent that the power plant has not, however, operated anywhere near full potential. In this evidently politically sensitive area, consistent data are hard to come by. People in a position

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to know concede that, even at last summer's peak flood, only seven turbines were in use; over the full year, the High Dam currently provides only about half of Egypt's power needs. This impression is bolstered by the expansion of thermal power plants in Egypt, notwithstanding the rising cost of fossil fuel.

Full use of the Aswan turbines is prevented by the impossibility of completely synchronizing the water flow-through requirements for irrigation, for maximum electricity generation, and for maintaining adequate overstorage capacity in the lake for flood control purposes.[11] Basically, agricultural needs dictate minimal releases during the winter in order to hoard water for the spring and summer planting, while electricity consumers demand a uniform flow throughout the year with, if anything, a peak in winter. If the flow were regulated to maximize power generation, much of the annual flood would surge out to sea at the wrong time of year and be lost to agriculture. Further, if the lake's level were maintained in the spring to assure optimal head for the turbines, you run the risk of inadequate storage potential to contain an unpredictable volume of flood in late summer.

There is evidently a constant pull-and-tug between the ministries concerned in drawing up the annual water release budget. To some extent, it involves a trade-off between agriculture and industrial development. Up until now at least, irrigation requirements have been deemed preëminent. Thus, in spring and summer, more water is released for irrigation than can be used by the turbines, while in fall and winter there is not enough flow-through to meet power demands. There has been some compromise, however, to maintain a minimum constant flow necessary for both navigation and power.

Another concern of some Egyptian planners has been that over-reliance by industry on cheap hydropower could lead to serious dislocations in the event that successive below-average flood years lowered the head flowing into the turbines. There are also persistent rumors of turbine maintenance problems and difficulties in obtaining Russian spare parts, but these were not possible to substantiate.

For a variety of reasons, including uncertain availability of power and distance from raw materials and markets, the dam has not led to development of heavy industry in the Aswan area, beyond the expansion of an important fertilizer plant. If the High Dam has not been able to play a pivotal rôle in triggering an industrial take-off, it has nevertheless contributed significantly to Egypt's power needs, and particularly to the expansion of rural electrification.

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[11] H. A. Thomas and Roger Revelle, "On the Efficient Use of High Aswan Dam for Hydropower and Irrigation," *Management Science*, April 1966, contains a good discussion of the trade-offs involved. See also Waterbury *op. cit.*, Part III, pp. 23 ff., and *New York Times*, May 4, 1975, p. 30.

Scouring and Degradation

The water passing through the turbines is, as noted earlier, different from the pre-dam Nile in a major physical aspect: it is clear. Up until 1964, the river carried in an average year 100 to 130m tons of suspended particles down the valley and through the delta, nearly all of it during the three-month flood period. The absence of this silt means that there is a continual pressure of clear water which exercises a scouring action on the river bed and banks. There are two major consequences of this. Firstly, scouring on the downstream side of bridges and barrages threatens eventually to undermine their stability; a high-level National Council reported to Egypt's President in 1975 that "the importance of protecting the barrages against erosion can hardly be exaggerated."[12] Secondly, the generalized degradation of the river bed can lower the level of water behind the barrages so as to diminish the potential off-flow into irrigation canals.

This customary riverine phenomenon was anticipated and is being carefully measured. Most of the scouring—approximately 40 centimeters—occurred in the 1964–68 period, after the river was blocked but while large amounts of the (now silt-free) annual flood still had to be released until the dam reached its maximum height. The rate of scouring has since slowed to an acceptable one centimeter per year, which means that total erosion to date amounts to about half a meter. No major strengthening of downstream structures has yet been considered necessary, although some protective measures were taken to blunt the water flow around their pillars.

When Lake Nāṣir reached its operating level of live storage, however, another threat became relevant: following a year of above-average flood, the lake's level should be drawn down again to prepare for the next year, or the risk is run that the lake would reach an overflow point and jeopardize the dam after a series of "wet" years. In any event, silt-free excess flood waters of indeterminate amounts would have to be released downstream, placing the barrages in serious danger.

A Russian study in 1975 recommended construction of weirs—mini-barrages—downstream of existing structures, which would slow the current in their vicinity (and simultaneously perhaps generate hydropower). Such structures might also, however, contribute to the general rising of the water table and thereby aggravate salinity problems discussed below.

The Soviet proposal has been temporarily shelved in favor of an ingenious scheme for diverting excess flood waters through a broad, 25-kilometer-long spillway into the Tushka depression in the desert southwest of Aswan. This safety-valve, which should be completed next year, should permit Egypt's hydraulic engineers to sleep a little easier.

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[12] National Council, *op. cit.*, p. 36. Discussion of river bed degradation and erosion is also found in Waterbury, *op. cit.*, Part III, pp. 7 ff. and Shibl, *op. cit.* pp. 68–69.

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Snails

Continuing the journey down the transformed river, one must recognize the possibility of increased schistosomiasis in the upper Nile Valley. This serious disease, traditionally associated with tropical irrigation, is not unique to Egypt and afflicts scores of millions of people throughout the world.[13]

The parasitic fluke responsible for this debilitating sickness is spread to humans by water snails. In the complex propagation cycle, the fluke's eggs, floating in water, hatch swimming larvae which enter the snail intermediary. Within the snail, the larvae undergo metamorphosis, liberating back into the water myriads of fork-tailed cercariae. These microscopic worms can, in a matter of minutes, bore directly through the skin of humans in contact with the water. Ensconced in blood vessels of the human host, the flukes mature, mate, survive for years, and produce a profusion of eggs, some of which are subsequently passed through the excretory system and find their way back into water, where the cycle recommences when they are absorbed by snails. Meanwhile, great masses of eggs accumulate within the human host, eventually clogging vital organs and producing general suffering and languor until still more serious, sometimes fatal diseases such as bladder cancer, take over.

Schistosomiasis is not new to Egypt: calcified ova were discovered in mummies of the Old Kingdom, and a papyrus of the 19th century B.C. contains the earliest record of the affliction in the hieroglyph "âaâ". As one prominent Cairo professor has noted: if Egypt has failed to eliminate the disease, it is also true that schistosomiasis has failed to eliminate the Egyptians.

Since the snail thrives in sluggish water, the proliferation of irrigation and drainage ditches creates propitious conditions for its spread. Early evidence indicated that schistosomiasis, already endemic in many rural areas of the delta, was moving upstream with the expansion of perennial irrigation—an indirect, if not unexpected, consequence of the High Dam. Under the new river régime, canals and ditches are neither flushed out by the annual flood nor dried out during a waterless season, thus resulting in a more hospitable year-round environment for water weeds, snails and the malevolent worms. Interestingly, the snails essential to the fluke have not become established in Lake Nāṣir itself, due to the constantly fluctuating water level.

The disease can be combatted by several techniques, and WHO and the World Bank have joined forces with the Egyptian government in major efforts. Health education, to increase awareness of the dangers in the ditches and of the benefits of better sanitation practices, has been combined with an expansion of piped fresh water into rural areas. These measures have had

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[13] An excellent survey of the etiology of the disease and methods of control is in E. E. McJunkin, *Engineering Measures for Control of Schistosomiasis* (Report to US Agency for International Development, 1970).

only marginal utility because of the realities of village life, e.g., the rôle of children in spreading the eggs, the frequent inefficacy of latrines because of high groundwater, the convenience of washing in canals, the need for farmers to spend time in wet fields and ditches. The expansion of subsurface field drainage systems, discussed below, will help, by reducing the habitat for snails. Chemotherapy for infected humans is on the upswing since undesirable side effects of earlier drugs have been overcome, but the problem here is the ease of reinfection. Breaking the fluke cycle by attacking the snails, through periodic cleaning out of canals and, more importantly, through molluscicides, appears to offer the most promise. This is the major component of several World Bank projects: for one treated area in the Fayoum, incidence of schistosomiasis between 1969 and 1974 fell from 46 to nine per cent, and transmission was essentially halted.[14] (The molluscicide also kills fish, but they can be eaten by humans with no ill effects.)

Several partial studies did show the predicted increase in the disease in Upper Egypt. But the most recent and comprehensive survey, undertaken by the University of Michigan throughout Egypt and based on historical records going back for decades, offers surprising evidence of a definite secular decline in schistosomiasis.[15] These results merit close analysis, for they suggest that the expected contributing effects of the High Dam to spreading the fluke are being overridden by a combination of the control efforts discussed above. The danger in any event appears to have been exaggerated by environmental critics of the dam, who underestimated possibilities for controlling the disease.

Incidentally, the threat of "killer mosquitoes" from Sudan has also not materialized. Egypt is aware of the menace from this exotic species, which caused over 60,000 deaths during a 1942 invasion. Under an accord with Sudan, a barrier zone has been established wherein both countries collaborate in periodic surveillance and larviciding operations.[16]

Protection of Antiquities

All along the Nile are found impressive vestiges of the ancient civilization that flourished on its banks. The preservation of these temples and statues is rightly of concern even beyond Egypt, as they constitute an irreplaceable part of the world's cultural heritage. Thus, an unprecedented international rescue effort was mobilized in 1963 to save the temples of Abu Simbel from

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[14] World Bank, *Appraisal of Delta Drainage II Project, Arab Republic of Egypt* (1977), Annex 12, p. 4.

[15] The University of Michigan study is not yet published, but its conclusions were announced by Prof. Mancy at the Annual Meeting of the Egyptian Academy of Scientific Research and Technology, Dec. 18, 1977; World Bank, *op. cit.*, Annex 12, p. 2, also noted a general downward trend. Contrasting earlier studies are cited in Mancy and Hafez, *op. cit.*, pp. 213 ff.; van der Schalie, "Aswan Dam Revisited," *Environment*, Nov. 1974; and Sterling *op. cit.*, who also states (p. 11) that Lake Nāṣir is "thickly infested" with snails, which is itself contradicted by van der Schalie's later findings. (p. 20).

[16] Mancy and Hafez, *op. cit.*, pp. 216–219, 305–306.

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17. Herodotus, *op. cit.*, II,

submersion under the rising waters of the artificial lake: the monuments, which had been sculpted from the cliff face itself, were cut into gigantic blocks which were then meticulously reassembled at a higher elevation. Similar operations were mounted for other edifices: the Ptolemeic temple of Kalabsha, for instance, was moved 50 kilometers and now commands a small island in sight of the High Dam.

Recently, some observers have expressed concern that rising water tables downstream in the valley may damage other monuments through chemical reactions of water and salts. To be sure, this too is not a new problem: nearly 25 centuries ago, Herodotus observed that "salt exuded from the soil to such an extent as even to injure the pyramids."[17] It is true that new evidences of surface moisture and salination are now clearly visible on half-sunk stones at the (already ruined) temple of Amenophis III behind the Colossi of Memnon at Luxor, 230 kilometers downstream of the High Dam; just across the river, one wall at Karnak has fallen since the dam was completed. On the other hand, part of the nearby Ramesseum collapsed in the not-distant pre-Aswan era. And geologists taking test cores in the Valley of the Kings found no evidence of seepage since construction of the dam.

In general, not enough is known about the processes involved. We know, for example, that salty water can be hard on sandstone, that under certain conditions rising groundwater could undermine foundations, that subtle changes in humidity combined with upward seepage through porous stone could lead to saline migration and flaking of carved inscriptions. But whether and when significant damage may occur is debatable. Before the Nile was transformed, many monuments, including Karnak, were partially inundated by the annual flood. The effects on the stone of year-round exposure to constantly moist ground, versus the previous process of immersion and drying out, are not yet known.

Clearly, the potential problem should not be ignored. Following discussions of this issue at the Egyptian Academy, it appears as if monitoring and development of data relevant to the preservation of ancient monuments may now be added to the comprehensive Nile research project already being conducted by that institution.

Waterlogging and Salinity

Leaving behind the monuments and entering the main downstream agricultural regions, we see that the same waterlogging/salinity conditions which have uncertain impact on ancient stone have a demonstrably present and pernicious effect on the tender roots of growing things. This again is not a new factor originating from the Aswan Dam: early Egyptian chronicles

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[17] Herodotus, *op. cit.*, II, 12.

document salt incrustation of previously fertile lands in the delta. But the modern dimensions of the problem are menacing: up to 80 per cent of the cultivated area upon which Egypt's economy is based suffers from slightly to severely reduced yields due to waterlogging and salinity.[18]

When the High Dam was being considered, the government had no anticipated such a serious waterlogging problem. Since the most pressing need was felt to be provision of year-round water for multiple cropping resources were concentrated on the distribution network, and a planned drainage program was shelved. Officials had hoped that lower average river and canal levels, resulting from impoundment of the Nile and regulation of its flow, would actually induce subsurface drainage from irrigated fields through underground aquifers back into the river.

In fact, this did not occur. Instead, a combination of processes conspired to raise the groundwater level and salt concentrations. As perennial irrigation spread, the year-round application of water meant that the water table never had a chance to sink; existing drainage ditches could not cope with the additional load of run-off. Seepage and percolation from the expanded canal and ditch network further raised the underground water table. At the same time, growing upstream use of fertilizers and chemicals combine with urban effluents to boost the salt content of irrigation water used in the delta. The end of annual flooding means that the land no longer receives a thorough flushing to dissolve and leach out accumulated salts. Finally, through evaporation and capillary action from the increasingly saline groundwater, salts become concentrated in the critical root areas of the upper soil, and fertility begins to suffer: the World Bank has noted reductions in yields of 30 to 50 per cent compared with unaffected soils in the same vicinity.[19] Unfortunately, when there is a high water table and inadequate drainage, the more water applied by the farmer to his land, the worse the salinity problem becomes.

A somewhat surprising and little-publicized factor is the growing re-use of (already brackish) drainage water—mixed with fresh water—for irrigating delta fields. Although sufficient fresh water is obviously available from behind the High Dam, there are delivery problems at the northern end of the distribution system, connected with the level and volume of water which the canals can currently handle. The growing water requirement stemming from the spread of perennial irrigation apparently implies a volume of release from Aswan which worries those concerned with downstream erosion. As one official put it: this is a debate between the engineers and the agronomists—the latter would prefer to use only fresh water in order to maximize yields. At any rate, recycled drainage is currently an important water source for

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[18] US Department of Agriculture (USDA), *Egypt: Major Constraints to Increasing Agricultural Productivity* (Washington, 1976), p. 85.

[19] World Bank, *op. cit.*, p. 9.

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20. *Ibid.*, Annex 2, p. 5 a

Egyptian agriculture, and scientists are studying its effects on productivity and researching ways of using it optimally.

The waterlogging/salinity cycle is reversible: the answer lies in improved drainage as well as more judicious use of water. In the Imperial Valley of California, once-prolific irrigated lands were becoming barren in the 1920s until installation of underground drainage pipes enabled them to be reclaimed from the desert for a second time. Some detailed experiments in Egypt running over ten years indicate that increased yields from affected lands of 50 per cent and more are possible when drainage is improved. Other experiments showed a one-year removal of three tons of salt per acre in the top 20 centimeters after subsurface drains were in place.[20]

The Egyptian government is making a concerted, and costly, catch-up effort. In cooperation with the World Bank, four major projects have been launched since 1970 to tackle the drainage problem in the delta and Upper Egypt. In all, over one billion dollars—of which 80 per cent is from Egypt—are being devoted to installation of underground drains and remodelling of surface drains. The high initial capital cost of subsurface drainage is compensated by the demonstrated production gains from the treated land, plus the substantial new croplands secured from covering the previous open-ditch network. By the end of 1982, an estimated three million acres—half of the total tilled area—will have been treated, and new projects are in planning to further expand the system.

Land Reclamation

Expansion of Egypt's cultivable area was a major theme during the 1960s. It was hoped that substantial land could be reclaimed from the desert by utilizing water from the High Dam as well as tapping the vast Nubian aquifer. That these dreams were not realized is not the fault of the dam.

With Egypt's total farmland hovering for decades around the six million acre mark, the High Dam was expected to provide irrigation water for an additional 1.3 million acres. As it happened, reclamation efforts were undertaken on about one million acres, but it is generally conceded that only about half of this total is currently producing. The visionary projects of tapping water from under the Western Desert were largely abandoned. By 1972, the Egyptian government officially called a moratorium on land reclamation schemes, and total acreage currently remains at approximately six million due to losses of farmland from encroachment of cities, roads and factories.

What happened was that planners had overestimated the quality of the potentially reclaimable land and underestimated the time and expense involved in turning it fertile. The soil was so inhospitable that it would take

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[20] *Ibid.*, Annex 2, p. 5 and Annex 4, pp. 3–5; USDA, *op. cit.*, p. 96.

10 to 15 years to build up its fertility. Enormous capital investments were needed for infrastructure: levelling, earth-moving, deep ploughing, roads, canals and drainage systems, plus construction of villages and facilities for new settlers who, it turned out, were often reluctant to relocate. In addition, unexpectedly high volumes of water were required for the periodic flooding necessary to reduce high salinity in the poor soils. The results were generally subnormal yields at relatively high cost; some new lands were actually lost again to the desert *via* secondary salination.[21]

As we shall see below, costly land reclamation schemes may yet be unavoidable if population pressure does not abate.

Silt, Fertilizer and Bricks

It was commonly believed by critics of the dam that loss of the flood's annual load of silt would inevitably diminish the fertility of Egypt's farmlands, and figures were thrown about to demonstrate that the Aswan Dam was thereby leading Egypt to growing reliance on artificial fertilizer. Increased use of fertilizer is, however, a worldwide phenomenon and, if anything, Egypt is lagging in the rate of growth. From the 1961–65 (predam) period to 1975, Egypt's per-acre consumption did rise by nearly 70 per cent—but in the rest of the world it was more than doubling.[22] While Egypt's per-acre consumption is significantly above the world average, this is not unexpected for a country where all the farmland is irrigated; by way of comparison, Japan's level in recent years was almost twice that of Egypt's, while France's per-acre consumption was about the same. It was in fact High Dam electric power which fueled a significant expansion of the domestic nitrogenous fertilizer industry, and the World Bank estimates that Egypt will soon reach self-sufficiency in fertilizers.[23]

It appears also as if the fertilizing impact of the silt deposit was exaggerated. Roughly 90 per cent of the 100–130m tons per year once carried by the Nile was swept out to sea in any case; the average layer of silt left on delta farmlands in any given year was insignificant. The silt was not present anyway in the significant volume of irrigation water that was lifted out of the canals by age-old Egyptian techniques for watering higher lying lands. Perhaps the most important fact, which also explains Egypt's high fertilizer use even before the dam, is that the Nile silt does not contain nitrogen, which is essential for the land to take multiple cropping. (The role of silt in con-

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[21] On soil quality and reclamation, see *ibid.*, pp. 36–37, 80–85; Waterbury, *The Balance of People, Land, and Water in Egypt* (American Universities Field Staff, 1974), pp. 21–22; *New York Times*, Jan. 2, 1972, p. 8.

[22] United Nations Food and Agriculture Organization (FAO), *Annual Fertilizer Review* (Rome, 1976), cited in USDA, *The U.S. Assistance Program for Egyptian Agriculture* (Washington, 1978) pp. 61, 63.

[23] World Bank, *Appraisal of Upper Egypt Drainage II Project, Arab Republic of Egypt* (1976), Annex 9, Table 2.

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[24] Waterbury, "Nile St
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[26] Herodotus, *op. cit.*,

tributing trace elements and improving soil structure is a subject currently under study.)[24]

Worthy of at least a footnote in the story of the now clear-flowing Nile is the fate of the Egyptian brick industry, which traditionally depended on the river's annual gift of silt and clay cleared from canals. Unquestionably brick production has plummeted and prices have rocketed in recent years. The government's answer is that the brickmakers should turn to sand, which is equally abundant and in any case more durable than handmade bricks of river mud, and that prices could be lowered by utilizing economies of scale and modern techniques.

Problem of Coastal Erosion

Our 1,200 kilometer journey downstream from Aswan now brings us to the Mediterranean Sea—and the problem of coastal erosion. For the billions of tons of silt which over the decades did not nourish the soil did indisputably reach the sea. Some observers assert that the High Dam will aggravate encroachment by the sea because of the termination both of this sediment deposit and of the river's outflow, which deflected offshore currents. This could be a serious problem, for if the narrow sand spits currently protecting the delta's brackish northern lakes were breached, rich agricultural lands could be threatened by underground salt seepage as well as by wave action over existing embankments.

In actual fact, very little is understood about the complex and varied processes of sedimentation, erosion and subsurface currents along the delta coastline. It is known that the coast's contour has varied considerably over the centuries; there are fascinating chronicles of moving coastline, wandering dunes, blocked and re-opened lake exits, and inundated settlements—all antedating the modern river control works. The frequently cited measurement of a 30-meter average annual coastline retreat since 1898 is revealed, upon closer analysis, to refer only to two specific promontories at the Rosetta and Damietta outlets, and *not* to the entire delta shore.[25]

In any event, the impact of the High Dam on these dimly understood and variable long-term processes is debatable. Some experts, for example, argue that most of the silt was carried out to sea rather than being deposited in a protective barrier at the delta river mouths; the sounding line cast by the helmsman of Herodotus brought up river mud a day's journey—over 100 kilometers—from landfall.[26] In modern times, no agricultural land has yet been lost to the sea. If the problem becomes threatening, there are solutions, even if costly: expansion of existing jetties, construction of new sea-walls, dikes, etc. Clearly, more needs to be known before major works

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[24] Waterbury, "Nile Stops . . . ," *op. cit.*, Part III, pp. 11–12.

[25] Kassas, "Impact of River Control Schemes on the Shoreline of the Nile Delta," in Farvar and Milton, *op. cit.*, pp. 181–182.

[26] Herodotus, *op. cit.*, II, 5.

are undertaken, and the situation is under study by Egyptian and international scientists.

Sardines and Nile Perch

Moving out to sea a bit, we confront an incontrovertible phenomenon blamed by critics on the High Dam: the disappearance of Egypt's sardine fisheries, which had netted 18,000 tons as recently as 1962. The dam is assuredly responsible for the absence of tremendous quantities of phytoplankton off Egypt's shore, which had formerly been carried there by the Nile and had attracted schools of feeding sardines.

As in other areas, however, this fact should not be judged in isolation. Egypt's fishing industry is in any case in a process of transition. Not only the offshore fisheries, but also the northern delta lakes have shown declining yields, in the latter's case because of overfishing, land reclamation from the shallow lake bottoms, and occasional mass fishkills due to overconcentration of agricultural and urban waste discharge. The northern fishing industry—which anyway accounted for less than one per cent of Egypt's GNP in 1962—is attempting to readjust in a variety of ways, including greater emphasis on offshore trawling, cultivation of high-valued eels, and venturing past Gibraltar onto the high seas. Egyptian scientists believe there is a potential for 3,000–5,000 tons of surface fish on the western side of the coast, and are currently studying the eastern side's possibilities for bottom fishing.

Overshadowing these northern developments, however, is the brand-new fishing industry spawned by Lake Nāṣir, which has already far exceeded the value of pre-dam sardine fisheries. From 750 tons in 1966, the reservoir's fish harvest has steadily grown to nearly 19,000 tons in 1977. This is almost double the cautious estimates of some observers a decade ago, and there is no evidence of overfishing.[27] The delicious Nile perch is thriving in its roomy new habitat.

Egyptian fishery experts are aware that careful management will be necessary in order to increase the take and avoid depletion. Among items in the planning stage are improved boats and gear to permit optimal fishing techniques in the lake's deeper waters, refrigerated floating storage stations and railroad cars, and processing facilities. (Currently, the fish is either salted or shipped to market on ice by rail.) The UK and Norway are reportedly involved in fishery development on Lake Nāṣir. The main current problem appears to be not enough fishermen in the sparsely populated lake region.

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[27] George, "The Role of the Aswan Dam in Changing the Fisheries of the Southeastern Mediterranean," in Farvar and Milton, *op. cit.;* A. F. A. Latif and El-Sayed A. Khallaf, *On the Fish Stocks of Lake Nasser* (Aswan, 1974).

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Return to Nubia

With the fisheries question, we return full circle to our original starting point on the shores of Lake Nāṣir. Here we conclude our journey by noting some social issues related to the High Dam.

Most directly, the creation of the artificial lake 15 years ago flooded the ancestral homes along the old Nile of approximately 60,000 Nubians, who were displaced from their traditional agricultural pursuits and resettled in new communities downstream. The Nubians appear to have adjusted reasonably well, although there has been some evidence of human distress and social disruption in the years immediately following relocation. The University of Michigan is currently studying sociological implications of the relocation.

Now that the lake's contours are stabilized, however, some movement back to Nubia is taking place. The city of Aswan has mushroomed in size from a pre-dam population of 30,000 to an estimated 170,000. Main new employment opportunities are in a growing tourist industry, commerce and banking, the expanded fertilizer plant and fish processing. Five thousand fishermen have migrated to the lake itself to profit from the new fishing situation. In addition, there are reports that many of the displaced Nubians are interested in returning to the lake area.

The Egyptian government is contemplating establishment of pilot agricultural communities on the lake shore, and a few planners for some time had visions of larger scale industrial development along the lake. There are problems, however, to be considered. Although the climate is conducive to production of high-value early-winter vegetables for export, at least one recent foreign study indicated that the soil quality around the lake is generally so poor as to make reclamation impractical. Because the lake's level changes appreciably throughout the year, floating pumps would be needed to supply irrigation canals. Possible health problems also need to be considered, as hundreds of kilometers of shallow, stagnant pools and bays are uncovered each year when the lake drops. Possible effects of effluents on the lake's ecosystem—and the implications for downstream water use—will have to be examined most carefully.

One of the most heartening consequences of the High Dam has been the increased coöperation between Egypt and Sudan in management of the waters crucial to both nations. There are even plans for an administrative merger of the two countries' Nubian provinces, north and south of the international border crossing Lake Nāṣir, in order to rationalize decision-making on factors which could affect the lake, including shoreline development. A not unappealing alternative, in light of the uncertainties, is to leave the vast region, with its thousands of kilometers of shoreline, essentially undisturbed save for fishing activity and recessional farming and grazing.

Aswan and Beyond

Cause and Effects

Fifteen years after the barrier at Aswan transformed the nature of the Nile, it is possible to strike a qualitative balance sheet on this momentous project. Egypt's decision finally to store and completely regulate the Nile floods was consistent with a tradition going back to the early pharaohs. It must be viewed in the context of the urgent pressure of an exploding population against the limited land and water bases of traditional farming. In the face of the critical need to increase agricultural output, the High Dam was expected to deliver year-round water even in drought years to permit higher intensity of cultivation on existing acreage, and to provide additional water for expansion of cropland through reclamation. The accompanying hydropower was an important step in the process of diversifying toward a modern industrial base. And finally, the security provided by the dam against dangerous floods was of profound human as well as economic import; electrification, housing and other rural infrastructure projects could now be undertaken with the assurance that they would not be swept away.

It is clear that the dam has largely achieved these objectives and is playing a central rôle in Egypt's development. Quantifying the various effects is an exercise of dubious precision, but it is worth noting that the most thoroughgoing economic study of the project to date, employing discounted present value analysis, demonstrates that the dam is yielding a significant economic return.[28]

The High Dam has made possible the final conversion of all of Egypt's tillable land to perennial multi-crop cultivation; a doubling of rice output alone has added significantly to export earnings. Some new lands have been reclaimed, enabling Egypt to at least hold its own against urban encroachment. Substantial cheap power, even at less than full capacity, has made possible rural electrification and some industrial expansion. A not insignificant side effect of the dam was the development of an experienced Egyptian construction engineering industry, which has turned into a foreign exchange earner. Finally, many observers believe the project proved its ultimate worth in the single year 1972, when one of the lowest floods in a century would have dealt a crippling setback to Egypt's economy had it not been for release of waters stored behind the dam; an estimated loss of over one-third of the harvest was prevented, saving crops worth about $600 million, mostly in foreign exchange.[29]

Our imaginary journey down the new Nile illustrated some of the fascinating interrelationships involved in river management. New upstream or lakeshore agricultural and industrial development must, for example, be eval-

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[28] Shibl, *op. cit.* ch. VII.

[29] *New York Times*, May 4, 1975, p. 30; Waterbury, "Balance . . . ," *op cit.*, p. 19.

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uated in terms of the additional chemical/biological burden imposed on the river ecosystem, which might have deleterious effects on downstream soils or fishing or drinking water. Greater use of fertilizers, herbicides, etc., can increase yields upstream but add to salinity problems downstream. If you release water through the dam according to irrigation requirements, you find the power-generating capacity cannot fully be utilized. At certain levels of water release, however, you need to worry about unacceptable degrees of scouring and river bed degradation. Agronomists would like to maximize use of fresh water on crops as opposed to recycled drainage, but this also has implications for the scouring problem. If you tackle scouring by erecting weirs, you may raise the adjoining water table and thus aggravate salination of fertile soils. When you install underground drains to combat salinity, you are able to fill in surface ditches, thereby gaining new cropland and simultaneously getting one up on disease-bearing snails.

These are only a few examples. The complex web of interdependency demands multidisciplinary research and coordinated decisions on any single aspect of lake and river management. The general impression emerges that the new Nile ecosystem *is* being comprehensively studied, and that problems will find their solutions. With the benefit of hindsight, we can say that certain remedial measures would have been more effective and cheaper if they had been instituted earlier—e.g., underground drainage certainly and, possibly, protective jetties on the Mediterranean coast to capture silt while it was still flowing in from the river. As for other potential problem areas, it appears that loss of water behind the dam through evaporation and seepage is within tolerable, anticipated margins. Downstream scouring seems to have stabilized and control measures are available. The sardine loss is more than compensated for by the new Lake Nāṣir fisheries. If anything, the High Dam may have served the beneficial purpose of focusing high-level attention and serious research on a number of subjects, such as waterlogging/salinity, river water quality and effluents, coastal erosion, schistosomiasis, which had been developing into potential problems for years due to urbanization, perennial irrigation or other factors.

The Future of Nilotic Agriculture

It is astonishing to consider that Egypt's population when Napoleon invaded was only two and one-half million. The seemingly inexorable population growth in recent years means that the long tradition of man-made works along the Nile will not end with construction of the Aswan High Dam. The agriculture sector still accounts for half the labor force, 30 per cent of GNP, and 80 per cent of export earnings. Despite large increases over the last decade in production of wheat, maize, rice, sugar cane and vegetables, population growth has transformed what used to be overall food surplus into a deficit: Egypt must now import a third of its food supply—mainly wheat, feedgrains, oils and beef—and the bill is growing at an alarming rate; increased local consumption has even cut into once-lucrative rice exports.[30]

If the estimated two to three per cent growth rate is allowed to continue, there could be 50 million Egyptians by the middle of the next decade, over 70 million by the end of the century. Until this transcendent problem is brought under control, the drive to increase agricultural output will continue. There are, ultimately, two ways of doing this: by increasing yields from existing acreage, and by expanding the cultivated area. Thus one comes up against the two possible limiting factors: land and water.

Egyptian yields already are among the highest in the world for such crops as cotton, wheat, maize and rice.[31] Nevertheless, agronomists believe they can be still further increased through more effective use of irrigation and drainage, new seed varieties and cropping patterns, and judicious application of fertilizers, herbicides and pesticides. World Bank and US AID projects are aimed at these objectives, which are undeniably important for the intermediate term. At some point, however, ever-higher yields will become increasingly difficult and expensive to obtain.

The limited availability of farm land is a present reality. Theoretically, any soil can be developed, with enough money, water—and time. At the present state of the art and cost/benefit ratios, many soil experts believe that most land not already under cultivation is simply not arable. Land reclamation must, however, be included in any future planning options.

As to water, the High Dam has bought only limited time. Although there are adequate current supplies of water, the rising population will inevitably lead to growing demands from competing needs: already the tension between irrigation and hydropower is evident, and municipalities and industries will also require greater quantities in the future; land reclamation would, as noted, impose particularly heavy demands. International experts estimate that it will still be 15 to 20 years before water becomes seriously scarce, but Egypt is already coöperating in a new World Bank/UNDP project to design a long-range water management plan. This would involve both improved water conservation and development of new water sources.

With respect to conservation, agronomists estimate that improved on-farm water management could save almost ten bcm annually, a figure of some significance when it is recalled that the additional water to Egypt from High Dam storage averages 7.5 bcm per year![32] More precise levelling of fields, sprinklers and recycling drainage water could all add to water savings—

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[30] Various data on agricultural trends can be found in National Council *op. cit.*, pp. 58–61; World Bank, "Appraisal of Nile Delta Drainage . . . ," *op. cit.*, Annex 8, Table 2; USDA, "U.S. Assistance . . . ," *op. cit.*, pp. 48–49.

[31] FAO, *Production Yearbook*. (Rome, 1970), cited in Shibl, *op. cit.* p. 24.

[32] *Ibid.*, p. 47.

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As for new water, a not unlikely future development, which had been iscussed for decades, is the Jonglei project: this would involve a 280-ilometer canal in the Sudan to by-pass the immense, weed-covered Sudd wamp, where the White Nile loses enormous quantities of water through vapotranspiration. This could yield an additional seven to nine bcm of water nnually to both Egypt and Sudan. Here again, environmental considerations, e.g. possible climatic changes, are being studied. In the same future ategory are additional upstream storage dams in Sudan and Uganda. ndeed, in a water-short future, excess flood waters diverted into the esert by the Tushka project (see above) would become re-evaluated as a sheer waste.

Even if these huge new quantities of water can be developed, the question arises how they can be transported — silt-free — down the Nile Valley in light of the erosion problem. We are now increasingly in the realm of imagination, but economic costs can change in peculiar ways if an indispensable resource becomes scarce and ever more precious. It might one day, for instance, be worthwhile to pay whatever is necessary to reinforce barrages and river banks, run colossal volumes of water downstream, and turn the delta into a gigantic underground reservoir for the Nile, managing the water table by pumping groundwater out for summer cropping and recharging it by pumps in fall and winter. Obviously, the physical and economic feasibility, power requirements, and possible side effects of such a scheme need to be thoroughly explored. An intriguing implication of delta storage is the opportunity it would offer for maximizing upstream electricity generation by obviating the current conflict between irrigation requirements and turbine capacity.

Existing groundwater could play an increasingly important rôle in meeting Egypt's future water requirements. There is generally good quality groundwater along the Nile and in the delta, currently recharged from the river, canals and irrigated fields. Estimates of 21 bcm in upper soil levels of the valley and 75 bcm in the delta represent only a fraction of total theoretical availabilities. Even more staggering in dimensions, although extremely difficult to recover under existing technology, is the mammoth underground pool underlying Egypt's Western Desert: as large as California and Nevada combined, the Nubian aquifer is probably the largest underground reservoir in the world — at least 100 to 3,000 meters thick, it is estimated to contain three *trillion* cubic meters of water in the upper 150 meters alone! Recovery and use, however, currently ranges from difficult to impossible, because of the costs of deep wells and of developing the extremely poor quality desert land, and because the water's chemical content renders it high corrosive to pumping equipment.[33]

Other conceivable future technological breakthroughs might inclu desalinization of Mediterranean water for agricultural use.

The flights of fancy in this section are merely designed to illustrate som of the possibilities which might become necessities, and which therefore a rightly on the minds of responsible scientists and planners. A plausib future strategy for Egypt, beyond the scope of this paper, might be to aban don any hope of feeding itself, accept a growing dependence on foreig food sources, and concentrate development efforts on light manufacture and such high-value export crops as rice, cotton, fruits and vegetables. cannot be overemphasized, however, that limitation of population growt is the essential prerequisite for future economic and social betterme in Egypt.

There are very few major rivers on this planet passing through populate areas which are not subject to some kind of flow control program. Fo millenia, the Nile has been the archetype. In examining criticisms of the mos recent of man's works on this river, one could easily forget that there was n idyllic past era of perfect ecological balance. Mistrustful of change, th critics seem to venerate an illusory equilibrium—as if Nature itself wer static. Yet, even without man's intervention, the Earth changes, shoreline advance and recede, upthrusting mountains and glaciers create, dam an destroy rivers.

The development and improvement of human conditions is profoundly a process of disequilibrium, of change. Mankind lives in a dynamic system of complex ecological interconnections. In our understandable striving for greater long term control over our fate, we also have an undeniable responsibility to examine the side effects of our projects and to respect the natural environment. Certainly some of the unusual schemes just mentioned illustrate the necessity for careful study before embarking on major alterations in existing ecosystems. Ultimately, however, the advancement of human welfare will be served by responsible, creative planning, and not by fear of change and rejection of possible solutions in deference to a fictitious and unattainable equilibrium, which does not even exist in Nature.

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[33] William E. Warne, *New Developments in Egypt's Western Desert Using Waters of the Nubian Sandstone Aquifer* (Cairo: General Petroleum Company, 1977), pp. 4 ff.; Thomas E. Eakin, *Ground Water in Egypt* (Report to US Agency for International Development, 1975); US Department of the Interior, Geological Survey, *A Brief Evaluation of Ground-Water and Soils Potential for Irrigated Agriculture, Western Desert of Egypt* (Washington, 1977), pp. 5–11, 17–19.