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DOMESTIC WATER SUPPLY AND SANITATION IN IRRIGATION PROJECTS

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DOMESTIC WATER SUPPLY AND SANITATION IN IRRIGATION PROJECTS

Prepared for the Office of Health,
Bureau for Science and Technology,
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under WASH Activity No. 208

by

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EXECUTIVE SUMMARY

Many Third World irrigation development projects have been linked to significant increases of waterborne and water-related diseases. Poor project design and management have increased human exposure to these diseases by forcing people to use irrigation water for non-agricultural purposes such as drinking, cooking, bathing, and disposing of human wastes and by creating sites for the breeding of vectors. It is apparent that such negative effects on human health are counterproductive in terms of the objective of irrigation development which is increased agricultural production.

It is the purpose of this report to draw the attention of irrigation program planners and designers to the health problems associated with irrigation projects and to recommend engineering, managerial, educational and related measures that will help to overcome these problems. While there are a wide variety of diseases associated with irrigation this report will focus on the three most widespread diseases--schistosomiasis, malaria, and diarrheal diseases.

Particular attention is drawn to the Gezira-Managil irrigation project of Sudan. Over a period of 25 years the irrigated area was increased and the use of biocides was gradually intensified. Agricultural pests caused sharp changes in crop production, and the incidence of disease, particularly schistosomiasis, increased at alarming rates. Malaria initially declined but later displayed sharp episodic increases and changes in patterns following agricultural intensification.

Several control measures are recommended to control schistosomiasis. They include:

- providing safe domestic water supplies,
- modifying human behavior (education),
- modifying snail habitats,
- implementing biological controls,
- applying molluscicides, and
- providing chemotherapy.

Costs to control schistosomiasis in Sudan through an integrated strategy using most of the above measures were modest, averaging about $2.40 per capita per year for continued operations.

Malaria can best be controlled through a multi-faceted approach similar to that for schistosomiasis with appropriate modifications for different vectors. Improved water supplies are not as effective for malaria control as for schistosomiasis except in relation to the distance between the water supply, which might be a mosquito breeding point, and human habitations.

For other water-related diseases, improved water supplies are a necessary, but usually not sufficient, condition to improve health. A multi-faceted approach is again necessary to combat a variety of potential diseases. Particularly important are health education, community participation, and the provision of sanitation facilities. Immunizations and oral rehydration therapy are also important components of a health program.

For Sudan, the cost for an integrated program of control of major irrigation-associated diseases was $6 per capita per year. The costs for Sudan should be applicable to other tropical and sub-tropical countries.

The cost of incorporating health measures into irrigation planning, design, and operations is usually a small percentage of the total irrigation infrastructure costs. The returns, however, on investments in health are likely to be recouped through increased human productivity and overall well-being.

Chapter 1

INTRODUCTION

The initial focus of this study of domestic water supply and sanitation in irrigation projects was to determine the extent to which health and sanitation activities are integrated into irrigation project planning and implementation in developing countries. A literature search was conducted and interviews were held with several specialists in USAID, the World Bank, PAHO, and other organizations concerned with irrigation and health. No instance was found in which engineering, vector control, human behavior, and other project design components were combined to reduce the disease side effects of irrigation projects.

Many Third World irrigation projects have been directly linked to acute increases in waterborne and water-related diseases. Such projects invariably create, ameliorate, or expand the habitats of disease-carrying vectors and hosts, most notably those for schistosomiasis (bilharzia)*, malaria, river-blindness (onchocerciasis), and diarrheal diseases. Poor project design and management increase human exposure to these diseases by inadvertently promoting the use of irrigation water for non-agricultural purposes, such as drinking, cooking, bathing, washing, swimming, and human excreta disposal, and by creating breeding grounds for disease vectors. It is apparent that such negative effects on human health are counterproductive to the objective of irrigation projects which is to increase agricultural production.

As a result, it was decided that the AID-funded Water and Sanitation for Health (WASH) Project should introduce irrigation system planners, designers, and operators to methods for improving health related to non-agricultural water use. Further, it was felt that guidelines were not needed, but rather a report which describes proven techniques and strategies for irrigation planners and engineers and includes costs and measures of effectiveness. This report is not meant to be a definitive technical manual but rather to provide useful recommendations for solving interdisciplinary problems in irrigation and health. It is limited to the diseases which are most common within irrigation projects in developing countries: schistosomiasis, malaria, and other waterborne diseases.

During the preparation of this report very few case studies were found of irrigation projects which have successfully instituted health programs as a part of their overall strategy. The Gezira-Managil Irrigation Scheme in Sudan has been used in this report as a case study and offers many insights for use in developing future projects. Many questions remain, however, and it is expected that this report will generate interest among irrigation and health professionals in attempts to find common solutions to diseases associated with irrigation development.

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* The term "schistosomiasis" is used in this report as a synonym for the disease "bilharzia." In Africa, "bilharzia" is the preferred term.

Chapter 2

GEZIRA-MANAGIL IRRIGATION SCHEME

Since 1950 the increased need for food and for cash crops such as cotton has led to the intensification and expansion of the large Gezira-Managil Irrigation Scheme along the Blue Nile River in Sudan. The system, constructed in 1925, grew from its original 500,000 hectares to 880,000 hectares by 1987, first through a series of small increments starting in 1950 and then more rapidly and intensely in the late 1960s to support the cultivation of wheat, sorghum, vegetables and eucalyptus forests in addition to the original crops of cotton and legumes (Figure 1). Cotton production expanded until 1970, and wheat production expanded rapidly until 1977.

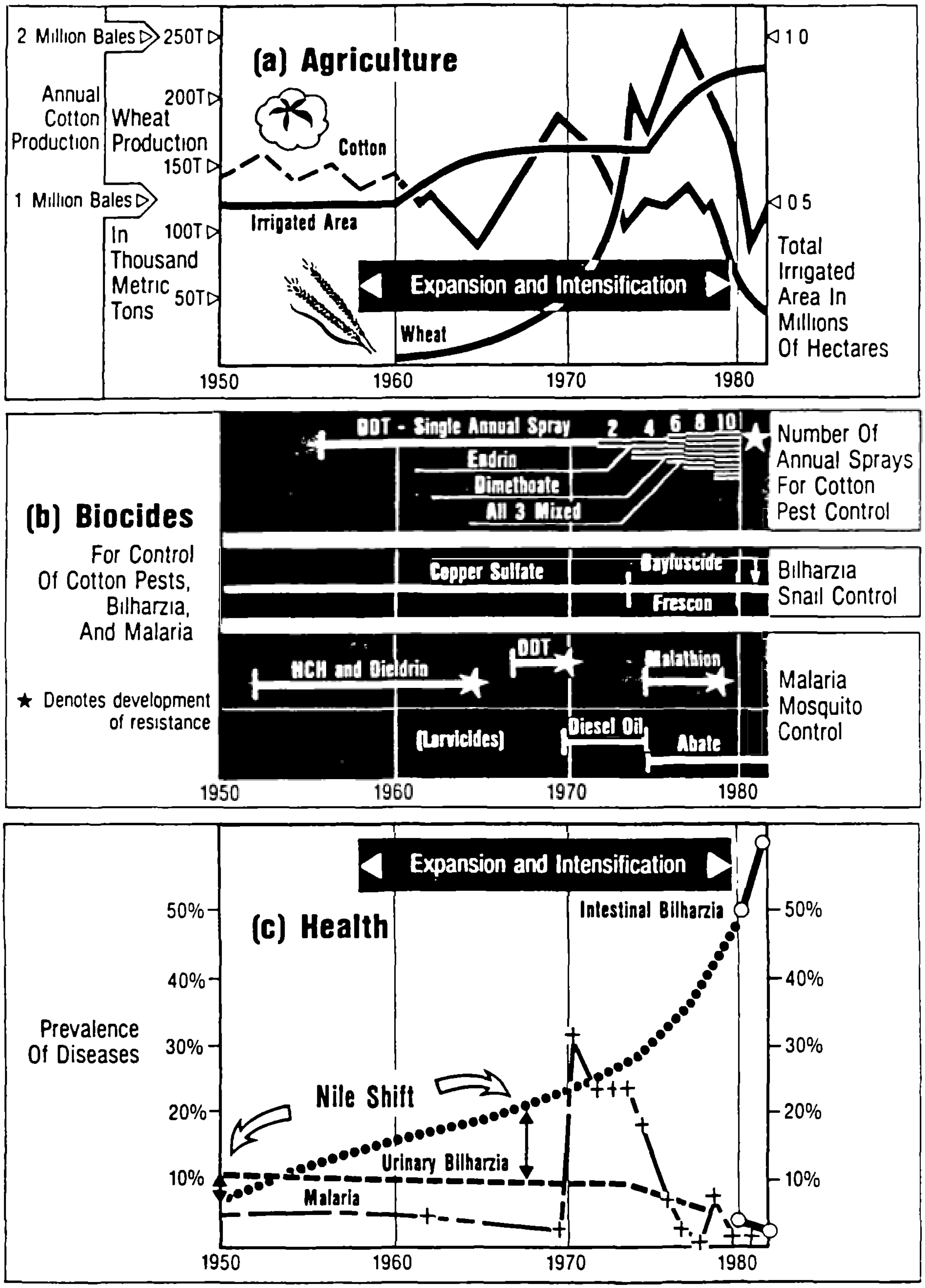
During the 1970s the expansion of irrigation resulted in the proliferation of agricultural pests, aquatic weeds, snails, and silt in the canals. Cotton was infested by the whitefly which damaged the plant and made the fibers too sticky to be ginned. People were exposed to anopheles (malaria-carrying) mosquitoes at night, to bilharzia-carrying schistosomes in the water by day, and continuously to contaminated drinking water.

From the half-million residents within the area affected by the scheme at independence in 1950, the population rose to over two million in 1987, primarily due to the demand for additional labor on the farms. Funds were not available for concomitant increases in community water supplies and sanitation facilities, thus the quantity per person of safe water declined considerably. Along with the ecological changes, the increase in population led finally to massive outbreaks of disease at the same time that the cotton pests increased beyond control.

2.1 Cotton and the Whitefly

Despite early success in managing the whitefly pest of cotton by agricultural practices, routine annual spraying of cotton with DDT after 1960 to combat this pest led to substantial increases in cotton production. Then, endrin and dimethoate were added to the chemical mix and applied to expanded areas planted with cotton, yielding a peak production of 1.5 million bales of cotton in 1970 (Figure 1a).

After 1970, however, the overuse of the pesticide caused the whitefly to adapt to it genetically and was no longer effective to control the fly with a single spraying. Gradually the number of sprayings was increased to two, then to four, and finally ten per season (Figure 1b). The insects were becoming resistant to the biocides, and apparently the enemies of the whitefly were more affected by the sprays than the whitefly itself. Thus, more and more chemical was needed to control it. By 1978 over 14 kilograms of DDT were sprayed annually on each hectare of irrigated field--over five kilograms per person or about 11,000 tons total (Eveleens, 1983). This chemical worked its way into human and animal milk and other food in the region, with unmeasured but serious risks to human health. Unfortunately even this extravagant use of pesticides was ineffective and, after a brief respite in 1976 due to increased spraying, cotton production fell to historic lows in 1981 and 1982 (Figure 1a).



History Of Agriculture And Health In The Gezira-Managil Irrigation Scheme 1950-1980

Figure 1

2.2 Malaria and Wheat

Malaria has been a recurrent but manageable problem since the irrigation scheme began, occurring for a few months after the rains (Figure 2a). Blood examinations of suspected cases showed a prevalence of 20 percent in October of a bad year.

In the early 1960s, however, in the initial stage of agricultural intensification, a second malaria season appeared during February and March (Figure 2b). This was touched off by the additional irrigation of citrus trees and eucalyptus forests during the winter months. This second peak was further amplified by the addition of wheat and its irrigation about 1970. Finally, when early irrigation was added for sorghum, peanuts, and vegetables, malaria was being transmitted all year long (Figure 2c).

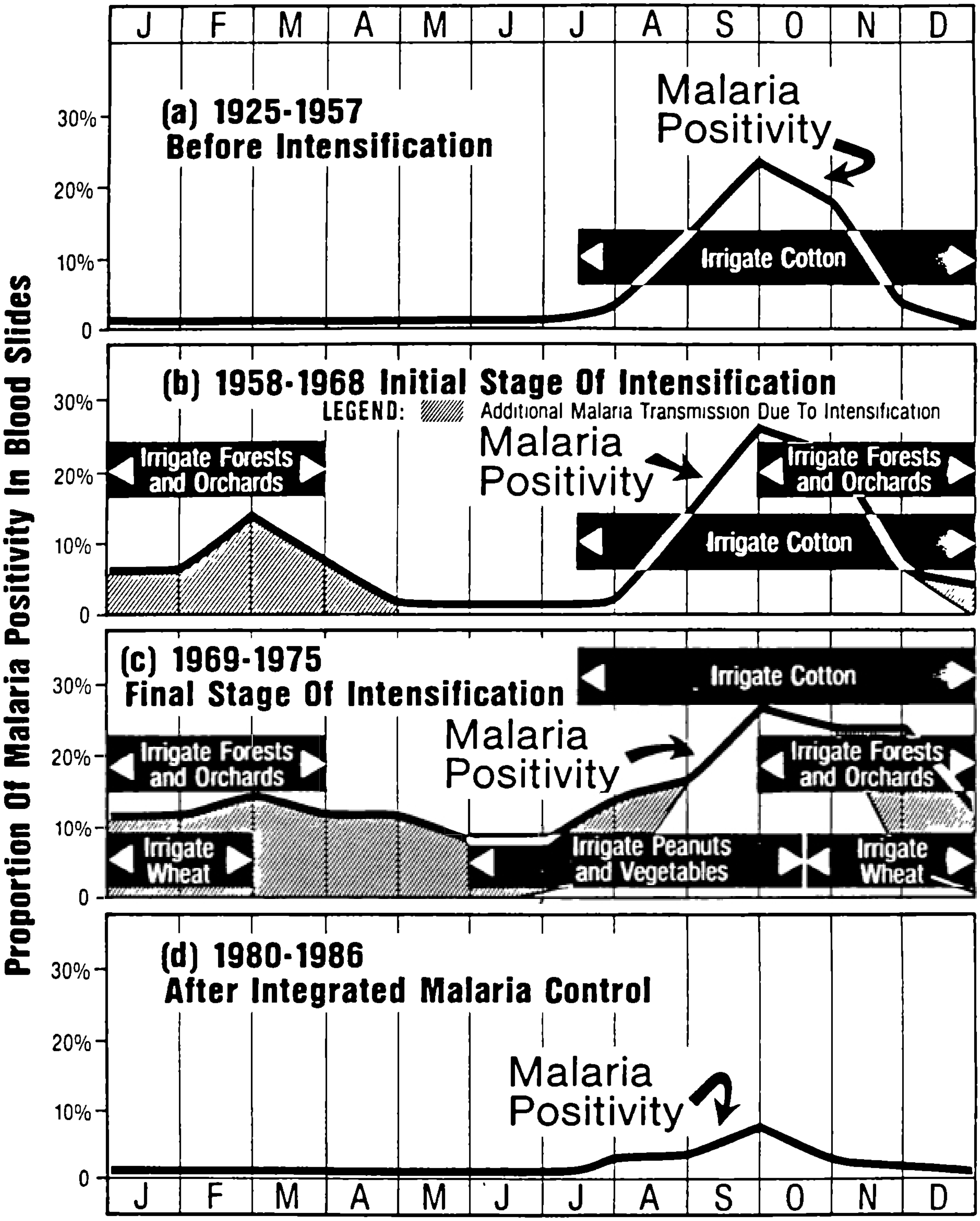
With the extended irrigation season, the canals were full for over five months. Increased irrigation flows in July and August meant increased diversion of the waters of the Blue Nile into the canals. The Blue Nile is heavily laden with silt at that time of the year due to rains in Ethiopia. The increased flow thus caused increased silting with deposits rich in nutrients and the subsequent overgrowth of aquatic weeds resulting in blockage of the canals. The aging of gates and other water control structures and the increased flow led to more frequent flooding and the creation of ideal mosquito breeding grounds. The adult mosquitoes also survived longer in the moist flooded areas, giving them more time to transmit the malaria parasites.

Malaria transmission was changed in one other way due to the agricultural spraying. Aerial spraying had caused serious contamination of the field irrigation ditches with DDT. Although ineffective against the anopheles mosquitoes which had become resistant as a result of house spraying, the DDT decimated fish which eat mosquito larvae and many insect enemies of mosquitoes. Thus the ecological controls of the anopheles mosquitoes were destroyed by the same means which eliminated the enemies of the whitefly.

The expansion of malaria transmission to the entire year also caused the peak prevalence to rise above its former maximum of 20 percent. Prevalences of 30 percent became common in October in the early 1970s because the rainy season outbreaks were coming on top of an existing high prevalence of background infections (Figure 2c). It was this unfortunate additive effect which provoked a labor crisis during the 1974-75 cotton season. Soldiers and students had to be called in to assist the population stricken with malaria in picking the crop. Although malaria was held temporarily under control by using fenitrothion, another new insecticide, it was clear that time was running out, as DDT and malathion had each produced resistance in the anopheline mosquitoes after about four years of annual sprays (Figure 1b).

2.3 Schistosomiasis and the "Nile Shift"

Intensified irrigation in the Gezira-Managil Scheme also caused a significant shift in the transmission of schistosomiasis as a result of changes in the environment of the aquatic snails which transmit the disease. This biological change is called the "Nile Shift" because it was first noticed in the Nile River Valley. After covering the intensely irrigated portions of Sudan and Egypt, it has now spread to other parts of Africa.



Changes In Patterns Of Malaria Positivity With Agricultural Intensification In Gezira-Managil Irrigation Scheme 1925-1986

Figure 2

Throughout the Nile Valley two species of schistosome parasites have existed in their human hosts since ancient times. The species which initially predominated was a short-lived worm which inhabits human blood vessels around the bladder and urinary tract, causing some disease in children but usually decreasing in its effect among adults. However, the intensified irrigation in the Gezira resulted in a shift of the predominant species of schistosome from the one which affects the urinary system to the more dangerous one which lives much longer in the human body and damages the intestines and surrounding organs.

This form of schistosomiasis is associated with sugar cane in Puerto Rico, with bananas in St. Lucia, with irrigated grains in lower Egypt, and with rice in Burkina Faso. The classic fatal episode occurs when the cane cutter or agricultural laborer drowns in his own blood as the distended veins around his esophagus rupture during heavy physical exertion.

The result of the Nile Shift in Sudan was increased disease and death for the people continually immersed in the canal water such as farm workers and children at play. Health records indicated that schistosomiasis in the Gezira-Managil Scheme became pronounced soon after agricultural intensification began (Figure 1c). By the late 1970s the hospitals were noticing the influx of seriously ill people at younger and younger ages, and by 1980 the disease had spread to more than half the population.

2.4 Obstacles to Progress

While there is abundant literature describing the links between illness and irrigation projects, there is less well-known literature on the control of water-associated diseases through the use of a range of techniques. Yet rarely have these measures been factored into planning a developing-country irrigation project. Several international scientists and research organizations, most notably the World Health Organization (WHO), have produced guidelines and recommendations for vector control (not necessarily elimination) in relation to water-associated diseases in irrigation schemes.

In a review of the literature conducted for WASH in irrigation, irrigation planning, and environmental health, there was, unfortunately, no firm evidence that health, water supply, or sanitation considerations had been routinely included in irrigation planning or implementation in developing countries beyond the customary pre-project assessments and recommendations from consulting health experts. It appeared that reports generated by health consultants did not cause significant changes in irrigation project implementation in spite of warnings that disease levels would be elevated by the projects. Many proposed irrigation projects did not have an environmental health assessment. There was limited evidence that health components had been added to irrigation projects after increases of disease forced remedial actions by governments or international donors.

The benefit-cost issues related to health activities are admittedly complex within irrigation projects. The expense of poor health is not routinely studied in developing countries and reliable health cost data are sometimes lacking. Nor can economists consider costs of labor lost due to ill health as serious economic factors in countries of chronic unemployment and underemployment. However, when comparisons are made of expenses of preparing a hectare of land for irrigation versus a per-capita cost for reasonably safe water, the land preparation is usually one or two orders of magnitude more expensive.

Another difficulty of incorporating health activities into irrigation projects is that development agencies are usually compartmentalized, and each compartment is focused on specific tasks. Among AID centrally funded projects, for instance, there are two projects, the Water Management Synthesis (WMS) Project and the Water and Sanitation for Health (WASH) Project, both of which place considerable emphasis on multidisciplinary planning, but there has been little exchange of information or skills between the two projects. There are professional reasons why irrigation engineers do not wish to tackle methods of disrupting complex life cycles of disease vectors or why public health specialists do not wish to delve into canal hydraulics or crop water requirements. However, there are more compelling reasons why these professionals should seek an exchange of design information in order to prepare projects which will not compromise health to increase agricultural production.

One frequently cited reason for not incorporating health concerns in irrigation development planning is an absence of technical "how-to" and "how much does it cost?" manuals for reducing disease while building or operating irrigation systems, although numerous technical manuals on water supply and sanitation are available. In the following chapters control measures for combating specific diseases are described and costs related to undertaking these measures are presented.

Chapter 3

SCHISTOSOMIASIS

Schistosomiasis is a water contact disease that infects over 200 million people in the tropics and its prevalence is probably increasing. It is spread through schistosome eggs in human excreta which hatch on reaching water. The resulting larvae invade suitable snail hosts and multiply. The free-swimming schistosome larvae are released from the snail and ultimately penetrate the wet skin of humans.

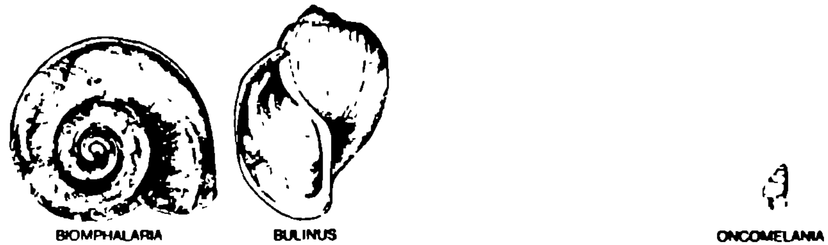
Along with malaria, incidence of schistosomiasis invariably increases significantly when irrigation projects are implemented in developing countries. For instance, prevalence of schistosomiasis has increased in project area residents from nearly zero to over 60 percent in most African water-development projects such as dam construction and irrigation. Rosenfield (1979) gives a brief but adequate documentation of these reported increases. Regrettably, more recent water projects have kept pace with earlier ones in fostering the spread of schistosomiasis. In addition, Rosenfield details a few cases where various management strategies have been employed to reduce incidence of schistosomiasis by using molluscicides, chemotherapy, and by providing safe water for domestic uses.

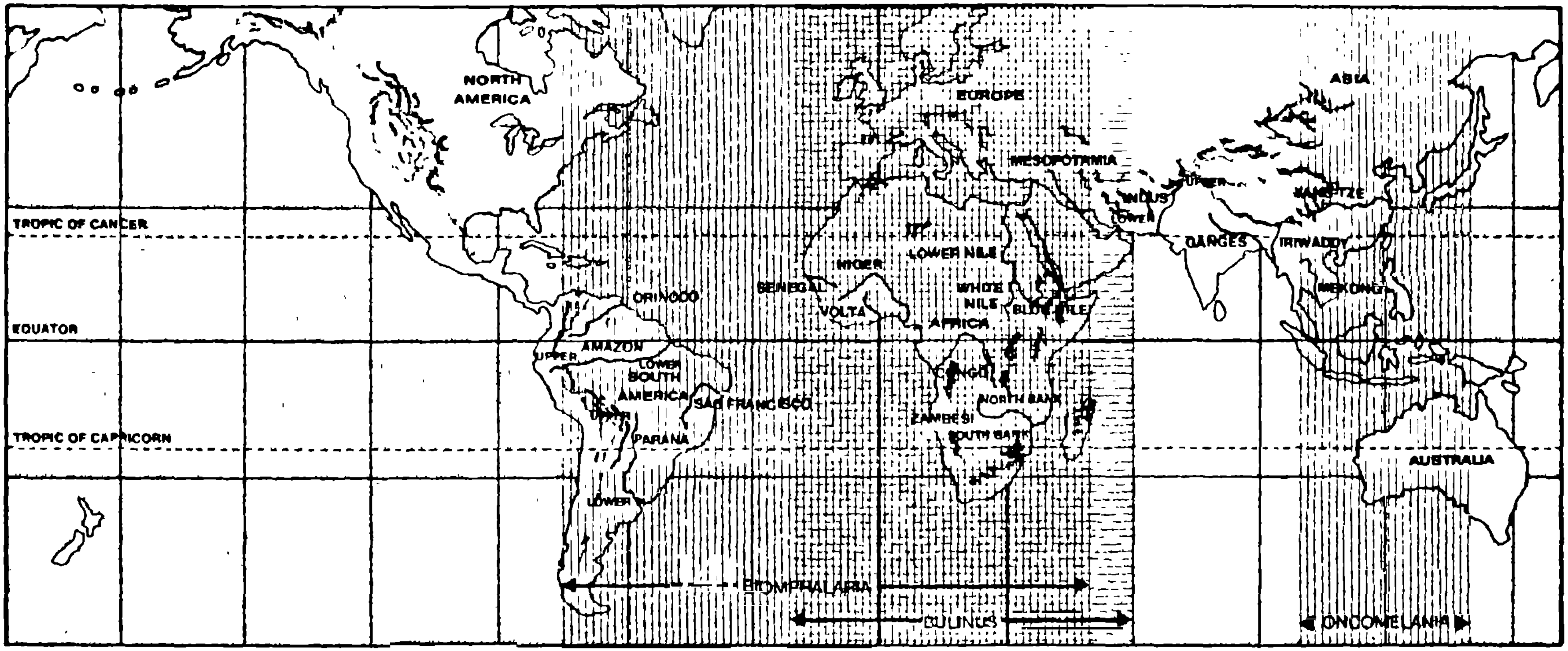
3.1 Global Distribution

The global distribution of the three main genera of schistosome-bearing snails (*Biomphalaria, Bulinus, and Oncomelania*) is discontinuous and irregular. As stated above, their distribution has also been drastically changed in the Nile River Valley and other places where large dams or irrigation systems have been constructed and where there has been an increase in disease transmission.

Although water temperatures determine the northern and southern distribution limits of these tropical snail genera, some other ecological features must determine the eastern and western longitudinal limits of each genus (Wright, 1973). The longitudinal distribution is highly discontinuous and is clearly not random. *Oncomelania* is found only in a narrow band in the Orient between longitudes 100E and 140E. *Bulinus* is found only in Africa and the Middle East between longitudes 20W and 60E, whereas *Biomphalaria* has a slightly wider distribution covering the Americas, Africa, and Arabia between 75W and 50E (Figure 3). *Bulinus* and *Biomphalaria* do not exist in Asia. The most interesting aspect of this distribution is that there are many tropical areas devoid of all three genera and many large areas where at least one genus is absent. Malacologists usually study snail habitat conditions in places where the snails are abundant but seldom study conditions in places where the snails are absent. The purpose of this analysis is to take the road less traveled and try to define the conditions which are not favorable for the snails.

The global distribution patterns of schistosome-bearing snails were analyzed to determine the gross habitat requirements for each genus. To eliminate microclimatic effects, data from major global regions, large river basins, and major island groups were analyzed. Each major geographical region was





MAJOR RIVERS OF THE TROPICS AND DISTRIBUTION OF BILHARZIA SNAILS

classified by the characteristics of its rainy and dry seasons--dry season being defined as that period when rainfall is less than two inches per month. Then the regions were identified in terms of which of the three genera were found in each. Climatic characteristics were taken from the Odyssey World Atlas, and snail distributions from a comprehensive review published in 1973 by Wright. The geographical regions included all 16 major river basins and all five large island groups in the tropics (Table 1). They were further subdivided into a total of 27 subregions to eliminate large climatic differences within regions.

A simple inspection of the distribution of the genera by region indicated that the mean annual rainfall and the length of the dry season were sufficient, in most cases, to explain which genus would be present in those regions where the annual rainfall was less than 100 inches. Where annual rainfall was greater than 100 inches none of the three genera were found. Where rainfall was 100 inches or less, *Oncomelania* was restricted to the very wet regions with short dry seasons, *Bulinus* occurred in the very dry regions with long dry seasons, and *Biomphalaria* in the regions of medium rainfall and dry seasons.

The numerical criteria (rainfall and length of dry season) defining the range of each genus are simple. *Biomphalaria* exists in regions where rainfall is from 38 inches to 60 inches and the dry season is moderate--two to seven months. *Bulinus* is found in extremely dry regions with dry seasons of 10 months or longer and rainfall less than 20 inches. *Oncomelania* is found only in wet regions with rainfall from 60 inches to 100 inches, conditions predominating in its habitats in the Orient. These simple criteria explain the snail distribution in 19 of the 27 subregions (Table 1). In another six subregions, further analysis showed obvious explanations for some of the exceptions to the simple criteria. In long, narrow river basins, especially those in which the sources of the flow are limited to an upper valley and most of the river passes through a long dry plain, the main snail habitats in the lower valley are in the flood plain, not in the main river bed. These snail habitats are flooded annually as a result of rainfall in the upper valley. When the flood recedes, snails are stranded in pools which soon dry up. These pools provide moisture for some time after the river has returned to its bed and also for longer periods between rains than for the rest of the terrain. The best examples are the Nile, Mesopotamia, Indus, and Senegal River Systems, of which the Nile River is the longest and narrowest. At Aswan the flood season lasts three to four months, although the local rainy season, if any, is less than one month. Thus in these regions, nominally the exclusive domain of *Bulinus*, this hydrological shortening of the dry season makes the lower valleys suitable also for *Biomphalaria*.

During the flood period 73 percent of the flow at Aswan is derived from the Ethiopian sources of the Blue Nile and Sobat Rivers. In the Ethiopian highlands which supply these rivers, the dry season is not clearly defined but is much shorter than the nearly continuous dry season of the lower Nile River Valley.

The construction of intensive irrigation systems in these long river valleys in the last few centuries has further shortened the so-called "dry" season, creating breeding areas for *Biomphalaria*. In these regions, *Biomphalaria* is found in rough proportion to the intensity of irrigation, as in the Nile Delta below Cairo. *Bulinus* persists on the fringes of these irrigated plains or in

TABLE 1

DISTRIBUTION OF BILHARZIA SNAILS AND CLIMATIC

CHARACTERISTICS OF MAJOR GEOGRAPHICAL REGIONS IN THE TROPICS

Key to snails: Present = +, Absent = -, Rare = (+)

RIVER BASIN OR ISLAND GROUP	MEAN YEARLY RAIN-FALL IN INCHES	LENGTH OF DRY SEASON IN MONTHS	PRESENCE OF SNAILS		
			BULINUS	BIOMPH-ALARIA	ONCOMEL-ANIA
AFRICA					
Lower Nile - Egypt	1	12	+	+a	-
Blue Nile - Sudan	12	10	+	+a	-
White Nile - Uganda	41	4	(+)	+	-
Zambesi - North Bank	38	7	+c	+	-
Zambesi - South Bank	12	10	+	+b	-
Congo	54	4	(+)	+	-
Niger	12	10	+	(+)a	-
Volta	54	4	+b	+	-
Senegal	12	10	+	(+)a	-
ORIENT					
Mesopotamia	3	12	+	-	-
Upper Indus	239	6	-	-	-
Lower Indus	3	12	-c	-	-
Ganges	450	4	-	-	-
Iriwaddy	250	4	-	-	-
Yang-tze	62	1	-	-	+
Mekong	100	4	-	-	(+)
Japan	62	1	-	-	+
Philippines	90	0	-	-	+
Indonesia	90	0	-	-	(+)
Australia	40	10	-	-	-
AMERICAS					
Upper Amazon	108	0	-	-	-
Lower Amazon	55	3	-	+	-
Orinoco	55	4	-	+	-
São Francisco	54	4	-	+	-
Upper Paraná	54	4	-	+	-
Lower Paraná	38	0	-	-	-
Caribbean	53	2	-	+	-

a. exception largely explained by hydrological modifications
b. exception correlating with local climatic anomalies
c. unexplained exception to simple criteria

micro-habitats within the irrigation systems where the apparent dry season is longer than seven months. This is also true of the irrigated areas of central Sudan.

In Africa, even allowing for these hydrological modifications, there are three apparent exceptions to the rainfall pattern criteria for Bulinus and Biomphalaria. The first is the presence of Biomphalaria on the southern bank of the Zambesi drainage system, despite a ten-month dry season (Table 1). The second is the presence of Bulinus in the Volta drainage basin although the dry season is only four months and the rainfall is moderate, about 54 inches. The third is the presence of Bulinus on the north bank of the Zambesi despite the annual rainfall of 38 inches, which is high for Bulinus.

Inspection of the climatic maps reveals that two of these basins have anomalies precisely in those areas where the exceptions to the criteria are found. Within the southern drainage of the Zambesi around Harare, Zimbabwe, there is a local discontinuity in the generally dry climate. In these highlands the mean rainfall is 38 inches and the dry season lasts seven months, satisfying the necessary conditions for Biomphalaria.

Conversely, in the lower Volta River Basin there is an area of extremely dry climate from Akosombo to the coast with annual rainfall of 12 inches and a long dry season of ten months, the conditions for breeding Bulinus snails. Thus the general criteria are also fairly accurate for the Volta Basin. With the explanation for these two apparent anomalies, the general criteria are satisfactory predictors in 25 of 27 geographical regions, a global average of 96 percent. The two unexplained exceptions are in the lower Indus River Valley and the north bank of the Zambesi River.

From the above, one would expect to find Bulinus in the Indus River Valley, as its gross climatic characteristics are identical to those of the Mesopotamian region, but the genus is absent from this valley. This could perhaps be related to the source of the river being in the lofty and frigid Karakorum Range of the Himalayas. The river's flow may therefore be unusual either because of water temperature or the shape of the flood wave as affected by the height of its source. The high salinity of the soil caused by over-irrigation in the lower Indus River Valley and the consequent saline surface waters, the relative humidity during the dry season, or the unusually high tides of the Indian Ocean may also be important.

Except for the northern Zambesi drainage and the lower Indus River Valley, there is thus a consistent guide to the presence or absence of each of these snail genera in the major geographical regions of the tropics. The mechanisms behind this distribution must be related to gross climatic characteristics, but further study would be needed to determine these mechanisms. Even without knowing the details of how climate affects snail distribution, however, the above observations may be useful for predicting the snail distribution after river hydrology has undergone major modification.

3.2 Control Measures

With its complicated but well documented life cycle involving human and snail hosts, schistosomiasis should be easy to control when efforts are appropriately focused. During passage of schistosome parasites between humans and snails, the schistosome has been shown to be extremely vulnerable. Further, the snail hosts have rather narrow habitat requirements, and their breeding and survival can be disrupted by modifying their habitat biocides and biological controls. Finally, when people can be kept away from snail-infested waters, the disease is also reduced or eliminated.

In order to attack schistosomiasis, six general strategies can be employed, most favorably if used in concert rather than individually. These strategies are:

- Providing safe domestic water supplies,
- Modifying human behavior (education),
- Modifying snail habitats,
- Implementing biological controls,
- Applying molluscicides, and
- Providing chemotherapy.

These categories are arranged more or less in order of preference. However, regardless of their rank, it is important to include all of them when designing or implementing irrigation projects.

3.2.1 Safe Domestic Water Supplies

Nothing is more durable and effective in long-term reduction of schistosomiasis and other diseases associated with irrigation than providing all residents with a safe water supply for drinking, cooking, and bathing. Since irrigation projects are massive exercises in storing, distributing, and using water, it would seem feasible to divert some of it to relatively simple water-treatment devices even if they are no more than settling tanks connected to slow sand filters. If farmers can grasp the complexities of water management for irrigation, some could also be trained to care for settling tanks and slow sand filters. Even without sand filters, schistosomiasis transmission can be interrupted if water can be held in snail-proof tanks for 24 to 48 hours, as most cercariae (larval stage) will die if they do not find a human host in that period. The effects on health of clean water are further enhanced by the construction of community laundry and shower facilities.

What is more difficult to address is a common and prevailing use of irrigation canals or storage ponds for recreation. Schistosomiasis infections are normally higher in young children, especially young males, owing to their inclination to use canals for swimming, even if bathing facilities are available with safer water. This problem is best handled through education rather than water engineering in that irrigation planners are not likely to accept additional costs for constructing swimming pools.

3.2.2 Health Education

A first step in modifying human behavior to combat schistosomiasis is to make people aware of connections between snail-infested irrigation water and the disease. Studies have shown that rural people realize that there is a connection between schistosomiasis and water but they may not grasp the connection between schistosomiasis and snails. Even if safe water supplies are available, education programs are necessary to assure continuing use of the clean supply, rather than returning to rivers or canals if they are more convenient for bathing and laundry or provide a social focus. If mothers are aware of the health risks of swimming in snail-infested water, they are likely to prevent their children from doing so. Farmers should also be persuaded to wear protective boots and gloves when working in snail-infested water.

In some areas, there may be variations in the degree of contamination with snails. For instance, turbid water is less conducive to the propagation of snails and and the survival of schistosome larvae than is clear water. Except in Asia, the snails commonly shed their cercariae later in the day. As a result, early morning may be the safest time of day for bathing, laundering, swimming, and for cleaning canals in the rest of the tropics. Educating the local people to these facts should contribute to reducing schistosomiasis.

Some behavioral modification can be accomplished by changing traditional village layouts or structures. Villages should not parallel nor be near canals as these conditions encourage non-agricultural use of irrigation water. If village streets and services are perpendicular to canals, people are less likely to be exposed to canal water or use canal banks for social gatherings. Fences or planted windbreaks can also be used to discourage contact with the water, although these can be costly and require continued maintenance. Planners can design simple bridges to allow people to cross canals without contact with water.

If people can be convinced not to defecate or urinate in water used for domestic purposes, schistosomiasis transmission will be curtailed. However, the adult worms in the human body are prolific egg producers and the continued schistosome life cycle requires only a small number of infected people. It is unrealistic to think that all adults, much less children, can be trained not to use canals and other open water sources as a toilet while swimming or bathing.

3.2.3 Modifying Snail Habitats

Engineers and biologists working together can modify habitats to make them less favorable to snails. Schistosome-bearing snails do not favor habitats where water flow exceeds 70 centimeters per second. If primary canals could be designed to exceed this flow, it would reduce the area for potential snail breeding. Secondary and tertiary canals do not flow this fast in most, if not all, irrigation projects. If some of these secondary and tertiary canals could be drained and kept dry for one or two weeks at intervals of three to four months, snails would either dry up or be exposed to predators. Emptying the canals by deliberately drawing down the water level is more effective than slow drying from evaporation.

Schistosomiasis snails also prefer shallow, clear water with emergent vegetation and gentle shoreline gradients. Thus deep and steeply-banked canals with vegetation removed periodically have few snails. Storage reservoirs should be as steeply sloped as possible to minimize snail habitats. Concrete-lined canals are preferable to earthen canals. Fluctuation of water levels in canals or storage ponds can also reduce snail proliferation. Canal screens have not been effective in preventing snail invasions. Wave action has an inhibitory effect on snails, thus gentle winds across ponds, reservoirs or canals should not be obstructed by vegetation or structures.

The removal of emerging vegetation in canals and reservoir margins is not only efficient for irrigation purposes but is also effective in reducing snail habitats. However, manual removal of this vegetation should be done by hand while snails are not shedding cercariae (such as in the early morning in some places) in order to reduce exposure of workers. It would be necessary to determine when local snail populations shed their cercariae rather than depending on a general supposition of late-morning shedding.

3.2.4 Biological Controls

Biological control of snails can be effective and economical if used in concert with other control strategies. Biological control alone is not effective. Original efforts at biological control of schistosomiasis emphasized fish, ducks, and geese which prey upon snails and remove aquatic vegetation. If managed appropriately, fish and fowl could be harvested for food.

In addition to fish and fowl, other species of non-schistosome-bearing snails can be used to prevent transmission in irrigation projects. These snails may decoy miracidia away from the schistosomiasis snails or function as ecological competitors as in the case of Marisa cornuarietis, a large ampullarid snail. These snails have been used in the Caribbean Region and have received preliminary testing in the Nile Valley and in East Africa.

In Puerto Rico the ampullarid snail Marisa cornuarietis has been tested and used extensively in a successful and integrated program of schistosomiasis control. The results have been most striking in irrigation ponds, canals, and reservoirs, and hydroelectric reservoirs. Thus most initial testing in other tropical countries has also been in irrigation systems, especially in Egypt and Sudan. There is considerable optimism about Marisa because of a variety of successful experiences in Puerto Rico.

Marisa was placed in 97 small irrigation ponds on the south coast of Puerto Rico and displaced the schistosomiasis snails from 89 of them within seven years, at an annual cost in 1965 of $1 per 100 cubic meters protected. Chemical control in the same ponds cost 60 times that amount.

Sixteen large reservoirs used for hydroelectric power and irrigation were also planted with Marisa to control the schistosomiasis snails. By 1979 the schistosomiasis snails had been eliminated or drastically reduced in 14 of them, at an extremely low cost. Complete displacement of historic populations of schistosomiasis snails by massive populations of Marisa occurred in the Patillas Irrigation canal on the south coast of the island and in the

Guajataca Canals on the north coast. Similar displacements were monitored in the late 1970s in small natural streams passing through the last remaining endemic communities on the north-east coast. Field studies in ponds had previously demonstrated this effect whereby the Marisa absorb schistosome larvae more readily then do the schistosomiasis snails, thus preventing successful transmission even before the snail populations are eliminated.

The experience with Marisa in Puerto Rico indicated that it was most successful in relatively permanent bodies of water, especially large lakes which seldom go completely dry. It is equally effective in flowing water and is not limited to irrigation canals or drains, but can also colonize permanent streams. It has also been successfully tested in pilot projects in Egypt, Sudan and Tanzania.

3.2.5 Chemicals

The wild Endod bush or soapberry plant, Phytolacca dodecandra, offers considerable promise as a natural molluscicide. The berries from this plant, native to Ethiopia, have been identified since 1964 as a natural, biodegradable substance toxic to snails. Recently, the International Development Research Centre of Canada teamed with UNDP and WHO to help evaluate the toxicity of Endod. UNICEF has also contributed to soapberry trials as part of its primary health care program.

Commercial molluscicides are expensive, but can be effectively used for spot applications on specific snail breeding sites or in areas of high human exposure to contaminated water, such as bathing or laundering points. Wide applications are quite expensive, thus molluscicides are most cost-effective when employed in concert with surveillance programs which identify the habitats heavily populated by snails.

3.2.6 Chemotherapy

Drugs are available for the treatment of schistosomiasis. Available drugs, however, may be toxic, produce serious side effects, require medical administration, and are expensive for developing countries. There are no drugs available to prevent infection. A single infected person can discharge large numbers of eggs into the environment, thus keeping the life cycle intact and dictating that treatment be on a community basis to stop transmission of schistosomiasis.

3.3 The Costs of Schistosomiasis Control

Recently the cost of snail control with chemicals has taken a favorable turn, primarily because the cost of the primary biocide for snail control has remained stable and has not increased with the general inflation. A second reason is the increased emphasis on epidemiological understanding of transmission before designing control strategies. This has resulted in increased reliance on focal strategies.

The decrease in cost of snail control with biocides is illustrated by comparing the costs from several projects which operated between 1960 and 1970 versus costs from five recent projects operating in the early 1980s. The earlier projects included Vieques Island off Puerto Rico, Cul de Sac Valley on the island of St. Lucia, three projects in Brazil, an area near Misungwi, Tanzania, and irrigation schemes in Egypt and Iran (Table 2). The costs for snail control in these projects ranged from $10 to $100* per 100 cubic meters of snail habitat treated (De Wolf, 1988).

The more recent projects were Lake Volta, Ghana; Bong County, Liberia; the Rahad Scheme; and the Gezira-Managil Scheme in Sudan. The cost of treating 100 cubic meters of snail habitat with Bayluscide, the most common molluscicide in large irrigation schemes and around reservoirs, ranged from $2 to $3 per 100 cubic meters of water (Table 3).

Analysis of costs of snail control with biocides must include geographical characteristics of the endemic area as these have direct influences on the cost of operations and the amount of biocide used. Cost of chemical control of snails correlates closely with geographic parameter G, equal to the ratio of cubic meters of snail habitat per square kilometer of land, divided by the annual rainfall. If G is large, the snail habitats are close together and flooded for only a short time each year, making chemical control easy and inexpensive. However, if an area has a small G, this indicates that the snail habitats are widely scattered and flooded a great part of the time, thus making chemical control expensive.

The snail-control costs for the projects operating in the 1980s were about five percent of the costs of those projects in operation in 1960-70, all adjusted to 1986 US dollar values. For G of 1,000 the cost in 1980 was $1.50 per 100 cubic meters treated, three percent of the cost of $45 for the projects in 1960-70 (Figure 4). For G of 200 the cost was eight percent of the earlier 1960-70 cost.

Development of inexpensive biological, educational, and primary health care programs for schistosomiasis has resulted in general reduction in the costs of controlling it. Although these methods are not as dramatic as drugs and biocides, their emergence offers strategies which are possible even with the scarce resources of most tropical countries. In Puerto Rico the large ampullarid snail Marisa has been used in reservoirs, canals, and natural streams to interrupt transmission. This biological method had an annual cost of $0.04 per capita of the affected population compared to biocidal snail control which costs $0.33 to $2.37 per capita and which requires hard currency. Health education costs about $0.01 per capita.

A simple and inexpensive educational effort was used to reduce exposure of irrigation and agricultural workers to schistosomiasis in Sudan. This effort was based on the daily cycles of the schistosome larvae which do not leave the snails until after the sun is high, usually about 10 in the morning. Thus

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* All costs quoted in this paper are in 1987 US dollars unless otherwise noted.

TABLE 2. COMPARISON OF MOLLUSCICIDE PROGRAM COSTS FOR SELECTED BILHARZIA CONTROL PROJECTS OPERATING BETWEEN 1960 AND 1970.

Project	St. Lucia	Brazil	Egypt	Iran
Annual Rainfall (cm)	250	160	30	30
Controlled Area (km2)	16	200	52	220
Population	6,000	20,000	17,000	18,000
Annual Volume of Snail Habitat treated (m3)	182,000	39,000	1,354,000	200,000
Habitat Volume per surface area (m3/km2)	10,000	195	16,000	2,300
Program Cost Breakdown				
Labor	50%	50%	5%	6%
Chemical	12%	11%	85%	19%
Transport and equipment	16%	15%		21%
Supervision	16%	24%		54%
Other	6%		10%	

TABLE 3. COMPARISON OF MOLLUSCICIDE PROGRAM COSTS FOR BILHARZIA CONTROL PROJECTS OPERATING IN THE EARLY 1980'S, IN 1987 US DOLLARS.

Project	Lake Volta	Liberia	Rahad	Gezira
Annual Rainfall (cm)	100	200	50	50
Controlled Area (km2)	80	60	1,260	265
Population	7,500	3,236	100,000	60,000
Annual Volume of Snail Habitat treated (m3)	422,143	3,422	3,288,000	1,040,000
Habitat Volume (m3)	35,179	3,422	411,000	86,000
Habitat volume per surface area/rainfall (m3/m3)	440	28	650	650
Cost	$18,700	$1,570	$98,300	$20,600
Program Cost Breakdown				
Labor	5%	70%	36%	8%
Chemical	30%	3%	54%	75%
Transport and equipment	63%	10%	1%	2%
Supervision	2%	8%	9%	15%
Other	-	9%	-	-

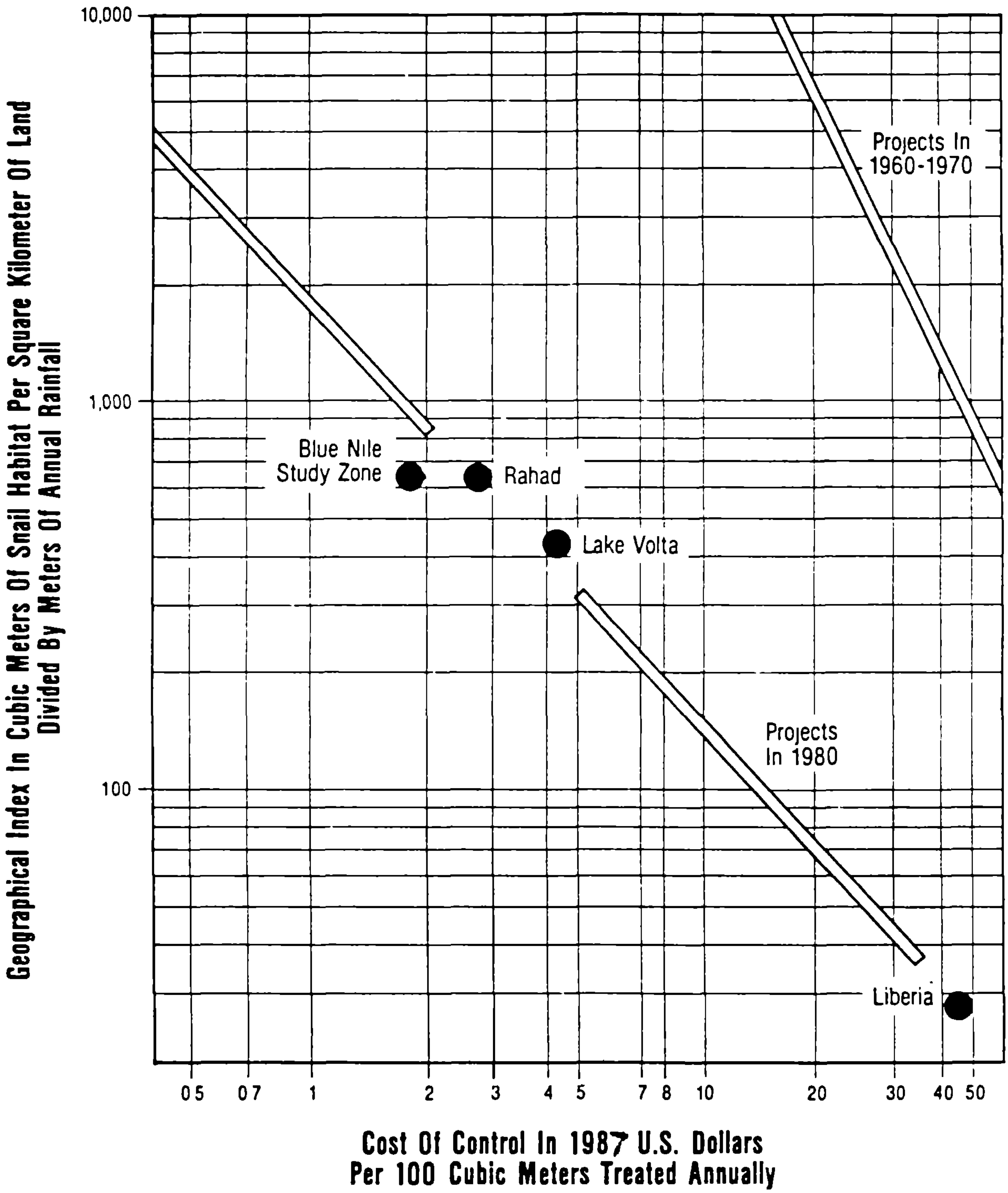


FIGURE 4

Cost Of Snail Control With Bayluscide, In 1987 U.S. Dollars Per 100 Cubic Meters Of Habitat Treated

canal cleaners and other agricultural workers are urged to limit their immersion in the canal water to early morning, saving other work for the latter part of the day. At virtually no expense this technique has resulted in a 50 percent decrease in transmission among irrigation workers in the Sudan.

Combining methods for control of schistosomiasis with a general rehabilitation of tropical irrigation schemes has been emphasized, resulting in major ecological improvements and consequent decreases in snail habitats. An extensive program of mechanical dredging and aquatic weed control was used in the canals of the Gezira-Managil Scheme to improve irrigation operations and thus increase delivery of water to meet agricultural needs. Although financed and carried out by the Ministry of Irrigation for agricultural purposes, these clearing operations also facilitated application of biocides for snail control and reduced the food supply of the snails. Probably ten percent of the cost could thus be apportioned to schistosomiasis control in this case.

The annual cost in 1982 was $371,570 for weeding and dredging the entire canal system including 174 km of minor canals with mean cross-sections of seven square meters, or 1,219,000 cubic meters. The branch and major canals raised the total volume to about 1.5 million cubic meters, with a resulting annual cost of $25 per 100 cubic meters in 1982, or $32 per 100 cubic meters in 1987 prices. However only 86,000 cubic meters of this water was snail habitat resulting in a cost of $27,000 for snail control. Only ten percent of this should be charged against snail control as the major benefit of the clearing was to improve water control as a means of increasing agricultural productivity, a highly significant benefit. Thus $2,700 for schistosomiasis costs due to weeding and dredging of snail habitats should be added to the $18,500 cost of chemical application for snail control, an inexpensive but important enhancement to the application of biocides (Table 4).

The costs of all these activities are illustrated in the Gezira-Managil irrigated area of the Sudan where schistosomiasis transmission was intense and a highly-effective strategy for integrated control of the disease was used in combination with an extensive agricultural rehabilitation program. Part of the rehabilitation included the new, mechanized program for dredging and removal of aquatic vegetation in the canals mentioned previously. During 1983 the annual cost was $17,600 for snail control through chemicals, plus $2,600 for weeding and dredging (Table 4). In addition the annual per capita costs for the population of 60,000 were $2.40 for an initial mass chemotherapy program, $0.03 for case-detection and treatment within the primary health care system, $1.47 for safe water supplies, $0.52 for latrines, and $0.01 for community health education.

The total cost apportioned to schistosomiasis control, for this integrated strategy, was $287,000 for the first year and $144,000 for subsequent years (Table 4). This resulted in a continuing program cost of $2.40 per capita, after the first year, for the population of 60,000. Mass chemotherapy during the first year had raised the total cost to $4.78 per capita.

TABLE 4. SUMMARY OF BILHARZIA CONTROL COSTS FOR THE STUDY ZONE IN THE GEZIRA-MANAGIL IRRIGATION SCHEME OF SUDAN, IN 1987 US DOLLARS.

INITIAL YEAR		
Molluscicide application		$18,500
Weeding and dredging*		2,700
Mass chemotherapy	2.40 x 60,000 persons =	144,000
Safe water supply**	1.47 x 60,000 " =	88,200
Latrines	0.52 x 60,000 " =	32,000
Health Education	0.01 x 60,000 " =	600
Total for initial year		$287,000
SUBSEQUENT YEARS		
Molluscicide application		$17,600
Weeding and dredging*		2,600
Maintenance chemotherapy	0.03 x 60,000	1,800
Safe water supply**	1.47 x 60,000	88,200
Latrines	0.52 x 60,000	31,200
Health Education	0.01 x 60,000	600
Total for subsequent years		$144,000

* from budget of Ministry of Irrigation
** from budget of Regional Water Agency

Chapter 4

MALARIA

Malaria is a water habitat vector-borne disease. Mosquito vectors of malaria require habitats for breeding similar to those preferred by schistosomiasis snails. Female mosquitoes seek standing water to lay eggs and mosquito larvae require still water to develop into adults. Presence of vegetation in shallow, still waters further improves mosquito habitats by providing additional points for egg attachment.

The epidemiology of malaria is slightly less complex than schistosomiasis in that the immature form of the malaria parasite does not require an intermediate host. A female mosquito injects the malaria parasites into humans while she is taking a blood meal. In the human liver the parasite changes form and becomes infective when it passes out of the liver and into the bloodstream. When an uninfected mosquito bites a person with malaria, the parasite in an advanced form is taken into the mosquito gut and, following further development in the mosquito, migrates to the salivary glands to renew the cycle. Fortunately, the life histories of mosquitoes and parasites are well-known and there are vulnerable points in the transmission cycle. In addition, malaria can be treated and prevented by relatively inexpensive medicine, as opposed to the higher costs for schistosomiasis treatment. The increased resistance to chloroquine, however, has caused treatment costs for malaria to rise in certain countries in recent years.

Control Measures

As with schistosomiasis, malaria is best controlled through a multi-faceted attack including:

- Provision of safe domestic water supplies,
- Modifying human behavior (education),
- Modifying mosquito habitats,
- Biological controls of the vector,
- Insecticides, and
- Chemotherapy.

Providing safe and easily accessible domestic water supplies which reduce human exposure to moist, humid environments favored by mosquitoes will reduce the incidence of malaria. However, care must be taken to assure that water supply points do not create mosquito breeding areas resulting from pools of standing water. Good operation and maintenance programs for water systems are necessary to maintain proper drainage in relation to the systems.

Modifying human behavior is a more productive strategy, especially when well-conceived health education programs are employed. As with schistosomiasis, it is important that people be aware of the connection between mosquito bites and malaria. It is also important that they be aware that mosquitoes breed in standing water. Simply put, the more standing water there is, the more mosquitoes there will be. People can also be educated to use mosquito nets, particularly those treated with pyrethroid insecticides, for sleeping and to avoid areas where mosquitoes are more numerous.

Habitat modification is as effective with malaria as it is with schistosomiasis. If canals can be designed to flow at velocities high enough to prevent snails, the canals will be unsuitable for mosquito breeding as well. Rapid fluctuations in water levels or rapid draining will disrupt larval cycles. Since aquatic vegetation improves conditions for larvae development, planners should make sure that canals are accessible for periodic weed removal. Wave action in water storage or conveyance structures should be maintained, wherever possible.

The operation and maintenance of irrigation systems has a profound effect on mosquito habitats. Irrigation control structures may provide inadequate or inaccurate flow control. This results in uncontrolled water-logging, erosion, and flow retardation, which increases the suitability of a canal for vector breeding. When water is abundant, too much water in a system compounds the problems. In rice cultivation the interval between plowing and direct seeding as opposed to transplanting also affect the breeding potential of rice fields.

Maintenance operations in irrigation must emphasize regular canal cleaning, embankment and structure repair, and proper land leveling to ensure undisturbed water delivery at all levels of control. Lack of maintenance will contribute to inundation, retarded flow, and other processes favorable to the formation of pools of standing water.

Biological controls are effective in repressing malaria. Many countries have successfully employed larvae-eating fish in storage ponds and canals. For instance, two species of such fish have been used in Somalia in its National Anti-malarial Service. Unfortunately these fish are usually small, top-feeding species and do not have much value as food. The fish are, however, considerably less expensive than biocides, and they will remain active over longer periods of time. It may be possible to design canals and ponds to provide better habitats for these fish than for mosquitoes.

The most common method of malaria control is the use of chemicals, usually a combination of larvicides and household spraying for adult mosquitoes. Larvicides are usually less toxic and can be applied more safely near human habitations. As with schistosomiasis, such applications for malaria are most effective if they are based on mosquito surveillance so that the most likely areas of contact between humans and mosquitoes or the most suitable breeding sites are sprayed at the most effective times. It is also best to vary biocide types so that chemical-resistant mosquitoes do not evolve, as frequently occurs with insect pests.

Treatment and prophylaxis with chloroquine derivatives are relatively inexpensive and quite effective. The major problem is the expanding ranges of malarial parasites which are becoming resistant to chloroquine. Unfortunately, these resistant forms are also the strains which cause the most virulent malaria. Alternative drugs are more expensive than chloroquine at present, and they have more undesirable side effects. Therefore, to be effective, a malaria suppression campaign must rely on mosquito control rather than depending solely on drugs.

It is important to note that mosquitoes are vectors of other diseases, such as yellow fever, dengue, filariasis, and Japanese encephalitis. Japanese encephalitis is spreading particularly in association with rice field irrigation and is receiving increasing attention. Although these diseases are spread by different mosquitoes, many of the malaria suppression activities will also help control the other mosquitoes. Habitat modification, integrated pest management, and health education can be quite effective in controlling these other diseases.

Chapter 5

WATERBORNE DISEASES

Other diseases associated with irrigation projects, in addition to malaria and schistosomiasis, are grouped together as waterborne diseases and include hepatitis, typhoid, cholera, and many other bacterial or viral infections. These diseases occur from direct ingestion of bacteria, protozoans and, to a lesser extent, viruses, from fecal contamination of a water or food source. These diseases are prevalent in the tropics with or without irrigation. Irrigation systems concentrate human densities (increasing a probability of infected people) and provide water vehicles for transmission. However, epidemics can occur without irrigation simply from contamination of domestic water or food sources.

5.1 Control Measures

A combination of control measures is essential in combating waterborne diseases such as hepatitis, typhoid, and cholera associated with irrigation projects. These measures include:

- Providing safe drinking water,
- Constructing facilities for human excreta disposal,
- Educating people in proper hygiene,
- Immunizations,
- Oral rehydration therapy, and
- Community participation.

In irrigation systems, these diseases are best controlled by providing dual water systems, one for drinking water and one for agriculture. The drinking water should be treated to pre-determined standards and be available to households at low cost. There are a variety of low-cost water supply and sanitation facilities which can easily be incorporated into irrigation systems. It is sometimes argued that the costs of these systems are expensive in comparison to other health control strategies. This is often true when a single health objective such as reducing morbidity or mortality from diarrhea is the basis of comparison. However, when the many additional health, social, and economic benefits of water supply and sanitation are considered, then improvements in water supply and sanitation become most cost effective. The range of benefits and value of water supply and sanitation are enumerated in various WASH reports (Okun, 1987 and Briscoe, 1987).

The education component is more of a social engineering solution, one of convincing people that safe disposal of feces is important and that washing hands and utensils prior to cooking or handling food will reduce the incidence of waterborne diseases. Health education is best achieved through community development and incorporating women into the process. Several WASH reports have documented these strategies (Simpson-Hebert, 1987; Donnelly-Roark, 1987; Eng, 1987; Elmendorf, 1981).

If the strategies to control schistosomiasis and malaria are incorporated into an irrigation system, the incidence of waterborne disease will also decrease, providing the education program is effective. Oral rehydration therapy is highly effective in reducing mortality from diarrheal diseases and, of course, vaccines are available for typhoid and cholera. A multi-dimensional approach is needed which will incorporate various health control measures into a program coordinated with irrigation objectives.

Community participation deserves particular emphasis as a strategy in combating waterborne diseases. Community participation is a necessary ingredient for the success of domestic water supply and sanitation projects. In communities which have established a system for determining problems, weighing solutions, and mobilizing to solve the problems, development is usually sustained. Assistance to villages in establishing effective community participation is important in irrigation projects as well as in water supply and sanitation projects and should be included in design plans. Mobilizing the community to act to solve health problems, for example, will likewise enhance the possibilities of success in seeking solutions to problems within the irrigation sector. Overall improvement in water management through community participation should be considered an important component of a disease control program in irrigated areas with a dual goal--improved health combined with agricultural productivity.

5.2 Impact of Safe Water

Improvement of domestic water supplies was a major component of the comprehensive strategy for control of water-associated diseases in the Blue Nile Health Project in the Sudan. The effects of safe water supply were confirmed in a study in 1981 which showed an inverse relationship between the rates of consumption of safe water and the prevalence of diarrheal diseases (Figure 5) and schistosomiasis (Figure 6). Proposed improvements in water supplies would cost about $0.64 per person in 1984 prices, to raise the consumption from the original 40L/cap/day to a design goal of 70 L/cap/day (Table 5).

Table 5

Costs in U.S. Dollars for Village Water Supplies
in Blue Nile Health Project for Existing and Improved Systems, 1982-1985

Cost Item	1982	1983	1984	1985
Capital	157;080	163,320	169,236	177,822
Increased supervision	3,264	4,380	4,380	4,380
Basic operation and maintenance	28,462	28,462	28,462	28,462
Increased O&M	5,668	19,735	20,034	21,041
Total annual costs	194,474	215,897	222,112	231,705
Annual costs per capita	3.41	3.78	3.89	4.05

Figure 5

RELATION OF PREVALENCE OF DIARRHEAL DISEASES AND SAFE WATER CONSUMPTION FOR INTENSIVE STUDY VILLAGES, 1981

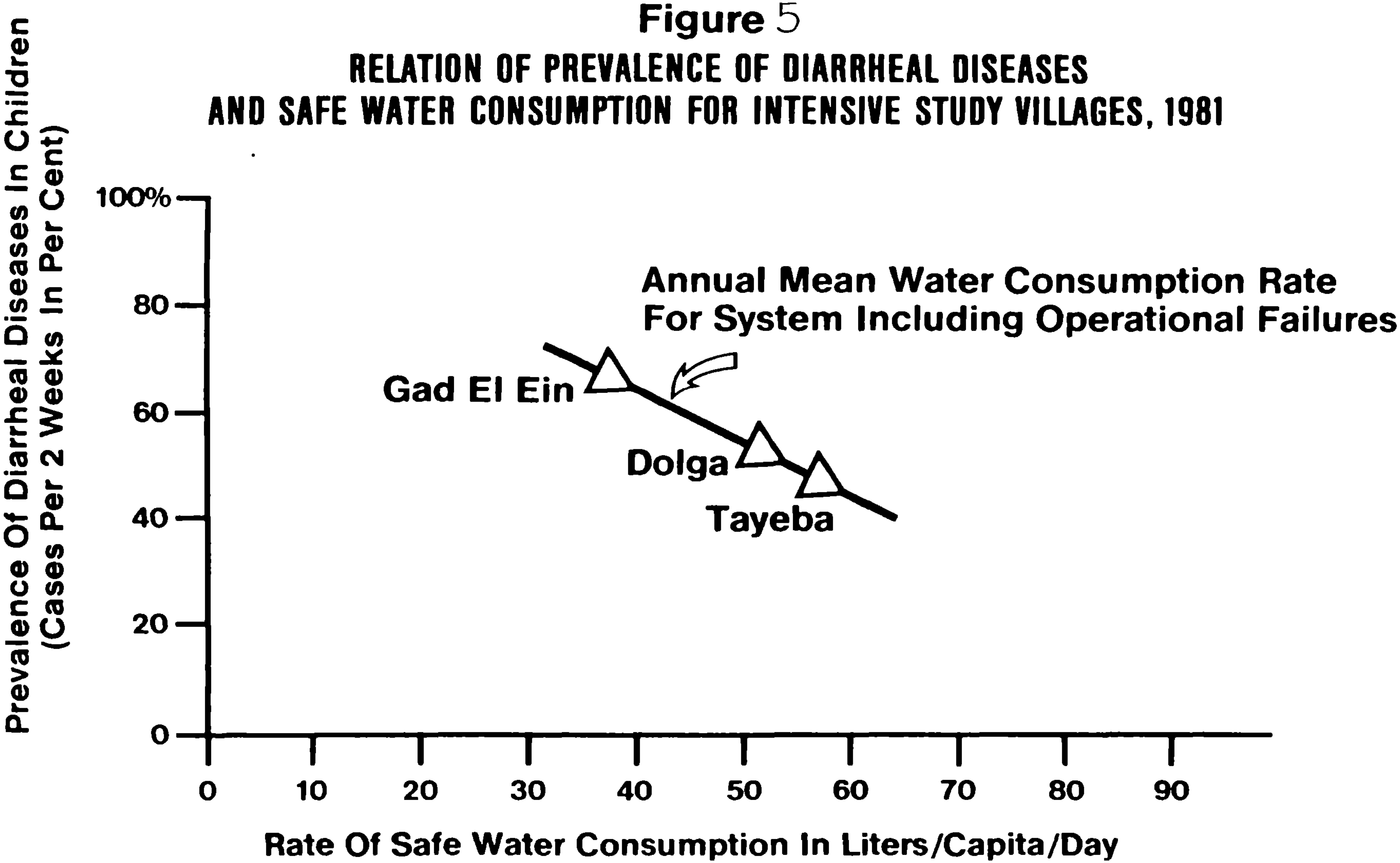
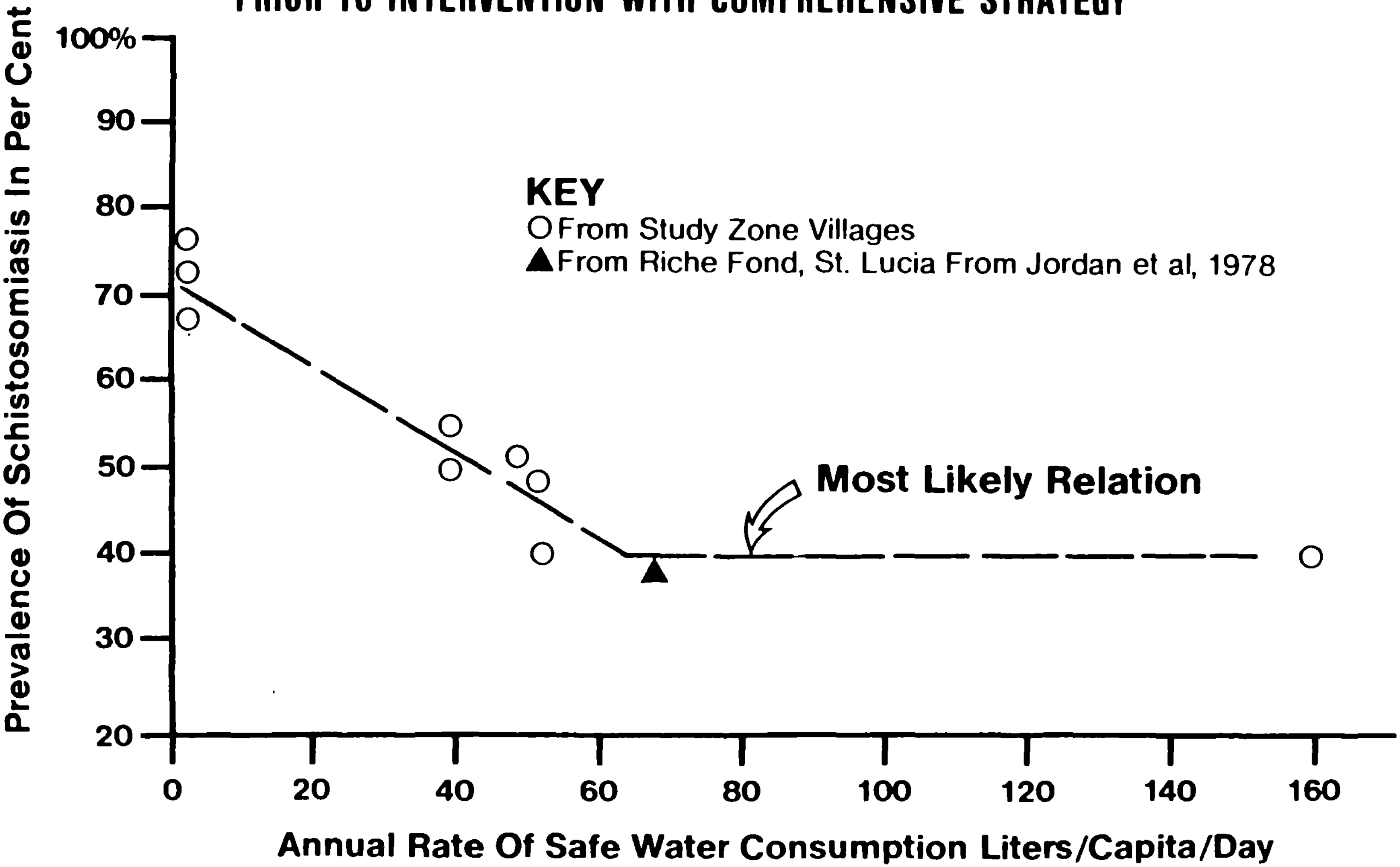


Figure 6

PREVALENCE OF SCHISTOSOMA MANSONI IN CORE VILLAGES OF THE STUDY ZONE VERSUS THEIR ANNUAL MEAN EXPERIENCE OF SAFE WATER CONSUMPTION IN 1981–1982 PRIOR TO INTERVENTION WITH COMPREHENSIVE STRATEGY



Combinations of the costs of the improvements with the previously derived relations between water consumption and disease indicate that increasing the annual per capita expenditures from $3.41 to $4.05 should have several benefits, correlating with the consequent increase of consumption. From the relation observed in the three villages shown in Figure 5, it was estimated that the increased consumption from 40L/cap/day to 70 L/cap/day would result in a decrease in diarrheal disease prevalence from 60 percent to 35 percent. Similarly, it was estimated that there would be a decrease in schistosomiasis prevalence from 50 percent to 40 percent and also a considerable savings in time and labor for the people served (Figure 6). These figures translate into preventing 170 infant deaths per year among the 60,000 people in the communities studied, and the prevention of schistosomiasis infections in over 5,000 of the same people.

5.3 Integrated Approach to Disease Control

In Chapter 2 the history of the disastrous impact on water-related diseases due to intensification of agriculture was documented for the Gezira-Managil Irrigation Scheme in Sudan. The combination of chemical resistant vectors, excess water wastage, deteriorating sanitation and overcrowding led to failure of the cotton crop and a national crisis. Coupled with the increased prevalence and intensity of endemic human disease, the eventual result of the cotton-crop failure was widespread suffering and civil strife, including food riots in 1981. Fortunately, it was possible to remedy the situation in the Sudan.

By the time that the irrigation expansion and other agricultural activities were perceived to exacerbate health problems in the Sudan, a philosophical change was occurring in the international health and agricultural agencies. They began ecologically oriented research aimed at solving regional problems, rather than studies on biocides or drugs for narrow uses. These trends resulted in a long-term project in the Sudan of integrated cotton pest control and comprehensive and integrated control of all water-related diseases in irrigation schemes along the Blue Nile River. These two activities overlapped in the Gezira-Managil Irrigation Scheme.

Most of the new strategies to combat the whitefly and the spread human diseases were introduced in 1982 and resulted in a doubling of agricultural production and dramatic decreases in endemic diseases. A major step was simply to curb the use of pesticides, limiting them only to those areas and times where they were clearly required. This, combined with better economic incentives, resulted in cotton production rebounding from the low of 0.4 million bales in 1981 to twice that in 1983, and remaining stable through 1987 at about one million bales.

The new strategy for disease control included the formation of village health committees which organized rapid systems of diagnosis and treatment of malaria infections, education of mothers in the use of oral rehydration salts to treat diarrhea in infants, improvements in community water supplies, drainage and latrines, and community spraying. Centrally operated programs of mass chemotherapy, drilling of new wells, canal weeding and maintenance, and limited pesticide spraying were coordinated with the community activities.

The prevalence of malaria had dropped markedly since the emergency house spraying program in 1976 and continued to decline, remaining below one percent through 1986 (Table 6). The prevalence of schistosomiasis and diarrheal disease among 60,000 people located in the area also fell dramatically and remained stable from 1983 through 1986.

Table 6

Prevalence of Malaria in Gezira-Managil Scheme
Based on Random Sample of Children in 52 Villages, 1981-1986

Year	Blood Examination	Malaria Infection	Prevalence
1981	8685	117	1.34%
1982	6737	17	0.25%
1983	5849	32	0.54%
1984	5492	12	0.21%
1985	5467	22	0.40%
1986	6054	17	0.28%

5.4 Costs of Disease Control

A complete rehabilitation of the aging irrigation, community water supply, and sanitation systems and expansion of disease control from the study zone to the entire two million people in the system were financed by a $100 million loan from the World Bank.

In contrast to the former programs which relied on drugs and biocides, the new integrated strategies were successful and economical. The maintenance phase of the comprehensive health strategy cost a total of $5 per capita annually (Table 7). Community water supplies and engineering improvements are handled by the Regional Water Agency and the Ministry of Agriculture and Irrigation respectively, and constitute the major share of the costs. When chemical methods are eventually phased out, the annual cost to the Ministry of Health would be only $1.50 per capita in 1987 U.S. dollars, about the same amount spent on health services in the Central Region in 1987. Such figures are useful for planning purposes in Africa and the Middle East, and give general indications for costs in the rest of the tropics.

Table 7

Annual Costs for Maintenance Phase of Comprehensive Strategy to Control Major Water-Associated Diseases in the Gezira System in 1987 U.S. Dollars

Item (includes supervision, labor, supplies and overhead)	F*	Annual Cost per Capita	Annual Cost for Two Million People
Rehydration salts		$0.21	$ 420,000
Water supplies *	2/3	2.94	5,880,000
Health education		0.04	84,000
Latrines *	2/3	1.05	2,100,000
Snail Control			
Biological		0.04	84,000
Chemical		0.30	609,000
Weeding *	1/10	0.04	84,000
Schistosomiasis drugs **		0.03	63,000
Engineering improvements of aquatic habitats			
Water control *	1/10	0.17	336,000
Main drainage *	1/10	0.36	714,000
Village drains *	1/2	0.02	42,000
Larval mosquito control			
Biological		0.08	168,000
Chemical		0.12	231,000
Malaria drugs		0.04	84,000
Adult mosquito spraying		0.55	1,092,000
TOTAL		$6.00	$12,000,000

* Includes only the fraction F of total cost apportioned to disease control activity.

** Does not include first year cost of $2.42 per person for mass treatment campaign.

Chapter 6

CONCLUSIONS

Several control measures have been recommended in this report to combat specific water-related diseases in the irrigation sector. Emphasis has been placed on the role of water and sanitation as particularly effective measures. The planning and construction of such entities as water wells, latrines, washing facilities, or treatment plants should become an integral part of the total irrigation project. Health education and community participation are strategies necessary to assure the optimum use and continued maintenance of these facilities.

The cost of integrating water supply and sanitation into irrigation projects is often a relatively small percentage of the total irrigation investment cost. This is particularly true when the integration occurs at the design stage. Irrigation investments may cost as much as $10,000 per hectare, while water supply systems are often constructed for $10 to $40 per capita.

The benefits of water supply and sanitation may be most impressive. The reduction in lost agricultural labor due to illness is often significant. Savings in time, particularly for women, in fetching water for family use can also be significant and this time saved is often converted to work in agriculture. Women and older children are very important to tropical agriculture. Fewer illnesses among children allow parents, again particularly women, more time to devote to agricultural pursuits.

During the past several decades a series of new development perspectives have been generated. Concerns related to health have become an explicit part of the planning process in the majority of developing countries. Improved health is frequently described as one of the goals and as an essential instrument of development. Yet, many studies conclude that new irrigation investments often have an adverse effect on health. Irrigation development projects have, on occasion, produced negative and unexpected impacts in the health sector. This report has shown the repercussions that some irrigation-related policies, programs, and projects have on affected populations.

In order to realize health benefits effective methodologies are needed to provide decision makers with useful and reliable information on the impact of their decisions on the health conditions of populations within the irrigation sector. Invariably, all of these decisions contain potential benefits as well as hazards. Decision makers should be aware of the potential benefits and hazards and analyze which approaches would best meet irrigation objectives and which complementary actions are needed to improve health. Mechanisms are needed to ensure the participation of the health sector in irrigation planning in a more regular and effective manner.

Addressing this situation continues to be one of the major tasks within the decision-making structures at the national and international levels. Clearly, the most effective and least costly point at which to address these issues is during the planning process.

There is a need to adjust both international donor and country policies, so they are analyzed by both health sector personnel and irrigation planners. When governments decide to pursue the joint objectives of irrigation and health, donors should supply the funds needed so that complementary programs and policies can be undertaken. At the country level, national institutions should be encouraged to identify vulnerable groups and to use their state of health as a basic indicator in the evaluation of development policies and projects. National irrigation agencies should also be encouraged to use data from the ministry of health and related institutions as a measure of the impact of policy decisions on the health of the population at large.

The prevention of adverse effects on health from irrigation projects will be possible only if there is a national capacity for analysis and control. Countries should strengthen this capacity through the integration of objectives within the irrigation, health, human resource training, and environmental control agencies. With effective integration of objectives the mutually compatible goals of increased irrigation production and improved health can be realized.

BIBLIOGRAPHY

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Abdu, K.; Haridi, A.; El Gaddal, A.; and Jobin, W. 1987. "Intensification of irrigated agriculture in Sudan and transmission of malaria and bilharzia. Bulletin of International Commercial Irrigation and Drainage, Vol. 36, No. 2 (in press).

Briscoe, John. 1987. "A Role for Water Supply and Sanitation in the Child Survival Revolution." PAHO Bulletin 21(2): 93-105.

De Wolf, J. 1988. Irrigation and Health. Wageningen, Netherlands: International Land Reclamation Institute.

Donnelly-Roark, Paula. 1987. New Participatory Frameworks for the Design and Management of Sustainable Water Supply and Sanitation Projects. WASH Technical Report No. 52 and PROWWESS Report No. 50. Arlington: WASH Project.

Elmendorf, Mary L. and Isely, R.B. 1981. The Role of Women as Participants and Beneficiaries in Water Supply and Sanitation Programs. Arlington: WASH Project.

Eng, Eugenia; Briscoe, J.; and Cunningham, A. 1987. Community Participation in Water Supply Projects as a Stimulus to Primary Health Care: Lessons Learned from AID-Supported and Other Projects in Indonesia and Togo. Arlington: WASH Project.

Eveleens, K.G. 1983. "Cotton-insect control in the Sudan Gezira: analysis of a crisis." Crop Protection Vol. 2 No. 3, pp. 273-287.

Haridi, A. and Jobin, W. 1985. "Estimated risks and benefits from introducing Marisa cornuarietis into the Sudan," Journal of Tropical Medical Hygiene Vol. 88, No. 2, pp. 145-152.

———. 1985. "Survival, growth and reproduction of the imported ampullarid snail Marisa cornuarietis in the Sudan," Journal of Tropical Medical Hygiene Vol. 88, No. 2, pp. 135-144.

Jobin, W. 1986. Long term cost effectiveness of environmental management for bilharzia and malaria control in water resource development. Technical paper for PEEM of WHO, Geneva.

———. 1986. "Designing hydro reservoirs to prevent tropical diseases," Water Power and Dam Construction November issue, pp. 95-98.

———. (in press). Economics of bilharzia control in Selected Papers for International Congress for Tropical Medicine, to be published by CRC for WHO, Geneva.

Jobin, W. and Laracuente, A. 1984. "Snail _Marisa cornuarietis_ in Tropical Hydroelectric Reservoirs," _Journal of Environmental Engineering_, ASCE Vol. 110, No. 2, pp. 356-368.

Jobin, W.; Laracuente, A.; Mercado, R.; and Negrón-Aponte, H. 1984. "Critical Water Velocity for Snail Habitats in Canals," _Journal of Environmental Engineering_, ASCE Vol. 110, No. 1, pp. 219-282.

Jobin, W.; Laracuente, A.; and Negrón-Aponte, H. 1984. "Inexpensive biological control of schistosome transmission in Montebello, Puerto Rico," _Bol. Asoc. Med. Puerto Rico_ Vol. 76, No. 2, pp. 157-160,

Okun, Daniel. 1987. _The Value of Water Supply and Sanitation in Development: An Assessment of Health-Related Interventions_. Arlington: WASH Project.

Rosenfeld, P.L. 1979. _The Management of Schistosomiasis_. Research Paper R-16. Resources for the Future. Washington, D.C.

Simpson-Hebert, Mayling and Yacoob, May. 1987. _Guidelines for Designing a Hygiene Education Program in Water Supply and Sanitation_. Arlington: WASH Project.

Tameim, O.; Abdu, K.; El Gaddal, A.; and Jobin, W. 1985. "Protection of Sudanese irrigation workers from schistosome infections by a shift to earlier working hours," _Journal of Tropical Medical Hygiene_ Vol. 88, No. 2. pp. 125-130.

Tameim, O.; Daffalla, A.; Mohamed, A.; Basit, S.; El Gaddal, A.; Fenwich, A.; and Jobin, W. 1987. "Water supply systems in Blue Nile Health Project." _Journal of Environmental Engineering_, ASCE (in press).

Tameim, O.; Zakaria, Z.; Hussein, H.; El Gaddal, A.; and Jobin, W. 1985. "Control of schistosomiasis in the new Rahad Irrigation Scheme of Central Sudan," _Journal of Tropical Medical Hygiene_ Vol. 88, No. 2. pp. 115-124.

Tillman, Robert E. 1981. _Environmental Guidelines for Irrigation_. New York Botanical Garden Cary Arboretum. New York.

Wright, W.H. 1973. "Geographical distribution of schistosomes and their intermediate hosts", Chapter 3 in _Epidemiology and Control of Schistosomiasis_ by N. Ansari. Basel, Switzerland: S. Karger.

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