Summary: Health Aspects of Man-Made Lakes

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Man-made lakes are formed as a result of engineering works constructed for a variety of purposes, such as hydropower generation, flood control, improvement of navigation, irrigation, recreation, and fish culture, that can all be combined in a single project. Each of these objectives confers benefits that are assessable. These benefits, however, will not necessarily accrue to the people in the immediate vicinity of the lake.

The formation of a new lake inevitably produces a number of local environmental changes, some favorable to the local inhabitants, some harmful. For instance, in an arid pastoral area the accessibility of water may improve agriculture and animal husbandry and provide a protein addition to the diet from fisheries. On the other hand, these advantages may be offset or outweighed by overgrazing and erosion, by the overstretching of local administrative and other facilities (e.g., schools, health units, and communications) due to an influx of population from elsewhere, and by the introduction of new diseases or the aggravation of existing diseases in the area.

The first man-made lakes to demand serious consideration in a public health context were those constructed some 40 years ago in the Tennessee Valley of the southern United States, and there the concern was that the transmission of malaria would be aggravated. For the same reason the government of India introduced a requirement 25 years ago that all dam construction and new irrigation systems be cleared first with the Health Ministry. In the last 10 years the public health aspects associated with man-made lakes have come into sharp focus with the construction in Africa of vast impoundments, such as Lake Kariba, Kainji Lake, Lake Nasser, and Volta Lake, all of which are now colonized by snail intermediate hosts of the causative organism of schistosomiasis. The raising of the water level of Lake Victoria (70,000 km²) by the Jinja Dam and the consequent small fluctuations in lake level have created new foci of schistosomiasis.

With other large dams about to be completed in Africa, such as the Kossou Dam in the Ivory Coast, the Cabora Bassa Dam in Mozambique, and the Tafilalet Dam in Morocco, not to mention those in Asia, it is necessary to learn from the lessons of the past what the future may hold. Since most impoundments constructed primarily for power are employed to supply different-sized irrigation systems, we have to consider the health hazards associated with irrigation water as well as with the impoundment of the lake itself, the spillways, and the river below the dam. At the dam on the Dez River in southwestern Iran, close to a focus of urinary schistosomiasis, efforts are being made to keep the irrigation system below the impoundment free from schisotosomes. In tropical areas outside Africa the developments planned for the Mekong Valley in southeast Asia and the San Francisco Valley in northeastern Brazil will entail health hazards from snail-transmitted and insect-transmitted diseases in both the impoundments and the associated irrigation systems. Just as the type of crops and their cultivation largely decide the receptivity of irrigation systems to the breeding of vectors and intermediate hosts, so does the type of vegetation growing along the shorelines and in the water decide the health hazards of the man-made lakes.

PLANT ECOLOGY OF MAN-MADE LAKES

Once the impoundment has been completed, the succession of plant growth colonizing the shorelines, and at times even the body of the lake, will influence the incidence and development of vector-borne diseases. Most of the early man-made lakes were located in temperate zones, often in uninhabited highlands, where their steep shorelines precluded colonization by plants. Moreover, there are many large natural lakes in the tropics that, apart from plants in shallow margins, are devoid of vegetation. It was therefore hardly expected that man-made lakes in tropical areas would be seriously invaded by aquatic vegetation and still less that the vegetation would result in such an increase in population with the attending public health problems.

In tropical lakes, two floating plants have caused considerable trouble, namely, the water hyacinth *Eichhornia crassipes* and the water fern *Salvinia auriculata*, both of South America, where they are apparently of little importance. *Pistia stratiotes*, the water lettuce, may also be an important invader. Large mats of floating vegetation may move over the surface of the lake, navigation channels being blocked and deoxygenated conditions inimical to fish being created. If such masses of sudd-type vegetation are subsequently removed from the shoreline, they are often replaced by submerged plants, such as *Ceratophyllum demersum*, which may harbor the snail intermediate hosts of schistosomiasis.

Salvinia auriculata was present for some years in the Zambezi River, and an explosive development of it occurred in Lake Kariba when the lake began to fill following clearing and burning off. Mats of the weed harbor the snail intermediate hosts of human schistosomes and may transport them to different locations; i.e., the mats of weed are foci of schistosome transmission. The area now occupied by the plant in Lake Kariba appears to be receding, although the plant still covers 6% of the total lake surface (about 320 km^2). *Eichhornia* has not been seen on Lake Kariba.

All man-made lake projects in tropical areas are faced with the problem of what to do about the natural vegetation along the shoreline of the flooded area. In some places, such as Lake Kariba, extensive clearing was carried out before inundation, and this proved very expensive; in others, such as Volta Lake, little clearing was attempted. The Brokopondo impoundment in Surinam offers an extreme example, since it is essentially a drowned rain forest because no clearing was done at all; the acid waters of the Surinam River, which feeds it, were apparently unfavorable for the development of snails.

Eichhornia and *Salvinia*, both of which have caused much trouble in other parts of Africa, seem to be absent from Volta Lake. Many new vegetation types have developed, including a floating sudd-type vegetation in the creeks feeding the Volta below the damsite, *Vossia cuspidata* being one of the components. The thick mats of *Pistia stratiotes* observed in the Afram area of Volta Lake do not persist, but the *Vossia* sudd, usually associated with submerged weeds, such as *Ceratophyllum*, *Utricularia*, and *Polygonum*, is more enduring. Whereas *Pistia* appears to be seasonal in growth, mats of the common sedge *Scirpus cubensis* build up in the quieter bays and periodically break off into the lake with their snail fauna. For the most part, Volta Lake escaped the initial explosive weed growth phase that occurred at Lake Kariba, but both *Pistia* and *Ceratophyllum* show a marked seasonal variation in quantity, reaching their maximum development following the rainy season, *Ceratophyllum* apparently forming extensive underwater meadows during optimal conditions.

Kainji Lake occupies what was previously wooded savanna, and only partial clearing was undertaken before inundation. Along the margins of the lake and immediately inland from the swamps are abundant growths of the sturdy grass *Jardinea congolensis*, and floating mats of uprooted swamp plants and floating aquatic plants are present.

Lake Nasser offers an extreme example in that virtually no vegetation existed before inundation and the lake is now bordered by sandy beaches and rock outcrops covered with algae. Nonetheless, these inhospitable substrates support a sizable snail fauna infected with schistosomes. Higher up the Nile the impoundment above the Jebel Aulia Dam has become heavily overgrown with *Eichhornia crassipes*.

Obviously, the decision to clear trees and other vegetation from areas that will form the bed of a man-made lake, whether reached for navigational, fishery, or public health reasons, calls for the inclusion of cost-benefit assessments in the initial planning for any project.

Ecological changes will be felt not only in the lake itself but also downstream, where they may affect the health of the river dwellers. Excessive weed or algal growth, for instance, may spread downstream. Action taken in the lake for the biological, chemical, or mechanical control of such weeds will result in dead vegetation in the river below, which may well be the source of the water supplies of riverine communities.

Not only will the vegetation of the man-made lake promote the breeding of schistosome-bearing snails and malaria mosquitoes, but it could also encourage the development of the filariasis vectors in the genus *Taeniorhynchus* (now placed as the subgenus *Ochlerotatus* of the genus *Aedes*). The organic detritus from vegetation settling to the bottom of the impoundment often produces plagues of chironomid midges, which constitute a real threat to those allergic to them. This detritus may also result in dense populations of clams and mussels, which are known to be concentrators of harmful chemicals and which can damage pumps and turbines if they are carried downstream.

SCHISTOSOMIASIS PROBLEM IN MAN-MADE LAKES

Schistosomiasis is essentially a 'water-based' disease, since it is dependent on an aquatic organism, namely, the snail intermediate host, for a part of its transmission cycle. This serious debilitating disease affects over 200 million people. The prevalence of the infection is nearly always enhanced by the impoundment of water in man-made lakes and by the irrigation systems frequently associated with them. Irrigation systems have long been known as areas of schistosomiasis insofar as they increase the availability of water and consequent human contact with it; it is now becoming apparent that the man-made lakes themselves produce similar deleterious effects.

It is important to emphasize that the definitive host, man, is responsible for the dissemination of schistosomiasis by contaminating the aquatic environment, where he in turn becomes infected. The snail is only a passive intermediate host. Therefore, for the epidemiology and control of schistosomiasis, consideration must necessarily be given to the ecology of the human as well as to that of the snail hosts.

Where schistosomiasis is prevalent, a man-made lake is likely to present a considerable hazard for lake users, including the increasing numbers of fishermen and lakeside settlers who may come from schistosomiasis-free regions. It may also seriously jeopardize the health of the resettled population displaced by the impoundment. In Lake Kariba, transmission of both urinary and intestinal schistosomiasis has been demonstrated in limited foci, where the respective snail intermediate hosts *Bulinus (Physopsis) africanus* and *Biomphalaria pfeifferi* are associated with mats of the water fern *Salvinia auriculata*. In 1968, a decade after completion of the dam, the prevalence of *Schistosoma mansoni* was observed to be 16% among all age groups, whereas that of *S. haematobium* among children reached a mean of 69%. It is therefore vitally important that the presently focal transmission of schistosomiasis be contained.

In the vast Volta drainage area some 20 years ago the prevalence of schistosomiasis was low, the aquatic ecological conditions being generally unfavorable for the snail intermediate hosts. It was, however, predicted that on the west side of the future lake a number of areas might become ideal breeding grounds for *Bulinus* and *Biomphalaria* snails. In 1967–1968 a sharp rise in the transmission of *S. haematobium* occurred in lakeside communities because of enormous densities of *Bulinus truncatus rohlfsi*, developing principally in association with the weed *Ceratophyllum*. Specimens of *B. (Physopsis) globosus* have been found only recently in one location on the lake, although this species is the most numerous and widely distributed intermediate host of *S. haematobium* throughout west Africa, including Ghana. *Biomphalaria pfeifferi* has not been collected from Volta Lake, but it is expected that the species may be found, particularly in the northern part of the lake. Although one authority has stated that the prevalence rates of *S. haematobium* will drop in conjunction with an observed decline in the number of bulinid snails in certain places, a recent limited survey indicated that transmission of the parasite by *B. truncatus rohlfsi* is focally intense and may become more widespread with the possible development of even more favorable aquatic vegetation for snails, such as that that would be afforded by *Potamogeton* or *Nymphaea*, both of which occur in Ghana. This apparent conflict of opinion regarding transmission may only be a reflection of the seasonal fluctuation in snail densities and concomitant infections and certainly underlines the need for careful longitudinal epidemiologic studies in the area as a whole.

In Kainji Lake, the snail intermediate hosts of both *S. haematobium* and *S. mansoni* are now in evidence, and transmission of the parasites in settled areas is taking place, the mean prevalence rates of the two schistosome infections in 1970 being 31 and 1.8%. These observations, made 2 years after closure of the dam, also established that the snails were still confined to scattered foci.

In Lake Nasser, transmission of *S. haematobium* takes place around the entire perimeter as a consequence of the large colonies of *B. truncatus* present on algae-covered rock surfaces. No species of *Biomphalaria* have been found in the lake. An inevitable increase in transmission of *S. haematobium* and perhaps *S. mansoni* is predictable in relation to the development of irrigated areas supplied from the lake.

Available evidence from the major man-made impoundments in Africa therefore clearly indicates that transmission of schistosomiasis is taking place in the main body of every lake as well as in the existing irrigation works. Despite the attempts to provide alternative water supplies in some resettlement villages, contamination of the environment through domestic, occupational, and recreational contacts by the new settlement and resettlement populations has resulted in new and increased transmission patterns in Africa.

Thus the containment and abatement of schistosomiasis calls for management of the impounded water by means of shoreline sanitation, education of the human population to improve its habits in disposing wastes and excreta, and sanitary engineering to minimize the contacts between man and lake water. These measures are particularly important in view of the impossibility of applying molluscicides over an entire lake to control the snail populations chemically.

INSECT-BORNE DISEASES

The ancient impoundment and irrigation system of Anuradhapura in Ceylon is a classic example of an engineering marvel that proved somewhat less than a marvel in health terms; one third of the population was wiped out by man-made malaria. In more recent times, devastating epidemics of malaria have been recorded following construction of the Sukkur Barrage in Pakistan and the Mettur Dam in India. The danger of outbreaks of malaria as a result of dam construction was realized by the Tennessee Valley Authority in the 1930's and was circumvented by shoreline sanitation, periodic water drawdowns, and insecticide application. Russian and Romanian health authorities paid particular attention to malaria abatement in their newly constructed reservoirs and irrigation systems. The increased amount of land devoted to rice cultivation in irrigated areas has in the past given rise to epidemic malaria in the southern United States and has contributed to the spread of malaria in Portugal, Greece, Venezuela, and California. The recent introduction of irrigation water into the Kano plain in northwestern Kenya has raised the population of *Anopheles gambiae* by 70 times. Two clear-cut examples of malaria outbreaks directly ascribed to dams and irrigation systems come from Tanzania, namely, a *funestus*-transmitted epidemic originating from a weed-grown impoundment on a tea estate near Amani in 1957 and a *gambiae*-transmitted epidemic in a 5000-ha area of irrigated sugar cane south of Moshi in 1951. A new irrigated area can be especially vulnerable, as witnessed by the buildup of malaria in the Gezira irrigation scheme, Sudan, between 1925 and 1935 as a result of the influx of farmers from malarious areas as far away as Nigeria. Conversely, there are numerous examples of nonimmune immigrants falling victim to malaria as soon as they entered a malarious region.

The great new African man-made lakes have not shown any patent malaria resurgence, but the water-filled hoofprints between the high-water marks and the low-water marks on Lake Nasser are perfect breeding places for *A. gambiae* should it succeed again in extending its range northward from the Sudan and repeat the malaria outbreak of 30 years ago, when the mortality rate in Abu Simbel rose from 2 per 1000 per month in 1941 to 34 per 1000 per month in 1942. Moreover, the new irrigation systems would greatly multiply the numbers of the existing vector *A. pharoensis*. The lush aquatic vegetation along the shores of Volta Lake could produce large populations of *A. funestus*, although unusually high numbers of larvivorous fish have been observed in the northern part of the lake.

The transmission of arbovirus diseases is associated mainly with the irrigation areas linked to the dams. Most thoroughly studied is the transmission of western encephalitis by the mosquito *Culex tarsalis*, which breeds in the outflows at the ends of the irrigation systems in the United States, particularly in California and the Rocky Mountain states. A related problem is created by *Culex tritaeniorhynchus*, the vector of Japanese encephalitis (JE) in eastern Asia, where breeding is particularly associated with irrigated rice cultivation. The development of dams in the Mekong Valley could exacerbate the situation. *C. tritaeniorhynchus* also extends across Africa as far west as Senegal, but JE has not been identified there. Another African species that could multiply in irrigation systems and impoundments is *Aedes caballus,* the vector of Rift Valley fever. The two important arboviruses transmitted by the domestic mosquito *Aëdes aegypti,* namely, yellow fever and dengue with its hemorrhagic form DHF, would not be expected to increase with the man-made lakes and irrigation systems. In reality, however, opportunities for the breeding of their vectors may increase, since the experience in resettlement villages is often that the pumping systems for piped water supply go out of order and large quantities of substitute water are stored in the houses.

Onchocerciasis in Africa is mostly transmitted by *Simulium damnosum,* whose larvae breed in the rapid sections of streams and rivers. The effect of impoundments is beneficial insofar as they drown out the breeding places for several kilometers above the dam. Although breeding may subsequently take place on the spillways and below the dam, the larvae may be artificially flushed away by opening the sluice gates, or insecticide may be administered to the outflow from the dam itself. A thorough program of *Simulium* control was necessary during the construction of the Volta and Kainji dams.

In tsetse-infested areas, there is a continuing danger of recrudescence of trypanosomiasis, since the extensive shorelines of the impoundments will constitute harborages for tsetse wherever they become lined with high vegetation, as they have in the Kossou and Kariba impoundments. There is evidence of decimation of cattle having been caused by bovine trypanosomiasis in the Lake Kariba area between 1962 and 1966. The contact of tsetse with man will be increased owing to the attractiveness of fishing boats and other lake shipping for these vectors.

RESETTLEMENT OF POPULATIONS DISPLACED BY THE MAN-MADE LAKE

In contrast to the dams constructed in uninhabited terrain in northern countries, large impoundments now being constructed in Africa and elsewhere in the tropics inundate territory occupied by sizable populations. Although the area around the River Niger that is now Kainji Lake had a population density of <10 people/km^2, the total impoundment of 1500 km^2 required the displacement of about 42,000 persons. The formation of Volta Lake, inundating some 9000 km^2, displaced a population of 80,000 persons, all of whom had to be resettled. The number of Egyptians and Sudanese demanding resettlement because of the impoundment of Lake Nasser amounted to 120,000.

If sufficient land is available, resettlement may be possible quite close to the shores of the new man-made lake, as it was at Lake Kariba, Volta Lake, and Kainji Lake. If land is scarce, the displaced population may have to be transferred to a new area at a distance of hundreds of kilometers, where they may have to face environmental hazards never experienced previously. The population to be uprooted and relocated is sometimes the bulk of an agricultural district, as it was in the Bandama Valley in the Ivory Coast, or even an entire large community, as it was at Wadi Halfa, Egypt. The Wadi Halfa community was moved 480 km to Khashm-el-Girba, near the Atbara River, where their staple diet was to be different and they were liable to meet with malaria, onchocerciasis, kala azar, and other serious anthropod-borne diseases for the first time. The road from Kossou to the resettlement area at San Pedro in the Ivory Coast runs through a sleeping sickness area, and the tsetse fly is present around San Pedro itself, another example of the hazards that must be foreseen and counteracted.

All experience hitherto gained emphasizes the formidable nature of any resettlement project, particularly in the respect of allocating and delineating land and of preparing the community physically and psychologically for their transfer. At Lake Kariba a considerable part of the valley community refused to move and suffered from famine as a direct result. At Kainji Lake, though resettlement was on the whole successful and atraumatic, there was delay in allocating land and paying compensation to the inhabitants of the most heavily populated sector, who were already suffering from the disruption of the onion farming that was their principal source of livelihood. On Volta Lake, resettlement was accomplished in a relatively smooth manner through prolonged and devoted work by the team concerned with it; nevertheless, it is doubtful whether the reallocated land will be sufficient for the future needs of the resettled population.

Specific health hazards are inevitable in the resettlement process, since the population densities increase in the reception zones and previously isolated communities are intermingled. Both of these factors are notorious for favoring the transmission of any communicable disease in an area where it previously existed at a low endemic level. The intermingling of nonimmunes with infected persons constitutes an explosive mixture, as is already well known in malariology; this statement could also apply to diseases such as poliomyelitis and water-borne, arthropod-borne, and soil-transmitted infections in general.

The health adviser in a resettlement project has a clear enough role. He must insist that communications, water, and environmental sanitation are basic essentials, even if these existed only in a rudimentary form beforehand. He must also stress the importance of intensifying the effective routine preventive measures now available for nearly all the common mass diseases of man, from malaria to tuberculosis and poliomyelitis, and of undertaking such action in combination with health education. His work should provide a basis for the health institution responsible for covering all the population affected by the dam.

UNSUPERVISED RESETTLEMENT OF THE LAKESHORE

As the great impoundments of Africa near completion, their shorelines become populated to a greater or lesser extent not so much by the original farmers as by immigrant fishermen. Numerous camps and settlements growing up along the shore are characterized by a lack of sanitary facilities and clean water supply. Here, rather than in the original construction workers, we can look for the source that infects a man-made lake with schistosomes. Even on the shores of Lake Nasser in the desert and Lake Kariba in the midst of game plains, unsupervised immigrant populations exist in sufficient numbers to contaminate the lakes. The situation on Volta Lake and Kainji Lake has been more thoroughly documented and can be described in detail.

In Volta Lake the 'biological explosion' that followed its formation involved first the aquatic weeds, then the fish, and then the snails, which transmit urinary schistosomiasis. The newly created rich fishing grounds attracted approximately 20,000 fishermen and their families, who settled themselves in over 1000 villages along the 6000 kilometers of lakeshore, usually without piped water supplies. The majority of these immigrants came from the Volta delta, a region with a high endemicity of urinary schistosomiasis. The 'seeding' of the lake by the infected urine of the fisherfolk led to a spread of urinary schistosomiasis among the families of the resettled farmers. It was found that 90% of the children in three resettlement villages situated within 1 km of the lake had become infected by 1968, and these villages were supplied with piped water. Among the immigrant fisherfolk themselves the intensity of transmission had evidently increased in certain areas of the lake, where the prevalence rates of infection surpassed the endemic level normally found in their original home in the Volta delta.

On the other hand, in Kainji Lake, which has a complete turnover of the water content annually and in which water stratification has only occurred once since 1968 (and then only for a month or two), weed formation has not been a problem along the 350 km shoreline. By late 1970, there were more than 300 fishing villages or camps of varying sizes on the lakeshores. Preliminary surveys in 1970 revealed the presence of infected *Biomphalaria pfeifferi* at Rofia-Jinjima, where the one and only lakeside road meets the water. At Shagunu and Amboshidi the lakeshore is not suitable for snails, except possibly in nearby creeks. In the main onion-farming area of Yelwa, both *S. haematobium* and *S. mansoni* infections were present, *S. haematobium* being much more common. No new infections were found among the former inhabitants of the riverside town of Bussa in their new home at New Bussa, 16 km from the lake and served by piped water. Neither were any new infections found at some smaller villages resettled at some distance from the lake.

HEALTH PROTECTION AND DAM CONSTRUCTION

Intrinsically, dam construction labor forces do not differ from those assembled for any other large public work. A dam construction labor force usually counts 7000–10,000 unskilled laborers drawn from the country in which the work takes place. The prospect of employment attracts a much greater number of persons, often from considerable distances. In recent years the policy of dam constructors has been to provide labor forces with good housing in pleasant towns with many amenities and thus to encourage them to bring their families. This development is most desirable and results in greater stability of the labor force, better nutrition (with wives doing the cooking), and less venereal disease. However, it does imply that the total population in the construction town will rise to over 20,000. These people, and the derelicts who fail to get work or become unfit, inevitably bring with them all the endemic diseases of the country and create an area of high population density in which potential for communicable disease is high.

Furthermore, since the construction work takes place close to water, the possibilities of transmission of water-related diseases increase to include intestinal infections everywhere, malaria and other arthropod-borne diseases almost everywhere, schistosomiasis in many tropical areas, and trypanosomiasis and onchocerciasis in Africa. Standards of environmental hygiene in construction towns may be high, but the problem of sanitation on the working site is difficult. Two particular hazards are thus created, namely, the spread of endemic and epidemic diseases in the labor force and its dependents and the introduction of diseases into an area previously free of them.

In contrast to the serious outbreaks of malaria and yellow fever among workers constructing the dams and lock systems of the Panama Canal, there has been no subsequent record of any serious outbreaks of communicable diseases during the construction of any major dam. On construction sites in Africa, such as Kainji Lake, Volta Lake, and Inga, the workers have been protected from the particular hazard of onchocerciasis by means of insecticide applications against the *Simulium* blackflies breeding in the river. At present, evidence that new endemic disease hazards have been introduced by a dam labor force is lacking. However, schistosomiasis and hookworm have been known to spread to some extent in certain labor forces, though they did not constitute a serious problem, and thus there is the possibility that a permanent infection might be established. In view of this nagging uncertainty, it would be desirable for health consultants to visit dam projects while they are in the construction phase.

ENVIRONMENTAL HEALTH REQUIREMENTS

The population groups displaced as a result of the construction of man-made lakes differ widely in their culture, levels of prosperity, allegiance to authority, and material requirements, but certain characteristics are common to all. They need water to drink and for domestic purposes; they produce wastes, which, if they are not hygienically disposed of, will endanger the health of their families and neighbors as well as of themselves; they bring new forms of sickness into the area and are susceptible to unfamiliar health hazards on their arrival; they need to eat, which usually means the establishment of markets and a degree of food processing and transport; they must be housed and clothed; they have to care for their domestic animals; and they need to produce food and cash crops or else to secure other employment to keep themselves and their families.

Authority and organization are essential prerequisites for the establishment of orderly communities, and, although schools, police, and places of religious worship are among the first priorities, the most pressing need is the preservation of health. To attain this objective, disease must be prevented by the provision of a healthy environment, controlled by anticipating and removing hazards, cured by providing medical attention and health services, and forestalled in the future by the study of relevant problems and the anticipation of dangerous situations. The education of the population, and in particular of children, will in time enable them more and more to look after their own living conditions.

These needs can be foreseen, and planning for them can be ensured in advance. Populations will move spontaneously under the physical and economic pressures of the new lake; it is useless to try to stop them, even if it were desirable. If they move without suitable preparation on the part of the authorities, the outcome is predictable: a breakdown of law and order and the upspring of unplanned agglomerations, where insanitary housing encourages the outbreak of epidemics, the pollution of the lake, and the spread of diseases. However, the identification of basic needs at the planning stage gives the authority the opportunity and sufficient time to create conditions conducive to the health and prosperity of the incoming settlers. These conditions would include the following: well-built and intelligently planned villages, which need not be much more expensive than haphazard development; a system of local government and infrastructure services; a health system based on local personnel trained in anticipation of the need; provision of market and trading facilities; and possibly a tax structure to pay for the running of the settlement in the future.

As far as the physical requirements of settlements are concerned, the usual measures of rural development, conditioned appropriately by the presence of the lake, will be taken. The communities displaced by the filling of the lake will probably be farmers and herdsmen, who had been attracted to their old sites by the fertile valley floor of the flood basin. They will presumably want to continue in their traditional occupations and are likely to be resettled downstream, on newly irrigated land, or some distance from the edge of the water. On the other hand, the fishermen who migrate into the area will approach the water as closely as possible, and it is their wastes that will pollute the lake water, which they and their families will drink and in which they will bathe and wash their clothes in the normal course of events.

Unless haphazard settlement can be checked and the immigrant population can be housed in preplanned communities, it will never be possible to provide the necessary sanitation services. Water that is safe and convenient must be a first priority if water-borne epidemics are to be avoided. The new water level in the lake will eventually raise the groundwater level for some distance around, so that wells can be used where the geologic conditions are suitable, but, since this change will not occur before the lake is full, other means of supply will be needed in the interim for the early settlements.

Excreta disposal either on an individual, familial, or institutional basis will be necessary to prevent the grosser sources of lake pollution. Washing slabs may be constructed in the village to relieve women from the necessity of entering the lake water with the attendant hazard of contracting schistosomiasis; swimming facilities may similarly prevent children from contracting the infection, but all precautions should be taken so that these additional water points do not themselves become foci of transmission. Segregation of animal watering places from those for human consumption may be desirable. Solid refuse must be disposed of otherwise than by throwing it into the lake.

HEALTH SERVICES REQUIREMENTS

Whenever a special program of development in a specific field of activity, supported by specific technical tools and a special budget, is superimposed on a general development program, health problems implied in the foreseeable changes are also considered in a specific categoric way. This consideration is perfectly justified, since it is quite true that ecological changes may involve new health hazards requiring new services to cope with them. However, two other aspects are often neglected: (1) the health situation prevailing in the area before the inception of the program of development, which will condition to a certain extent the success of the program, and (2) the structure and level of development of the health services in the area concerned, especially of the basic health services.

So far the experience with man-made lake projects has usually been that, although the ecological and epidemiologic aspects have been taken into account in a more or less satisfactory manner, the implementation and development of a health service structure (to cope with present and prospective health hazards) have been regrettably underestimated or neglected. Moreover, when the responsibility for health along with other concerns of the project was placed under an ad hoc institution (the dam authority or valley authority), the normal authority (the health ministry) has sometimes relinquished its duties.

For these reasons a responsible health institution, preferably part of or closely related to the health ministry, should be established to deal with the area concerned as soon as a development project involving a man-made lake has been decided on. A public health administrator-planner, assisted by advisers in the environmental fields of epidemiology, ecology, biology, sanitation, and any others that are required, would make a comprehensive diagnosis of the situation and establish base lines, including a complete inventory of the existing health facilities. He would then make a prognosis, taking into consideration the predictable health hazards and the demographic factors, with regard to the population already settled in the area; the labor force, and eventually their families, brought in for the construction of the dam and allied works; the population displaced by the lake and demanding resettlement; and the immigrants attracted to settle along the new shoreline.

Long-term plans and short-term programs would then be elaborated accordingly for the development of comprehensive basic health services covering the new communities. Mental, social, and welfare services should be grafted on these to alleviate the emotional stress of migration and minimize the 'pathology of social adaptation.'

These plans and programs for the area concerned should fit into those already established at the national level. They would be incorporated in the national health plan, if there is any, or at least in the health priorities in the general socioeconomic development plan. The programs would be coordinated as closely as possible, preferably by a coordination unit, with the general health services and with specific programs, such as malaria eradication, smallpox eradication, and family planning, the ultimate objective being their integration. A joint demonstration zone could profitably be located in the area of the man-made lake project.

The health services thus created with the substantial support of the development program for the man-made lake area could act as a model and as a stimulus for the general development of health services in the rest of the country.

PLACE OF PUBLIC HEALTH IN MAN-MADE LAKE ADMINISTRATION

Experience with the new man-made lakes has shown that the allocation of authority for public health matters often fell short of being satisfactory, and the remedy evidently lies in proper planning at the inception of such projects. Health planning along broad lines should be done in the earliest stages, i.e., when the dam itself is being planned. Forecasts of the new population should be made so that the health service needs may be estimated and the pressure on the environment from grazing or fishing may be restrained accordingly. Sites for settlement should be chosen, and road accesses should be planned. The needs of the different categories of settlers should be ascertained, and the program of construction should be developed so that at least the nucleus of each settlement is ready to receive the first-comers in each category. The cost of housing, water, latrines, and other construction works should be estimated, programed, and budgeted for by the dam authority.

The appropriate authorities and institutions must be set up at the same time. Whatever the system of local government in the country, it must be ready for implementation before the arrival of settlers. If a local population already exists in the area, the problem will be one of strengthening local institutions to assume the new responsibilities. If no local population exists, the problem is more difficult, since as a first step a new authority must be set up at the time that the new village itself is being established.

It is at this stage that coordination between the dam authority and the regular departments responsible for the welfare of the country will be especially important. The health authorities in particular are going to be concerned with construction as well as maintenance of environmental facilities; to what extent they delegate their responsibility to the local institutions will depend, among other considerations, on the availability of suitable personnel for training as doctors, engineers, and sanitarians and in other related disciplines. Training must start at the earliest possible moment if the staff are to be ready to take up their duties when the need arises.

Because new populations will be arriving from elsewhere, the enforcement of sanitary and other regulations will become inevitable. The better the initial planning, the less enforcement is likely to be needed. It is easier to attract settlers to an area provided with prebuilt amenities than to use force to stop them building haphazardly elsewhere. Education of the public in the practice of hygiene and the creation of a local sense of participation in the community are likely to be a more efficient means of instilling sanitary habits than enforcement, though a degree of compulsion may be necessary for the common good. However, sanitary surveillance is going to be needed for some time to a greater or lesser extent, and it is important that the staff be armed not only with the necessary training and experience to know what has to be done but also with the weight of public opinion reinforced by suitable legal powers to ensure that preventive measures are implemented for the benefit of all.

When an irrigation system is planned, and the crops from irrigated farming are counted as assets to be derived from the formation of the lake or construction of the dam, the maintenance of a healthy labor force to cultivate those crops is essential. Since endemic diseases, such as malaria or schistosomiasis, will logically be expected to increase the overhead costs by reducing the efficiency of farm labor, the necessary precautions against sickness from such diseases are proper charges on the project and may well prove to be profitable economically as well as desirable on humanitarian grounds.

Just as the benefits gained by the man-made lake may be foreseen and assessed, so may the remedial and precautionary measures necessary to counteract ill effects. Consequently, the principle should be accepted that those benefiting should assist those suffering; for instance, part of the revenue from electricity sold should be used to pay for health services and to provide environmental facilities in new settlements for populations displaced by flooding. In drawing up the budget of the project as a whole, one should include public health expenditure as a legitimate charge.

Therefore a single authority seems to be called for to ensure that debits and credits are accurately balanced, to receive revenue, and to be responsible for disbursements therefrom for all costs arising directly or indirectly from its generation. There are many ways in which man-made lakes can improve health and well-being if intelligent foresight is used in their planning, maintenance, and operation; neglect at any of these stages, however, may result in jeopardizing the health or the lives of those living near the lake to provide economic benefits for another section of the population. The onus for ensuring that this does not happen must rest clearly on a single body so that divided responsibility may not be used as an excuse for neglect.

ENVIRONMENTAL RESEARCH

In major projects it is increasingly the normal practice to devote a percent of the profits to research into improved methods and development of new techniques and equipment. If commerce and industry find this profitable, so will the dam authority. Setting up a continuous program in this field, not data collection or the recording of conditions but a search for simpler, cheaper, and more efficient ways of reducing disease and improving health, will prove a most rewarding investment in the long run. Well before the dam construction starts, pilot studies should be undertaken on the most appropriate forms of housing and sanitary installations with respect to the local way of life, local soil and climate, and maximum use of local materials and skills. Stress should be laid on simple solutions that later could be applied throughout the country.

For long-term health studies the new lake constitutes an ideal location, since the health problems characteristic of man-made lakes and associated irrigation systems only become apparent as they mature and as epidemiologic patterns develop. Just as is true of the plant successions that form the background of these patterns, a dynamic process characterizes infestations of insect vectors and snail intermediate hosts and the colonization of the new environment by man. Many of the ensuing health problems are directly related to man's activity and his pollution of the environment. In many of the existing impoundments, serious health hazards are already encountered, and potential ones are predicted. Unfortunately, the information available is scanty and may be representative of only a very small part of a given problem in time and place.

There is unquestionably an urgent need to obtain information by continuous study in order to observe changes that may occur in time and place and therefore to avoid the fluctuations and vagaries that arise from sporadic sampling, particularly where schistosomiasis is concerned. Point prevalence surveys offer valuable information, but regular assessments of the rate of infection, the so-called incidence, are more valuable in establishing relationships between the observed infection levels and the constantly changing conditions that give rise to them.

We know that marked increases have occurred in the prevalence of schistosomiasis in certain man-made lakes, but, since the full public health significance of the disease has still not been assessed in quantitative terms, longitudinal epidemiologic surveys must be made to obtain such assessments. The changing ecology of the impoundments must be observed, and human settlement and activity must be borne in mind if we are to improve both water and man management in relation to these changing conditions.

Such continuous observations obviously call for a special project that would be worthy of interagency support on an international basis. From the start it should have a clear concept of the objectives sought with provision at the planning stage for appropriate funding and specialized personnel. There is also a need for a training center, where health personnel from various countries can gain the additional expertise necessary to understand the problems of man-made lakes. It is encouraging that a project of research on the epidemiology and methodology of the control of schistosomiasis in the major man-made lakes in Africa is being supported by the United Nations Development Project following a request by the World Health Organization. The extension of research and monitoring activities to embrace all disease vectors and the underlying ecology of the lakes appears necessary to ensure that their health hazards be continually kept to a minimum.

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