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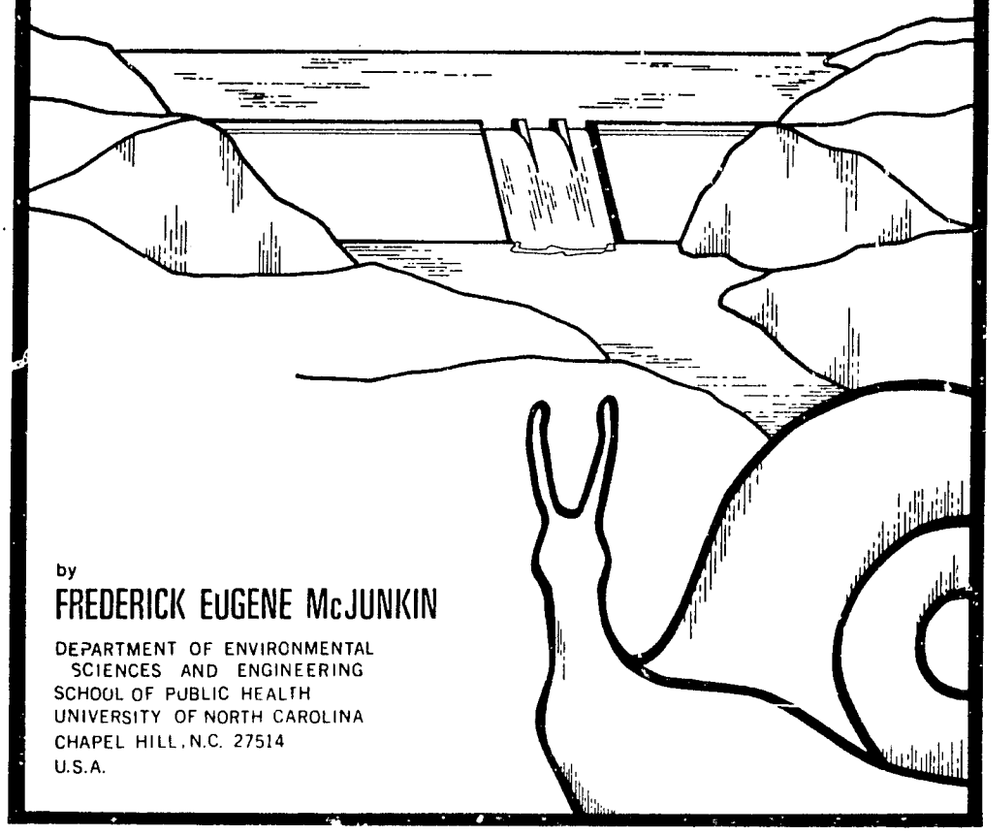

by
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A Report to the

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1970

ENGINEERING MEASURES FOR CONTROL OF SCHISTOSOMIASIS

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A REPORT

For the

Office of Health
Bureau of Technical Assistance
Agency for International Development
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TABLE OF CONTENTS

Description **Page**

I. BACKGROUND 1

A. Introduction 1
B. Life Cycle of the Schistosomes 1
C. Clinical Manifestations in Man 4
D. Distribution and Prevalence 4
E. Economic Impact 7
F. Relation of Schistosomiasis to Irrigation 8
G. "Ecological Horror Stories" 9
H. Purpose of Report 10

II. ECOLOGY OF INTERMEDIATE SNAIL HOSTS 11

A. Introduction 11
B. Physical Factors 12
C. Chemical Factors 12
D. Biological Factors 13
E. Pollution 13
F. Seasonal and Climatic Factors 13
G. Summary 13

III. CONTROL OF SCHISTOSOMIASIS 15

A. Therapeutic Treatment of Human Victims 15

1. Limitations
2. Outlook

B. Prevention of Eggs Reaching Water 16

1. Education (Habits)
2. Sanitation
3. Environmental Design

C. Destruction of Eggs and Miracidia 16

1. Direct Destruction
2. Indirect Destruction

D. Destruction of Intermediate Snail Host 16

1. Chemical Control (Molluscicides)
2. Biological Control

3. Physical Control
4. Agricultural Practices

E. Destruction of Cercariae 18
F. Prevention of Cercarial Infection of Man 18

1. Immunization
2. Education (Habits)
3. Personal Protection (Fabrics, Ointments, Repellents)
4. Water Treatment
5. Environmental Design

IV. ENGINEERING MEASURES FOR CONTROL 21

A. Disruption of Life Cycle 21
B. Creation of Unfavorable Environment for Intermediate Snail Hosts 21
C. Distribution and Drainage Systems 23

1. Channel Design

a. velocity
b. canal linings
c. cover (including pipe)
d. shape
e. layout and siting
f. protection
g. drainage

2. Operation

a. Intermittency
b. Maintenance

3. Control of Vegetation

a. weed clearing
b. trees

4. Special Structures

D. Storage Reservoirs 36

1. Reservoir Design

a. shoreline
b. intakes
c. spillways
d. access

2. Operation (Water Level Fluctuation)

E. Environmental Sanitation 39

1. Effectiveness of Sewage Treatment
2. Effectiveness as a Control Measure

F. Public Water Supply 40

1. Effectiveness of Water Treatment

a. storage
b. coagulation and filtration
c. disinfection

2. Bathing, Laundry, and Recreational Use

G. Agricultural Practices 41

1. Crop Selection
2. Irrigation Practices
3. Land Preparation
4. Management

H. Miscellaneous Control Measures 45

1. Mechanical Barriers and Screens
2. Radiation
3. Electricity
4. New Technology

I. Relation of Engineering to Chemical Control 47
J. Summary 47

1. Advantages of Environmental Control
2. Limitations

V. RECOMMENDATIONS 49

A. Better Use of Existing Knowledge 49

1. Manual
2. Education

B. Research 49

1. Monitoring
2. Agricultural Research
3. Systems Analysis
4. New Technology

C. Role of Environmental Control Measures 53

REFERENCES 55

PHOTO CREDITS 69

I. BACKGROUND

A. Introduction

Man's use of water antedates history. His use of water for purposes other than the simple quenching of thirst may well have been the dawn of history. The food resources in, on, and near water made possible the sedentary societies that developed agriculture, precursor of civilization. Farming of arid lands led inevitably to irrigation which led equally inevitably to increased social organization. The combination of increased agricultural productivity and social organization (and specialization), together with the relative ease of water communication and transport, made possible the early, great civilizations on the Nile, Euphrates, Indus, and Hwang Ho. Early civilization may indeed be called hydraulic civilization.

Water, however, can be a curse as well as a blessing. Increased population and consequent polluted waters have led directly to illness and death for millions. In this century, fortunately, such waterborne scourges as typhoid and cholera have been all but eliminated in the West and much reduced elsewhere, largely due to environmental sanitation measures implemented by engineers.

However, there is one water-related disease that infects more people today than ever before in history, perhaps as many as 200 million people. That disease is schistosomiasis (also known as bilharziasis) and its increasing incidence and widespread prevalence are due in large measure to tropical irrigation schemes, implemented by engineers.

B. Life Cycle of the Schistosomes

Schistosomiasis is a disease caused by certain parasitic worms known as schistosomes (Greek for "split, divided body") after the appearance of the adult male worm which is flat with the sides of his body inverted so as to form a groove, in which he carries the female.

Three species of schistosomes are important parasites of man. Two cause intestinal and hepatic (liver) disease: *Schistosoma japonicum* and *Schistosoma mansoni*. The third, *Schistosoma haematobium*, causes vesical or bladder disease. Aberrant human infections by certain other species have been reported in localized instances, e.g., *S. mattheei* in South Africa.

The larvae of certain schistosomes of birds and rodents may penetrate the human skin causing a dermatitis known as "swimmer's itch." This is prevalent among bathers in lakes in many parts of the world including North America; also in certain coastal sea water beaches. These schistosomes do not mature in man (Benenson; Levy and Folstad).

Sexually mature schistosomes, depending on the species, vary in length from about 7 to 26 millimeters (mm) and in width from about 0.3 to 1

mm and have the appearance of elongated threads. Once mated, the male and female schistosomes proceed in pairs, *S. mansoni* and *S. japonicum* to the veins of the bowel, and *S. haematobium* to the veins of the bladder. The females periodically leave their mates (partially or entirely), squeeze their slender bodies into the smallest veins, deposit their eggs, and return to their mates. A few eggs are carried in the blood stream to the liver, lungs, and other parts of the body, but most penetrate the vein walls into surrounding tissues. Some are trapped there and die but others work their way into the bowel or bladder and leave the body in feces or urine. As the disease progresses, tissues around the veins thicken and the proportion of arrested eggs increases.

To survive, the discharged eggs (70 to 170 microns long, 40 to 70 microns wide) must reach water within a month, a task greatly aided by inadequate sanitation. The change of osmotic pressure on entering the water results in the hatching from each egg of a small, ciliated, swimming larva known as a "miracidium." Miracidia must penetrate the body of a suitable freshwater snail (the intermediate host) within 24 hours or die.

Within the snail the miracidia undergo an essential development stage, lasting 4 to 8 weeks, and, by a process of asexual reproduction, each miracidium produces thousands of larvae known as cercariae. Liberation of cercariae may continue over a period of several months. The fork-tailed cercariae, which average 0.4 to 0.5 millimeters in length, swim about vigorously, tail first, for 24 to 72 hours without feeding and die if they fail to contact their definitive host which as a rule must be man in *S. mansoni* and *S. haematobium* and is often man in *S. japonicum* but may also be dogs, cat, rats, cattle, pigs, deer, or horses.

On contact with human skin, the cercariae attach by means of suckers and penetrate their host within several minutes. Within hours they are in the blood stream and are eventually carried to the liver, where they grow to maturity within a few weeks. They mate and travel together against the flow of blood to small blood vessels in the wall of the intestine or bladder. Egg production starts about the fortieth day after penetration of the skin by the cercariae. The parasite has been known to survive as long as 35 years in man (Maldonado, p. 10) but the life span of the schistosomes is generally much less than that, typically from 1 to 4 years.

The life cycle of *Schistosoma haematobium* is shown in Figure No. 1.

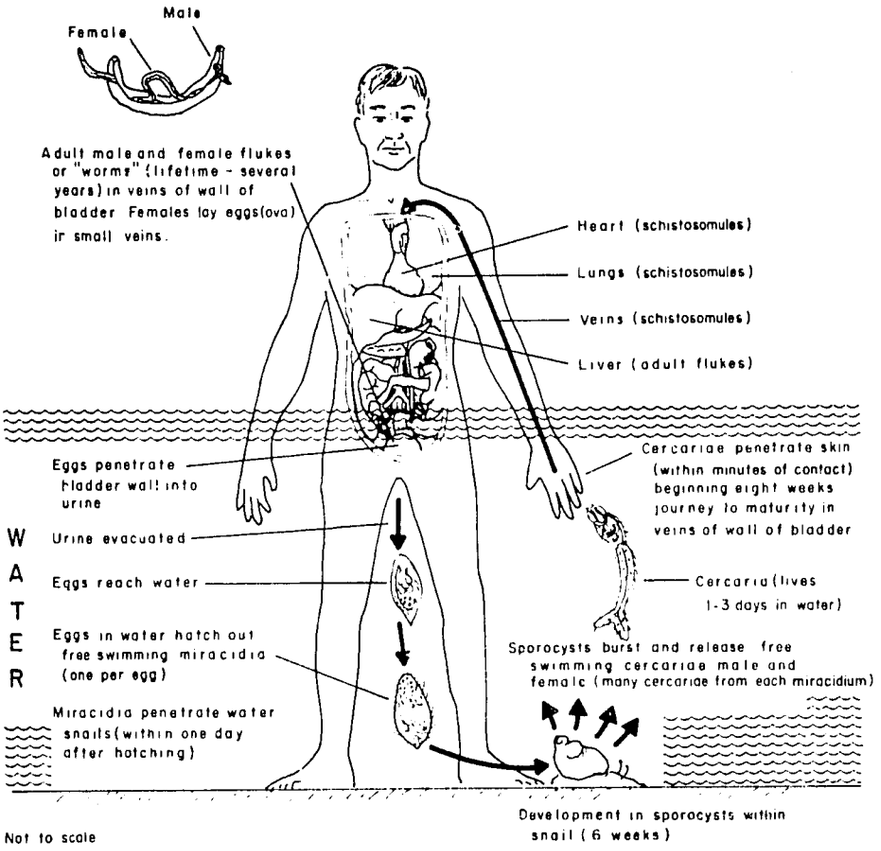


Figure No. 1. LIFE CYCLE OF SCHISTOSOMA HAEMATOBIUM.

C. Clinical Manifestations in Man

The symptoms and signs of schistosomiasis caused by *S. japonicum* and *S. mansoni* are much alike. During the incubation period, there is often a skin rash and characteristic diarrhea with liver enlargement and tenderness, variable fever, and sometimes lung disturbances. During the period of egg laying and extrusion there is typical dysentery with frequent bloody stools, liver and spleen enlargement and tenderness, often rectal lesions and other even more serious complications. In the final period of tissue reaction and repair, various lesions such as intestinal papillomata, ulcerations, and fistulas may develop. The spleen and the liver are often greatly enlarged, there is usually serious diarrhea, and there may be ascites (accumulation of serous fluid in the abdomen) and other major disturbances. See Figure No. 2.

In *S. haematobium* infections, the urinary system is involved and there are often serious lesions of the bladder, ureters, and other organs, with fever and general distress. Bloody urine is a usual sign. (The disease is sometimes called "red-water fever.") In uncomplicated cases there is usually no diarrhea or dysentery in *S. haematobium* infections.

During the incubation period the symptoms and signs of schistosomiasis are due primarily to toxic products of the worms and to allergic reactions. In the egg-laying period the extrusion of the eggs causes tissue damage with consequent bleeding and distress. Gradually, celluar reactions tend to block the eggs and to cause fibrosis of the affected organs, thereby impairing functional activity of the liver and intestines or of the urinary system. Bacterial infections of damaged tissues may cause abscesses and fistulas.

One larva penetrating the skin can develop into only one worm. Thus, the seriousness of the disease depends on the number of larvae acquired, the frequency of reinfection, and the length of time the individual is subject to reinfection. Ordinarily, the disease develops slowly as more and more worms are acquired during childhood, and the maximum number is reached at about 15 to 20 years of age. Although the factors involved in the rate of acquisition differ greatly in different places, the slow, insidious nature of the disease and the great disability it causes are always the most important aspects.

With modern treatment in uncomplicated cases the chances of avoiding death are quite good and in early cases full recovery may be expected. But vital tissues are destroyed as the disease becomes chronic and in advanced cases the prognosis is bleak.

D. Distribution and Prevalence

S. mansoni occurs in Africa, the Arabian peninsula, northeastern and eastern South America and the Caribbean area. *S. haematobium* occurs in Africa, the Middle East, and a small focus in India. *S. japonicum* occurs in

the Orient (China, Japan, Philippines, Celebes, Laos and Thailand). In some endemic areas more than half of the population is affected. None of these species is indigenous to North America.

Figure Nos. 3 and 4 are graphic presentations of the worldwide distribution of schistosomiasis.

There are no precise or reliable data on worldwide schistosomiasis morbidity and mortality. There are wide differences of opinion even within single countries on the significance of schistosomiasis infection (WHO, 1965a, p. 8). A World Health Organization (WHO) expert committee, (WHO, 1965a, p. 7) has estimated that "there are at present 180-200 million persons infected with bilharziasis throughout the world."

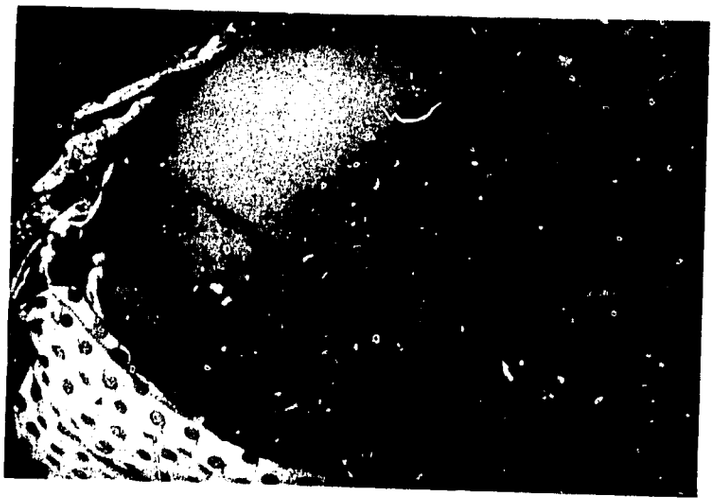


Figure No. 2. YOUNG WOMAN WITH DISTENDED ABDOMEN DUE TO S. MANSONI

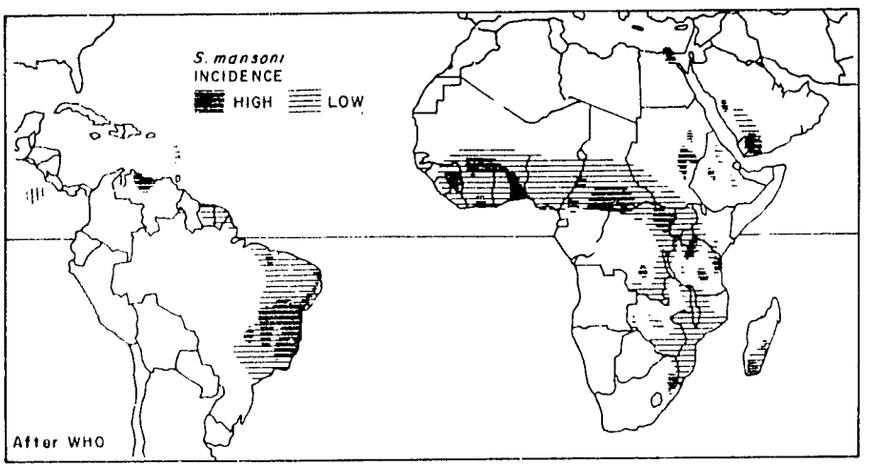


Figure No. 3. THE WORLD DISTRIBUTION OF SCHISTOSOMA MANSONI.

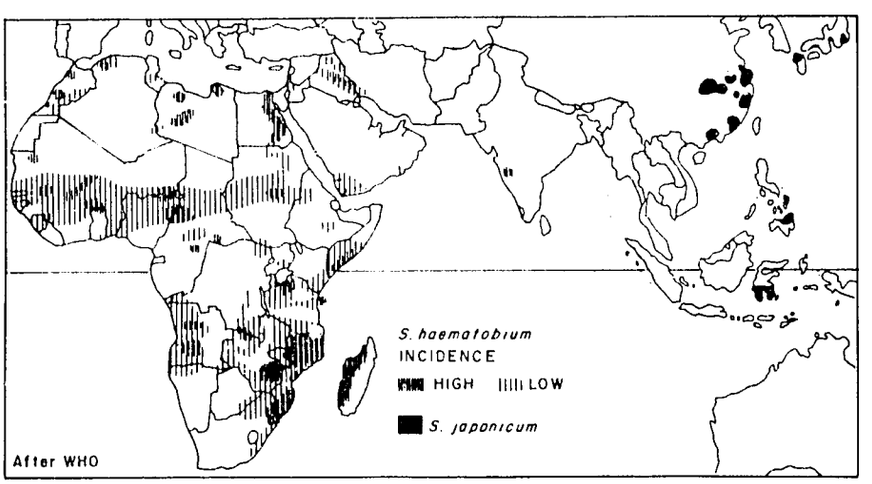


Figure No. 4. THE WORLD DISTRIBUTION OF SCHISTOSOMA HAEMATOBIUM AND SCHISTOSOMA JAPONICUM.

Wright (1968), more conservative, estimates the number of persons exposed and infected to be about 118 million. His estimates by regions are shown in Table No. 1. It should be noted that of the 33,309,000 infections shown for the Orient, 32,778,000 are attributable to China (mainland). Similarly of 6,302,000 infections estimated for the Americas, 6,000,000 are estimated for Brazil. (As an illustration of data difficulties, during the two year period 1963-64, only 6,425 cases were reported to the Pan American Health Organization; more than 10 times more cases were reported from New York State (Puerto Rican infections) than from the whole of Brazil).

Table I - WORLD DISTRIBUTION OF SCHISTOSOMIASIS, TOTAL REGIONAL POPULATION, POPULATION EXPOSED AND POPULATION INFECTED**

Region	No. of countries or islands	Total population	Population exposed	Population infected
Africa	43	301,770,000	187,568,280	74,383,310
Mascarene Islands	2	7,161,000	5,471,000	677,000
Southwest Asia	9	84,386,000	9,977,300	3,232,520
The Orient (except eastern Asia)	6	857,856,000	101,910,000	33,309,000
The Americas	11	97,033,494	49,436,000	6,302,200
Totals	71*	1,348,206,494	354,362,580	117,904,030

*India has been omitted from this compilation because only one small focus of the disease is known to exist in that country.

**After Wright

It should be noted that schistosomiasis is a serious, potential threat in many areas where it is not now endemic. Any new reservoir or irrigation scheme anywhere in Africa, for example, should be rigorously reviewed in this respect.

E. Economic Impact

There seems to have been little formal analysis of the economic impact of schistosomiasis. Farooq (1963) in a study of economic losses due to schistosomiasis in the Philippines, estimated them at $6.5 million annually, considering only expense of medical care and impaired productivity. This was $26 average annual loss per infected person, higher than per capita malaria loss. The cost of a long-range (15 years) control plan to eliminate these losses was estimated to be about $500,000 per year.

Farooq (1964) reports annual loss per infected person in Egypt as $3.50 to $15.00, Iraq as $24.00, and Japan as $26.00.

Wright (1968) has estimated monetary loss in Africa as follows:

"The latest available figure of per capita gross national product for Egypt is $139 and that for Africa except for Egypt is $135. If one assumes then that the 2.1 per cent of persons who have schistosomiasis with heavy clinical involvement are totally disabled, the annual monetary loss for Africa as a whole from this single factor would be approximately 212 million dollars.

Assuming that the 30.5 per cent of persons with moderate disease have a lowered working capacity of 10 per cent, then on the same basis the annual monetary loss from such a factor would be 308 million dollars for Africa as a whole. The total annual economic loss for these two degrees of disability would be 520 million dollars.

I hold no brief for the validity of these figures and can say only that they are probably on the conservative side. They do not include costs of public health programs, medical care, or recompensation for illness."

Farooq (1967) has estimated the annual economic loss for Egypt alone to be $560 million.

F. Relation of Schistosomiasis to Irrigation

The importance of irrigation in the spread of this disease is stressed by many authorities (Jackson, McMullen, Mozley, Olivier, PAHO, Scott, Sturrock, Van der Schalie, WHO; *et. al.*). A striking example (see Table II) of such a situation is quoted by Lanoix (1958) in connection with a scheme for perennial irrigation of four areas in Egypt. There the percentage of the population infected with schistosomiasis increased from as low as 2 percent to as high as 75 percent within three years after introduction of irrigation.

Table II - SCHISTOSOMIASIS PREVALENCE IN SELECTED AREAS OF EGYPT BEFORE AND AFTER INTRODUCTION OF IRRIGATION
(Quoted by Lanoix)

Area	Percentage of Population Infected	
	1934	1937
Sibaia	10	44
Kilh	7	50
Mansouria	11	64
Binban	2	75

Water is the medium in which eggs, miracidia, cercariae, and snails exist. Without water there can be no transmission of schistosomiasis. Provision of water where none existed before increases both human population density and the population density of their aquatic messmates, snails.

G. "Ecological Horror Stories"

The irrigation-schistosomiasis "ecosystem" has rather surprisingly (considering its antiquity and its remoteness to North Americans) attracted considerable public attention during the recent surge of public interest in environmental pollution and ecology. The new high dam at Aswan, U.A.R., in particular, is a newfound "classical" example of "narrow-minded technology." Relevant articles have appeared not only in such specialized journals as *Science* (Carter), *Environment* (Henkin), and *The Biologist* (Van der Schalie), but in the popular press as well, including *Time* (Anon.), the *Washington Post* (Hardin; Tuohy), the *Wall Street Journal* (Carley), and others (McCaull; Murdoch and Conell). Farooq (1967), a World Health Organization (WHO) consultant on schistosomiasis, based in Alexandria, has estimated that 2,650,000 new cases of schistosomiasis can be expected as a result of the Aswan project. An unnamed WHO official has been quoted (Scott, 1969) as estimating that the number of new victims will be 6,000,000. Other "negative benefits" include drowning of archeological sites, movement of villages, loss of the fertility of flood sediments formerly deposited on fields but now trapped by Lake Nasser, less water discharged to the sea resulting in increased salinity and a reduced sardine catch in the eastern Mediterranean, and possible earthquakes due to the massive weight of the impounded water.

Over 14 million of Egypt's 30-odd million population already suffer from schistosomiasis; to suggest as some have that the planners of Aswan were unaware of a possible increase in prevalence of schistosomiasis seems impertinent. To imply that the Aswan project should have been abandoned (and with it the hopes of millions of wretched fellaheen) may itself be "narrow-minded." Schistosomiasis need not be inevitable. Estimated costs (McMullen, 1962) for controlling schistosomiasis transmission in Egypt using molluscicides (killing the intermediate host snails, thereby breaking the transmission cycle) average $2.50 - $3.00 annually per irrigated acre. (Egypt now has 5.5 million acres under perennial irrigation and hopes to add 1.7 million more after completion of Aswan. Egypt spends about one million dollars annually on snail control). (Farooq, 1967). As Wolman suggested some years ago (1953), "scientific knowledge is sufficiently far in advance of application to make it possible for us to reduce or even eliminate many of the environmental diseases, provided we could produce the economic and social climate essential for the introduction of our well understood techniques. Money, therefore, becomes almost the major key to disease eradication in many areas . . ."

Compare McMullen's cost for a schistosomiasis control program for Egypt, $7 - 16 million dollars per year, with Farooq's estimate of annual economic loss due to the disease, $560 million dollars. Assuming the control program eliminates transmission of schistosomiasis and taking losses avoided as a benefit, just as one does with flood control projects, yields a benefit/cost ratio of from 35:1 to 80:1! Unfortunately, the benefits of a schistosomiasis control program are not so conspicuous or quantifiable as kilowatts, cotton, or corn. (Note: McJunkin (1969) has reviewed the economics of investment in water supply. Many of the arguments are equally applicable to schistosomiasis control programs.) Examination of health prob-

lems arising from environmental changes is one facet of the program undertaken by the Lake Nasser Development Centre with assistance from the United Nations Development Program (Special Fund) and the Food and Agricultural Organization (Lagler).

Development is not a simple matter. There are no quick and easy solutions. Let us hope that the Aswans will make possible the essential "economic and social climate" described previously by Wolman.

H. Purpose of Report

New irrigation and hydroelectric projects will be built in developing countries. Shorelines will be developed and marshes reclaimed for human habitation and use. Old projects will continue. Engineers and engineering are and will be major components of such programs and works. Schistosomiasis is or will be a problem or potential problem in many of these projects. This report seeks to:

(1) provide sufficient background on schistosomiasis and its control to enable engineers to work effectively with other professionals in design and operation of schistosomiasis control programs,

(2) summarize the present status of engineering measures for schistosomiasis control,

(3) improve understanding on the part of epidemiologists, malacologists, physicians, and others of the role or potential role of engineers (other than dispensers of molluscicides) in control of schistosomiasis,

(4) suggest and outline some possible approaches and opportunities for more effective control of schistosomiasis by engineers, and

(5) provide a relevant bibliography.

II. ECOLOGY (BIONOMICS) OF INTERMEDIATE SNAIL HOSTS

A. Introduction

Before it attacks man, each schistosome worm lives as a parasite of a snail. Thus there is an opportunity to prevent the human disease by destroying the intermediate snail host, in much the same way as mosquito extermination is used to prevent malaria. Many methods of killing the snails, or otherwise eliminating them, are possible, but two are most common: direct destruction with toxic chemicals (molluscicides) and indirect elimination (prevention) through creation of an untenable environment.

The schistosomes are specific in the choice of their intermediate hosts. *S. haematobium* infects snails of the genus *Bulinus* with isolated exceptions; *S. mansoni* the genus *Biomphalaria* (also known as *Australorbis* in the Americas); and *S. japonicum* snails of the genus *Oncomelania*. Members of the genera *Bulinus* and *Biomphalaria* spend their lives in water. *Oncomelania* is amphibious.

The factors that cause snails to favor certain waters and to be absent from others are not known with certainty. Prediction is further complicated in that species and varieties of the same genus may act as hosts in one locale and not in another.

Broadly speaking however, *Bulinus* species, hosts of *S. haematobium*, exhibit a preference for stagnant or slowly moving water, are more numerous in moderately polluted waters, and prefer pools with bottoms rich in silt and organic matter, but often occur in apparently barren water. Although *Bulinus* species are generally found only in permanent pools in Egypt and Iraq, species responsible for schistosomiasis in equatorial Africa may often be found in seasonal water holes and borrow pits.

Biomphalariae, hosts of *S. mansoni*, thrive in running water of moderate velocity and therefore are common inhabitants of streams and irrigation systems. In contrast to man-promoted transmission closely related to agriculture, there are areas, such as northern Brazil, where transmission is not closely linked with agriculture. There, *Biomphalaria glabratus* (often called *Australorbis glabratus*) lives in natural water courses and transmission occurs primarily through recreational and domestic activities.

Oncomelania species, hosts of *S. japonicum*, are amphibious, being able to live on land and to withstand drying due to the presence of a protective operculum or shield. Basically swamp animals, they have adapted themselves to irrigation systems, rice fields, roadside ditches, and other manmade habitats.

The World Health Organization and others have published monographs (Abbot, Malek, Mandahl-Barth, Pan American Health Organization) on snail species that have been incriminated as snail hosts, but their location and identification generally require the skill and experience of a biologist. Snails

under suspicion must be tested to determine whether they can, in fact, pass the infection. If the tests are positive, then the offending species can be specifically identified at the World Health Organization central reference laboratories in Copenhagen and Belo Horizonte. Snails can be shipped to distant places if certain simple precautions are followed.

Specific identification of the suspect or proven intermediate host may not be absolutely essential to development of a snail control program but is generally helpful in as much as the biology of the species incriminated may have bearing on control procedures.

Which relationships between the snail hosts and their environments offer opportunities for control?

B. Physical Factors

All snails that transmit schistosomiasis appear to tolerate considerable variation in the temperature of their habitat, from about 18°C to 32°C. A more important aspect for control purposes is the effect of annual temperature variations on the breeding season. Thus *Bulinus truncatus* in northern Iraq produces only a single generation annually, whereas *Biomphalaria glabratus* in Brazil breeds all year around.

The long term survival of snail hosts of schistosomiasis in complete darkness is a matter of some conjecture (WHO, 1957). Resolution of this question could be of practical importance in covering or piping irrigation channels.

The effect of water movement on snails has been a topic of more than passing interest. The failure of some species to establish themselves in rapidly flowing water has already been noted. Waves, floods, and, to a lesser extent, turbulence are detrimental to snails. They are also rarely found in water over 1.5 to 2 meters in depth.

The ability of snails to survive desiccation when stranded on land is another physical factor of interest. Although many snails die, enough survive to repopulate the habitat when water levels rise again.

C. Chemical Factors

The intermediate snail hosts of schistosomiasis seem tolerant of a wide range of concentrations of dissolved solids, including chloride and mineral salts, although salts of copper, barium, nickel, and zinc are toxic to the snails. A wide pH range is also tolerated. Except for molluscicides, there would seem to be little possibility of economically controlling snails by adding or removing chemicals.

D. Biological Factors

Snails have few natural enemies or predators. Very little is known about snail parasites and diseases. It is doubtful that diseases or predators would eradicate snails, but their numbers might be reduced.

Vegetation seems to be a desirable but not essential feature of the habitat of snail hosts. Snails are omnivorous, but prefer partly decayed vegetable matter, and to a lesser extent, decaying organic matter of animal origin. Living water plants are important to aquatic snails as depositories for eggs and for the growth of unicellular green algae, a favorite snail food. Plants also provide shelter from sunlight and current. Some species of plants have been shown to be antagonistic to snails.

E. Pollution

Moderate pollution is definitely favorable to the establishment of large populations of snail hosts. Not just human excrement but animal and plant rubbish as well. Chemical pollution from industrial wastes is almost uniformly deleterious however.

F. Seasonal and Climatic Factors

The effects of rainfall, water level, and temperature - all related to season and climate - have already been noted. Their effects on snail demographics may be profound and must be understood if normal decreases in numbers are not to be mistaken for effects of control measures. Variations in snail population and cercarial production may reduce the time period during which molluscicides must be applied.

G. Summary

An understanding of snail ecology can help control programs through identification of more effective control measures. One example: determination of the optimal time periods for molluscicide treatment.

III. CONTROL OF SCHISTOSOMIASIS

A. Therapeutic Treatment of Human Victims

1. *Limitations.* Mass human treatment would seem to be the easiest, most promising, most humane method of schistosomiasis control. However therapeutic measures alone have always proved inadequate. The reasons include:

(1) lack of a completely satisfactory drug, easily administered over a short period of time, free from side effects, and producing a high rate of parasitological cure,

(2) difficulty of reaching all the infected population,

(3) a certain number of positive cases exist for whom chemotherapy is contraindicated,

(4) many who start treatment fail to complete it,

(5) positive refractory cases and relapses occur among those who complete the full course,

(6) human treatment does not overcome the problem of animal reservoir hosts, especially of *S. japonicum* and to a lesser extent, *S. mansoni*,

(7) with many positive cases and unchanged habits of pollution and water use, reinfection and new infection take place and the life-cycle is maintained, and

(8) lack of funds and personnel to implement programs on scale needed; many developing countries spend less than $3 per capita annually on health programs.

Although chemotherapy alone will not interrupt transmission of schistosomiasis, it does ameliorate the condition of the individual and fewer cases reach an advanced state. Reduction in total worm population and egg production has a probable but as of yet ungaged effect.

2. *Outlook.* A recently developed drug, hycanthone, shows great promise as the long-sought one-shot drug (Katz; Gottschalk; and Olivier). Hycanthone has proved highly effective in tests with several thousand persons in Brazil, Venezuela, South Africa, Rhodesia, and Egypt. Further testing is necessary to determine its safety for mass therapy, particularly whether it can be given to large numbers of people with little information concerning their individual state of health. Even if hycanthone were 100 percent effective, however, it would reduce but not eradicate schistosomiasis (see above). Combined with chemical or environmental control measures, it might be feasible and desirable to use mass treatment with hycanthone to

further reduce transmission and to decrease morbidity due to the infection (Olivier).

B. Prevention of Eggs Reaching Water

1. *Education (habits).* If the eggs do not reach water, the transmission of schistosomiasis is halted. If the feces (or urine for *S. haematobium*) of infected individuals does not reach water, then the eggs do not. Therefore the public should be educated to the danger of defecating or urinating in or near water. The life-cycle of the parasite and the method of transmission, the effect on the health of the individual, and the economic impact of the disease on the community should be explained. Public support should be sought.

Unfortunately habits are slow and difficult to change. The inhabitants of areas endemic for schistosomiasis include many farmers, herdsmen, or fishermen who spend their day out of doors, inconvenient to latrines. But children and adolescents are the most difficult problem. "They are the most important source of viable, hatchable, schistosome ova and snail-penetrating miracidia and, because of their habits, are also the main source of infection to snails and thus of the maintenance of the life-cycle of *Schistosoma*" (Ayad, p. 341).

2. *Sanitation.* Adequate and acceptable facilities for excreta disposal, *if used,* can be an important support to a schistosomiasis-control program.

3. *Environmental Design.* The location and layout of villages and housing relative to surface waters; provision of safe and adequate water supplies, public laundries, and of washing, bathing and recreational facilities; and protection of nearby waters with pipe, covers, or fencing reduce the need or eliminate the opportunity for water contact.

C. Destruction of Eggs and Miracidia

1. *Direct Destruction.* Eggs and miracidia are destroyed by many of the molluscicides. They are also destroyed in anerobic waste treatment tanks, in trickling filters, and in long-detention time oxidation ponds.

2. *Indirect Destruction.* Eggs and miracidia perish when they fail to reach water, or reaching it, fail to find suitable host snails.

D. Destruction of Intermediate Snail Hosts

1. *Chemical Control (Molluscicides).* This has been the principal focus of control measures intended to interrupt transmission of schistosomiasis. The literature on the use and effectiveness of molluscicides is extensive and its review is beyond the scope of this report. The World Health Organization has published a comprehensive practical monograph on the subject (WHO,

1965b, Chapter 4, pp. 123-183). Several examples of testing and evaluation of molluscicides are cited in the bibliography (Ferguson, *et al*, 1965, 1968; and Jobin and Unrau, 1967b).

Molluscicide programs offer several advantages:
(1) rapid cessation of transmission is obtained,
(2) public cooperation is not required for success,
(3) administration is usually under one agency,
(4) complete eradication of snails is possible in certain situations, and,
(5) the technology is well known.

Disadvantages include:
(1) rapid reestablishment of snail populations is a frequent occurrance,
(2) application must be repeated when (1) occurs,
(3) toxicity to other fauna and flora, and
(4) development of molluscicide resistance, unknown as yet but a possibility.

Chemical control of snails can be combined with chemical control of weeds by using chemicals that are both molluscicidal and herbicidal (Dawood, *et al.*).

Snail control may be useful in reducing disease in men and livestock due to other trematodes (parasitic flatworms including the flukes) for which certain snails are intermediate hosts. These diseases (and the parasite) include, for example, chlonorchiasis (*Chlonorchis sinensis*), fascioliasis (*Fasciola hepatica*), paragonimiasis (*Paragonimus westermani*), *et al.*

Since snails are chemotropic, the use of baited traps is possibly an under-utilized measure. The use of decaying palm leaves in snail surveys is well-known. Cardarelli and his associates at the Creative Biology Laboratory at the University of Akron have demonstrated that development of toxic attractants or baits may be feasible.

Another new chemical control concept under study by Cardarelli (Akron), Paulini (Belo Horizonte), and others is incorporation of molluscicides, such as organotins, in "slow-release" form in "biocidal rubber" sheets and pellets. This concept has been successfully applied by the U.S. Army for mosquito control.

2. *Biological Control.* This method has wide popular appeal. A frequent suggestion is that snails might be controlled by predators such as certain species of ducks, fish, turtles, crustaceans, water rats, leeches, and aquatic insects; by competitors such as the snail *Marisa cornuarietis*, which appears to have rendered some Puerto Rican habitats unsuitable for the *S. mansoni* vector *Australorbis;* or by parasites and diseases of snails. Some predators attack miracidia or cercariae rather than the snails, e.g., the common guppy. In pools with steep banks fish do appear to reduce the snail population. (A long list of predators and parasites is given by Michelson).

With the possible exception in Puerto Rico of the snail *Marisa,* (Jobin, *et al.*, 1970; Ruiz-Tiben, *et al.*) most of these measures have been found to be ineffective, although very little is known about snail diseases and parasites. Even in the Puerto Rican instance, the evidence is equivocal and controlled, scientific experimentation is needed for confirmation (Jobin, private communication).

Predator-prey relationships are unlikely to result in snail eradication. Continuous periodic fluctuations in the numbers of both species are more likely. Some predators are susceptible to certain molluscicides. The predator itself may become a pest, e.g., *Marisa* has a voracious appetite for some crops. There is no proven practical biological control technique in active use today.

3. *Physical Control.* Since all vector snails require water, at least for breeding, management of water is a potential control method. This is described in specific terms in a later section.

4. *Agricultural Practices.* Also described later.

E. Destruction of Cercariae

Failure of the cercariae to penetrate a host within 48 hours means their death. This observation is sometimes used to advantage in storing drinking water. Most of the previous comments pertaining to destruction of eggs and miracidia are relevant here - destruction by molluscicides, prevention of human contact, etc.

F. Prevention of Cercarial Infection in Man

1. *Immunization.* This is a theoretical possibility, but so far has not been made practical. Many epidemiologists who have worked with schistosomias are convinced that there must be some immunity to reinfection, or conditions would be much worse than they are (Scott, 1969). At present, however, the possibility of induction of immunity by vaccination or other means is too remote to influence control programs. Smithers (1969) has recently reviewed schistosomiasis immunology.

2. *Education (Habits).* See previous comments (Sect. III.B.1).

3. *Personal Protection (Fabrics, Ointments, Repellents).* Military operations during and following World War II have stimulated the search for protective measures for avoiding schistosome infections. All types of uniform cloth afford some protection to the wearer, particularly if tucked into the top of boots with ample slack to form a cuff over the boot top. Protection is increased by impregnating fabrics with certain chemical and waterproofing agents. Certain ointments and repellents also provide protection including several made from natural plant oils, e.g., oil of cedar.

Ignoring problems of cost, distribution, and education, ointments are rubbed off by workers in constant contact with water. Clothing impregnated with protective substances or of sufficiently close weave to prevent the invasion of cercariae is intolerably hot and uncomfortable. Most importantly, schistosomiasis is a disease contracted by children and adolescents.

Pellegrino (1967) has recently reviewed this topic.

4. *Water Treatment.* Removal or destruction of cercariae from treated water is completely feasible. However, transmission of schistosomiasis through drinking water, although possible, is not a major route of infection.

The provision of a treated or protected water supply is important in preventing contact with cercariae-infested waters when collecting water, bathing, swimming, laundering of clothes, and other frequent daily activities. (See Section IV.F.2).

5. *Environmental Design.* The same actions that vitiate against eggs reaching water also tend to prevent human contact with cercariae. These measures include siting of housing away from canals, provision of adequate and safe water supply and sanitation, protection of surface water by covers, pipe, or fencing, provision of protected facilities for bathing, water recreation, and laundering, and similar measures which reduce human contact with cercariae-infested water.

IV. ENGINEERING MEASURES FOR CONTROL OF SCHISTOSOMIASIS

A. Disruption of Life Cycle

The six stages of the life cycle of human schistosomes together with possible control measures for each are shown in Figure No. 5. Complete disruption of any one stage of course terminates transmission. Four stages occur generally in a water environment (eggs are initially deposited in the human host, then found in the host's excreta, but they must ultimately find water; sporocysts of *S. japonicum* are specific to the snail genus *Oncomelania*, an amphibian). Engineering opportunities for disruption of the life cycle include classical sanitation, creation of a land environment inimical to human contact with water, and creation of a water environment unfavorable to snail vectors. Engineers are also often assigned the task of applying molluscicides.

B. Creation of Unfavorable Environment for Intermediate Snail Hosts

Elimination of the snail intermediate hosts is at present the most effective single method of controlling schistosomiasis. They can be killed outright using molluscicides or their environment can be molded so as to disfavor their continued propagation. The latter course of action is one than engineers are uniquely qualified to implement. The sinister synergism of irrigation and schistosomiasis has been stressed, however to a large extent it is defective and untidy irrigation, wasted water, and waterlogged land, rather than irrigation *per se*, that magnify the tragedy. Schistosomiasis engineering in considerable degree is simply good irrigation practice.

Although good engineering can eliminate many snail habitats and render others unfavorable for snails, it alone is usually insufficient for complete control and must be reinforced by application of molluscicides. The efficiency and effectiveness of molluscicides are much enhanced and the cost reduced by proper engineering of irrigation systems. Increased agricultural productivity, sometimes trebled (WHO, 1960a), is another benefit. Control of malaria and fascioliasis, a schistosome disease of livestock, is also made easier.

The relative ease of application and proven effectiveness of molluscicidng suggest it as the method of choice but proponents sometimes fail to consider its economic feasibility. The fact that estimates indicated that the annual cost for molluscicides alone in the Philippines would have exceeded the total annual budget of the Ministry of Health stimulated an interest in studies of ecological methods (ponding, filling, drainage, removal of vegetation, etc.) for reducing the extent of the snail colonies and transmission sites. The evidence gathered as a result indicates that proper water management and improved agricultural methods can be used to greatly increase crop production and to eliminate 95 percent of the snails at the time. The few remaining colonies in such areas became amenable to control by molluscicides (Hairston and Santos, 1961; McMullen, 1962).

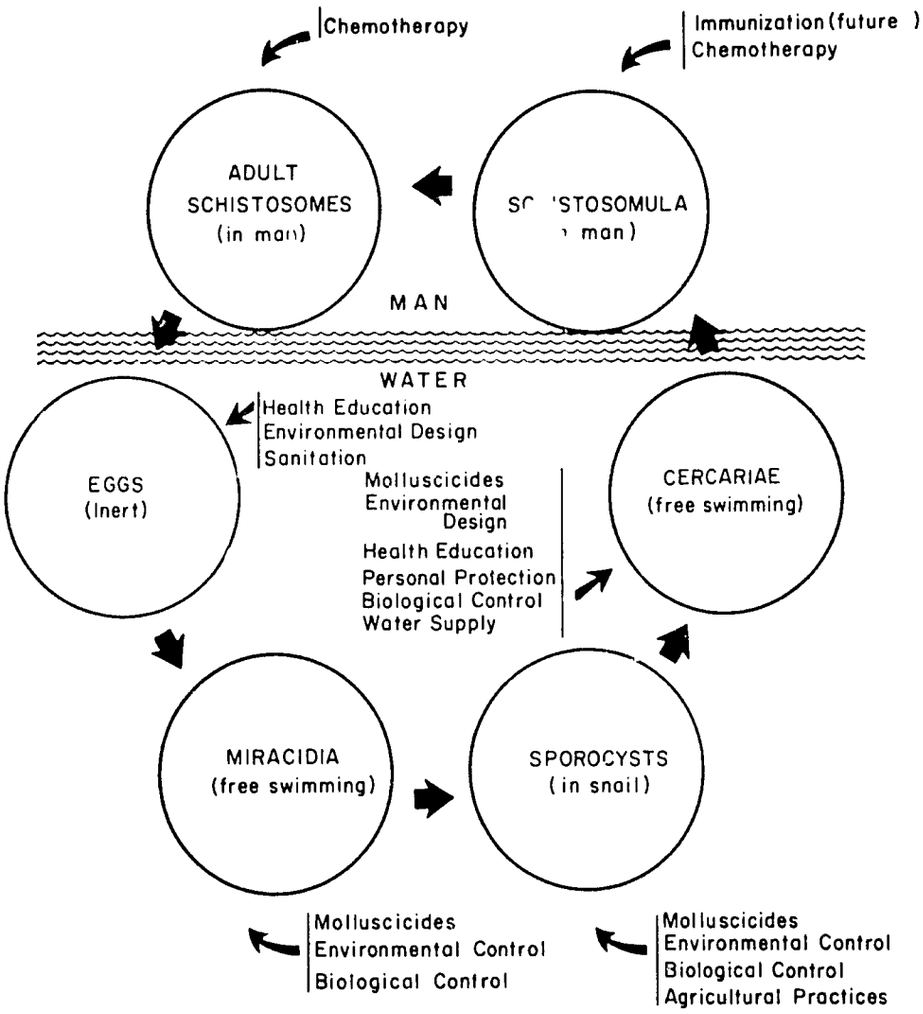


Figure No. 5. LIFE STAGES OF HUMAN SCHISTOSOMES SHOWING POSSIBLE ENTRY POINTS FOR CONTROL OF TRANSMISSION.

C. Distribution and Drainage Systems

1. *Channel Design*

a. *velocity*. The frequent observation that vector snails are rarely seen in streams and canals having average flow velocities in excess of 30 to 35 centimeters per second (cm/sec), approximately 1.1 feet per second (fps), poses the question: "What is the minimum velocity which will discourage establishment of snails?" The question is not as simple as it might appear. Snails can more easily cling to a firm smooth surface, such as that of concrete or stone, than to a loose and shifting surface such as silt or loam. Snails with conical shells such as *Oncomelania* and *Bulinus* may have lower drag coefficients than snails with flat discoidal shells, such as *Biomphalaria*. Aquatic vegetation may shelter snails from the current. As velocity increases, snails are first immobilized, then dislodged. Immobilization may suffice for control where velocity is maintained constant. An important design note is that it is not the *mean* velocity in the channel but the peripheral velocity that dislodges snails.

The latter question has been extensively examined (500 measurements) by De Araoz (1962) in a study of earth canals of stabilized parabolic cross section. De Araoz's findings are best summarized by reproduction of his diagram of equal velocity lines (see Figure No. 6). If the surface velocity at the canal centerline is taken as unity, then the velocity at any other coordinate of the cross section, as a decimal fraction of the centerline velocity, can be determined from the diagram. Thus peripheral velocities from the water edge to the center point of the bottom average about 0.40 of the velocity on the water surface at the centerline. If the surface velocity at the centerline were, say, 2.5 fps, then the peripheral velocity would be about 0.40 x 2.5 or 1.0 fps.

Engineers are accustomed to working with mean (average) velocities. A common formula (Manning's) is:

$$V = \frac{1.49}{n} (R)^{2/3}(S)^{1/2}$$

where

- V is the average velocity in feet per second
- R is the hydraulic radius in feet; it is equal to the water area divided by the perimeter of the wetted part of the channel
- S is the longitudinal slope of the bottom of the canal expressed as a decimal
- n is a surface roughness coefficient.

According to De Araoz the mean velocity is 0.729 of the velocity on the water surface at the centerline. Thus the average velocity calculated by the Manning formula should be multiplied by

$$\frac{1}{0.729} \times 0.40 = 0.55$$

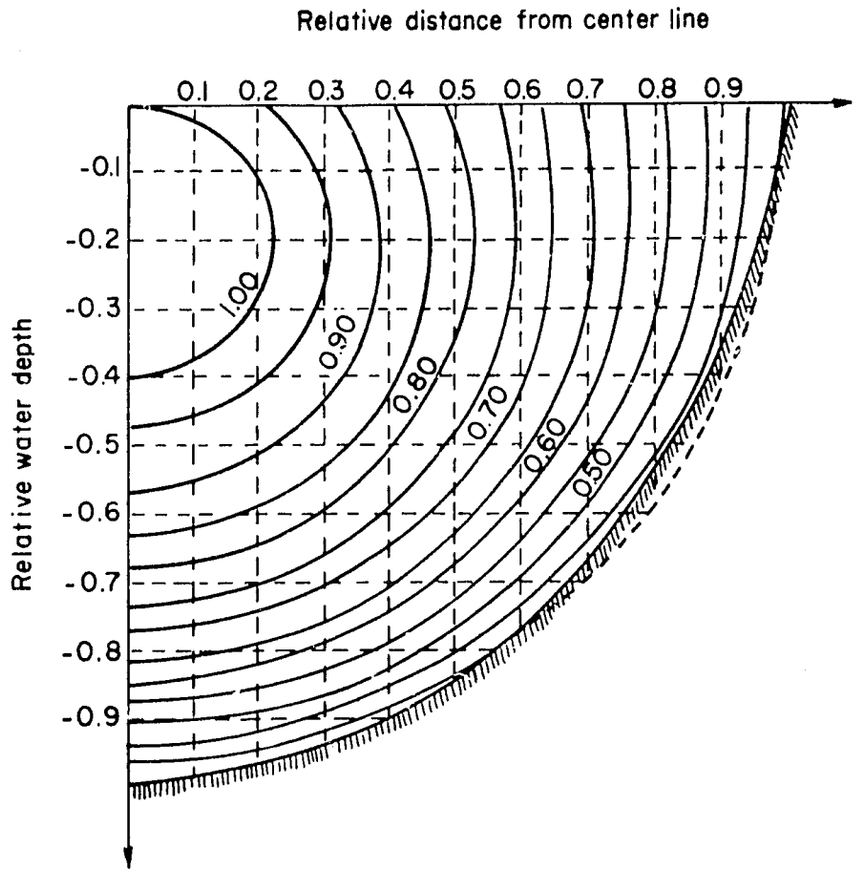


Figure No. 6. DIAGRAM OF EQUAL VELOCITY LINES
(After DeAraoz)

to obtain the peripheral velocity. Or conversely, if a desired peripheral velocity is sought, say 1.25 fps, then the Manning formula must yield

$$1.25\text{fps} \times \frac{1}{0.55} = 2.3\text{fps}$$

as the average velocity.

Inspection of the Manning formula indicates three ways to increase velocity: (1) use a smoother surface, for example concrete (n = 0.014) rather than earth (n = 0.025 ±); expensive, (2) steepen the gradient, S, largely impractical since it must generally parallel the surface of the ground if frequent pumping is to be avoided, or (3) change the channel cross-section making it narrower and deeper. Channel cross-sections are generally designed for hydraulic efficiency - maximum discharge for a given cross-sectional area - since cost is generally proportional to cross-sectional area. To significantly increase velocity, for a given discharge, gradient, and roughness, over that obtainable with a hydraulically efficient open channel section requires a radical, expensive change in section, if for no reason than that the steeper side slopes will require structural support.

The hydraulic aspects of dislodgement of one snail species, *Biomphalaria glabratus*, have been studied in a hydrodynamics laboratory (Jobin and Ippen, 1964). A velocity at shell height (1.3 cm) of 33 cm/sec (1.08 fps) was shown to immobilize and 65 cm/sec (2.14 fps) to dislodge *B. glabratus* from a smooth plastic bottom. Using the method of correlating boundary velocities to mean velocities developed by De Araoz (1962), Jobin and Ippen (1964) have calculated, for a wide range of channel geometries and discharges, the mean velocities required for control of *B. glabratus* (see Table No. III). The mean velocities proposed are based on immobilization rather than dislodgement - they "are still significantly higher than values recommended from field observations and should therefore prove quite conservative in design."

Table III - MEAN VELOCITIES IN TRAPEZOIDAL CHANNELS FOR CONTROL OF AUSTRALORBIS GLAERATUS*

Discharge		Immobilizing Mean Velocity	
(m^3/sec)	(cfs)	(cm/sec)	(fps)
1	35	58	1.90
5	175	67	2.20
10	350	71	2.33
20	700	75	2.40
30	1000	78	2.60
50	1750	81	2.66

**After Jobin and Ippen*

Jobin and Ippen also furnished their snails with harnesses and trained them to pull "very light loads", leading to the fascinating finding that "the output of 2.5 million snails would be equivalent to 1 horsepower, hardly an incentive for development of this power source."

For canals excavated in certain soils, velocities high enough to discourage snails may cause damage or destruction by erosion. The determination of nonscouring, nonsilting velocities has attracted the attention of many investigators over a long period of time and a considerable mass of data and formulas, e.g., tractive force, has been accumulated. However for preliminary purposes, and for design in many cases, use may be made of the approximate values proposed by Fortier and Scobey and, shown in Table No. IV. Because small canals erode at a lower mean velocity than large ones, the values shown should be reduced 20 percent for canals less than 1.0 meter (3.28 feet) deep and may be increased 20 percent for canals greater than 2.5 meters (8.20 feet) in depth (Lane, 1955).

Table IV - PERMISSIBLE CANAL VELOCITIES

Original material excavated for canal	Velocity after aging, of canals carrying					
	Clear water, no detritus		Water transporting colloidal silts		Water transporting noncolloidal silts, sands, gravels, or rock fragments	
	fps	mps	fps	mps	fps	mps
Fine sand (noncolloidal)	1.50	0.45	2.50	0.75	1.50	0.45
Sandy loam (noncolloidal)	1.75	0.52	2.50	0.75	2.00	0.60
Silt loam (noncolloidal)	2.00	0.60	3.00	0.90	2.00	0.60
Alluvial silts when noncolloidal	2.00	0.60	3.50	1.05	2.00	0.60
Ordinary firm loam	2.50	0.75	3.50	1.05	2.25	0.67
Volcanic ash	2.50	0.75	3.50	1.05	2.00	0.60
Fine gravel	2.50	0.75	5.00	1.50	3.75	1.12
Stiff clay (very colloidal)	3.75	1.12	5.00	1.50	3.00	0.90
Graded, loam to cobbles, when noncolloidal	3.75	1.12	5.00	1.50	5.00	1.50
Alluvial silts when colloidal	3.75	1.12	5.00	1.50	3.00	0.90
Graded, silt to cobbles, when colloidal	4.00	1.20	5.50	1.65	5.00	1.50
Coarse gravel (noncolloidal)	4.00	1.20	6.00	1.80	6.50	1.95
Cobbles and shingles	5.00	1.50	5.50	1.65	6.50	1.95
Shales and hardpans	6.00	1.80	6.00	1.80	5.00	1.50

Note: fps = feet per second; mps = meter per second

SOURCE: Fortier and Scobey

The effect of water velocities on the infection of animals exposed to cercariae has been studied by Rowan and Gram (1959), Radke *et al* (1961), and Webbe (1966a). Webbe has also studied its effect on infection of the snail vector *Biomphalaria*. A consensus is that infection increases with increasing velocity, then decreases. The velocity of maximum infection is imprecisely known, perhaps between 1 and 3 feet per second. Some infection occurred at all levels tested. Webbe (1966a) suggests that this finding, coupled with knowledge of the peak cercaria-shedding "may be useful and of practical importance in relation to the use of infested waters for bathing and clotheswashing where no other water-supplies are available"

The role of water velocity in irrigation canals in determining their suitability as snail habitats is well-established. However its use for snail control has probably been unconscious, the serendipitous by-product of such factors as favorable topography and soils. Its expense is likely to limit its large-scale use to areas where irrigation systems with similar velocities would be implemented in any event. Nevertheless it should not be overlooked, especially where hydraulic head may be available. It should not be used alone but supplemented with continuing surveillance and spot application of molluscicides.

b. *canal linings.* Canals are lined for many reasons: seepage control, erosion control, safety, reduction of maintenance, reduction in size of complementary structures, reduction in land required for rights-of-way, appearance, public acceptance, weed control, reduction of plant transpiration losses, and reduction in *total* annual cost. Benefits include more water for crops, increased land available for cultivation, protection of low areas from seepage and water logging, and reduction in areas favorable to snails. Under certain conditions and against certain species of snails, hard-surface linings have proven extremely effective (Lanoix, 1958; WHO, 1968). The relatively high velocities possible, the relative absence of aquatic vegetation, the potential for rapid draining and drying, reduced seepage to low-lying breeding sites, and the enhanced efficacy of molluscicide application are aspects favorable to snail control.

Canal linings may be arbitrarily classified according to the material used:

(1) paved or hard-surfaced. The most expensive, but also the most desirable. Portland cement or asphaltic concrete, brick, tile, half-pipe sections, stone, rubble, shotcrete, etc. Figure 7 is typical.

(2) exposed membrane. Flexibility their strong point. Butyl rubber sheeting, asphalt-felt sandwiches, asphalt-coated jute. These are more subject to surface damage, weeds, and ageing than is concrete. Butyl more successful than asphalt. See Figure 8.

(3) buried-membrane. Any water tight membrane with a long life in soil, from bentonite or clay to asphalt to plastic or rubber sheeting. Slow to dry with consequent prolific weed growth. Readily installed. See Figure 8.

(4) compacted earth. Economical where suitable soils available. Maximum channel velocity of 3 fps. See Figure 9.

(5) earth and chemical sealants. Attractive idea with only partial success. Applied as an emulsion of water and waxes, asphalts, resins, lignins, or polymers. Thin surface, short-lived.

The cost of linings, like other construction, varies widely with location. For the purpose of comparing linings, Table V shows average construction costs in the western United States.

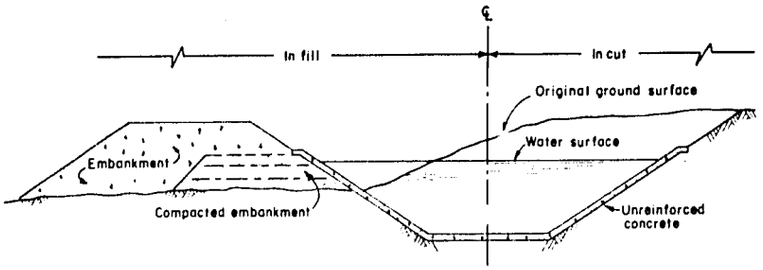


Figure No. 7. TYPICAL SECTION OF CONCRETE CANAL LINING

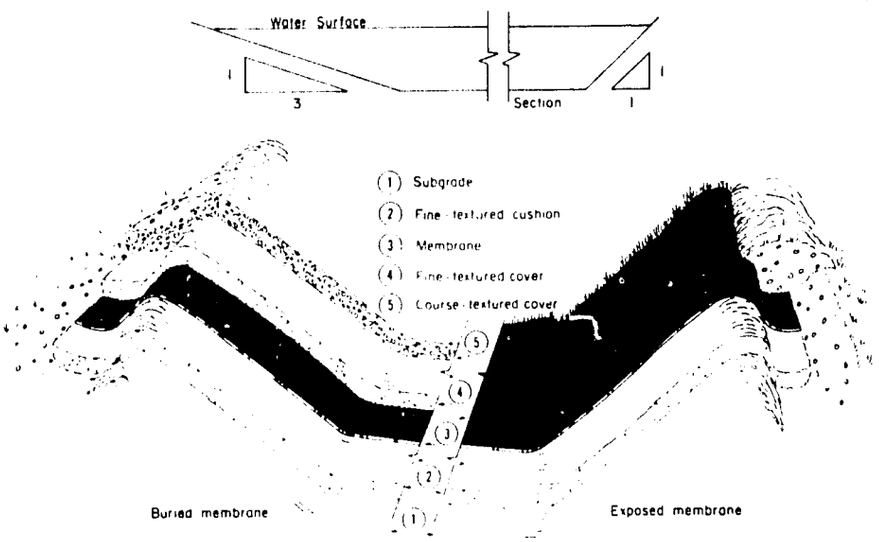


Figure No. 8. TYPICAL SECTION OF EXPOSED AND BURIED MEMBRANE LINING

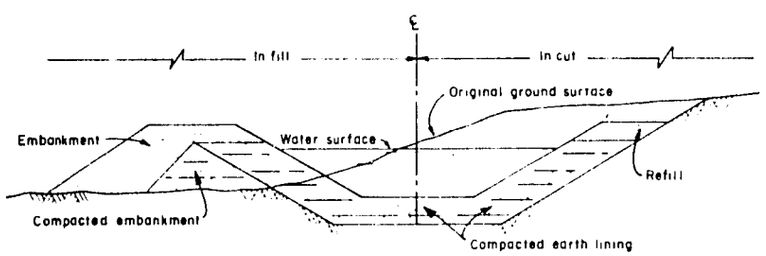


Figure No. 9. TYPICAL SECTION OF THICK COMPACTED EARTH LINING

In comparing costs, it should be noted that the size of a canal to carry a given discharge varies with the hydraulic "smoothness" of its surface. The Manning "n" for concrete is 0.014, for buried asphalt membrane (BAM), "n" is 0.025. Thus the flow velocity for the same depth in a BAM-lined channel will be only 0.014/0.025 = 0.56 as large as in a concrete-lined channel of similar shape and slope. This means that for equal discharge, the cross section (and depth and perimeter) of the BAM-lined channel must be substantially increased. Typically, a BAM-lined channel may require 1.5 times the lining surface, for comparison 1.5 x $1.10 = $1.65 for each $3.00's worth of concrete rather than $1.10. Truly comparative costs should also consider service life and maintenance requirements.

Table V - CANAL LININGS: APPROXIMATE CONSTRUCTION COSTS IN DOLLARS IN WESTERN UNITED STATES

Lining	Material	Other*	Total
Portland cement concrete, 3-inch unreinforced	1.20	1.80	3.00
Portland cement concrete, 2-inch unreinforced	.80	1.70	2.50
Asphaltic concrete, 2-inch	1.00	1.50	2.50
Asphaltic membrane, burried (BAH)	.33	.77	1.10
Prefabricated plank type, exposed	1.66	.50	2.16
Asphalt-coated jute, exposed	.85	.30	1.15
Asphalt-coated jute, buried	.85	.90	1.75
Polyethylene film, 10-mil, buried	.23	.62	.85
Vinyl film, 10-mil, buried	.45	.62	1.07
Butyl sheeting, 32-mil, buried	1.25	.62	1.87
Butyl sheeting, 60-mil, exposed	2.40	.10	2.50
Earth, compacted, 3 feet			1.10
Earth, compacted, 1 foot			.50

*Subgrade preparation, installation, and covering, when applicable.

Asphalt in place.

SOURCE: Lauritzen (1968)

The costs of lining may appear out of reach for a schistosomiasis control program. The major benefits, however, may be in reduction of seepage. It is a truism that conveyance losses alone are from 1/4 to 1/2 of all water diverted.

The U. S. Bureau of Reclamation (1963) has published a helpful 134-page manual on linings for irrigation canals.

c. *cover (including pipe).* "Of all snail control measures, the use of closed conduits is the most effective" (WHO, 1965b, p. 93). Probably the most expensive too. Covering large canals for any appreciable distance is prohibitively costly. However the use of low-pressure concrete pipe for moderate discharges (less than 10 m^3/sec or 350 ft^3/sec) is becoming increasingly more feasible. Such pipe is readily manufactured in field factories by moderately skilled labor.

Closed systems, in addition to providing an unfavorable environment for snails, have minimal transport losses due to leakage and evapotranspiration, provide protection from pollution, are safer, have lower maintenance and operational costs, and allow more land to be irrigated than do open lateral systems. In one Egyptian province (Beni Suef) a drain covering scheme underway will add an estimated one feddan (1.04 acres) in eight of agricultural land which in addition to the environmental improvement will adequately meet the cost of the program.

There are a number of examples where piped distribution combined with modern agricultural practices has been successful in areas endemic for schistosomiasis. The Miwani Sugar Estates, Kenya, is noteworthy (WHO, 1960a; McMullen, 1962ab).

d. *shape.* The concept of hydraulic efficiency was previously defined in the discussion of velocity. For the most frequently used open channel section, the trapezoid - the most efficient section is a half-hexagon - the sides slope up 60° from the horizontal. For a rectangular cross-section, the most efficient section has a depth equal to half its width. These slopes, 60° and 90°, are too steep for the stability of earth canals. Side slopes commonly vary from 3 horizontal units to 1 vertical unit (3:1, or 18.4^o from the horizontal) to 1:1 (45°) for highly stable materials.

The depth of water is not usually a critical element in the design of irrigation channels. In large earth canals, however, the depth is limited to protect high embankments against water pressure and to reduce the danger of an embankment failure. Consequently, depths in excess of about 10 feet (3 m) are usually avoided.

From the standpoint of snail control, canals should be provided with vertical sides and the maximum possible depth. These factors would discourage both marginal and bottom vegetation, increase vulnerability to preying fish, and reduce the penetration of light. A canal with vertical sides would of course have to be lined, and this, for the irrigation engineer, means increased costs and a totally different design. Thus, it can be seen that the points of view of engineers and malacologists are sometimes quite divergent. Would such a radical modification in design be justified for the sake of controlling snails and schistosomiasis, and perhaps other diseases? Another question the engineer would like answered is what combination of depth and turbidity of water is necessary to prevent aquatic vegetation of the type favored by snails?

e. *layout and siting.* The necessity of preventing cercarial exposure of the individual and also preventing excretal contamination of the irrigation system requires that the distribution and drainage systems be carefully sited relative to residential areas. Residential sites should not give ready access to irrigation water and whenever possible should be sited in a relatively dry area away from the main intakes and channels. Layout of field channels and drains should be planned or controlled rather than left entirely to local farmers. When canals isolate villages from main roads, they should be bridged. Borrow pits and sections of old canals should be filled, drained, or otherwise eliminated as snail habitat

For the new land to be reclaimed by water from the Aswan High Dam, ". . . whenever possible canals will be constructed at least 500 metres away from the villages, and where this cannot be done the irrigation authorities have agreed to pass the canals within the precincts of the villages and for five hundred metres on each side between perpendicular walls, rising a few metres above the level of the ground . . . there will also be no sharp curves to favor stagnation, there will be no blind ends, and . . . any disused canals will be filled in." (Ayad, p. 377).

f. *protection of access.* Several methods for protecting access to the irrigation system and thereby preventing transmission of the disease to both man and snail have been described: closed conduits, e.g., pipe; physical barriers, e.g., walls; fences, or heavy brush; distance, e.g., 500 meters between housing and canals. Some of these involve capital investment which can be reduced by confining control measures to the more likely points of infection.

Access may be protected indirectly by eliminating the need for contact with snail-infested water through provision of such facilities as bridges and culverts, public water supply, and protected facilities for bathing, washing, watering of livestock, laundering, and water recreation.

That access could be effectively protected by statute is doubtful since children are notoriously unimpressed by trespass rejoiners. Boats might be kept off the smaller canals by statutes and physical barriers conjoined. Boatmen are known to have high infection rates - 52.0 percent in one area of Egypt (Farooq, 1966a).

g. *drainage.* When land is irrigated, drainage problems almost always follow, particularly high ground water and development of salinity. These are controlled by drainage affected by means of open ditches or underground tile-drains. In the latter case, there is no snail growth, but the problem may be extremely serious in open drains. Such ditches often serve flat areas, so that their slopes and velocity of flow are very small. Drainage flow includes not only excess irrigation water but also normal surface runoff, the determination of which forms the basis for drainage design. Lack of drainage results in stagnant pools, wet areas, and seepages which are often good snail habitats.

While it may not be economical to line open drains completely, it is perhaps advisable to provide them at least with lined inverts (prefabricated concrete inverts, for example), which would have the advantage of concentrating small flows and of increasing water velocity.

The cost of drainage can be surprisingly low compared with the value of the land reclaimed and the benefits in terms of increased crop yields resulting from keeping the water table within the desired distance of the root zone. In reclamation work in the Nile Delta, the cost of subsoil drainage using 4- and 6-inch (10-cm and 15-cm) diameter concrete pipes was about $70 per acre. This represented about one-tenth of the market value of the land reclaimed. However, this cost was completely offset by the saving in land which would otherwise have been required if open drains had been used. In addition, there are hardly any maintenance costs involved as compared with open drains. (WHO, 1965b, p. 113).

A possible cost breakthrough in drains may be the use of plastic pipe, locally manufactured and "plowed" into place (McJunkin and Pineo, 1970).

Low lying areas such as are found in the Egyptian delta can only be drained by means of pumping stations. The capacities of such stations need not be as great from the point of view of schistosomiasis control as for the growing of crops. Thus so long as water is drained away within two or three weeks the chances of the creation of snail habitats are practically eliminated. For crop requirements the water must be drained away over a much shorter period in order to prevent damage to crops.

An effective way of reducing the quantity of drainage water is to exercise strict water control in the irrigation canals, and to charge high rates for excess water used by irrigators (WHO, 1965b, p. 10).

Where large drains are provided to handle storm run-off or excess irrigation water, and are therefore used only occasionally, it is worth considering their drainage in turn by the installation of small diameter tile drains, or 1/3 round pipes, so that they can be kept dry between large discharges.

Research is showing that drainage requirements could be practically eliminated in some areas if conveyance losses were controlled and if water were applied to the land in accordance with soil and plant requirements. There are few, if any, places where this goal has been achieved, however, and except in places where good natural drainage exists, provision for controlling ground-water elevation is still necessary (Lauritzen, 1968b).

Drainage of swamps may also be beneficial to schistosomiasis control. Canalization and drainage of the Lataniere River in Mauritius, a mosquito and malaria control measure, reduced *S. haemotobium* infection among children in a nearby school from 63 percent to 25 percent (WHO, 1960a, p.33).

A successful example from South Africa of a control program using only these methods outlined in this subsection is described by Pitchford (1962, p. 360):

> "Recently a survey was done on a sugar/citrus irrigation scheme nine years old and 13,000 acres in extent. All the main canals were protected by storm-water drains and fencing. This resulted in protection of all storage dams leading from the canals. All canals, whether main, subsidiary or feeder, were cement-lined. All labour was housed below the main canals and faeces were deposited in the cane where they were comparatively harmless. Drains were deep, with perpendicular banks, and were consequently comparatively inaccessible. *Biomphalaria* were present in all water types. Swimming and clothes washing were both done either in the large river which did not tend to form pools, or in the cement-lined feeder canals leading from the protected storage dams. Swimming was discouraged in these dams, mainly because they were the source of European household water. The incidence of *S. mansoni* infection in this scheme was less than 2 percent in 180 children examined from all over the area. No other antibilharziasis measures had ever been practised."

2. *Operation.*

a. *intermittency.* The possible ability of snails to survive in the absence of free water is important inasmuch as channels in well-designed irrigation systems can be dried out periodically. Species and strains of snails show great variation in resistance to desiccation. Resistance to the lethal effect of desiccation is high in the case of certain strains of snail host species that have been investigated under suitable conditions both in the laboratory and in nature. Survival out of the water for periods of from 3 to 11 months has frequently been achieved under experimental laboratory conditions (WHO, 1967, p. 10). In nature, these snails may occur in temporary pools in Africa and South America which dry up for several months during the hot season, obliging the snails to aestivate. Not all snails survive this dry period, but a sufficient proportion do so to repopulate the habitat when it is once more filled with water.

If a single snail is introduced into a favorable habitat it is possible, owing to its exceptional reproductive capacity, to have a flourishing snail colony in about 40 days and transmission of schistosomiasis in about 60 days. Snails may be carried by canal flow, on plants, by birds, or in other ways from infested habitats hundreds of miles distant.

In unlined canals, snails are able to bury themselves or are stranded in the bottom mud and survive for several months when irrigation is suspended and the canals are dried out. This is especially true in irrigated areas where the ground water level is sufficiently high to keep the earth layer at the bottom of the canals in a moist and cool condition. Clay bottoms, however, do not appear favorable to certain types of snail. In concrete or similarly

lined canals, snails are unable to dig in and they and their eggs are killed by desiccation and the heat of the sun.

Complete drying-out of irrigation channels, especially if carried out at frequent intervals, may not succeed in destroying each individual snail, but it so interferes with the life and reproduction of colonies that they become reduced in number and, if the periods of drought are either sufficiently frequent or sufficiently prolonged, may eliminate them entirely. The latter statement is particularly true in the case of lined canals. It is for this reason that terminal distributory channels in the Tigris-Euphrates valley are almost always snail-free (WHO, 1957, p. 30). In different climatic regions, experimental research is needed to determine the most suitable frequency and periodicity of such an operation.

b. *maintenance.* The following measures are helpful:

(1) removal of vegetation and muds from banks and shallow margins,
(2) cleaning and re-grading canals,
(3) straightening canals,
(4) backfilling, grading and draining, or fencing borrow pits, neighboring low ground, and unused canal branches,
(5) flushing canals at periodic intervals,
(6) inspecting canal banks for seepage,
(7) inspecting canals and structures for snail lodgement sites,
(8) inspecting sluice gates, distributing chambers, float wells and other equipment for leaks and lodgement sites,
(9) inspecting for improper deliveries of water, quantities and locations,
(10) inspecting for general untidiness, here a pipe missing, there a leaky gate, and
(11) checking for wasted water.

3. *Control of Vegetation.*

a. *weed clearing.* Weeds in irrigation canals and drains provide suitable habitats for snails, and, where they hamper the application of molluscicides, their removal becomes necessary. In addition, they reduce the carrying capacities of the distribution system, consume considerable quantities of water, and thus reduce the amount available to crops. Control of weeds is important, therefore, not only for snail control but also for proper functioning of irrigation schemes.

In planning irrigation schemes, adequate provision should be made for weed control. The importance of weed growth in irrigation systems can be illustrated by the case of a large irrigation scheme in Asia, completed during the 1960's, with discharge at the head equivalent to that of the Seine at Paris. Within 5 years after the system was opened, submerged aquatic weeds had cut the flow of water in the canal by 80 percent (Holm, *et al,* 1969). While such a case is rather unusual, records show that a reduction of one-third to one-half of the carrying capacity of an earth canal in from three to five years is not unusual. In the Gezira irrigation scheme in the Sudan, more than $143,500 a year is spent on mechanical weed control (WHO, 1965b).

For the control of weeds in irrigation schemes, both mechanical and chemical methods are used. They have their respective fields of application depending on local conditions, the size and characteristics of the irrigation area, types of weeds, and relative costs. Mechanical methods comprise dredging, pulling out by specially designed scrapers, burning, chaining, cutting, mowing and grazing. Chemical methods comprise the use of selective herbicides for bank weeds and aromatic solvents for aquatic weeds. The effectiveness of chemical control depends largely on the choice of herbicide, which is governed by the type of weed, and on the method, timing and frequency of application. The number of selected herbicides is being continually extended and at least one of them, acrolein, is lethal to host snails (Ferguson, *et al*, 1965). Such a double effect may result in substantial savings in areas where snail control has been established and molluscicides are used.

As far as snail control work is concerned, weed removal is an important factor. With mechanical methods, snail habitats are either destroyed or seriously disturbed. However, such disturbance may also facilitate the movement of snails by floating them down irrigation canals to new areas.

Weed control operations are facilitated by the provision of places for the application of herbicides, and roads for use of mechanical equipment. In certain circumstances, provision should be made for the use of boats, both for herbicide application and for cutting of weeds. In some areas flat-bottomed boats, paddle-propelled and fitted with cutting knives, have been found practical for this purpose. The cut weeds float downstream and are collected at convenient stations.

Comprehensive accounts of methods are given in publications of the U.N. Food and Agriculture Organization (Helgeson), U.S. Bureau of Reclamation (Otto, 1965, 1966), and the U.K. Ministry of Agriculture, Fisheries and Food (Robson).

b. *trees.* The practice, often followed, of planting trees immediately adjacent to canals should be prohibited, for eventually the roots encroach on the canal walls and bed, providing snags and obstructions, and leaves and branches fall into the water. Maintenance thus becomes unnecessarily complicated. If trees are desired they should be planted some distance away from the canals. The shade provided by the trees is inadequate to discourage snail lodgement, at the same time preventing the sun from effectively drying out the canals on the occasions when it may be possible to empty them and allow desiccation to take place, and tempting passersby to leave their schistosome ova. The organic rubbish that often collects in the water near a lone tree may stimulate development of a large snail and cercarial population in the immediate vicinity, an unnecessary hazard to health.

4. *Special Structures*

Special structures required for the proper functioning of an irrigation system and for the control of host snails should be made part of the

irrigation scheme during the planning stage. Such structures include mechanical snail traps, molluscicides-dispenser sites, crossings over or under siphons, flumes, drop structures, chutes, culverts, bridges, division boxes, turn-outs, checks and waste-ways. Provision should also be made for the protection of the distribution system by means of lateral spillways, drainage inlets and drainage of natural watercourses over or under the irrigation canals. It is also desirable from the point of view of efficient operation to provide bridges to facilitate traffic movement and the transport of cleaning and maintenance equipment. For the application of molluscicides, staff guages erected in canals to indicate discharges at various depths are useful in calculating molluscicide dosage and concentration (WHO, 1965b).

D. Storage Reservoirs

1. *Reservoir Design*

a. *shoreline.* Water conservation and storage is essential for development of arid and semiarid areas. These bodies of water may range in size from stock-watering ponds to mammoth regional irrigation and hydroelectric reservoirs. Located in areas endemic for schistosomiasis, they tend to increase the number of snail habitats. With human contact an increase in schistosomiasis is always a potential threat.

Where host snails occur, they are usually established in shallows along the shoreline. The habitat then may be rendered less suitable for snails or transmission by deepening and straightening all margins and removing vegetation, preferably before construction or during low water; shortening shoreline with dikes and fill, with particular attention to isolated ponds; where human access is unavoidable, erecting piers to transfer human contact from near the shore to an offshore area where cercariae are less numerous or frequent; constructing access roads for weed control and molluscicidng operations; and locating shoreline villages at points where maximum wave action can be expected. These actions are helpful for natural lakes too.

b. *intakes.* Reservoirs may serve as breeding aquaria or as traps for upstream snails. Intakes therefore should be located some distance from shore, well submerged, and provided with galvanized screens having eight meshes per inch and protected by coarser screens. Intakes in "night reservoirs" should be avoided if possible. Snails and cercariae have been known to survive passage through hydraulic machinery (Pitchford, 1953).

c. *spillways.* Schistosomiasis, occurs in some areas endemic for onchocerciasis. Spillways have become the site of abundant breeding places of *Simulium damnosum,* the vector of human onchocerciasis and dam building in Africa has caused a considerable northward shift in the area where *S. damnosum* occurs. Stepped spillways, being particularly favorable to *S. damnosum* should not be used (Quilannac, *et al.*).

d. *access.* The comments on access to distribution systems are equally applicable to reservoirs.

2. *Operation (Water Level Fluctuation)*

The success of the Tennessee Valley Authority in controlling mosquito population through fluctuating water levels in its reservoirs (Figure No. 10), combined with the occasional observation of reduced snail populations in some tropical irrigation systems where water levels have fluctuated has stimulated consideration of planned fluctuation of reservoir levels as a method of snail control (Tennessee Valley Authority, 1947; Russell, *et al.*, p. 605; Lanoix; McMullen, 1967ab; Kruse and Lesaca).

When stranded on dry land by a falling water level, snails that transmit schistosomiasis, especially *Biomphalaria*, make little or no attempt to escape back into the habitat, although their degree of mobility would enable them to do so (WHO, 1957, p. 10). They are thus exposed to the risk of death by desiccation, by the action of the heat of the sun, or by consumption by terrestrial predators (land birds, wild rodents, pigs, others) normally unable to reach them and a large proportion of snails so exposed perish. The death-rate depends on length of exposure, rapidity with which the water level falls, presence or absence of shade, and relative humidity of the atmosphere. Prolonged exposure, rapid fall of water-level, absence of shade and low relative humidity all tend to increase the death-rate and to accelerate death. Thus rapid and regularly repeated changes of level might be a useful and practical means of controlling aquatic snail hosts in certain types of irrigation channels and reservoirs.

Based on a laboratory study using *Biomphalaria glabrata*, Jobin and Michelson (1969) calculated that:

> ". . . during the day snails can be stranded with a vertical rate of drawdown greater than 23 cm per hour on a 5:1 slope and 0:1 cm per hour on a 100:1 slope. At night the rate of drawdown can be reduced 82 percent or even greater, as snails are thought to reverse their migration at night. In an analysis by mathematical model, a symmetrical pattern of fluctuation of water level (best suited to reservoirs on rivers of medium size) was estimated to strand snails most rapidly if the periods of fluctuation were 5 to 10 days. The asymmetrical pattern appeared to be more effective than the symmetrical for fluctuations of the same frequency. The periodic, rapid discharge from such a reservoir might also flush snails from downstream habitats."

In field studies by Jobin (1970) in Puerto Rico, 10-cm (4-in.) diameter siphon spillways were constructed in November 1967 on two ponds containing stable populations of *B. glabrata*. The siphons cause periodic drops (about once a month in the rainy season) in the water level of 0.5 meters (1.64 feet) in one day. By October 1968 all snails had disappeared from the ponds with siphons. In two untreated control ponds, snails continued to be present in substantial numbers.

The drawdown rate required limits this technique to small reservoirs. Such reservoirs generally employ earth dams. The requisite spillway and

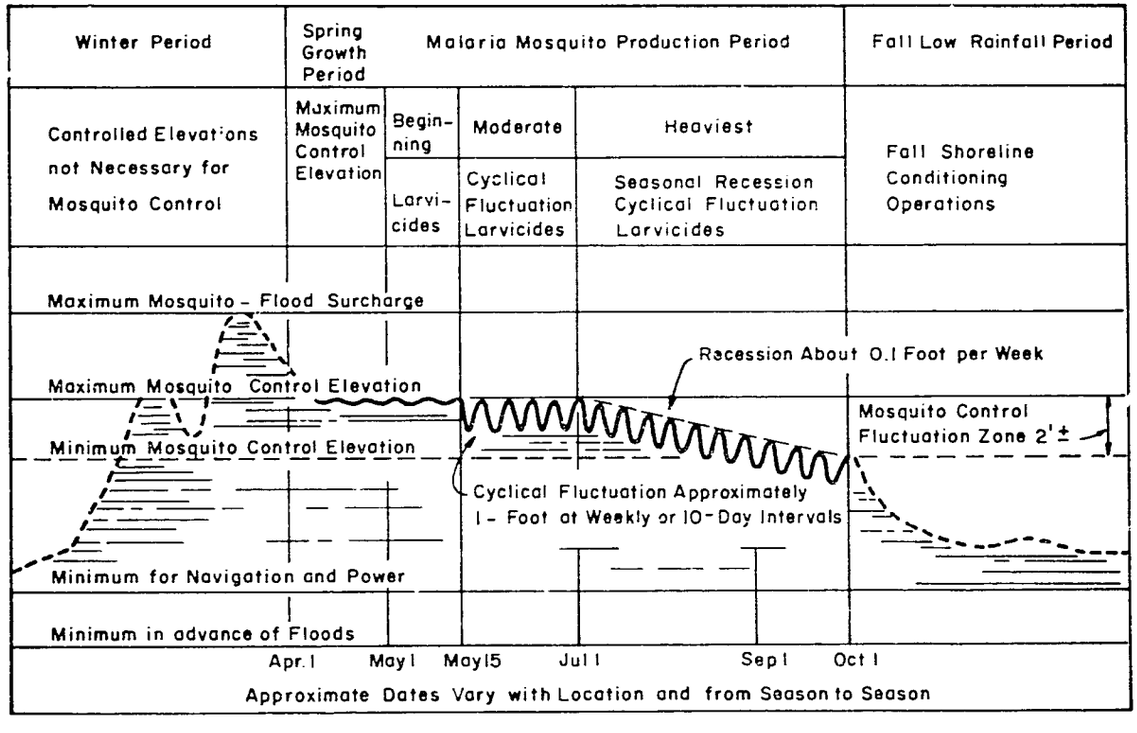


Figure No. 10. MOSQUITO CONTROL BY FLUCTUATION OF WATER LEVEL ON A TVA LAKE SHOWING RESERVOIR ELEVATION VERSUS DATE

gates, or other mechanism, and their operation and maintenance, could be prohibitively expensive. Pipe siphons, particularly mass-produced of plastic, could be feasible. Earth dams require that the horizontal pipe across the dam be of considerable length; the resulting large volume of entrapped air creates priming problems for the siphon. For example, one of the Puerto Rican siphons described above losses 200,000 liters before priming, almost as large as the drawdown of 230,000 liters. Since the very purpose of the reservoir is conservation of water, losses of such magnitude are generally unacceptable.

Development of improved siphon designs and further field studies would seem to have merit.

3. *Night Storage Reservoirs.*

The practice of using small reservoirs for overnight collection and storage with distribution the following day is condemned by all authorities. Such reservoirs tend to have fantastic densities of snails and cercariae and disseminate highly contaminated water over the area irrigated. Where indispensable, their number should be reduced by using larger sizes and they should be *completely* emptied during the day - no fish culture.

E. Environmental Sanitation

1. *Effectiveness of Sewage Treatment.*

Primary sedimentation for the usual detention periods removes the "majority" (Jones, *et al*, 1947c) of *S. japonicum* eggs and 83 percent (Rowan, 1964b) of *S. mansoni*. "In practice ova of *S. japonicum* in settled sewage could be expected to pass the trickling filter and both ova and miracidia would be recoverable from the effluent." (Jones, *et al*, 1947c). Rowan (1964) found that trickling filters remove 99.7 percent of *S. mansoni* eggs. The aeration tanks of activated sludge tanks appear to be an excellent hatching medium, although most ova are removed, e.g., 99.7 percent of *S. mansoni* (Rowan, 1964b). "Where there is a possibility of ova reaching the aeration tanks, some additional treatment of effluent would be indicated to remove or destroy miracidia." (Jones, *et al*, 1947c). Of 3,967 laboratory-raised *Australorbis glabrata* snails exposed to flowing effluent from trickling filter and activated sludge plants treating ova-containing wastes, not one acquired an infection of *S. mansoni* (Rowan 1964b).

Jones, *et al* (1947c) found the maximum survival time for *S. japonicum* in anerobic digesting sludge to be approximately three weeks and on sludge drying beds, fourteen days. Also that ova of *S. japonicum* are effectively removed from settled sewage by intermittent sand filtration.

Sewage stabilization ponds hold great promise as an economical process for use in developing countries. Kawata and Kruse (1966) found maximum survival time of *S. mansoni* eggs and miracidia in anerobic ponds to be 10 hours but that aerobic and facultative ponds "are not likely to suppress the

hatching of the eggs or significantly affect the survival of miracidia of *Schistosoma mansoni* or the vector snails." They recommend therefore the inclusion of a preliminary anerobic chamber in stabilization pond design.

Based on studies in Puerto Rico of *S. mansoni* eggs and miracidia, Rowan (1964a) recommends chlorination at a level sufficiently high to give a 15-minute residual of a least 2.5 milligrams per liter. Jones and Hummel (1947b) found that miracidia of *S. japonica* were killed within 30 minutes after chlorination with total 30-minute residuals of 0.4 milligrams per liter (0.6 for *S. mansoni*) but that *S. japonicum* ova required up to 11 milligrams per liter for 30-minute total residuals. (Also see Section IV.F.C.)

Aside from anerobic stabilization ponds, no conventional form of sewage treatment, without chlorination, can be said to remove *all* eggs and miracidia. There is no epidemiological evidence to predict whether one or a thousand eggs is the threshold value for transmission in a given locale. Chlorination of sewage effluent is rarely practical in developing countries. If the purpose is solely for schistosomiasis control, the money is probably better spent on molluscicides. The relatively low cost of stabilization ponds is of particular import in developing countries. Their ability to destroy schistosome eggs and miracidia is as those master tautologists, the admen, say "an extra added bonus."

2. *Effectiveness of Sanitation as a Control Measure*

Sanitation alone is unlikely to eliminate this disease. The role of children in maintaining the schistosome life-cycle, the need for sanitation in fields as well as in homes, and the tremendous number, perhaps millions, of cercariae that may result from a single fecal evacuation rule out such a solution. (See, e.g., Scott and Barlow and MacDonald).

F. Public Water Supply

1. *Treatment*

a. *storage.* Since schistosome cercariae perish within 48 hours in water, provision of two days of storage capacity can be used as an effective method of treatment, assuming that no cercariae-shedding snails have entered the storage tanks. Storage tanks should be protected against *Aedes aegypti* in areas endemic for yellow fever.

b. *coagulation and filtration.* Alum in the strongest concentrations employed for water purification does not destroy cercariae. (Jones and Brady, 1947a; Pellegrino, 1967; Witenburg and Yofe, 1938). They become entangled in the flocs but soon free themselves and swim above the sediment. Although limewater has been shown to affect cercariae, Witenberg and Yofe (1938) demonstrated that the lethal activity is mainly due to a high concentration of hydroxyl ions (pH of 11.6) never reached in water treatment plants.

Sand and diatomaceous earth filters are effective in removing cercariae (WHO, 1970), provided that they are properly designed, constructed,

operated, and maintained. Treated water that is coliform free will generally be free of cercariae.

c. *disinfection.* The effectiveness of water chlorination has been extensively investigated. However, most of the work prior to Wittenberg and Yofe (1938) is inconsistent as virtually no experimental attention was given to pH and little to contact time. Wittenberg and Yofe reported that *S. haemotobium* and *S. mansoni* are killed within 30 minutes by one part per million (ppm) total available chlorine for a pH range of 7.5-8.9. The most recent study (Frick and Hillyer, 1966) found that minimal free available chlorine concentrations inactivating *S. mansoni* cercariae in a 30-minute contact period at 20°C were 0.3 ppm at pH 5.0, 0.6 ppm at pH 7.5, and 5.0 ppm at pH 10.0. The World Health Organization recommends 1.0 ppm chlorine residual for 30 minutes with no pH given (WHO, 1965b, p. 102).

Cercariae are destroyed by heating to 50°C (122°F) for 3 minutes. Water for washing or bathing can be effectively treated by cresol at 100 ppm (Thresh, cited in Pellegrino, 1967). Seawater with a salinity of 3 percent may be considered absolutely safe for bathing (Ingalls, cited in Pellegrino, 1967).

2. *Water for Bathing, Laundering, and Recreational Use*

Farooq (1966ac) has examined the personal, social, and religious habits of the population of an Egyptian province as they relate to water contacts) see Table No. VI). Frequency and type of water contact varies greatly by age but certain major opportunities for cercarial infection are noteworthy. For young males, virtually all contact is through bathing and playing. Urination is common during this activity. For older males, principal contact activities are washing of cattle, ablution, and wadu, the ritual washing by all Muslims before prayers (five times daily), all at the water's edge. Young females bathe and play frequently also but the most frequent activity is washing of utensils. Utensils are washed by women, accompanied by children, standing in the water or sometimes squatting on a stone. The estimated body-surface exposure is 20 percent. Washing of clothes is done in similar fashion. To draw water, done by females only, they wade into the water to wash, rinse, and fill their earthenware *ballas* or *zalas.* (Also see Figure No. 11).

Provision of protected facilities for bathing, laundering, and recreational use thus is more than a mere convenience - even if it is only a dug pond separate from the canal but kept clear of vegetation and rubbish and treated regularly with molluscicides.

G. Agricultural Practices

1. *Crop Selection*

The selection of crops that require less water is an obvious potential control measure. Thus, in Egypt, the prevalence of schistosomiasis is less in areas where wheat and barley are grown than where rice is grown. Crop

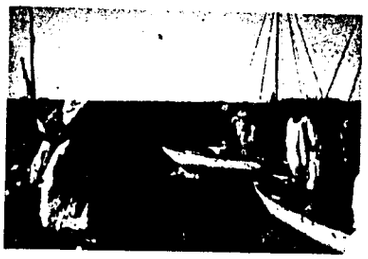
Table VI - FREQUENCY OF OUTDOOR SOCIAL AND RELIGIOUS WATER-CONTACT ACTIVITIES BY SEX AND AGE*

Activity	Males							Females							Total activities (both sexes)
	No. of activities in age-group (years)					Total activities		No. of activities in age-group (years)					Total activities		
	0-4	5-9	10-14	15-24	25+	No.	%	0-4	5-9	10-14	15-24	25+	No.	%	
Washing clothes	—	—	—	—	3	3	—	—	3	31	57	63	154	10	157
Washing utensils	—	—	2	—	—	2	—	37	230	173	192	236	868	57	870
Washing animals	1	2	11	33	18	65	9	—	1	3	6	10	20	1	85
Washing vegetables	—	—	2	5	4	11	2	—	1	1	—	—	2	—	13
Bathing and playing	194	129	20	7	6	356	50	208	39	—	3	7	257	17	613
Swimming	—	12	9	—	—	21	3	—	—	—	—	—	—	—	21
Urination	5	3	—	10	16	34	5	4	—	—	—	1	5	—	39
Defaecation and urination	7	10	—	4	26	47	7	10	1	—	—	—	11	1	58
Ablution	3	—	1	8	40	52	7	2	—	—	—	—	2	—	54
Wadu	—	—	2	15	71	88	13	—	—	—	—	—	—	—	88
Taking water	—	1	1	—	4	6	1	—	14	30	70	105	219	14	225
Angling	—	13	9	—	1	23	3	—	—	—	—	—	—	—	23
Net-fishing	—	—	—	—	2	2	—	—	—	—	—	—	—	—	2
Total	210	170	57	82	191	710	100	261	289	238	328	422	1 538	100	2 248

*After Farooq and Mallah for an Egyptian Province

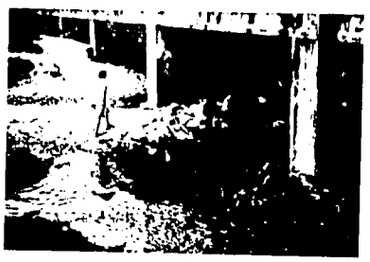
Farming Flooded Rice Paddy

Seining for Fish



Boating at Marshy Shore

Watering Livestock at Rainpool



Washing Clothes and Dishes

Pumping (Archimedes Screw) and Laundering

Figure No. 11. SOME COMMON FORMS OF HUMAN CONTACT WITH SCHISTOSOME CERCARIAE INFESTED WATERS.

rotation may make possible irrigation practices that could prevent snail breeding, especially *Oncomelania.*

2. *Irrigation Practices*

Farming practices may be scheduled with some regard to seasonal fluctuations in snail breeding so that the water may be turned off at suitable intervals to interrupt this activity. Major breeding periods may occur one or more times a year, but the pattern must be known before planting, irrigation and harvesting operations can be used to control snail populations.

The practice of planting or sowing rice in rows simplifies weed control and increases yield. The attendant cultivation tends to eliminate *Oncomelania* snails in the fields, as has been demonstrated in Leyte and Japan (WHO, 1965b).

The traditional methods of rice growing in the Far East result in the formation of habitats for snail breeding and in the transmission of schistosomiasis. Evidence now shows that rice can be grown just like many other crops without standing water in the basin. The traditional practice may have developed from the desire of farmers to store water in the rice fields as drought insurance. Weeds and pests may have also been factors.

It was demonstrated in the Philippines that irrigation water can be turned off after an initial application of 7 cm, and then additional irrigation applied when the soil begins to show signs of drying. By proper farming practice, it was demonstrated in the Philippines that in a field where rice was grown by ponding, the number of snails averaged 200 per square meter. After the adoption of intermittent application of water the number of snails dropped to less than 1 per square meter and rice yield increased by more than 50 percent. The application of irrigation at intervals of about 10 days is often adequate to bring the crop to satisfactory harvest (WHO, 1968). In Japan schistosomiasis is disappearing with the introduction of modern agricultural practices and improved irrigation.

The use of lift irrigation, as at Aswan, facilitates control of the groundwater table and associated seepage.

The development of new pipe technology has made sprinkler irrigation more feasible in recent years. With some crops, such as potatoes and sugar beets, this application of water increases production even in areas that are well adapted to irrigation from ditches (Lauritzen, 1968b). Such irrigation would eliminate many breeding sites for snails.

3. *Land Preparation*

Land leveling contributes greatly to irrigation efficiency. The presence of heavy construction equipment for this purpose on new projects is an opportunity to eliminate many snail habitats.

4. *Management*

Irrigation projects that are notable for both agricultural production and snail control are characterized by good management. Successful management requires a backdrop of adequate administrative and legal powers, and real coordination and cooperation by relevant authorities and specialists.

H. Miscellaneous Control Measures

1. *Mechanical Barriers and Screens*

Where a reservoir serves as a nursery for snail propagation, screens or other barriers may be placed at entrances to diversion canals. The long-run effectiveness of such screens seems doubtful - a mesh small enough to stop all snails, including juveniles would be so close as to create loss of head problems, would be readily clogged by suspended fines, debris, and vegetation, and would require continuous maintenance. Private discussions with irrigation engineers active abroad have not been encouraging in this regard.

Screens are, however, an established control procedure in the Gezira irrigation scheme (the Sudan) which obtains its water by gravity from the Sennar Dam where "experience with the screens in the Managil Extension has justified their use" (Rahman and ed. Din, p. 700) in preventing or delaying infestation of new canals. (Also see Malek, 1962a).

The Gezira screens are made of iron rails and wire screen with 8 meshes to the inch (approx. 3 per cm) and the barrier and its iron angle supports are painted to prevent rust. The barrier is more or less L-shaped, with the lower sides of the "L" submerged and at an angle of 80° to the erect part. About 20 cm (0.65 ft.) of the erect part is submerged and the remaining 60 cm (1.95 ft.) is above the water. The width is 2.15 meters (7.0 ft.). It was not possible to submerge the barrier for more than 20 cm due to objections from agricultural authorities (Malek, p. 49). (See Figure Nos. 15 and 16).

2. *Radiation*

Radiation doses of 150 to 250 kilorads have been shown to kill *A. glabratus* (Farver and Cember, 1969) leading the experimenters to suggest that "a possible procedure for destroying the snails in open and moving water is to treat them with gamma radiation from a suitable shielded gamma irradiator such as cobalt-60. Such an apparatus might be conceivable to serve as a screen or barrier (see above) but as Deininger points out with his "kinetic energy applicator" (a carpenter's hammer), means of delivering the snails to the gamma irradiator are lacking (Deininger, 1970).

3. *Electricity*

"Under laboratory conditions, low-frequency pulses of direct current (dc) caused *A. glabratus* dispersed in shallow water to migrate in a straight

Fig. No. 12. Spraying Molluscide

Fig. No. 13. Hand removal of vegetation

Fig. No. 14. Control vegetation by paving slopes

Fig. No. 15. L-shaped mechanical barrier

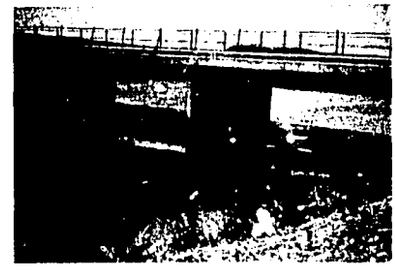


Fig. No. 16. Mechanical barrier in place

line toward the negative electrode. When the snails reached this electrode, they attached themselves until the stimulus signal was turned off. Attachment was observed to persist for at least 180 hr." (Street and Branch). The experimenters suggested that their device might be useful for sampling snail populations.

4. *New Technology*

The author is aware of no new or potential technology which will radically change the snail control picture, with the possible exception of a perfect vaccine. Progress is more likely to come as a by-product of economic development and old technology, paved linings for example.

Some small improvements in technology may be possible. For example, hand-operated portable Archimedes screws are widely used in Egypt for lifting water into the fields. (Figure No. 11). Avoiding water contact when using such devices is impossible. A RAND Corporation engineer has designed a "robot shadoof", an unconventional heat engine that has its most familiar embodiment in the "drinking bird" toy (Murrow, 1966). Such a device, if successfully developed, could replace Archimedes screws, shadoofs, Persian wheels, and other primitive pumps.

The desirability of a quick-sealing siphon has been presented elsewhere in this report.

I. Relation of Engineering to Chemical Control

It cannot be overemphasized that virtually every activity or structure designed for environmental control of snails enhances chemical control as well as making it more efficient, more effective, and less frequently necessary.

J. Summary

1. *Advantages of Environmental Control*

These might be summarized thusly:

(1) Under certain conditions, agricultural production is increased through utilization of previously wasted lands and waters.
(2) Improved irrigation and agricultural methods generally reduce the number of snails and increase crop yields.
(3) Environmental control will contribute to the control of filth-borne and arthropod-transmitted diseases.
(4) Environmental control reduces the area and frequency of necessary molluscicide use on residual colonies.
(5) Local labor and materials can often be used in environmental control programs.
(6) Environmental control usually has a more lasting effect than molluscidal control.

(7) The risk of damage to man, livestock, and crops is less than with chemical control.
(8) Control of waterlogging and salinity build-up may be enhanced.

2. *Limitations*

(1) Environmental control may be very costly since it usually involves heavy capital expenditure, careful planning and close integration with other engineering activities.
(2) In many endemic areas, economic and educational levels are not advanced to the point where the local inhabitants are capable of employing modern agricultural practices and economical water use as a means of snail control.
(3) Environmental control, although often referred to as "permanent", always involves periodic expenditure for maintenance which must be considered in cost accounting.
(4) Environmental control generally requires a degree of cooperation between various public service agencies and the local inhabitants which may not be easy to attain because of conflicting interests and ignorance of the problem.
(5) Environmental control in some high rainfall or heavily irrigated areas will not eliminate all snail colonies and molluscicides also will have to be used.

V. RECOMMENDATIONS

A. Better Use of Existing Knowledge

1. *Manual*

Engineers engaged in water resources development in tropical countries are being frequently accused, and properly so in too many instances, of neglecting the impact of their projects on the spread and incidence of schistosomiasis and other water-related parasitic diseases. This neglect is largely due to ignorance. Comprehensive informatic · on schistosomiasis is not readily available to engineers ı.ı useful, accessible, and attractive form. To remedy this defect, preparation and distribution of a design manual on "Irrigation Engineering With Special Attention to Schistosomiasis Control" is recommended.

The emphasis on irrigation engineering in the title is deliberate. The manual should contain enough design aids to insure retention and use by the engineer who has only peripheral interest in schistosomiasis. The manual should also include actual examples, graphics, and cost data of engineering facilities favorable to schistosomiasis control in the field. A schistosomiasis design checklist for project review should be a prominent part of the manual.

2. *Education*

Periodic short courses on engineering control of schistosomiasis should be commissioned. An orientation course might be held in Washington for engineers employed by the Agency for International Development, the World Bank, Pan American Health Organization, and others. The location of such courses could be rotated, for example, between Caracas, Belo Horizonte, Nairobi, Khartoum, Cairo, Rabat, Accra, and Manila. Manuals in the appropriate language should be distributed to each participant.

B. Research

1. *Monitoring*

Considerable research on such potential snail control measures or aids as canal lining and weed control is underway by the U.S. Bureau of Reclamation and others. Both the research and the measures themselves are expensive, so much so that they are not likely to be used solely for snail control. However this work should be monitored periodically for application in snail control, particularly if unit costs of these measures can be reduced. Knowledge of benefits other than snail control, e.g., increased agricultural production, can be used to strengthen justification of their use.

2. *Agricultural Research*

2. *Agricultural Research*

Changes in crop selection and farming practices can have major impact on schistosomiasis transmission and control. These possibilities should be periodically brought to the attention of agricultural ministries, schools, and research institutes in endemic areas. Appropriate research at major centers might also be profitably reviewed periodically.

3. *Systems Analysis*

A disturbing element in this review is the sparsity of information on effectiveness and costs of various control measures, especially when several operate simultaneously. The complex web of casual relationships and the imperfect knowledge and accounting of costs make identification of optimal control programs impossible.

One approach to this type of decision problem is that known as *systems analysis.* Systems analysis has several elements. The first and most important is the *objective* (or objectives). What are we trying to accomplish with the programs that the analysis is designed to compare? Eliminate snails? Eliminate schistosomiasis?

A second element is *alternatives.* By what alternative technologies, projects, and tactics may the objective be accomplished. The alternatives are frequently referred to as systems because each combines all the elements needed to accomplish the objective. An obvious alternative is chemotherapy plus molluscicides, with equal investment in each. Another might be 50 percent chemotherapy, 40 percent molluscicides, and 10 percent spent on drainage. Certain requirements may be mandatory for all alternatives, i.e., they may be *constrained.* For example, all alternate systems may have a budget constraint.

Costs or resources used is the third element. How much does each alternate cost? Cost data for environmental control data are meager but can be generated.

The fourth element is a *model or models.* Models are abstract representations of reality which help us to trace the relations between inputs and outputs, resources and objectives for each of the systems to be compared. Some preliminary work has been done on population and epidemiological models for snails and schistosomes by Hairston, MacDonald, Jobin and Michelson, and by Goffman and Warren. Further relationships must be developed linking these models to control measures and to cost functions.

Models need not be mathematical but if they are, they can take advantage of the numerous mathematical procedures for selecting optimal or best solutions, in this instance, control programs. Precision cannot be expected of course - indeed one practitioner has defined systems analysis as "the art of finding bad solutions to problems for which worse solutions are given." Improvement is sought, not perfection.

Figure 17 is taken from an epidemiological model constructed by MacDonald and projects the course of the disease over a 20 year period if certain control measures are undertaken.

According to the model, a program limited to prevention of excreta reaching water would have little effect. Even with good sanitation, so that only one 5,000th of the excreta reaches water, the number of miracidia in the water remains higher than the number of snails and the chain continues almost unabated.

Reduction of the snail factor or of the exposure factor yields approximately similar results with ultimate eradication but only over a long time span, over 20 years.

Improvement of snail or exposure control to a level approaching perfection would only slightly reduce the time involved, to 14 or 15 years, due to the mean life span, 3 years, postulated for the worms. However, combining either of these measures, snail control or exposure control, with systematic treatment produces a rapid result with final effects within 4 to 5 years.

McDonald's model is a hypothesis that should be verified in the field. Assuming its correctness, both its logic and the values set for its parameters, it is still an incomplete analysis for decision-making. It tells nothing about relative costs.

For control measures other than treatment, the engineer is the best source of costs. Further he has the mathematical and computer background needed to team with physicians and malacologists for effective systems analysis.

Studies are needed that analyze the cost-effectiveness of various control programs. The relative ease of calculation for molluscicidng and chemotherapy may have biased decision makers towards these programs. Other measures may be receiving insufficient attention. Even crude, imperfect analyses may provide new insight. These remarks apply to subsystems as well. Jobin (1968) has shown, for example, that in a molluscicidng program in Puerto Rico, "the chemical with the highest market price would be the cheapest to use in terms of cost per kilometer of stream treated."

4. *New Technology*

No "technological fix" is foreseen for schistosomiasis control, but rather evolutionary improvements in the prosaic techniques already known. For special problems, special solutions may be possible, for example the use of siphon spillways for small reservoirs. The technology that accompanies economic development will reduce exposure, for example, the replacement of shadoofs with modern pumps. New agricultural technology should be evaluated prior to use to assure that it is not counterproductive for schistosomiasis control.

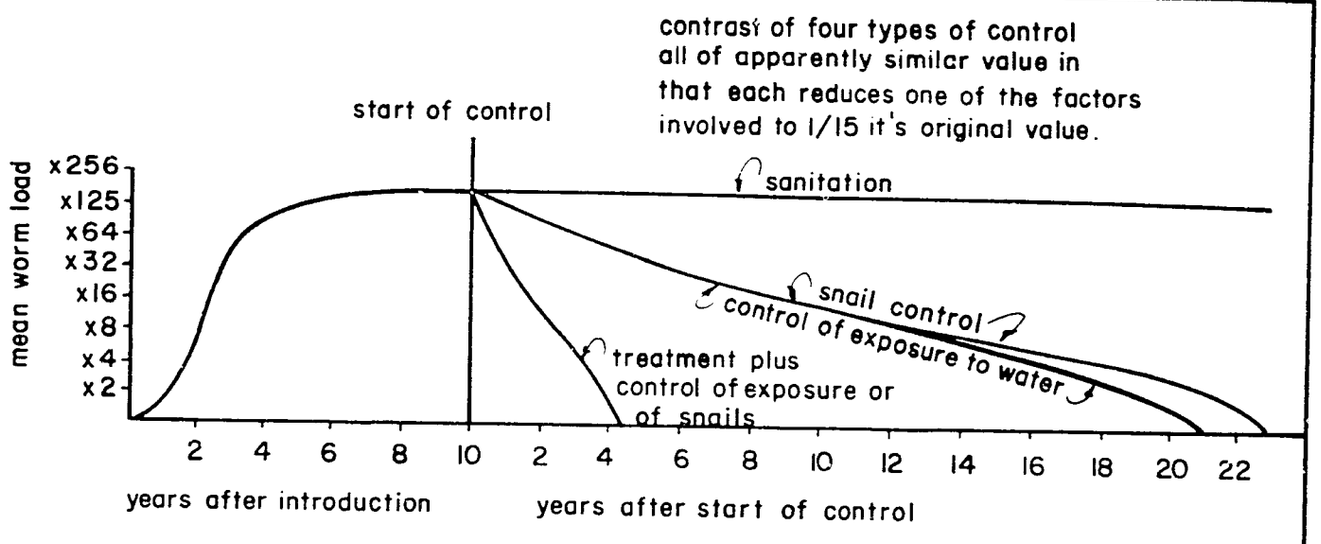


Figure No. 17. THE RISE AND FALL OF A SCHISTOSOMIASIS INFECTION.

C. Role of Environmental Control Measures

Present knowledge of snail ecology is probably sufficient to guide engineering design of environmental control measures. However such design is complicated both by the wide habitat tolerance of snail vectors and by the great variation in natural environments and irrigation schemes. Furthermore, engineering measures affect more than snails, most importantly, agricultural productivity and project economics. There is little doubt that engineers could eliminate snails if unconstrained as to water or money. This complexity of requirements, some conflicting, has meant that environmental control has only rarely been the sole measure of an effective schistosomiasis control scheme, at least consciously. This situation seems likely to prevail in the future.

Possibly for these reasons engineers have not been used as advantageously as they might have been. Engineers are often attacked as narrow in their professional outlook; yet many physicians and malacologists see them only in the role of molluscicide technicians.

Water resources projects have been designed with little attention given to their impact on diseases. This has not been due to maliciousness of callousness or even stupidity but because of ignorance.

There is a role for engineers and for engineering control measures. In considerable degree schistosomiasis engineering is simply "good engineering." The number of engineers working in schistosomiasis control agencies is small, the number in irrigation agencies is large. With proper orientation and education of the latter group, the role of engineering control measures could be increased to the ultimate benefit of all.

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