**SCHISTOSOMIASIS AND WATER RESOURCES DEVELOPMENT:
A RE-EVALUATION OF AN IMPORTANT ENVIRONMENT-HEALTH LINKAGE**

By

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ABSTRACT

Many people argue that water resource development projects have negative health effects. In particular, they claim that an increase in schistosomiasis almost automatically results from building dams, irrigation systems, and other water-related activities in regions endemic for the disease. However, this literature review finds many cases where no such increase seems to occur. Some people explain this phenomenon by the adopting of preventive measures, such as providing adequate sanitary and water facilities and appropriate water management practices. Even when these are absent, there is often no increase in schistosomiasis transmission. Ecological variations in snail populations may be more important.

Generalizations are usually misleading. For example, in Mali and northern Ghana, some studies associate small earthen dams with schistosomiasis transmission. But other studies from northern Cameroon, Burkina Faso, northern Nigeria, and northern Ghana did not find any transmission of schistosomiasis from impounding small bodies of water. In Asia, schistosomiasis occurs only with specific methods of rice cultivation in certain areas of China and the Philippines. In Africa, most evidence fails to show an association between irrigated rice cultivation and schistosomiasis.

Water resources and agricultural development projects often receive unfair blame for creating health hazards such as schistosomiasis. The Aswan High Dam in Egypt is the most notable case. It might be prudent, however, for planners and policy makers to protect against possible increases in schistosomiasis transmission from water resource development projects. As part of project proposals, careful studies should be made of snail species and of existing patterns of schistosomiasis transmission.

Further, a percentage of investment and operating funds should be allocated for appropriate water supply and sanitation and for health care to treat local populations for any water-related or other ailments associated with the project.

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INTRODUCTION

What is the purpose of another literature review on the association between schistosomiasis and water resources development projects in the Third World? A large number of such reviews already exist ("e.g." Lanoix 1958, McMullen "et al." 1962, Hughes and Hunter 1970, Bruijning 1971, Rosenfield and Bower 1979, Hunter "et al." 1982, Dzik 1983, Weil and Kvale 1985, Service 1985, WHO 1985). Each review concluded that we can expect schistosomiasis to spread as countries build dams and irrigation projects in tropical regions endemic for the disease. However, these reviews focused on a few cases to illustrate their thesis. A few mentioned counter examples of water resources development projects that did not appear to increase schistosomiasis transmission, but the reviews treated these as exceptions to the rule.

The primary reason for this paper is that it provides a more comprehensive review of international literature on schistosomiasis relating to water resources development than previously published papers. This literature search accessed Medline, Popline, and Wilson computer databases and the online library catalogue of the University of Michigan. Citation lists in these articles provided additional references. More than 200 articles, books, and other documents form the base for this review. Hopefully, the bibliography appended to this paper will serve as a useful reference, even for those who might not agree with this paper's conclusions.

A second area where this paper may contribute is to lead to a more balanced health risk assessment of water resources development projects. In particular, a rereading of evidence suggests that the truth is more complex than previous summaries were able to reveal. While some research ties dams and irrigation projects to the spread of schistosomiasis, it is also true that other research has not implicated many similar projects. The association of schistosomiasis with water projects varies within different ecological zones in a single country as well as between countries and global regions. Consequently, it may be misleading to generalize beyond very specific ecological habitats. On the other hand, given the health impact of uncontrolled schistosomiasis transmission, it is prudent to follow the advice of the World Health Organization (WHO) to take measures against schistosomiasis as part of any major water resources development project planned for a region endemic for the disease [note 1].

THE BIOLOGY AND PATHOLOGY OF SCHISTOSOMIASIS

Schistosomiasis is an infection caused by parasitic worms or blood flukes of certain species of the genus "Schistosoma." Adult parasites live in the blood of mammals, but their life cycle requires a phase of asexual multiplication within a fresh-water snail host.

The fluke's life cycle begins when adult female schistosomes deposit eggs in the mammal host in the veins surrounding the bladder or intestines. The mammal then continues the cycle by excreting the eggs in urine or feces, near or in water. This links schistosomiasis closely to poor excreta control, especially by children.

Once the eggs reach water, they hatch into miracidia, which must find and infect an appropriate snail host. Within the snail host, each miracidium produces hundreds of cercariae, organisms that penetrate snail tissue, enter the water, and seek the skin of the appropriate species of mammal to burrow into.

The flukes infect humans by entering their exposed skin in water, usually through swimming, bathing, or wading. After migrating to the right location in the body, the parasites mature and mate. The female produces hundreds of eggs each day. The mammal host excretes a fraction of the eggs in urine or feces, depending upon the species of schistosome and its location. Most eggs remain in the host's tissue, indirectly causing the symptoms associated with schistosomiasis.

The three most important species that infect humans are "Schistosoma haematobium, S. mansoni," and "S. japonicum." The first of these dwells in the vesical veins surrounding the urinary tract. The mammal host usually excretes its eggs in urine. Commonly called urinary schistosomiasis, "S. haematobium" is found throughout most of Africa and in parts of Western Asia.

Two species cause intestinal schistosomiasis. "S. mansoni" usually occupies the mesenteric veins around the large intestine, and "S. japonicum" usually occupies the mesenteric veins around the small intestine. The mammal host excretes the eggs in feces.

"S. mansoni" exists throughout sub-Saharan Africa, the Nile Delta in Egypt and in Yemen, and in South America (chiefly Brazil) and the Caribbean. "S. japonicum" exists in Japan, China, the Philippines, and in two small parts of Indonesia. A closely-related species, "S. mekongi," exists along the Mekong River in Laos and Cambodia.

Each species of schistosome can infect only a single species of snail. Geographically distinct strains have different abilities to infect a given species of snail (WHO 1985). Therefore, the possible transmission of each form of schistosomiasis depends on a suitable snail host. The "Bulinus" family of snails are the snail host for "S. haematobium". "S. mansoni" require "Biomphalaria" snails, and "Oncomelania" snails are the essential intermediate hosts for "S. japonicum."

Various species of schistosomes have different water temperature, current, turbidity, and desiccation tolerances. A common factor in the population dynamics of many vector species is that they thrive on organic material and firm mud substrates. Usually they live in abundant aquatic vegetation that increases dissolved oxygen and provides food through green algae encrusting the submerged portion of the plants. Decayed vegetation also provides food and a suitable surface for depositing egg masses (Malek 1958).

Environmental management and modification to control schistosomiasis in water resources development projects includes preventing or removing aquatic vegetation, lining canals with cement or plastic, regularly fluctuating water levels, and periodic rapid drying of irrigation canals. Combined with measures to prevent contaminating water bodies with feces, these measures help control schistosomiasis. (WHO 1985, Pike 1987).

The type and extent of health complications associated with schistosomiasis appear to vary with the species and strain of parasite and by the characteristics of the human population. Some reports from sub-Saharan Africa, where most schistosomiasis infections occur, suggest that acute morbidity associated with schistosomiasis is less severe than elsewhere. These researchers argue that because the symtoms of schistosomiasis in many African countries appear mild, the disease is of debatable public health significance (Ndamkou and Ratard 1990, Gryseels and Polderman 1991). But this is definitely a minority opinion (see Southgate 1992).

Schistosomiasis usually causes blood and nutrient loss in either the stool or urine. Research has linked urinary schistosomiasis in Kenyan children to anemia and retarded physical growth (Stephenson "et al." 1989). More serious and very common complications include bladder or ureter calcification in urinary schistosomiasis and an enlarged liver and spleen in intestinal schistosomiasis. Periportal fibrosis of the liver characterizes "S. japonicum" infection, whose eggs frequently calcify in tissue. Portal and pulmonary hypertension are potential complications of "S. mansoni" infection. Research also links an increased risk of bladder cancer to urinary schistosomiasis (WHO 1985).

A REVIEW OF REVIEWS AND THE HISTORICAL RECORD

In recent decades, cautionary warnings have accompanied many irrigation and dam projects regarding the likely impact of increased schistosomiasis transmission. In some cases, these prophecies came true, including the Volta Lake project in Ghana in the 1960s and the Kainji Lake project in Nigeria around 1970. Most recently, research appears to confirm the prediction by Malek and Chaine (1983) that constructing a dam across the mouth of the Senegal River would lead to a surge in schistosomiasis transmission (Talla "et al." 1990). However, many dire predictions have not come true, regardless of whether or not people have taken preventive actions. Most spectacular were the warnings that the Aswan High Dam in Egypt would result in a "tremendous increase" in schistosomiasis in that country (Van der Schalie 1974). When little change resulted, the alarms fizzled out (Miller "et al." 1979).

Most authors writing on irrigation and schistosomiasis seem to presume that the relationship is well-established. They often only present evidence to illustrate the principle that water-resources development projects have an "inevitable" adverse effect on health and the environment (WHO 1985). This review, in contrast, takes a more skeptical approach. This is not to try to show irrigation never aggravates schistosomiasis but to improve our understanding of the specific range of conditions where this is likely to occur. It is also helpful to understand which practices to adopt to avoid such an occurrence in the future. Schistosomiasis is a public health threat in many countries. It would be unwise to downplay its importance, especially in relation to water resources development projects.

The literature on schistosomiasis in relation to water development is large. Therefore, it is helpful to break it down into distinct groups. We will discuss schistosomiasis relating to:

1) large dams, including dams built for hydroelectric power. This paper will specifically refer to transmission through their reservoirs, impacts on snail populations downstream through changes in hydrology, and human changes involving resettlement of the displaced population.

2) large-scale irrigation systems

3) irrigated sugar cane cultivation

4) decentralized irrigated rice cultivation

5) small dams, especially earthen dams in semi-arid climates

6) miscellaneous human activities that impact upon surface water, including aquaculture, mining, and the drainage of wetlands.

This paper does not extensively address the role of human migration in spreading schistosomiasis to new areas and in bringing uninfected groups into areas endemic for schistosomiasis. This paper examines the effect of physical changes in habitats. Let's begin by summarizing and critiquing a few of the many literature reviews on this topic.

For more than 40 years, people associated schistosomiasis with large dams and irrigation systems on the African continent. In 1950, a Joint OIHP/WHO Study Group on Bilharziasis in Africa issued a report, that stated, "The introduction or development of irrigation schemes, as well as the change from basin to perennial irrigation, has always resulted in a considerable increase in the incidence and intensity of bilharziasis wherever that infection existed or was introduced by outside laborers." The recommendation to introduce health concerns into all irrigation projects was largely ignored (Lanoix 1958).

Similarly, Watson (1958: 887) states, "The introduction of perennial irrigation into areas of bilharzial endemicity appears to be invariably accompanied by a rapid and striking rise in the incidence of bilharziasis in the human population." These statements were based on evidence almost entirely from the arid climate of North Africa, Egypt and Sudan in particular. Evidence from other countries, including Iraq, was vague.

The most frequently-cited review of the schistosomiosis water resources literature is Rosenfield (1979), also summarized in Rosenfield and Bower (1979). Seven case studies are discussed. Following are the main points as stated by Rosenfield, along with corrective notes by this reviewer. In part of Upper Egypt, schistosomiasis prevalence is said to have increased from 6 to 60% three years after the Aswan low dam was completed in the early 1930s (not the Aswan barrage in 1906 as stated by Rosenfield). Second, following the construction of the Sennar dam in Sudan in 1926 and the Gezira scheme which followed, schistosomiasis spread. Rosenfeld cites an unreliable estimate that put prevalence at 30 to 60% in the early 1940s but this prevalence was probably not reached until the 1970s [note 2]. Third, at the Arusha Chini irrigation project in Tanzania, finished in 1937, research reported the prevalence to be 85% in 1962. However, this estimate is misleadingly high when compared with other studies [note 3]. On the southwestern shore of Lake Volta in Ghana, prevalence is reported to have reached 90% two years after the lake was filled in 1966 (in children, overall prevalence was much lower)[note 4]. In Zambia, prevalence at Lake Kariba in 1968, 10 years after the Zambezi river was dammed, was 15% in adults and 70% in children [note 5]. At Kainji Lake in Nigeria, finished in 1969, prevalence increased from 30% one year later to 45% two years later. Finally, in the Dez irrigation project in southwestern Iran, completed in 1965, prevalence reportedly rose from 15% to 30% after two years, although this appears greatly overstated [note 6].

There are many examples where there is more mixed evidence on the health effects of irrigation than commonly reported. Hughes and

Hunter (1970) cite a report from the 1950s that "S. mansoni" infection prevalence in the Eastern Transvaal in South Africa was twice as high on European-owned farms. Research attributes the difference (African Reserves with 33.4%, versus 68.5% in European farming areas) to irrigation used in European farming areas. "S. haematobium" prevalence was the same in both areas. In "protected" European-owned farms, prevalence of "S. mansoni" was only 29.3%. But Pitchford (1958a) reported a much smaller difference. In the Eastern Transvaal, the prevalence of "S. mansoni" among children and adolescents was 43% in two communities in native reserve areas with rainfed agriculture. Two irrigated commercial farm areas had 57% "S. mansoni" prevalence, while both communities had the same "S. haematobium" prevalence. Moreover, Pitchford argued that population density, rather than cultivation techniques, explained variations in prevalence of intestinal schistosomiasis.

The evidence offered by Service (1989) is also incomplete. In his review, Service cites the claim by journalist Claire Stirling that schistosomiasis prevalence rose from 0 to 80% in the Kom Ombo plain just below the Aswan High Dam after dam construction. Miller et al.(1979) refutes this claim.

In Liberia, Service reported 87% schistosomiasis prevalence in a village that adopted irrigated rice farming, compared to 9% in an ostensibly similar village that had not yet done so (Kazura et al. 1985). But there are serious doubts about how representative the two communities in that study really are. Also, other researchers in the same area of Liberia (Dennis et al. 1983, Roundy 1985) as well as in neighboring Sierra Leone (White et al. 1982) failed to find any effect of swamp rice development on schistosomiasis.

In their review, Hunter, Rey, and Scott (1982) note that the only "before and after" evidence on the negative health effects of water projects relates to schistosomiasis in Africa. In Southeast Asia, schistosomiasis transmission is focal, and water development projects have not resulted in the spread of the infection. In Latin America, they credit preventive health measures for avoiding adverse health results from dams. In Africa, the authors cite studies of adverse effects from Egypt, the Sudan, Ghana, and Mali. The first two cases relate to irrigation systems made possible by dams. The third relates to the reservoir of a hydrodam, and the fourth case relates to small earthen dams. Like most other reviews, they do not clearly distinguish between reservoirs and downstream irrigation systems when discussing the health effects of dams. They give little attention to studies that suggest health effects were minor.

LARGE DAMS AND RESERVOIRS

There is an important distinction between the reservoir impounded by a dam, regardless of the dam's purpose, and the irrigation system that may accompany the dam. In the Volta, Kariba, and Kainji hydrodams, there were no irrigation plans and the health effects are mostly associated with populations living along the shores of the reservoirs. In contrast, the Aswan dams in Egypt and the Sennar dam in the Sudan are interesting because of the irrigation plans they helped, not because of the reservoirs themselves. Watson (1958) noted that the reservoirs associated with large dams in the Middle East and North Africa do not seem to be major sources of schistosomiasis transmission. The Aswan and Sennar dams caused problems only because of their irrigation potential.

Similarly, Malek (1958) noted that the Sudan had two large dams, the Sennar dam on the Blue Nile and the Jebel Awliya dam on the White Nile south of Khartoum, which impounds the river for about 300 miles in a long, narrow lake. Research implicates only the Sennar dam, associated with the famous Gezira irrigation scheme, in local schistosomiasis transmission. Also, the "Biomphalaria" snails, hosts for the "S. mansoni" parasite, are present in the Gezira irrigation area, but not in the Sennar reservoir itself. Interestingly, the Jebel Awliya dam played an indirect role in spreading the "S. mansoni" infection to Gezira. It displaced part of a population already highly infected by this parasite and caused them to move to the new Gezira scheme to find work (Greany 1952).

The case of the Aswan High Dam and Lake Nasser is of some interest because of the alarms raised before the dam's construction as well as rumors that exist today. Miller (1978) challenged widely published reports of early claims or fears of widespread transmission in the lake ("e.g." Brown and Deom 1973, Van der Schalie 1974, Farid 1975). Miller asserted there was no evidence of transmission of schistosomiasis in Lake Nasser. The few fishermen working in the lake continue to receive careful screening to prevent transmission (WHO 1985).

Similarly, there was much alarm about the fate of the Nubian population displaced by the Aswan High Dam. Fortunately, excellent studies on both the Egyptian and Sudanese Nubian populations may allay this concern. In Egypt, the prevalence of "S. haematobium" infection among Nubians declined from 15.7%, before displacement in 1964, to an adjusted figure of 7.2% in the Kom Ombo area after resettlement (Miller "et al." 1979). The decline occurred because resettlement communities, located away from the irrigation courses in the Kom Ombo plain, received piped water and electricity. Also, the Nubians hired local workers to till their fields (Miller 1978).

The Sudanese Nubians were somewhat less fortunate. Omer (1980) reports that the Nubians, resettled from Wadi Halfa to Khashm el Girba in the east of the Sudan, exchanged the urinary schistosomiasis, prevalent in their own homeland, for the intestinal form prevalent in their new settlement. "S. mansoni" infection rose from zero to 8.3% by 1970-71 and to 13.2% in 1972, while the prevalence of infection with "S. haematobium" fell from 11.6 to 3.4%.

The influence of the Aswan High Dam on downstream hydrology led to reports expecting increased transmission of both forms of schistosomiasis. This was said to be the result of interrupting the annual Nile flood in the Nile Delta, the Nile's low turbidity, abundant aquatic vegetation, irrigation canals, and marked increases in the densities of both "Bulinus truncatus" and "Biomphalaria alexandrina" snails (Malek 1975). Later, El Alamy and Cline (1977) and Abdel-Wahab "et al." (1979) reported instead that changes in the Nile's hydrology actually resulted in major declines in "Bulinus" snail populations. As a result, the prevalence of "S. haematobium" infections in the Nile Delta declined sharply. In a large-scale 1983 survey, Cline et al. (1989) reported an average infection of "S. haematobium" of 5% in selected Delta villages compared to an average of 55% in the same villages in 1935. For one locality studied in 1972 and 1978, Abdel-Wahab et al. (1979), found the percentage of urine samples positive for "S. haematobium" decreased from 30 to 9%. Conversely, the "Biomphalaria" snails that transmit "S. mansoni," increased and may have benefited from the changes in Nile hydrology. This species continued to expand south within the Delta with some reports of infestations in Upper Egypt. It is debatable whether this expansion is a result of the Aswan High Dam or a continuation of a long-term phenomenon of unknown origin. The prevalence of "S. mansoni" infections increased in the southern Delta but has probably remained stable in the northern Delta (Cline "et al." 1989).

The two Koka dams in the Awash Valley in Ethiopia present an analogous case of the different effects a dam has on the two forms of schistosomiasis through the reservoir, downstream hydrology, and irrigation. Kloos "et al." (1988) reported that these two dams, built in 1958 and 1964, appeared to have no effect on transmission through their reservoirs as assessed in 1968. The dams did, however, enable "S. mansoni" transmission to occur in the upper Awash Valley by changing its hydrology and introducing irrigation. However, the dams apparently decreased the risk of "S. haematobium" transmission in the middle Awash Valley by reducing the supply of water to the swamps where the "Bulinus abyssinicus" snail hosts live. In the upper Awash valley, as a result of the Koka dams, the water is now clear, with abundant aquatic vegetation and a weak current flow. These conditions favor breeding of "Biomphalaria pfeifferi" snails that were previously absent from the Awash valley. Below 800 m altitude, higher water temperatures deter this snail (Kloos 1985), so that intestinal schistosomiasis does not affect irrigation schemes in the middle Awash valley.

The Akosombo dam in Ghana may have favored schistosomiasis transmission through both its reservoir (Volta Lake) and through downstream hydrology in the Volta River. An early study by Hilton and Tsri (1970) reported that the Akosombo dam's effect on downstream hydrology reduced schistosomiasis transmission by eliminating backwaters created by seasonal flooding. However, a subsequent study (Wen and Chu 1984) reported dramatic increases in urinary schistosomiasis downstream. At Bator, infection increased from 17% in 1963 to 27.1% in 1972 and to 74.6% in 1981. At Mepe, the corresponding figures were 26.5, 36.4, and 88.0%. They attribute these changes primarily to the downstream hydrology effects of the Akosombo dam but don't specify the mechanisms involved.

Filling Volta Lake, beginning in 1964, undoubtedly caused schistosomiasis to worsen in central Ghana. MacDonald predicted this in 1955, at least 10 years earlier. Paperna (1970) reports that a schistosomiasis outbreak occurred on the southwestern shore of Volta Lake in 1967. Ewe fisher folk, who migrated to the new lake shore from the coast, brought the infection from the Volta delta area where it had already infected most children. The explosive growth of aquatic weeds in Volta Lake favors fast snail reproduction. Before water filled the dam, prevalence of "S. haematobium" in the central area was 1-5%; by 1968, infection was up to 40%. Later, a careful study by Scott "et al." (1982) found prevalence averaged 72-73% at the lake's southwestern shore during 1973-74. Transmission was local, affecting the indigenous Krobos almost as much as the newly-arrived Ewes. Prevalence of schistosomiasis was virtually absent in communities more than 7 km from the lake that did not use lake water (WHO 1985).

At Kainji Lake in Nigeria, evidence strongly supports the lake's role in increasing transmission of schistosomiasis. The evidence, however, only applies to the period directly after workers finished the dam. A WHO team collected data on prevalence of schistosomiasis from a group of people at lakeside villages on the southwestern shore of Lake Kainji between 1970 and 1972. Deom (1975) cites them as reporting that prevalence increased from 64.4 to 89.1% in those age 10-14, and among 15-19-year-olds, prevalence rose from 37.5 to 94.7%. In comparison, at New Bussa, settled by river people who moved away from the lake, infection remained stable. Among those aged 10 to 14, prevalence declined from 54.5 to 40%, and among those aged 15 to 19, it remained at 25.0%. Most significantly, in children under age 5, at the lakeside villages, the infection rate increased from 15.8% in 1970 to 64.3% in 1972. At the same time in New Bussa, away from the lake, transmission decreased from 4.0 to 0.0% since no new transmission occurred. However, Adekolu-John and Abolarini (1986) note that the same WHO team found much less change in prevalence between 1970 and 1972 at two towns on the northern end of Lake Kainji. Unfortunately, nobody has conducted systematic follow-up research.

It is difficult to make generalizations from the experiences of the dams just discussed. The lesson drawn by Waddy (1975) is that constructing other dams will similarly spread schistosomiasis. In particular, he expressed concern about the Cabora Basso dam in Mozambique, the Kossou dam in Cote d'Ivoire, and the dams on the Nam Pong river in northeastern Thailand. But in later years, no reports have linked schistosomiasis to any of these dams. Elsewhere, in northern Thailand, a reservoir, filled in 1963, remains free of the snail vector for human schistosomiasis (Temcharoen 1992). Third World countries constructed many large dams in the last two decades. Interestingly, very few reports link them to schistosomiasis transmission.

Among the few reports on recent dam projects, two from West Africa implicated large dams in increasing transmission of schistosomiasis. When the Diama dam at the mouth of the Senegal River became operational in 1986, it prevented salt water from penetrating upriver, allowing irrigation development in the lower Senegal River valley. Intestinal schistosomiasis, reported by Talla "et al." (1990), surged. Determined from clinical data in the town of Richard-Toll, the infection rate rose from 2% in 1988 to 72% in 1989. Diaw "et al." (1991) indicated that population-based estimates of the prevalence of "S. mansoni" infection rose from 12% in 1988 to 43% in 1990. However, research linked the geographically narrow focus of the outbreak to a massive irrigated sugar cane cultivation project at Richard-Toll, rather than to any general effects of the dam.

Brinkmann "et al." (1988) reported prevalence data before and after construction of the Selingue dam in western Mali. The research covered 10 villages displaced by the dam. In four villages that previously had no "S. haematobium", infection rates ranged from 6 to 22%, three to four years after resettlement. In two other villages, the prevalence of urinary schistosomiasis increased from roughly 2% before the dam to 22 to 42% afterward. The other four villages had much smaller increases. The data for all 10 villages suggest an 8-fold increase in "S. haematobium" infection from an average prevalence of roughly 4% before the dam to nearly 32% afterward. The average prevalence of "S. mansoni," on the other hand, decreased slightly, from 2.2 to 1.6%.

There is concern that the new Itaipu hydroelectric dam, on the border of Brazil and Paraguay, could result in schistosomiasis spreading to areas in which it is still unknown (Bousfield, 1979). Some fear the host snails will colonize the lake impounded by the dam, and infected migrants from elsewhere in Brazil will result in local transmission and a severe public health problem. Little documentary evidence exists on water resources development projects in Brazil and the spread of schistosomiasis. Water development projects in the San Fernando valley possibly resulted in new endemic foci of intestinal schistosomiasis (Malek and Chaine 1989). No studies, however, tested this hypothesis. Reviews agree that the spread of schistosomiasis during this century in Brazil resulted from infected migrants from the northeastern part to the country transmitting the infection in areas where the host snails already exist (Buttner 1958, Almeida Machado 1979, Kvale 1981). Therefore, it is not clear whether environmental change, including large dams or irrigation systems, spread schistosomiasis in Brazil.

The Amazon jungle, shared by Brazil and its northern neighbors, of which parts of Venezuela and Suriname are endemic for schistosomiasis, appears to remain free of schistosomiasis. In Suriname, the Brokopondo dam, completed in 1964, did not cause snail-breeding because of the acidity of the river water (Brown and Deom 1973, Leentvaar 1975). " Biomphalaria glabrata" snails exist only in soil with lime. In most of the Amazon, the soil and water are acidic and therefore, do not support the snails. Deforestation in the Amazon, however, could change this. Similarly, in Africa, schistosomiasis is also mostly absent in dense rain forests (Wright 1973). Kloos suggests (1988) that deforestation in western Ethiopia, combined with resettling infected migrants, could result in a new wave of schistosomiasis.

LARGE-SCALE IRRIGATION SYSTEMS

The two clearest examples of irrigation systems spreading schistosomiasis come from the Nile Valley. First, in the Nile Valley south of Cairo in Upper Egypt, researchers have known for a long time that displacing basin irrigation (by the flood waters of the Nile) with perennial irrigation results in a dramatic increase in schistosomiasis. Reports verified (Khalil and Azim 1938, Khalil 1949) that four locations changing irrigation methods in the mid-1930s, following Aswan Low Dam construction, experienced a surge in "S. haematobium" infections. Infection rates went up from 2 to 11% in 1934 to 44 to 75% in 1937. Similarly, cross-sectional data collected by Scott (1937) shows urinary schistosomiasis prevalence at 60% in areas of perennial irrigation in Upper Egypt and only 5% in areas with basin irrigation. Later, schistosomiasis increased in Sohag governorate from 3% in 1937 to 42% in 1955 with the shift from basin to perennial irrigation. In three districts with perennial irrigation, prevalence ranged from 56 to 68%, while in two districts with basin irrigation, prevalence was 9 and 13% (Wright 1973). Basin irrigation allows the land to dry out seasonally, killing almost all snails. Under perennial irrigation, the land is wet year round.

The major risk of the Aswan High Dam for increasing schistosomiasis transmission was in areas that switched from basin to perennial irrigation or areas being cultivated for the first time because irrigation water from the dam made it possible. Farooq (1973) estimated that these changes would affect 5 million people. Seventy percent of these people would become infected, adding 2.7 million new cases to 14 million existing cases in Egypt. However, Miller claims that by 1968, almost all of Upper Egypt was already under perennial irrigation.

Therefore, the Aswan High Dam could not have a major additional adverse effect on schistosomiasis (Miller "et al." 1979). However, Mobarak (1982) reports that after 1970, prevalence of urinary schistosomiasis in Upper Egypt reversed a previous downward trend and began to increase again because of the shift from basin to perennial irrigation. In either case, increased use of chemotherapy is bringing schistosomiasis under control in Egypt. In the northern part of Upper Egypt, prevalence dropped from 29.4% in 1977 to 11.5% in 1983, while further south, prevalence reportedly fell from 26.4% in 1980 to 16% in 1983 (WHO 1985).

The other Nile valley large-scale irrigation system implicated in schistosomiasis transmission comes from the Gezira irrigation scheme in the Sudan. In this area irrigated by the Sennar Dam (constructed in 1924 but extended after 1950), "S. haematobium" prevalence increased from under 1% before 1940 to 5% in adults and 15% in children in 1950 (Greany 1952). In the late 1950's, schistosomiasis seemed temporarily under control in the Gezira. Wright (1973) cites an unpublished 1961 report by Farooq stating that among 7-year-old entrants to 19 Gezira schools, prevalence of "S. haematobium" fell from 28.3% in 1957 to 3.3% in 1960. "S. mansoni" infections reportedly held steady or declined during the 1950s.

The major increase in prevalence of schistosomiasis in the Gezira came after 1960. One factor, instituted by the Gezira scheme, was the cropping rotation change to include "winter" wheat. Farmers kept the canals filled with water from March to May, when they were previously dry (Fenwick 1989). Another factor was the creation of the adjoining Managil extension which left tenants without adequate water supplies or sanitation facilities. Also, there was an influx of migrant laborers in the original Gezira scheme, who lived near irrigation canals, under very poor sanitary conditions. Tameim "et al." (1985) reported low prevalence of "S. haematobium" but 50 to 60% prevalence of "S. mansoni" infection during 1981-82, in six sentinel villages in the Gezira and Managil schemes. Fenwick states (1989) that prevalence of "S. mansoni" was much higher in Managil villages than in Gezira villages. He found 65% in a representative Managil village versus 31% in a typical Gezira village.

Most experts agree that applying the proper combination of sanitary engineering, water control management, snail control, infection surveillance, and treatment drugs, can avert irrigation's effect on schistosomiasis. Even without water control measures and environmental sanitation, chemotherapy with or without treating water to kill snails may adequately control schistosomiasis transmission. Fenwick (1989) notes that in the newer Rahad irrigation scheme, east of the Gezira plan in the Sudan, because of the use of drugs and snail control, schistosomiasis remained very low, despite very poor sanitary conditions. In 1985, prevalence of "S. mansoni" in 12,801 Rahad school children was 9.0% and "S. haematobium" was only 2.3%. Relaxing control measures, however, would cause a predicted surge in schistosomiasis, presumably reaching levels similar to those in Managil.

In the Middle East and North Africa, research has associated even small-scale irrigation plans, decentralized at the village level, with increases in schistosomiasis transmission. Malek (1962) reports that, in Sudanese villages along the Nile north of Khartoum, prevalence of urinary schistosomiasis in children was 11-12%, compared to an average of less than 2% in other areas. Wright (1973) reports that in the rural area around Baghdad, Iraq, prevalence of schistosomiasis increased from 10 to 25% because of the installation of lift pumps.

However, in Iraq, new large-scale irrigation projects never fulfilled the prophecies of dramatic increases in transmission of schistosomiasis. Abdel Azim and Gismann (1956) suggested that Iraq in the mid-1950s was at the same point as Egypt earlier in the century. They reported that large-scale irrigation projects would trigger a massive spread of schistosomiasis as happened in Egypt. Later, Wright (1973: 157) also referred to "vast new irrigation systems which will inevitably lead to spread of infection by "S. haematobium" unless exceptionally vigorous measures of prevention are undertaken." However, the only evidence offered is the case of the Musayeb irrigation project. Settlers moved there in 1956, and, by the end of 1958, 28% of the 13,000 settlers screened had the disease.

McMullen "et al." (1962), who also cite this case, note that one could not rule out the possibility that settlers imported the infection since prevalence was the same or higher throughout southern Iraq. Yacoub and Southgate (1987) reported that, in Southern Iraq, mass chemotherapy reduced the prevalence of urinary schistosomiasis to very low levels, where the highest endemic areas now average less than 10% prevalence. These authors did not address the question of the role irrigation systems might have played in the changing prevalence of schistosomiasis in Iraq.

In West Africa, the French colonialists established the "Office du Niger" system in Mali between 1934 and 1948 to irrigate cotton and rice. Deschiens (1970) reported that the irrigation dams at Sansanding and Markala, near Segou, resulted in a marked increase in urinary schistosomiasis, even during the colonial period. Later, both urinary and intestinal forms of schistosomiasis became highly endemic in the Office du Niger area. Brinkmann "et al." (1988) compared areas in the Office du Niger plan to fishing and farming communities along the Niger river and the internal delta. The irrigation scheme had a mean prevalence of "S. haematobium" of 64.4% compared to the river communities' 19.9%. The scheme had a mean prevalence of "S. mansoni" of 53.9% compared to the river communities' 1.9%.

However, Wright (1973) reports that upstream, along the Niger river in western Mali, the prevalence of "S. haematobium" was about 75% in the area of Kayes, and downstream, in the Niger Republic, prevalence averaged 45% in river communities. Therefore, it is not clear how much the Office du Niger project increased transmission of urinary schistosomiasis, although the worsening of intestinal schistosomiasis is unmistakable.

In southern Africa, Pitchford (1958b) warned that large-scale irrigation plans in the eastern lowveld part of Swaziland would increase transmission of schistosomiasis. Wright (1973) cites unpublished information reporting that this prediction came true.

Specifically, in the Mhlume irrigation scheme, prevalence of "S. haematobium" increased from 25% in 1959 to 56% in 1962. In the Ngonini scheme, the mean prevalence rose from 34% in 1958-59 to 73% in 1963. In the Big Bend scheme, prevalence rose from 15% in 1958 to 50% in 1962.

Elsewhere in the region, evidence on the effect of large-scale irrigation systems on schistosomiasis is lacking. In southeastern Zimbabwe, it is claimed that a 30,000-hectare irrigation scheme, developed between 1963 and 1971, worsened schistosomiasis, but nobody collected data until control measures took effect (Shiff "et al." 1973). This irrigation plan was much larger than contemporary projects in Kenya, Tanzania, or the Eastern and Southern Africa regions. Only the Awash Valley schemes in Ethiopia, totaling 60,000 hectares as of 1986 (Kloos "et al." 1988), appear to match it. Nobody has collectively evaluated the Awash Valley plans in any systematic fashion. Data are only available for the Wonji sugar estate (see below).

Andreano argued (1976) that perennial irrigation and double-cropping can intensify exposure to schistosomiasis through much larger irrigation distribution networks and year-round transmission. After 1958, large-scale gravity-fed irrigation projects expanded dramatically in China. He suggests that the prevalence of schistosomiasis probably increased as a result.

The number of cases declined by more than 90% between the mid-1950s and mid-1980s (Chen 1989), contradicting this prediction. Wiemer (1984) offers evidence consistent with a temporary increase in prevalence. In Kunshan county, Jiangsu province, prevalence was 55% in 1957. With a national thrust at control, the prevalence rate fell to 22-25% during 1959-61. But prevalence rebounded to 35% in 1963 and exploded to 62% in 1964, and 80% in 1965. A second national control program reduced prevalence to 3% by 1977.

IRRIGATED SUGAR CULTIVATION

In some places, studies have associated sugar cultivation with increasing schistosomiasis transmission. The best documented case is in southern Puerto Rico. Jobin (1980) reported that examinations of many stools in Puerto Rico during 1906-09 revealed only small, scattered foci of schistosomiasis linked with natural water courses. After 1910, new irrigation schemes allowing sugar cane cultivation resulted in major increases in the prevalence of schistosomiasis. In particular, the South Coast Irrigation System, constructed in 1914, increased local prevalence of "S. mansoni" infection from zero before 1910 to roughly 25% by 1930. Control efforts beginning in the 1930s almost eliminated infection by the mid-1960s. Jobin (1978, cited by Service 1989) acknowledges that sugar cultivation in the southern plain of Puerto Rico was a special case. The land provided an ideal habitat for snails since it was swampy and quickly became waterlogged. Sugar cultivation on better drained land in Puerto Rico did not promote schistosomiasis transmission.

Elsewhere in the Caribbean, researchers did not implicate sugar cultivation for increasing schistosomiasis transmission. On the island of Saint Lucia, for example, research suggests the opposite. Cultivating bananas, instead of sugar increased prevalence considerably during the 1950s (Helminiak 1971, cited in Weisbrod "et al." 1973). In contrast with sugar cane, bananas grow year-round with the foliage providing shade, keeping ditch water from drying out. Research cites cross-sectional evidence showing higher average prevalence among banana workers than other cultivators, (58 vs. 34%).

There is mixed evidence in Africa regarding sugar and schistosomiasis. Many blame the Arusha Chini estate in Tanzania for increasing transmission of schistosomiasis. Nobody, however, adequately documented this because there was no baseline survey. Foster (1967) noted that the proportion of newly-recruited workers in 1963 showing immunological evidence of current or previous infection was almost as high as that for existing workers. This suggests that people imported many, if not most, of the infections.

Sturrock (1965) noted that four out of six irrigation projects he visited in Tanzania did not increase schistosomiasis transmission. The other two, including Arusha Chini, could not rule out the possibility that high prevalence was the result of infections imported by migrants coming from endemic areas. The Miwani sugar estate in Kenya, located near Arusha Chini and developed at the same time, used metal piping instead of open ditches to deliver irrigation water. This deterred snail breeding and schistosomiasis transmission (McMullen et al. 1962, Highton and Choudhry 1974).

Elsewhere in Tanzania, Sturrock (1965) reported a 22% infection rate at the Kilombero sugar estate, but Zumstein (1983) reported the same prevalence in a nearby area without any irrigation facilities. In Nigeria, Thomson (1967) reported that the irrigated sugar estate at Bacita did not increase schistosomiasis. Transmission occurred almost exclusively through the local swamp and river, rather than through the irrigation system. Similarly, in Mauritius, researchers found host snails for schistosomiasis only in natural bodies of water, not in the irrigation systems of the island's many sugar estates (Gaud 1961).

In Ethiopia, several authors since Bruijning (1969) blame irrigated sugar cultivation at the Wonji sugar estate in the upper Awash valley for spreading intestinal schistosomiasis. Initially, Kloos and Lemma (1977) doubted claims of increasing prevalence in this area, but later reports confirmed a major problem. Migrant laborers had the first cases in 1964, 10 years after irrigation started. Prevalence rose from 7.5% in 1968 to 9% in 1972, 17% in 1975, and 20% in 1980 (Kloos "et al." 1988). Both the infection and the "Biomphalaria" host snails were unknown in the area before starting irrigation. Migrants introduced the infection from the north central highlands of Ethiopia where "S. mansoni" is endemic (Meskal and Kloos 1989). Later, Simonsen "et al." (1990) reported that, in 1988, the prevalence of "S. mansoni" infection in children in one labor camp at the Wonji estate reached 82%, a dramatic increase over the 1980 level. A major contributing factor is extremely poor maintenance of water and sanitary facilities at the Wonji estate labor camps. Some of the latrine pipes that led to septic tanks leaked directly into canals.

The large sugar complex at Richard-Toll in the lower Senegal River Valley was the site of a recent outbreak of "S. mansoni" infection. Talla "et al." (1990) found "Biomphalaria pfeifferi" host snails only in irrigation canals, not in natural water bodies. A second article, by Diaw "et al." (1991), confirms that the snails are not present in the Senegal River. Diaw found that infected snails were highly prevalent in a rechanneled stream passing through workers' residential areas as well as in irrigation canals. Research shows prevalence of schistosomiasis to be much higher (58%) in areas bordering the stream than in residential areas bordering the main irrigation canal (22-34%). No one would have rechanneled the stream or had people live near it without the sugar company. Therefore, one may attribute the outbreak, directly and indirectly, to the existance of the sugar complex at Richard-Toll.

DECENTRALIZED IRRIGATION FOR RICE AND OTHER CROPS

Many people blame irrigated rice cultivation, sometimes unfairly, for increasing the transmission of schistosomiasis. This is particularly the case for "Schistosoma japonicum" infection, the main human schistosomal parasite found in some of the rice-growing countries of East and Southeast Asia (May, 1950). However, research associates it with rice only under very specific ecological conditions. For example, in China, surveys in the early 1950s showed that roughly two-thirds of schistosomiasis cases occurred in less densely-settled, hilly and marshland areas, where animal reservoirs were an important factor in transmission (Mao and Shao 1982). Researchers associated rice cultivation with infection only in these hill regions, where the "Oncomelania hupensis" snails live in terraced rice paddies. This is unlike the flood plains where the snails inhabited rivers, lakes, and large canals rather than rice fields (Wright 1973).

In the southern Philippines, where "S. japonicum" is endemic, Pesigan "et al." (1958) found the snail host "Oncomelania quadrasi" only in flat, water-logged areas. On the island of Mindanao, the snails live in swamps, not in rice fields. Only in northeastern Leyte, the main focus in the Philippines, do snails mainly occupy rice fields. Research attributes this association with rice in Leyte to relatively primitive methods of cultivation used only there. The snails' original homes in Leyte were probably swamps, sluggish streams, and flood plain forests that people converted to rice fields without constructing drainage or irrigation systems, plowing, or weeding. In Bukidnon, as in Mindanao, when people converted wet lands to rice cultivation, they eliminated the snails within seven years because plowing and weeding disturbs the "Oncomelania" snail's habitat. Similarly, irrigated rice cultivation projects in other islands in the Philippines did not develop "Oncomelania" populations (Hairston 1976).

Elsewhere in Southeast Asia, rice cultivation does not affect schistosomiasis. Places in Laos and Cambodia report "Schistosoma mekongi" infection along the Mekong River. But transmission appears to be exclusively from the river, where the "Tricula aperta" snail hosts live (Harinasuta 1984). Similarly, in Central Sulawesi, Indonesia, the primary focus of "S. japonicum" infection consists of three small villages along a natural lake (Wright 1973). It is clear that biological differences in disease vectors make it difficult to generalize about disease patterns across countries or regions.

In Africa, a number of reports claim to link rice cultivation to schistosomiasis transmission, but only one of these studies offered unequivocal "before and after" evidence. A recent study (Howarth "et al." 1988) reported a place in western Madagascar with a small rice irrigation scheme constructed in 1979, where urinary schistosomiasis reached 74% in primary school children. A 1971 survey found only 13% infection at the same primary school. But this has not always happened in Madagascar; apparently the methods of rice cultivation and irrigation are critical factors. Gaud (1955) reports that in one locality in western Madagascar, migrants from another part of the island introduced rice cultivation methods with longer periods of standing water. This markedly increased the prevalence of urinary schistosomiasis. However, traditional methods of cultivation did not let the snails propagate in the rice fields. In the case studied by Howarth and colleagues, the irrigation system appears to have been poorly designed and uses water excessively. The lack of drainage caused waterlogging, a high water table, and standing pools of water where snails breed and children play. This case study is not characteristic of rice cultivation in general.

In the Rusizi plain of Burundi, schistosomiasis is endemic, a fact which Gryseels and Nkulikyinka (1988), attribute largely to irrigated rice cultivation. They acknowledge that there are natural occurrences of "S. mansoni", especially in the marshy delta areas. But they say these concentrations are sporadic while they are supposedly normal in irrigated areas. However, the data does not support this conclusion. Matched pairs of non-irrigated cotton and heavily irrigated rice areas within the same ecological zones do not show any difference in infection rates. In the Rusizi delta, rates are 44% for cotton and 47% for rice-growing areas. A little further inland, rates are 37% for cotton and 36% for rice-growing areas.

Similarly, initial reports linking rice cultivation in Cameroon to schistosomiasis transmission appear premature. For example, Yelnik "et al." (1982) reported that prevalence of urinary schistosomiasis was higher in three communities in northeastern Cameroon which cultivate rice than in another nearby community. Infection rates were 62.4, 56.9, and 31.6% in the three rice villages and 20.1% in a fourth, non-rice growing village. Similarly, Audibert "et al." (1983) reported that the first phase of an irrigated rice cultivation project in the Mayo Danai district caused a higher prevalence of schistosomiasis and warned that the second phase would likely make the situation worse. But, they (1990) later reported that studies between 1979 and 1985 did not reveal an increase in prevalence in the area covered by the project's second phase. Audibert and colleagues also reported that the higher prevalence associated with the first phase was actually due to an existing source of transmission in the Mayo Guerleo river. They stress the well-designed and well-maintained nature of the project that prevented transmission. Most conclusively, Ratard "et al." (1990) wrote that a systematic, nation-wide survey in over 500 places in Cameroon did not find any statistical association between prevalence of schistosomiasis and presence of irrigated rice cultivation.

Recently, in northern Liberia and neighboring Sierra Leone, external funding supported a number of swamp rice development projects. In Liberia, two projects funded by USAID included schistosomiasis surveillance. In Bong County, Liberia, Kazura "et al." (1985) alleges that one of these projects resulted in an outbreak of schistosomiasis. They compared one village, Balama, that started swamp rice farms in 1974, with another community, Gbarta, located 50 km away, that had not begun swamp rice farms by 1980. The prevalences of "S. mansoni" and "S. haematobium" infections in Balama were 87 and 42% vs. 9 and 11% in Gbarta. However, these differences probably do not result from the project. Studies show that in parts of Bong County both forms of schistosomiasis are endemic. But, in another part of the county, prevalences of both are low, consisting entirely of imported cases (Roundy 1985). Ecological differences unrelated to the project can probably explain most of the cross-sectional differences in prevalence observed between the two communities. Saladin "et al." (1980) confirms this. They reported that in three traditional villages near Balama, "Schistosma mansoni" and "S. haematobium" were endemic, with prevalence of 68-79% and 50-58% respectively. Further, Dennis "et al." (1983) reported the pre-project prevalence of "S. mansoni" infection in Balama village at 79.4% in swamp rice farming families, compared to 63.6% among other villagers.

The data from Liberia do not show that swamp rice development makes schistosomiasis worse. In the same project Kazura (1985) refers to, Dennis (1983) reports host snails were entirely absent from new rice paddies constructed under the Bong County agricultural development project. A few older indigenous rice swamps, however, did have snails. Irrigated rice paddies are dispersed and far from settlements, which lowers the risk of transmission. Similarly, Roundy (1985: 65) states that there are no snails in any rice swamps developed in Lofa County and Bong County agricultural development projects. Transmission occurred though contact with water used for domestic purposes. "To date, therefore, newly developed project swamps have been of little significance to schistosomiasis epidemiology."

Also, a study in Sierra Leone did not find any negative effects of swamp rice development on schistosomiasis. Seventy-four villages in Eastern Province recently developed rice swamp farming under an Integrated Agricultural Development Program, supported by the World Bank. White "et al." (1982) surveyed this area for schistosomiasis, onchocerciasis, and their vectors. "Schistosoma haematobium" and "S. mansoni" prevalence was low, 8.2 and 2.5% respectively, and showed no association with swamp rice development. Mean infection rates were 11.7 and 4.7% in six villages with no swamp rice, 8.6 and 3.1% in 21 villages with rice swamp developments started in 1977, and 9.9 and 0.8% respectively in 11 villages whose projects dated to 1973. White "et al." (1989) notes that in this area, host snail populations in natural swamps were very low. Further north in Sierra Leone, snail populations were much higher in both natural and rice swamps.

Evidence from Zimbabwe suggests that decentralized irrigation does not worsen the disease. Taylor and Makura (1985) cite a national survey in 1981-82 that found significant differences in prevalence of "S. haematobium" infection between irrigated commercial and rain-fed communal areas in the low-rainfall, western part of the country. However, since irrigated farms are usually close to rivers, the small variations between irrigated and rainfed farming areas found in their survey might be due to different surface water conditions rather than irrigation. Mason (1986) corroborates this by finding 21% prevalence of "S. mansoni" in children living at a commercial farm located next to a river, but less than 6% in a nearby commercial farm located further from the river. Also, less than 6% of the children in surrounding subsistence communities had the disease.

Chandiwana "et al." (1988) claim that the prevalence of schistosomiasis in Zimbabwe is much higher on irrigated farms than in communal, rain-fed farming areas. They based their assertion on just one commercial, irrigated farm that had 34.8% infection of "S. haematobium" and 5.4% prevalence of "S. mansoni". They compared these rates with lower rates in new settlers coming from a nearby communal area with 18.2% "S. haematobium" and 3.3% "S. mansoni" prevalence. They concluded that irrigation on the commercial farm caused this difference. However, the study by Mason showed that such a comparison is meaningless unless distance to a river is controlled for.

Researchers could make a stronger case that the designs of the irrigation and settlement systems may play a key role in schistosomiasis transmission. Wright (1973) reports that many state-owned farms in South Africa practice control measures including fencing canals, lining irrigation canals with cement, locating settlements away from canals, and prohibiting swimming in reservoirs. In one farm, infection of "S. haematobium" was under 20% and that of "S. mansoni" was under 5%. Private farms that did not use such controls had much higher rates (see Pitchford and Visser 1965). The latter authors reportedly reduced both forms of schistosomiasis in one commercial farm from 40% to under 20% in five years by providing safe water and swimming facilities.

SMALL DAMS

Throughout the semi-arid areas of Africa, people have constructed many small earthen dams to provide irrigation water for dry season cultivation. While reports often blame these dams for spreading schistosomiasis ("e.g." Masaba 1983), there is little evidence to substantiate such claims. Two important exceptions exist in Ghana and Mali.

In East Africa, Webbe (1962) noted that in northern Tanzania researchers found snail vectors for schistosomiasis in seasonal pools of water. They did not find them in the year-round reservoirs created by small dams that provided water for livestock during the dry season. Taylor and Makura (1985) report that 10,000 small dams recently constructed in Zimbabwe did not increase schistosomiasis prevalence. They compared prevalence estimates from each region of the country to estimates from the 1960s. The 1981-82 national survey could not substantiate the claim by Clarke (1977) and Shiff "et al." (1973) that connected schistosomiasis increases to these and other water resources development projects.

Small dams in the semiarid zone of West Africa get the greatest amount of attention. In northern Nigeria, studies show that the dominant snail species change when people build dams (Tayo and Jewsbury 1978, Olofin 1982, Betterton 1984). However, this does not necessarily change transmission patterns because transmission can occur mainly through a vector species found only in other water sources. Betterton "et al." (1988) report that two different villages near Kano experienced transmission of schistosomiasis not from newly-constructed dams, but from rain-fed pools used by most children to bathe. Research suggests that "Bulinus senegalensis," which inhabits seasonal pools, may be the primary host for "S. haematobium" in this area. Therefore, although the two dams built for dry-season irrigation extended the range of "Bulinus rohlfsi" snails, a common vector for "S. haematobium" in West Africa, this did not cause any noticeable increases in prevalence of urinary schistosomiasis.

A well-publicized case in international scientific literature is the small earthen dam at Ruwan Sanyi in Malumfashi, Kano State, northern Nigeria. Pugh and Gilles (1978) initially predicted that this dam, built in 1977, would increase transmission of schistosomiasis. They said this would spread the disease in the region since a World Bank-funded agricultural development project would build 80 similar dams. However, Pugh "et al." (1980) reported the 55.8% infection rate in school boys in 1979 was no higher than it was in 1971 (59.3%) before the Sahelian drought of 1972-73. But the rates were higher than in 1975 (33.8%) and 1976 (41.2%), before dam construction. They did not speculate whether it was the dam or a return to more normal rainfall that caused the change.

Less cautiously, Gilles "et al." (1983) report in their project summary, "Although a rise in prevalence was already occurring two years after the drought (presumably because the dry season pools of water were now once again available to the community) a further and much sharper rise occurred in 1979." Actually, the annual increment between 1976 and 1979 was only 4.9%, lower than the 7.4% increase between 1975 and 1976. Despite the inconclusive nature of this evidence, others use the articles by Gilles and colleagues to support claims that small earthen dams generally spread schistosomiasis.

Several studies in the same Sudano-Sahel ecological zone as northern Nigeria noted that evidence linking small earthen dams to schistosomiasis was lacking. In Burkina Faso, a comparison of three villages near Kaya showed schistosomiasis infection was lowest in a village with rice irrigation since 1967-68. The rate was almost as low in a village with access to natural lakes. Schistosomiasis was highest in a village with a small stream. For the three villages, urinary schistosomiasis in males was 12, 18, and 40%. In females it was 8, 9, and 25%. Apparently, the "Bulinus globosus" snails in this area prefer small streams over lakes or reservoirs (Le Bras "et al." 1982). Similarly, Doumenge (1984) reports that, in Burkina Faso, natural seasonal ponds infested by "Bulinus truncatus" snails are more common and dangerous locations of infections than are artificial reservoirs created by dams or impoundments.

In the semi-arid Sudano-Sahel zone of West Africa, schistosomiasis transmission typically occurs through seasonal pools of water, rather than permanent bodies of water. This contradicts what we might expect, based on data from other regions. The "Bulinus senegalensis" snail that causes this surprising phenomenon (Wright 1959, Greer "et al." 1990) is dormant during the summer (Betterton "et al." 1983). Numerous rain-filled pools in hard laterite surfaces favor the breeding habits of this snail species. Therefore, in the east central part of The Gambia, schistosomiasis in children was six times higher in villages located on a laterite plateau than in river villages cultivating swamp rice (Duke and McCullough 1954, also cited in Wright 1973). Similarly, in the middle Senegal valley, a 1977-78 survey found the infection rate in 10 flood plain villages was only 0.7%. Five villages located on higher ground, where "Bulinus senegalensis" snails commonly live in seasonal laterite pools, had 10.4% average infection rate (Malek and Chaine 1989).

Until recently, people in Cameroon assumed that small dams and irrigation caused a higher rate of schistosomiasis. However, Ratard "et al." (1990) reported that a nation-wide survey, at more than 500 locations in Cameroon, failed to find an association between the rate of schistosomiasis and small dams. Instead, temporary ponds and snail hosts adapted to low seasonal rainfall permits intense transmission of "S. haematobium" and "S. mansoni" throughout northern Cameroon, regardless of dams. Previous studies, comparing just two or three locations, did not have enough observations to reach valid conclusions.

Contrary to the experience in Cameroon, Nigeria, and Burkina Faso, one study in northern Ghana showed small dams to be linked to schistosomiasis (Hunter 1981, also cited in WHO 1992). Data collected during 1960-61 showed much higher prevalence of schistosomiasis in the eastern, more densely settled, part of what was the Upper region of Ghana. USAID funding had paid to construct over 120 small earthen dams in this region during the late 1950s. The mean prevalence of urinary schistosomiasis in the region's eastern part was 19.8% in 15 districts without dams, 42.3% in 16 districts with dams 1-2 years old, and 52.0% for 6 districts with dams 3 years old. Areas in the western part of the region with few or no dams had infection rates under 10% in 6 districts, and 10 to 29% in 10 others. In contrast, prevalence was over 70% in 2 of the 3 western districts containing dams.

The evidence offered from northern Ghana by Hunter (1981) is strong, even if cross-sectional in nature. However, Lyons (1974: 623) reports that in the western part of the same region of northern Ghana studied by Hunter, the prevalence of schistosomiasis in 1969 to 1971 was 17.6% among individuals using only river, stream, or pond water. This compared to 8.1% for people using water from small dams present in 11 of the 43 locations studied. Most of the reservoirs examined did not have infected snails and,

"The great majority of infections with "S. haematobium" are contracted through contact with rivers and streams at points other than where they have been impounded."

Studies from similar zones in neighboring Burkina Faso also did not connect small dams and schistosomiasis transmission.

The only place in West Africa where unequivocal evidence exists on the effect of small dams on snail vectors is the Dogon country of Mali (Bandiagara district). In this barren plateau, workers built 20 small earthen dams in the mid-1970s. In one year, between 1976 and 1977, urinary schistosomiasis rose from 79.4 to 93.4%. Researchers assumed this number was even lower before the dam construction. Citing this case and that of northern Ghana, Hunter "et al." (1982) generalize about the adverse health effects of small earthen dams to impound water.

Brinkmann "et al." (1988) compare the Bandiagara villages to selected savanna villages elsewhere in Mali that do not have any water resource projects. The average prevalence of urinary schistosomiasis was 67.2% in the Bandiagara villages and 13.4% in the savanna villages. The mean prevalence of intestinal schistosomiasis was 12.0 and 1.6% respectively. Assuming that the two areas are comparable, this would imply that prevalence of urinary schistosomiasis increased 6-fold because of the dams. Recent evidence confirms that schistosomiasis is much higher in Bandiagara villages with impounded water than in those without [note 7]. However, in the dry savanna of western Mali without dams, "S. haematobium" was as high as 85% in the Koulikoro area (Wright 1973). This suggests that the situation in Bandiagara may not be generalizable even to rural Mali.

AQUACULTURE, MINING AND DRAINAGE

Miscellaneous human activities that affect the characteristics of surface water often affect the prevalence of schistosomiasis by changing snail populations or human exposure. One of these activities is pond construction to raise fish. Several authors cite this increase in the transmission of schistosomiasis in sub-Saharan Africa (Gaud 1958, Hira 1970b, Deschiens 1972).

One report from southern Ghana (Thomas 1965) states that fish ponds provide an ideal habitat for the "Bulinus globosus" snail hosts, but a seasonally-filled reservoir behind a small dam did not. The only studies that document the role of fish ponds in schistosomiasis transmission are from Cameroon. Gariou "et al." (1961) report that "Biomphalaria camerunensis" snails infested a series of fish ponds created near Yaounde between 1948 and 1956. "S. mansoni" infected many of the snails. Doctors identified the first locally contracted human case in 1956. The number of cases identified in stool samples quadrupled between 1958 and 1960, and "S. mansoni" infected 64% of the staff living near the fish ponds. Later, Ripert et al. (1982), with cross-sectional evidence, showed much higher prevalence of schistosomiasis in urban residential quarters where fish ponds were present.

McMullen "et al." (1962) note that aquaculture does not need to favor schistosomiasis transmission. They cite two projects in Ghana that avoided this problem, either by using ducks to eat snails or by regularly drying out the fish ponds. Hairston and Santos (1961, cited in Hairston 1973) state that fish ponds are not suitable habitats for the amphibian "Oncomelania quadrasi" snails that are hosts for "S. japonicum" in the Philippines.

Research has also implicated surface mining for gems and minerals in the spread of schistosomiasis in sub-Saharan Africa. Gillet and Wolfs (1954) report that in northern Kivu and Ituri, Zaire, alluvial gold mining greatly expanded "S. mansoni," extending it to new areas. In 1951/52 in Butembo, the infection rate was 27%

among miners, 4% among the indigenous population of the plain, and none of those in the surrounding hills had the disease. Also in Zaire, Polderman (1986) reported more than 90% of the people had schistosomiasis in an alluvial tin mining area in Kivu. Researchers attribute this high prevalence to extensive ecological changes that result from tin mining and the long time tin miners spend standing in water. In Sierra Leone, diamond mining reportedly created many abandoned pits that provided breeding places for snails. Prevalence of "S. mansoni" soared in an area where it was previously unknown (Gbakima "et al." 1987, White "et al." 1989).

Similarly, researchers associate abandoned pits from road construction, as well as blocked ditches or culverts, with schistosomiasis transmission (Jordan "et al." 1980, Hira 1970b, McMullen 1973). The only documented report of this transmission source is from Khuzistan, Iran (Arfaa "et al." 1967), where borrow pits are the most common breeding site for host snails. In the Kilombero river flood plain in southeastern Tanzania, Zumstein (1983) reports that the prevalence of schistosomiasis is highest in an area where both a main road and railroad pass. However, this might be a coincidence. Of the three water contact sites with the highest proportion of infected snails, one was a pond used for making bricks, one was a natural swamp with a track leading through it, and one was a partially-filled river with naturally-occurring ponds.

Conversely, people often associate draining wetlands and channeling or making canals in rivers with reduced prevalence of schistosomiasis. In Mauritius, channeling and lining the Latanier river with cement and rubble reduced the prevalence of "S. haematobium" in school children from 63% in 1950 to 25% in 1957 (Gaud 1961, also cited in McMullen 1973). In Soufriere, St. Lucia, the infection rate among school children fell from 34% in 1973 to 7.4% in 1976 as a result of canal construction in the river in 1972. Researchers did not associate this with the well-known schistosomiasis control project on the island (Jordan 1985). Draining swamps and marshland reportedly reduced schistosomiasis transmission in Japan (Kobayashi 1983), Mozambique (McMullen "et al." 1962), Kenya (Korte 1973, cited in Service 1989), Puerto Rico (Palmer "et al." 1969), and other places. Ecological modifications (loss of wetlands and natural rivers) can inhibit schistosomiasis as well as make it worse (large dams, cultivation of flood plains).

CONCLUSIONS

This review finds the association between water resources development and schistosomiasis less consistent than most other authors suggest. Ample historical evidence exists, most notably in the Nile Valley of Egypt and the Sudan, that constructing dams and irrigation systems can increase schistosomiasis infection rates. Many have known about this fact for several decades. However, a little-known fact is that just as often research has not shown that water resource development projects, in countries endemic for schistosomiasis, increases transmission of the parasite.

One reason for the apparent confusion regarding irrigation and schistosomiasis is the lack of rigorous, random-sample survey data. Many case reports made broad comments on the effect of irrigation on schistosomiasis from cross-sectional comparisons of very few irrigated and non-irrigated areas. Systematic, nation-wide surveys in Cameroon (Ratard "et al." 1990) and Zimbabwe (Taylor and Makura 1985) failed to support previous studies that claimed higher prevalence in irrigated areas than in non-irrigated areas in those two countries. Until researchers carry out national schistosomiasis surveys in other African countries, it will be difficult to check the validity of comparable reports from other countries.

Evidence relating to water resource development projects and schistosomiasis is inconsistent. Evidence is also sparse in relation to the number of such projects. There is a need for more research in this area, including the long-term consequences of earlier projects. While a few projects, including the Gezira scheme in Sudan and Volta Lake in Ghana, had follow-ups for quite a while, many others did not. The most frustrating problem is the lack of data on the long-term consequences of projects such as the Kainji dam in Nigeria where researchers did not collect data for the last 20 years (Brightmer 1986). It is unclear if the Aswan High Dam construction and irrigation system change exposed more people to intestinal schistosomiasis. Researchers don't widely recognize the fact that there was a marked decline in the prevalence of urinary schistosomiasis where most Egyptians live (Abdel-Wahab "et al." 1979, Cline "et al." 1989).

This paper does not make any radical break from the existing policy conclusions. Given the evidence that water resources development projects may make schistosomiasis worse, that there are serious public health consequences in many cases, there is no reason to disagree with the conclusion reached by the World Health Organization more than 40 years ago. Specifically, WHO stated that in areas endemic for schistosomiasis, water resources development projects should have schistosomiasis prevention and control built into program design and implementation. Furthermore, even in cases where irrigation does not increase schistosomiasis infection rates, careful irrigation practices and proper drainage may improve agricultural productivity. As part of project proposals, careful studies should be made of snail species and of existing patterns of schistosomiasis transmission.

Further, a percentage of investment and operating funds should be allocated for appropriate water supply and sanitation and for health care to treat local populations for any water-related or other ailments associated with the project.

NOTES

1. This review does not deal with the economic impact of schistosomiasis. Previous reviews, including Barlow and Grobar (1986), did not find consistent evidence of lower productivity in workers suffering from schistosomiasis, except in those with extremely heavy infections. However, it is difficult to place an economic value on discomfort and suffering.

2. The true surge in schistosomiasis in the Gezira scheme appears after 1960 (Fenwick 1989). Stephenson (1947) reported that in 15 villages the prevalence of S". haematobium" was 21% in adults and 45% in children. A much larger and more representative survey in 1950 found infection rates of "S. haematobium" to be only 5% in adults and 15% in children, with a similar level of prevalence in "S. mansoni" (Greany, 1952). In contrast, by 1982, the prevalence of schistosomiasis in Gezira school children was as high as 70 to 80% (El Gaddal 1985).

3. Foster (1967) reports a prevalence of approximately 85% for the Arusha Chini estate in Tanzania. However, an extremely sensitive diagnostic technique determined this infection rate. A more conventional technique to compare results from different studies would yield a prevalence of about 30%. Further, many of these infections were imported.

4. Other sources ("e.g.", WHO 1985) cite Paperna (1970) as reporting a peak age prevalence of 90% among children aged 10-14. The overall prevalence in 1968, one year after the lake was filled, was 40%.

5. A subsequent national schistosomiasis survey in Zambia found average prevalence of "S. haematobium" of 58% in the area bordering Lake Kariba (Wenlock 1977). At Kariba, no one measured prevalence before dam construction. Hira (1969; 1970a) claims it was very low, but not zero. However, the national survey found that parts of southern and western Zambia bordering the Zambezi river upstream of Kariba had average infection rates of about 40%. This suggests that the increase around Lake Kariba may have been much less than widely believed.

6. The statistics presented for Dez are not confirmed by the Iranian sources cited (Arfaa "et al." 1967; 1970). The author's own previous publication (Rosenfield "et al." 1970) gives a graph suggesting that the local increase in average prevalence was from 22% during a one-year peak in 1967, an increase of 27% rather than 100%. Further, according to Farooq (1973) the total number of cases of schistosomiasis in Khuzestan province declined from 50,000 in 1959 to 8,000 by the end of 1967.

7. Long "et al." (1992) report that the average prevalence rate of urinary schistosomiasis in 174 children examined for blood in their urine was 63%. They report that the rates were highest, at or close to 100%, in four Dogon villages with dams and much lower, as low as 14%, in two villages without dams or access to dams. Two villages with partial access to dams had intermediate rates of 31% and 44%.

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