Health and Irrigation

Incorporation of disease-control measures in irrigation, a multi-faceted task in design, construction, operation

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Publication 45

International Institute for Land Reclamation and Improvement/ILRI
P.O. Box 45, 6700 AA Wageningen, The Netherlands 1994.

First Edition 1988
Reprinted 1994

ISBN 90 70754 177

Printed in the Netherlands

Preface

At the beginning of the 1980's, the International Institute for Land Reclamation and Improvement (ILRI) approached the Dutch Directorate of International Cooperation (*DGIS*) with a proposal that *DGIS* assist in financing an ILRI publication entitled *Health and Irrigation.* This publication would be concerned with health care in irrigation projects in areas where water-related diseases (e.g. malaria, schistosomiasis, filariasis, onchocerciasis) were endemic or could become endemic through the implementation of water-resources-development projects.

Before any irrigation project is planned, implemented, and operated, ILRI feels that a study should be made of the project's potential consequences for human health. This study should be holistic and multidisciplinary; it should identify any expected negative effects on human health, and should make a cost-benefit analysis of the measures that need to be taken to prevent, treat, and control any of the identified diseases. It should focus particular attention on environmental-management measures and on the institutional aspects of incorporating safeguards into the project. In this way, it would adhere to the principles of PEEM (Panel of Experts on Environmental Management for Vector Control), which was established jointly by the World Health Organization, the Food and Agriculture Organization, and the United Nations Environmental Programme.

DGIS's response to ILRI's proposal was positive, in principle, but before making a definite decision, it wished to discuss the matter with WHO and to hear the opinions of Dutch engineering bureaux working on projects in developing countries. The result of these consultations was that, in mid-1983, DGIS made funds available for the preparation of the manuscript of *Health and Irrigation.* In making this decision, *DGIS* added the provisos that the book give ample attention to practical examples and case studies, and that a Steering Committee be created to advise and guide the authors. The Steering Committee met eight times. Its members were:
- Dr D.C. Faber (Centre for World Food Studies, Wageningen);
- Ir W.C. Hulsbos (Euroconsult, Arnhem);
- Dr J. M. Lelyveld (Department of Environmental and Tropical Health, University of Agriculture, Wageningen);
- Drs F. Meyndert (*DGIS*), later succeeded by
- Drs M. de la Bey (*DGIS*);
- Dr A.M. Polderman (Institute for Tropical Medicine, University of Leiden);
- Ir K. Roscher (Department of Civil Engineering and Irrigation, University of Agriculture, Wageningen);
- Ir C. Storsbergen (DHV Consultants, Amersfoort);

The Group's Secretaries were:
- Ir W.T. Lincklaen Arriens (ILRI), later succeeded by
- Ir B.T. Ottow (ILRI).

In meeting the *DGIS* proviso of practical examples and case studies, Dr Jobin contributed greatly. The case study in Sri Lanka was taken from the field work of the students

J.J. Speelman and G. van den Top (Department of Irrigation and Civil Engineering at the Wageningen University of Agriculture). Another case study was derived from the literature study conducted by Ir W.B. Snellen of ILRI on 'Sanitation Works in Java, Indonesia'.

Information on the geographical distribution of vectors and vector-borne diseases was drawn from WHO publications. For schistosomiasis, a separate literature study was done by Jos L.M. Boeren, a student at the Department of Public Health, Wageningen University of Agriculture. The support given him by Dr S. Frandsen of the Danish Bilharziasis Laboratory in Charlottlund, and by Dr F.S. McCullough of WHO's Ecology and Vector-Control Unit in Geneva, is gratefully acknowledged.

Originally, *Health and Irrigation* was to be presented in one volume. Special circumstances, however, seemed to justify giving priority to the accelerated publication of parts of the book, namely the case studies and practical examples. Accordingly, these are presented in a separate volume, Volume 2, which is preceding the publication of Volume 1. Apart from providing some general information, therefore, this Preface is limited to matters that have a direct bearing on Volume 2. (The Preface to Volume 1 will contain more extensive acknowledgements.) Complying with the request of *DGIS*, however, we include the following passage:

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> Responsibility for the contents and for the opinions expressed rests solely with the authors; publication does not constitute an endorsement by The Netherlands' Minister for Development Cooperation.

Introduction

Health and Irrigation is being published in two volumes. The first contains the main subject chapters and three technical notes. The second volume is a separate appendix with a series of practical examples and two case studies. A geographical overview of vector-borne diseases and the vectors themselves are included in the appendix.

– Title Health and Irrigation
Incorporation of disease control measures in irrigation; a multi-faceted task in design, construction, and operation

Annex 3: – Tennessee Valley Authority, U.S.A.
– Lake Volta, Ghana.
– North-east coast reservoirs, Brazil.

Experience gained from working in these schemes suggests that the most rational way of avoiding serious health problems in reservoir areas is to use a variety of measures combined in a carefully planned and integrated program. These practical examples illustrate Chapter 5 in Health and Irrigation.

Annex 4 and 5

Annex 4
– The Gezira-Managil Irrigation Scheme, Central Sudan.
– Puerto Rico.
– Dez Pilot Irrigation, Iran.
– Sanitation Works, Java, Indonesia.

Annex 5
– Rice Cultivation, Niger River.
– Asian Bilharzia and Rice, the Philippines.
– Irrigation and vector-borne diseases, Sri Lanka.

Recent experience has emphasized the importance of environmental factors in the transmission of water associated diseases. Irrigation system design is at present inadequate to deal with the health aspects of water resources engineering. Examples in these two annexes show clearly that it is possible to exploit environmental factors in the development of stable, long term strategies for disease prevention and control.

Ecological methods were largely discarded when 'miracle' pesticides and drugs, symbolized by DDT and penicillin, were discovered in the 1940's. Gradually, ecological strategies towards disease control are being re-introduced. This is of particular importance to design engineers who can make provision for them in new irrigation schemes at a relatively low cost.

The examples of Annex 4 illustrate Chapter 6 in Health and Irrigation. The examples and case study of Annex 5 relate to Chapter 7.

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Annex 3

Annex 4

Annex 5

Annex 1
The geographical distribution of vector-borne diseases and vectors

1.1 Introduction

The diseases considered in this annex have been selected because their prevalence is probably related to the effect of irrigation. They include malaria, schistosomiasis, filariasis, onchocerciasis, a number of arbo-viral infections such as Japanese-B encephalitis, dengue fever, dengue haemorrhagic fever, and Chikungunia virus disease.
These diseases are discussed using the following regional classification (WHO 1982)

Region 1 Central America and the West Indies
Region 2 South America
Region 3 The Mediterranean region
Region 4 North Africa and the Arabian Peninsula Desert
Region 5 Africa (excluding the countries covered in Region 4)
Region 6 Northern European and Asiatic regions
Region 7 The Middle East and South Asia
Region 8 South East Asia (coastal)
Region 9 South East Asia (hill)
Region 10 The Chinese region
Region 11 Oceania and Australia

A different regional classification has been used for schistosomiasis.

The habitat requirements of the mosquito vectors have been referred to using fairly broad categories. A classification of breeding habitats and the geographical distribution of mosquitoes can be found in Chapter 3, Section 3.2.5. For more detailed information about mosquito breeding habitats see WHO Manual *Environmental Management for Mosquito Control* (1982) and Manson *Tropical Diseases* 1982.

1.2 Malaria

With the exception of some countries in Regions 3, 6, and 11 malaria is prevalent world-wide. Malaria vectors are listed in Table 1.1 (WHO 1982).

1.3 Filariasis

The disease is prevalent in the following countries in Region 1: Panama, the Bahamas, Haiti, the Dominican Republic, Puerto Rico, and the Lesser Antilles. Region 2: Trinidad, Guyana, Surinam, French Guyana, and Brazil. Region 4: East Turkey, Egypt, and Oman. It exists in nearly all the countries of Region 5 and in many of the countries of Regions 8 and 9. Some countries of Region 11, including Fiji, Tonga, the Pacific

Ocean Islands, Irian Jaya, and Papua New Guinea also host filariasis. The vectors of filariasis are listed in Table 1.2 (WHO 1982, 1984).

1.4 Onchocerciasis

Onchocerciasis occurs in Mexico and Guatemala in Region 1. In Region 2 it is found in Venezuela, Colombia, and Brazil, and in Region 5 it is found in almost all countries. The largest endemic area occurs in Region 5 and in the Volta basin area. It incorporates parts of Benin, Ghana, Ivory Coast, Mali, Niger, Togo, and the whole of Burkina Faso. WHO has its Onchocerciasis Control Programme (OCP) in this area. The vectors of onchocerciasis are listed in Table 1.3 (WHO 1976).

1.5 Japanese B-encephalitis

The disease is prevalent in the countries of Regions 8, 9, 10 and in some countries of Region 11, for example Irian Jaya and Papua New Guinea. The vectors of Japanese B-encephalitis are *Culex tritaeniorhynchus*, *Culex vishnui*, *Culex gelides* (which maintains the virus in pig-to-pig transmission), and *Culex annulus* (WHO 1982, 1985).

1.6 Dengue fever

The disease is found in nearly all the countries of Region 1, in many of the countries of Region 2 with the exception of Brazil, Peru, Paraguay, Uruguay, Chile and Argentine, and almost all the countries of Region 5. It also occurs in the countries of Regions 8 and 9, Bangladesh, Sri Lanka and Nepal, and in Australia in Region 11.
The vectors of dengue fever are *Aedes aegypti*, *Aedes albopictus*, *Aedes scutellaris* and *Aedes polynesiensis* (WHO 1982, 1985).

1.7 Dengue haemorrhagic fever

The disease is prevalent in Cuba and Jamaica in Region 1, in India in Region 7, and in a number of countries in Regions 8 and 9. It is found in Taiwan in Region 10, and in New Zealand, Fiji, Tonga, Pacific Ocean Islands, Irian Jaya, and Papua New Guinea in Region 11.
For the vectors of dengue haemorrhagie fever see Section 1.6 (WHO 1982, 1985).

1.8 Chikungunia virus disease (O'Nyong Nyong)

The disease is prevalent in all countries of Region 5 with the exception of Ethiopia, Somalia, Sudan, Uganda, Kenya, and Tanzania. The disease also occurs in India in Region 7.

The vectors of Chikungunia virus disease are *Aedes aegypti, Aedes albopictus, Aedes africanus, Aedes taylori,* and *Aedes furcifer* (WHO 1982, 1985).

Table 1.1 Mosquito Vectors (Anopheles species) of Malaria

Region 1	*quadrimaculatus; freeborni; albimanus(*); pseudopunctipennis; aztecus; aquasalis; bellator; punctimacula.*
Region 2	*darlingi(*); balbimanus(*); aquasalis; pseudopunctipennis; nuneztovari(*); balbitarsis; punctimacula; bellator; cruzii.*
Region 3	*sacharovi(*); labranchiae labranchiae; labranchiae atroparvus; superpictus(*); claviger; macullipennis messeae; sergentii; hispaniola.*
Region 4	*sergentii(*); pharoensis(*); multicolor; hispanolia; culicifacies; arabiensis*(*).
Region 5	*dthali; pharoensis; gambiae(*); arabiensis(*); melas(*); merus; funestus(*); nili; moucheti.*
Region 6	*labranchiae atroparvus; sacharovi(*); pattoni; macullipennis messeae; sinensis.*
Region 7	*culicifacies(*); dirus; stephensi(*); minimus; fluviatilis(*); varuna; annularis; philippinensis; hyrcanus(*); pulcherrimus(*); superpictus(*); sundaicus; dthali.*
Region 8	*sundaicus; letifer; umbrosus; balabacensis(*); dirus; maculatus; minimus; minimus flavirostris; subpictus; sinensis; aconitus; campestris; donaldi; philippinensis; leucosphyrus.*
Region 9	*minimus(*); annularis; maculatus.*
Region 10	*sinensis; pattoni; lesteri; martinius.*
Region 11	*farauti(*); koliensis(*); punctulatus(*); bancrofti; subpictus; karwari.*

Source: WHO 1982
* Species responsible for continuing transmission

Table 1.2 Mosquito Vectors of Filariasis

Region 1 and 2	*Wucheria bancrofti-periodic: Culex quinquefasciatus and Anopheles darlingi.*
Region 4	*Wucheria bancrofti-periodic: Culex molestus and Culex quinquefasciatus.*
Region 5	*Wucheria bancrofti-periodic: Culex quinquefasciatus; Anophetes arabiensis; Anopheles funestus; Anopheles gambiae; Anopheles melas; Anopheles merus.*
Region 8 and 9	*Wucheria bancrofti-periodic: Culex quinquefasciatus, Aedes poicilius, Anopheles balabacensis, Anopheles dirus, Anopheles donaldi, Anopheles flavirostris, Anopheles candidiensis, Anopheles anthropophagus, Anopheles letifer, Anopheles leucosphyrus, Anopheles maculatus, Anopheles minimus, Anopheles sinensis, Anopheles subpictus, Anopheles vagus, Anopheles whartoni.* *Wucheria bancrofti-subperiodic: Aedes harinasutai, Aedes niveus.* *Brugia malayi-periodic*: (South-east China, Vietnam, Thailand, Malaysia, Indonesia, Philippines); *Anopheles anthropophagus, Anopheles barbirostris, Anopheles campestris, Anopheles donaldi, Anopheles kweiyangensis, Anopheles sinensis, Mansonia annulata, Mansonia annulifera, Mansonia uniformis.* *Brugia malayi-subperiodic*: (South-east China, Vietnam, Thailand, Malaysia, Indonesia, Philippines); *Mansonia annulata, Mansonia bonneae, Mansonia dives, Mansonia uniformis.* *Brugia timori-periodic*: Indonesian islands of Flores and Timor; *Anopheles barbirostris.*
Region 11	*Wucheria bancrofti-periodic: Culex pipiens pallens, Culex quinquefasciatus, Anopheles farauti, Anopheles koliensis, Anopheles punctulatus, Culex quinquefasciatus.* *Wucheria bancrofti-subperiodic: Aedes cooki, Aedes fijiensis, Aedes kesseii, Aedes oceanicus, Aedes polynesiensis, Aedes pseudoscutellaris, Aedes samoanus, Aedes tutuilae, Aedes upolensis; Aedes vigilax.*

Source: WHO 1982, 1984

Table 1.3 The Fly Vectors of Onchocerciasis

	The vectors are Simulium flies (black flies)
Mexico	: *S. ochraceum, S. metallicum, S. callidum*
Guatamala	: *S. ochraceum, S. metallicum, S. callidum*
Colombia	: *S. exiguum*
Venezuela	: *S. metallicum, S. exiguum*
Brazil	: *S. ochraceum*
All African oncho-countries	: *S. damnosum complex*, i.e. *S. samboni* and in Zaire and Uganda also *S. neavei*
Egypt, Tanzania, Malawi	: *S. woodi* (occurs very locally)

Source: WHO 1976

1.9 Schistosomiasis

Table 1.4 gives an overview of the geographical distribution of snail species which can act as intermediate hosts for six types of schistosomiasis species: *Schistosoma haematobium* (H), *Schistosoma intercalatum* (I), *Schistosoma japonica* (J), *Schistosoma mansoni* (M), *Schistosoma mekongi* (Mek) and *Schistosoma rhodani* (R). These letters H, I, J, M, Mek, and R are also used in Table 1.4 to indicate the schistosome. *Biomphalaria, Bulinus, Ferrissia, Oncomelania, Robertsiella,* and *Tricula* are intermediate hosts and the table indicates their relationship to the schistosomes. It gives their habitat characteristics and geographical distribution by country and region.

Snail nomenclature is a problematic area. Information about snails and snail classification found in the literature is often inconsistent. In Table 1.4 the old names are listed under the most recent ones as 'subspecies' or 'synonyms' in situations where there might be confusion. Whether they really represent subspecies is sometimes doubtful.

The following symbols are used in Table 1.4 to indicate the relationship of the intermediate hosts to the schistosomes:

'!' very important intermediate host

'?' assumed to be acting as intermediate host although this has not yet been proved either experimentally or in nature

'exp.' proved to be a possible intermediate host under laboratory conditions

Table 1.4 Geographical Distribution of Schistosomes, its Vectors and Vector Habitats

Snail Species and Schistosome	Country	Habitat
Snail Species Biomphalaria		
B.albicans and M exp.	Puerto Rico	

B.alexandrina and M	Egypt: Saudi Arabia Yemen	Nile Delta Menia Province	Slowly flowing irrigation channels, brackish lakes near outflows from freshwater drains and terminal canals
B.alexandrina and M?	Libya: Sudan:	Taurorga, the Mediterranian coast west of Misurata between Khartoum and Kosti	Stable conditions with fairly dense aquatic vegetation
B.amazonica and M	Brazil:	Manour, Careiro island, along Salimoes Madeira and Jurua Rivers in the State of State of Amazonas	Slowly flowing water with abundant *Eichhornia*. Ph 6.0-7.0
B.angulosa and M	Malawi: Zambia:	Swamps 70 km north of Nkota Kota Chambezi Wantipa near Mbesuma Chozi River	
B.angulosa and M exp.	Tanzania:	Kalenga swamp and irrigation scheme, Little Ruaha swamp, Iringa district	The Kalenga swamp dries out in the dry season but is up to two meters deep when full
B.arabica and M	Arabian peninsula: southern region		see: *B.pfeifferi*
B.camerunensis and M	Benin Cameroon Central African Republic Nigeria Togo Southern Zaire		Shallow water on thick mud bottom, heavily shaded by palm trees. Slowly flowing or stagnant waters with abundant vegetation including papyrus where *B.pfeifferi* is not found
B.camerunensis and M?	Ghana Nigeria Togo Zaire		
B.chilensis and M exp.	Chile		
B.choanomphala (= *B.elegans*) and M	Kenya: Tanzania: Uganda:	Lake Victoria, Kisumu Lake Victoria, Bukoba, Mwanza Albert Nile Victoria Nile Lake Victoria, Entebbe Lake Albert Lake Kyoga	Kisumu: on stones at the water's edge, found at depths of ten meters. Mwanza: on mixed substrata of sand and mud. Entebbe: on gravel and soft sedimentary rocks at depths of two-three meters off-shore

			from sandy beaches where higher plants were present.
B.glabrata and M	Antigua Brazil Curacao Dominica Dominican Republic French Guyana French St. Martin Guadeloupe Haiti	Hispaniola Martinique Montserrat Puerto Rico St.Christopher St. Kitts St. Lucia Surinam Venezuela	Standing or moderately flowing fresh waters. Adapts to wide ranges of water temperature, to salinity, and to pH (5.8-9.0) Found at depths of ten meters below water surface
B.havanensis and M	The Antilles region Central America Mexico South America (northern part)		Standing waters, and the bottom of shallow streams
B.helophila and M exp.	Belice Cuba Guadeloupe Puerto Rico Peru		Shallow standing and slowly flowing waters, and environments subject to seasonal drought
B.peregrina and M (exp.)	Argentine: west of Andes from the equator to Lat 41 °S Bolivia: Barbosa (eastern areas) Brazil: eastern part between 43 °W and 15 °S Chile Colombia: east of the Andes between Lat. 11 ° and 15 °S Ecuador Uruguay		
B.pfeifferi (= *B.adowensis*) (= *B.bridouxiana*) (= *B.gaudi*) (= *B.germaini*) (= *B.hermanni*) (= *B.nairobiensis*) and M!	All African countries between Lat. 15 °N and 15 °S, including Madagascar, but excluding the eastern coasts at the Indian Ocean from Somalia southwards to Northern Mozambique. Algeria: isolated stations in Sahara Chad: isolated stations in Sahara Libya: South West Sahara Saudi Arabia South Yemen and Yemen		Streams, seepages and a variety of man-made water-bodies, including irrigation channels, dams and swimming pools but not found in small seasonal pools or large swamps such as those inhibited by *B.sudanica*. Depth does not seem to be a limiting factor.
B.pfeifferi (subsp. *adowensis*) and M	Ethiopia: Adowa		see: *B.pfeifferi*
B.pfeifferi (subsp. *bridouxiana*) and M	Zaïre: Lake Tanganyika western shore		see: *B.pfeifferi*

B.pfeifferi (subsp. *gaudi*) and M	Senegal:	Dakar area	see: *B.pfeifferi*
B.pfeifferi (subsp. *germaini*) and M	Algeria:	Southern Algeria	see: *B.pfeifferi*
B.pfeifferi (subsp. *hermanni*) and M	Namibia		see: *B.pfeifferi*
B.pfeifferi (subsp. *nairobiensis*) and M	Kenya:	Nairobi area	see: *B.pfeifferi*
B.pfeifferi (subsp. *ruppelli*) and M	Ethiopia: Kenya Sudan Tanzania Uganda Zaire	Eritrea	
B.philippiana and M exp.	Ecuador		
B.riisei and M exp.	Puerto Rico and other islands in the Antilles		Standing waters
B.salinarum and M exp.	Angola: Namibia	six localities between Cangandala and Vila Artur de Paiva	
B.sericea and M	Ecuador:	Los Rios, Guayar	
B.smithi and M exp.	Uganda:	Lake Edward Lake Mirambi	Vegetation growing on sand; depths up to four meters
B.stanleyi and M exp.	Chad: Ruanda: Uganda:	Lake Chad Lake Tsohoha Lake Edward	Vegetation on sand in one meter of water
B.straminea and M	Argentina: reaching to 35°S Brazil, Costa Rica, French Guyana, Grenada, Martinique, Panama, Paraguay, Peru, eastern regions Trinidad, Venezuela		Standing and slowly flowing fresh waters – well adapted to seasonal drought
B.sudanica and M!	Cameroon, Central African Republic, Chad Ethiopia: Lakes Awasa, Margherita, and Zwai Ghana Kenya: Liberia Sudan: Tanzania:	 Lakes Jipe, Naivasha, and Victoria northwards towards Shambat Arusha, Lake Victoria	Swamps which are sufficiently permanent to support a rich aquatic vegetation. The intermediate host of Schistosomiasis is common to the papyrus swamp near

	Zaire: Zambia:	South-eastern Zaire, Lake Edward, Lake Kisale, Lake Tanganyika Northern Zambia	Lake Victoria. This distribution might be associated with the spread of *Eichhornia sp.*
B.sud.rugosa and M?	Chad: Zambia:	Lake Chad Northern Zambia	
B.sud.tanganyicensis and M?	Tanzania: Zaïre:	Lake Tanganyika Lake Tanganyika	
B.tenagophila and M	Argentine Bolivia: Brazil: Peru:	 Santa Cruz, Chiquitos from Lat. 15° southwards Paraguay, Uruguay, Cajamarca	Standing and slowly flowing fresh waters
Snail Species Bulinus			
B.abyssinicus and H	Ethiopia: Somalia:	Marshes near the Awash River at Assaita, Gewani and further upstream towards Lake Lyadu Shebeli River Basin, Giuba River Basin, Lakes near the border with Kenya	Ethiopia: apparently restricted to marshes associated with the Awash River and not found in irrigation systems. Somalia: canals and drains of sugar estates (with *B.forskalii*).
B.africanus and H	Ethiopia: Kenya: Lesotho, Mozambique South Africa: Tanzania: Uganda: Zaïre: Zambia: Zimbabwe:	Jimma, Lake Tana, North-East of Gondar Nairobi District, Thika District, Machakos District, and around Lake Victoria northern provinces of Natal and westwards to the foot of the Drakensberg Escarpment in the Tugela Basin. Southwards along the coast to the Numansdorp area and through the Vaal Basin to the Warrenton District Mwanza district and near Iringa westwards to Arua Katanga Lake Bangweulu area around Harare	A variety of water bodies with or without higher plants; some regularly become dry but *B.africanus* does not inhabit such briefly filled pools as *B.nasutus*. Usually not successful in irrigation systems. Kenya: in some seasonal streams with *B.nasutus*. South Africa: higher toleration to cool condition than *B.globosus*
B.bavayi and H exp.	Aldabra Atoll: Madagascar:	South Island widespread	Aldabra: shallow and highly alkaline ponds. Madagascar: in a variety of water bodies including rice fields and

			irrigation drains. It is often present in many sites which lack other B.species. Some sites have considerable salinity.
B.beccarii and H	Yemen:	Khouzaiga Valley between Taiz and Hodeida	Perennial streams with a high calcium content
B.camerunensis and H and I exp.	Cameroon:	Western Cameroon, Lake Barombi, Lake Kotto, and Lake Debundsha	
B.cernicus and H and I exp.	Mauritius		Waters of widely different chemical composition. Present in the slowly flowing parts of streams from 600 meters down to sea-level
B.crystallinus and H and I exp.	Angola:	The northern escarpment of Angola and the Salazar District	Slowly flowing streams with rotting vegetation and irrigation channels
B.forskalii and I and H exp.	Range comprises much of African continent including Cape Verde Islands and Madagascar. Cameroon, Gabon North Africa: Sahara; Tejerhi, Air		A wide variety of natural and artificial water-bodies, including the margins of lakes and permanent swamps. Most abundant in small water-bodies.
	Mali:	Northern Mali	
	Nigeria:	Northern Nigeria	
	Chad:	Lake Chad, Jebel Marra	
	North-East Africa: Nile Delta southwards to Luxor Southern Africa: Namibia and the lower Orange River. Natal and Eastern Cape Province		
	Ethiopia:	Common at low altitudes and not found in highlands with the exception of the Lake Tana Basin	
	Somalia:	from Webbi Shebeli area southwards	
	Sudan:	Nile/Atbara confluence southwards	
B.globosus and H!	Present in most of Africa south of the Sahara. The limits apparently lie in Senegal and Southern Sudan. Southern limits lie in Angola or on the lower Cunene and Okavango Rivers. South Africa: Northern Transvaal and the Natal coastal plain		Common in stagnant or slowly flowing waters with rich aquatic vegetation. Found also in rivers with bottoms of gravel or sand and seasonal pools.
B.globosus and I!	Zaïre		Ghana: the establishment of dense populations in

			streams within the forest seems to be the result of human activities.
B.hightoni and H exp. and I exp.	Kenya:	north-eastern Kenya (near Hola on the lower Tana River)	Shallow depressions filled seasonally by rain though with aquatic vegetation including waterlilies. The only other snail found was *B.forskali*
B.jousseaumei and H	Chad Gambia: Gambia River Guinea Bissau Mali Mauretania: Monguel Region Niger Senegal Sudan		Gambia: abundant on waterlily leaves in the slower flowing parts of permanent streams (*bolons*) in the upper Gambia. No great ability to aestivate being absent from temporary pools unlike *B.senegalensis*
B.nasutus and H	Kenya: Tanzania:	south-eastern Kenya Kitui and coastal area coastal region, south to Tunduru and westwards to Mbarali in the Southern Highlands	Associated with seasonal water bodies which must(!) dry out for periods of about five months. Particularly isolated pools formed by seepage, residual pools in stream-beds and roadside ditches. Uncommon in irrigation schemes except in Tanzania and Kenya.
B.natalensis and H (exp.)	Ethiopia Kenya Mozambique Somalia South Africa: particularly in Natal Tanzania Zimbabwe		A wide variety of water bodies, including small pools and slowly flowing rivers, also in lakes.
B.obtusispira and H	Madagascar:	western Madagascar including the lower Mangoky district, Majunga, and Tananarive	Common in rice fields and capable of aestivation for at least seven months
B.productus (= *B.nasutus*	Kenya: Tanzania:	western Kenya Lango district	See: *B.nasutus*

productus) and H		eastwards to the shores of Lake Victoria and extending further eastwards along the shore to Shinyanga	
B.reticulatus and H exp.	Ethiopia:	north of Gondar	Small pools which contain water for brief seasonal periods. Kenya: on the Kano Plain in the west. It is only found during the main rainy period from March to May. It has the capacity to aestivate for prolonged periods, longer than *B.senegalensis* and *B.scalaris*.
	Kenya:	Rift Valley at Marigat and north of Nakuru; the plains near Lake Victoria, Masai Mara Game Reserve.	
	Mozambique:	Masingere in Sul do Save	
	South Africa:	Numerous localities centering on an area which includes Upington and Aberdeen, and extending up the Orange River Valley towards the Lesotho border	
	Tanzania:	Moshi, Misungwi district near Mwanza, Mbarali	
	Zambia:	Mazabuka	
	Zimbabwe:	Nyabira near Harare, Fort Victoria	
B.scalaris and I (exp.)	Angola:	coastal plain, northern plateau	Ethiopia and Kenya: only in seasonal pools which lack higher aquatic plants. Angola and Namibia: a wider range of habitats is reported including concrete lined irrigation channels, nearly permanent ponds and a ditch flowing from a warm spring.
	Ethiopia:	Gondar, Jimma	
	Kenya:	Kano Plain near Lake Victoria	
	Namibia:	Ovamboland, Kaokoveld	
	Uganda:	Lira; between Mbarara and Masaka	
	Zaïre:	South-eastern Zaire	
	Zambia:	Mbale, Monze, Mazabuka	
	Zimbabwe:	Newlands bridge near Harare	
B.senegalensis and H and I (exp.)	Gambia Mauritania Senegal		Abundant in seasonally filled rain pools on the laterite plateau along the Gambia River. Between rainy seasons, survives in the mud.
B.truncatus (= *B.guerni*) (= *B.contortus*) (= *B.coulboisi*) (= *B.rohlfsi*) and H!	Algeria:	Inkermann-Saint Aimé, Foundouk, Biskra A number of isolated localities in the Algerian Sahara	A wide variety of water bodies, including seasonal pools, irrigation systems and concrete cisterns. Also successful in lakes, including the man-made Lake Nasser Tunisia: in drainage areas around artesian wells and in irrigation canals.
	Cameroon		
	Chad:	Lake Chad	
	Egypt:	Delta region	
	Ethiopia:	Roseires, irrigation systems in the Awash Valley, lakes in the southern Rift Valley and streams in the highlands	

	Ghana		Egypt: in channels and drains, to a lesser extent in the main channels but occurs even in the Nile itself and in some of its tributaries e.g. the Rosetta and Damietta branches.
	Iran:	Khuzistan region	
	Iraq		
	Israel		
	Italy:	Sardinia, Sicily	
	Kenya:	Kano Plain	
	Lebanon		
	Libya:	Isolated localities in the southern part of the country	
	Malawi:	Karonga	
B.truncatus (= *B.guerni*) (= *B.contortus*) (= *B.coulboisi*) (= *B.rohlfsi*) and H!	Mauritania:	Atar District	Especially in back-water baylets, with vegetation or in residual pools. Occurs also in some oases although they had been removed from them in 1952. Distribution in the rest of Africa can only be established by further studies of snails identified as *B.t.rohlfsi* or *B.guernei*. The finding of what appears to be typical *B.truncatus* in the Atar district of Mauritania provides a tenuous link between the populations living in a tropical region and those inhabiting North-West Africa
	Morocco:	in the vicinity of the coast and southern Morocco	
	Nigeria		
	Portugal		
	Saudi Arabia:	south-western high-lands	
	South Yemen		
	Spain		
	Sudan:	Jebel Marra Region, Faya District certain oases	
	Syria		
	Tanzania:	Mwanza	
	Tunisia:	Chott Djerid region	
	Turkey		
	Uganda:	some localities	
	Yemen		
	Zaïre		
B.truncatus (subsp. *contortus*) and H	Egypt		
B.truncatus (subsp. *coulboisi*) and H	Burundi:	Lake Tanganyika	Lagoons and streams on the shore of Lake Tanganyika, not found within the lake itself.
	Kenya:	lakes in the western Rift Valley	
	Rwanda		
	Tanzania:	Central Tanzania and Lake Tanganyika.	
	Uganda		
	Zaïre:	Lake Kivu	
B.truncatus (subsp. *guerni*) and H	The Gambia:	northern Gambia	Small shallow streams, flowing rapidly among clumps of grass.
	Mauritania:	south-western Mauritania, particularly in Rosso	Small pools fed by springs and containing water

			lilies. After several years of drought abundant in rice-paddies
B.truncatus (subsp. *guerni*) and H exp.	Cameroon Gambia Ghana Mauritania Senegal		
B.truncatus (subsp. rohlfsi) and H	Angola: Cameroon: Congo Republic: Dolisie, Loudima Gare Ghana: Ghana: Chad Niger Republic Burkina Faso and Mali: from Lake Chad westwards Zaïre:	northern coastal plain Lake Barombi Mbo Lake Barombi Kotto northern and south-eastern regions and Lake Volta common between Tshela and Kinshasa	Small permanent pools, small lakes, rivers flowing over sand. Weed-beds of *Ceratophyllum sp.* provide favourable conditions.
B.wrighti and H and I exp.	Oman: Saudi Arabia: Central Province, Riyadh Province, Arfaa South Yemen: Hadhramaut and Upper Aulaqui regions	north-west of Saiq in Jabal Akhdar	Pools filled temporarily by rain water.
Snail Species Ferrissia			
F.tenuis and H	India:	surroundings of Bombay and small area north of Bombay	Slow running streams and standing waters.
Snail Species Oncomelania hupensis			
O.hup.hupensis and J!	China:	Yangtze River drainage system	Amphibious snails
O.hup.lindoensis and J!	Indonesia:	Sulawesi near Lake Lindu, Napu Valleys	Amphibious snails
O.hup.nosophora and J!	China: Japan:	southern region including Anhwei, Chekiang, Hunan, Hupeh, Kiangsi, and Kiangsu Jamanashi Prefecture, Kofu Basin, Middle Basin Chikugo River, Katayama and Hiroshima Prefecture, and Tone River	Amphibious snails. In irrigation ditches from sea-level up to 40 meters. Low temperature and rather dry periods acceptable.
O.hup.quadrasi and J!	Philippines:	Mindanao, Samar Islands, Leyte (eastern part), Luzon (extreme south-eastern part), Mindoro (eastern part), Bani, and Siargao	Amphibious snails. Flood plain forests, swamps, rice fields (not in Mindanao), streams, near dams and wallowing sites. Irrigation ditches.

Snail Species Robertsiella		
R.kaporensis and M!	Malaysia	

Snail species Tricula		
T.aperta and Mek!	Kampuchea: Kratie	
	Laos:	Mekong River (Kong Island)
		Thailand: Mum River

References

Abdourahmane, S.O.W. 1978. Bilharzia and Irrigation in Mauritania, African Environment, 3(2), p. 83-93.

Anderson, R.M. (ed.). The Population Dynamics of Infectious Diseases: Theory and Applications, Imperial College, London University, Chapman and Hall, London/New York, p. 180-208.

Ansari, N. (ed.) 1973. Epidemiology and Control of Schistosomiasis, Basel etc., S. Karger on behalf of the World Health Organization.

Appleton, C.C. 1976. Geographical Factors that Affect the Distribution of Schistosomiasis, Medicine in a Tropical Environment – Proceedings of an International Symposium in South Africa, p. 678-688.

Brown, D.S. 1980. Freshwater Snails of Africa and their Medical Importance, London, Taylor & Francis Ltd., p. 148, 170-274, 283-433.

Bruce, J.I. et al. (ed.) 1980. The Mekong Schistosome (Copenhagen), Danish Bilharziasis Laboratory, p. 227.

Cheng, Tien Hsi 1971. Schistosomiasis in Mainland China, American Journal of Tropical Medicine and Hygiene, 20(1).

Choudry, A.W. 1974. Seven Years of Snail Control at Mwea Irrigation Settlement, Kenya: Results and Costs, East African Medical Journal, Vol. 51, p. 600-609.

Chu, K.Y. 1978. Trials of Ecological and Chemical Measures for the Control of *Schistosoma haematobium* Transmission in a Volta Lake Village, Bulletin of the World Health Organization, 56(2), p. 313-322.

Colette, J. et al. 1982. Etude Epidémiologique de la Substitution de *Schistosoma haematobium* par *Schistosoma mansoni* dans une zone d'Endémie Bilharzienne d'Afrique de l'Ouest (Haute Volta), Médecine Tropicale 42(3), p. 289-296.

Driel, P. van 1977. Irrigatie en Bilharzia, Wageningen, Landbouwhogeschool Wageningen, Verslagen, Rapporten, Scripties en Nota's 1977-28, 88 p.

Gool, P.H. et al. 1983. Control of Schistosomiasis in Adwa, Ethiopia, Using the Plant Molluscicide Endod (*Phytolacca dodecandra*), Tropenmed. Parasit., vol. 34, p. 177-183.

Hira, P.R. 1969. Transmission of Schistosomiasis in Lake Kariba, Zambia, Nature, Vol. 224, p. 670-672.

Hunter, J.M., L. Rey & D. Scott 1982. Man-made Lakes and Man-made Diseases, towards a Policy Resolution, Social Scientific Magazin, Vol. 16, p. 1127-1145.

Jobin, W.R. & E.H. Michelson 1969. Operation of Irrigation Reservoirs for the Control of Snails, American Journal of Tropical Medicine and Hygiene, 18, p. 297-304.

Jobin, W.R. 1970. Population Dynamics of Aquatic Snails in Three Farm Ponds of Puerto Rico, American Journal of Tropical Medicine and Hygiene, 19(6), p. 1038-1048.

Jobin, W.R. 1970. Control of *Biomphalaria glabrata* in a Small Reservoir by Fluctuation of the Water Level, American Journal of Tropical Medicine and Hygiene, 19(6), p. 1049-1054.

Jobin, W.R. 1979. Cost of Snail Control, American Journal of Tropical Medicine and Hygiene, 28(1), p. 142-154.

Jordan, P. & G. Webbe 1982. Schistosomiasis, Epidemiology, Treatment and Control, London, Heinemann, 361 p.

Kooyman, C. 1977. Field observations on the Ecology of *Bulinus (Ph.) globosus* Morelet, in connection with the Control of Schistosomiasis in the Hola Irrigation Scheme, Kenya, Landbouwhogeschool Wageningen, Verslagen, Rapporten, Scripties en Nota's, 1977-33, 23 p.

Magendantz, M. 1972. The Biology of *Biomphalaria Choanomphala* and *B.sudanica* in relation to their Role in the Transmission of *Schistosoma mansoni* in Lake Victoria at Mwanza, Tanzania, Bulletin of the World Health Organization, 47, 331-342.
Makiya, K. et al. 1981. Population Studies on *Oncomelania quadrasi*, the Snail Intermediate Host of *Schistosoma japonicum*, in the Philippines. I. Distribution Pattern of the Snail in the Field, Japanese Journal of Experimental Medicine, 51(3), p. 179-185.
Malek, E.A. Snail Hosts of Schistosomiasis and other Snail-transmitted Diseases in Tropical America: a Manual, Geneva, Scientific Publication of the World Health Organization, No. 478.
Malek, E.A. 1958. Factors Conditioning the Habitat of Bilharziasis Intermediate Hosts of the Family *Planorbidae*, Bulletin of the World Health Organization, 18, p. 785-818.
Malek, E.A. & Th. C. Cheng 1974. Medical and Economic Malacology, New York and London, Academic Press.
May, J.M. (ed.) 1961. Studies in Disease Ecology, New York, Hafner Publishing Company Inc., Chapter 10, p. 261-327.
McMullen, D.B. et al. 1951. Observations on the Habits, Ecology and Life Cycle of *Oncomelania nosophora*, the Molluscan Intermediate Host of *Schistosoma japonicum* in Japan, American Journal of Hygiene, 54, p. 402-415.
Morrow, R.H., P.G. Smith and K.P. Nelson 1981. A Quantitative Method of Assessing the Health Impact of Different Diseases in Less Developed Countries, Ghana Health Assessment Project Team, International Journal of Epidemiology, Oxford University Press, 10(1) p. 73-79.
Morrow, R.H. Jnr. M.D. The Application of Quatitative Approach to the Assessment of the Relative Importance of Vector and Soil Tranmsmitted Diseases in Ghana, Special Programme for Research and Training in Tropical Diseases, World Health Organization, 23 pp.
McMullen, D.B. et al. 1973. Biological and Environmental Control of Snails, Epidemiology and Control of Schistosomiasis, Karger, Basel and University Park Press, Baltimore, p. 533-591.
Negron-Aponte, H. and W.R. Jobin 1979. Schistosomiasis Control in Puerto Rico, twenty-five years of Operational Experience, American Journal of tropical Medicine and Hygiene, 28(3), p. 515-525.
Nihei, N., S. Asami & H. Tanaka 1981. Geographical Factors Influencing the Population Numbers and Distribution of *Oncomelania nosophora* and the Subsequent Effect on the Control of *Schistosomiasis japonica* in Japan, Soc. Sci. Med., 15D, p. 149-157.
Onabamiro, S.D. 1972. Studies in Schistosomiasis in Sierra Leone, II, Seasonal Fluctuation in the Population Density of *Bulinus (Physopsis) globosus* and *Bulinus forskalii* in a Schistosomiasis Endemic Town in Sierra Leone, Annals of Tropical Medicine and Parasitology, 66(3), p. 375-383.
Pesigan, T.P. et al. 1958. Studies on *Schistosoma japonicum* Infection in the Philippines, Bulletin of the World Health Organization, 18, p. 481-578.
Reijenga, T.W. 1971. Verspreidingsecologie van *Biomphalaria glabrata* (Say 1818) in relatie tot Bilharziasis in Suriname, Leiden, Rijksuniversiteit, 128 p.
Reynolds, D.C. & E. Suchart Upatham (eds.) 1984. Schistomiasis in Southeast Asia and East Asia, Bangkok.
Rosenfield, P.L., R.A. Smith & M.G. Wolman 1977. Development and Verification of a Schistosomiasis Transmission Model, The American Journal of tropical Medicine and Hygiene, 26(3), p. 505-516.
Rosenfield, P.L. & B.T. Bower 1979. Management Strategies for Mitigating Adverse Health Impacts of Water Resources Development Projects, Prog. Water techn., 11(1/2), p. 285-301.
Schistosomiasis Control Leading Group, Huajung Country Party Committee, Hunan 1976. Destroying Snails by Storing Water within Low Embankments, a Summary of Mass Experience in Schistosomiasis Control, Chinese Medical Journal, 2(5), p. 347-352.
Sodeman Jr, W.A. The Distribution of Schistosome Vector Snails in Central Liberia, Annals of Tropical Medicine and Parasitology, 67(3), p. 357-360.
Spoel, S. van der et al. (ed.) 1979. Pathways in Malacology, Utrecht, Bohm, Scheltema & Holkema, Chapter 11, p. 251-277.
Yue-Ying, L. A Note on the Distribution of *Biomphalaria straminea* (*Pulmonata: Planorbidae*) in Hong Kong, The Malacofauna of Hong Kong and Southern China, Hong Kong University Press.
Walsh, J.A. & K.S. Warren 1979. Selective Primary Health Care (special article), New English Journal of Medicine, 301(18), p. 967-974.
Watson, J.M. 1965. Snail Control in the Prevention of Bilharziasis, Geneva, World Health Organization Monographs Series; No. 50, 255 pp.
White, P.T., M. Coleman & B.P. Jupp 1982. Swamp Rice Development, Schistosomiasis and Onchocerciasis in Southeast Sierra Leone, American Journal of Tropical Medicine and Hygiene, 31(3), p. 490-498.

Wilcocks, C. & P.E.C. Manson-Bahr Manson's Tropical Disease, 17th Edition, London, Baillière & Tindall, Chapter 12, p. 285-319.

World Health Organization 1965. Snail Control in the Prevention of Bilharziasis, geneva, World health organization, Chapter 2, p. 45-122.

World Health Organization 1976. Epidemiology of Onchocerciasis. WHO, Geneva, Technical report Series 597.

World Health Organization 1980. Epidemiology and Control of Schistosomiasis, Report of a WHO Expert Committee, Geneva, WHO Technical report Series No. 643, p. 10-55.

World Health Organization 1982. Manual on Environmental Management for Mosquito Control with special emphasis on malaria vectors. WHO, Geneva, Offset Publication no 66.

World Health Organization 1984. Lymphatic filariasus. WHO, Geneva, Technical Report Series 702.

World Health Organization 1985. Arhropod-borne and rodent-borne viral diseases. WHO, Geneva, Technical Report Series 719.

World Health Organization 1985. The Control of Schistosomiasis, geneva, World Health Organization Technical Teport Series, No. 728, 113 p.

Annex 2
Case study: Gorgol Rice Irrigation System, Mauritania

2.1 Introduction

This is an account of a pre-construction study carried out in the Gorgol River Valley, southern Mauritania. A rice irrigation system had been proposed and health problems were expected to arise because of the prevalence of malaria and bilharzia (*Schistosoma haematobium*)*. This case study shows how a health impact assessment can be conducted and what types of design modifications minimize disease problems in irrigation systems.

The study was in three parts: problem identification, feasibility analysis, and design. The problem identification phase was started by staff of the principal financing agency. From experience, they recognized that the area, like other parts of the Sahel, was subject to malaria and bilharzia infestation whenever water was impounded or used in irrigation systems. They initiated a feasibility analysis. A health consultant conducted a literature search and established what insects, snails, and diseases existed in the Gorgol River Valley. A simple computer model simulating the seasonal population dynamics of the bilharzia snails was then developed. This model was based on data from Egypt and other regions of Africa climatically similar to Mauritania.

The consultant analyzed the preliminary engineering design and confirmed that the Gorgol River from the proposed upper reservoir at Foum Gleita down to its confluence with the Senegal River near Kaedi (see Figure 2.1) was a potential transmission

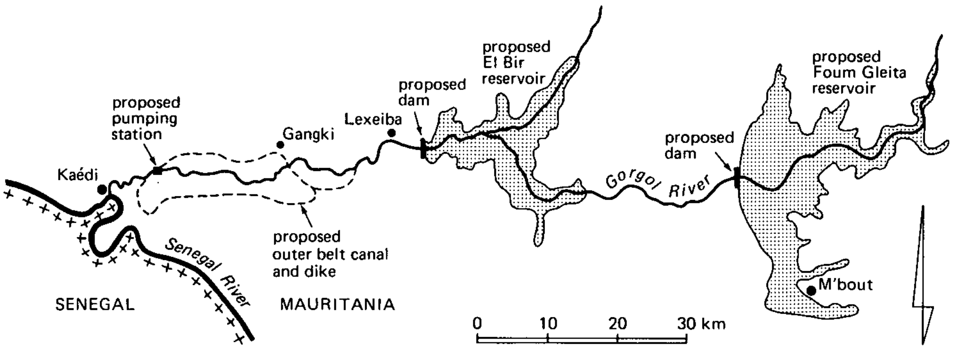


Figure 2.1 Proposed Gorgol Irrigation Project

* Case study of design revisions for rice irrigation system in Mauritania selected from the Health Study for the Gorgol Irrigation Project carried out for the Islamic Republic of Mauritania, W.R. Jobin, 1974. Presented at a Seminar on the prevention and control of vector-borne diseases in water resources development projects, Alexandria/Khartoum, March/April 1978.

zone for both malaria and bilharzia. With this information and the computer model, two field surveys were planned. Each would last one month. They were carried out in May and November of 1974 and they measured transmission of bilharzia and malaria at the most critical times of the year.

The staff conducting the field surveys included a public health engineer, an entomologist, and an epidemiologist-physician. There was also a laboratory technician, who translated French and the local Peuhl language for the physician. Skin tests for bilharzia and blood-slide examinations for malaria and other parasites were made amongst school children in the two major towns of the project area. School children in several villages along the river were also tested. All water bodies were examined for snails and insects, and mosquitoes trapped in homes and other buildings were examined. Human patterns of water contact were observed along the river and general information on water quality and temperature was collected from a pilot rice farm and from existing rice fields. The field data on snails and aquatic ecology made it possible to improve the snail population model and to better simulate conditions in the project's reservoirs and canals.

The analysis indicated that extensive measures were needed to control malaria and bilharzia. Changes in project design were made and a control and monitoring scheme was set up. The project did not go beyond the pre-construction study stage, so the effectiveness of the safeguard measures cannot be analysed.

2.2 Summary and recommendations

The Gorgol Project was a rice irrigation scheme which would rely on the annual flood waters of the Gorgol and Senegal Rivers. It was feared, however, that the benefits of the scheme might be off-set by an increase in malaria and bilharzia in the project area. Below is a summary of the field investigations carried out in 1974 and the theoretical analyses which was made concerning the possibility of future malaria and bilharzia transmission within the irrigation system. Design recommendations were given to help minimize disease transmission.

Surveys of the Gorgol area in May and November of 1974 showed that bilharzia and malaria were common, although apparently at fairly low levels. This was because the transmission seasons were short and varied annually with rainy season water and humidity levels. The prevalence of bilharzia in children was directly linked to the presence of snails and the cultivation of rice. Although infections in children were common, they were light infections with little severe disease. Computer predictions were made using a model of snail populations calibrated for the Gorgol area. This indicated that the proposed reservoirs, new drainage systems, and the Gorgol River bed downstream of the irrigated perimeter would readily support snail populations. Expected water contact and contamination by people would be high in these areas and intense transmission would occur throughout the year.

The malaria transmission season would also be lengthened as a result of the impact of project constructions. Mosquito populations around the reservoirs and rice fields would be high and this would increase malaria transmission in an area which was already heavily endemic.

Several design measures were suggested which might help decrease the prevalence of both bilharzia and malaria. Steady water levels in the Foum Gleita Reservoir could be alternated with rapidly dropping levels in the period December-April. This would make the reservoir less suitable for snails and mosquitoes and at the same time the El Bir Reservoir would become particularly unsuitable for them. All trees and vegetation in the draw-down zones of both reservoirs could be cleared to destroy snail and mosquito habitats and depressions and pockets capable of holding water in the draw-down zones of both reservoirs could be filled. If farmers housing were to be located well outside the irrigated perimeter, mosquito biting rates would be reduced and contact with snail-infested water would also be lessened.

In order to minimize mosquito reproduction in the rice fields, an alternative strain of rice was suggested. This variety could be dried out once a week, a measure to be incorporated into the normal agricultural cycle.

A laboratory was planned for Kaedi with base camps at both reservoirs. One team would be equipped for mosquito and snail control and a second team for administering chemotherapy. It was also suggested that canals and rice fields be constructed in a manner which allowed them to be drained quickly.

In addition to these measures against malaria and bilharzia, several other design modifications were suggested. The most important of these was the provision of improved water supplies for domestic use in M'Bout and Kaedi. Improved water supplies would also be installed in any new settlements which might be established later. The provision of adequate pedestrian bridges over the Outer Belt Canal was planned in order to reduce human contact with snailinfested waters.

During the construction phase of the Gorgol Project, it was proposed that the entire work force be regularly examined by a competent physician for signs of malaria and bilharzia. Treatment was to be given where necessary and prophylactic anti-malarial drugs would be given to everyone. A physician and laboratory technician were allocated for this work. Plans were made to provide construction workers with information about both diseases. When extensive water contact was needed, it was suggested that this work be limited to the early morning hours before 9 am when the risk of bilharzia infection was minimal. Rubber boots would be provided for anyone who had to work continually in water.

2.3 Analysis and predictions

This section summarizes the process of analyzing the population distributions and dynamics of snails in the Gorgol area. The analysis was carried out to gain an understanding of the present distribution of snails in the area and to predict what snail populations might be expected in the proposed reservoirs, canals, rice fields, and drains. There were three stages in the analysis. Firstly, preliminary trials were begun and existing data on the snails in their natural habitats analyzed. Secondly, a prediction was made of what snail population might come into being in the proposed irrigation system, and thirdly an estimate was made of the effect modifications in the original irrigation design would have on the snails.

2.3.1 Preliminary trials for estimating snail populations in existing natural habitats

Preliminary estimates of snail populations in the Gorgol area were made in order to effectively plan the first field survey of May 1974 (Jobin and Michelson 1969; Jobin et al. 1976). These estimates were based entirely on literature values of biological and environmental parameters for similar snails and habitats. The pre-survey analysis with the computer model indicated that population of *Bulinus guernei* would peak in December and that reproduction would be limited to seven months of the year: July to December and again in the month of March. Fairly dense populations were predicted for the existing pond situation. A maximum of over 2800 snails per cubic metre of habitat was anticipated in December and a minimum of one per cubic metre was calculated for July, this being the beginning of the rainy season.

By adjusting the data used in the model to include observations from the field surveys made in 1974, it was possible to make basic calibrations and a sensitivity analysis of natural habitats such as temporary pools and the Senegal River itself. Several changes were made in the amount of food assumed for each habitat. This was because it was one of the most sensitive parameters in the model, and precise measurements could not be calculated from field surveys.

2.3.2 Prediction of snail populations in the original system design

All the available field information was incorporated into the model and a series of predictions were made for each component of the original system design. This included the rice fields, main canal, the proposed drainage system in the original Gorgol River bed, and the reservoirs proposed at Foum Gleita and El Bir. The extent to which these habitats would be able to support colonies of the *Bulinus guernei* and *Biomphalaria pfeifferi* snail type was evaluated. The computer simulation indicated that the new rice fields in the Gorgol irrigation system were unlikely to become habitats for the snails, despite the presence of abundant vegetation suitable for snail food. The dry periods before harvest would interrupt the snail populations at critical times and the habitat was therefore unsuitable for anything more than temporary colonization. As long as these two dry periods occur each year, snail populations will probably not develop in these fields (see Figure 2.2).

2.3.3 Prediction of effects of water level fluctuations

Computer runs were made to simulate a rapid drop in water level of four centimetres a day vertical recession rate from December to August every year. This was done in order to evaluate the effect of weekly fluctuation in the water level of Foum Gleita reservoir.

Snail eggs would then be killed by desiccation and the adult snails would have a very low survival rate. The simulations indicated that the snails would be unable to survive this kind of treatment (Figure 2.3). The effect produced downstream in the lower reservoir of El Bir would make it an even less favorable habitat for snails. Annual fluctuation of water level in Foum Gleita appeared a feasible means of snail control.

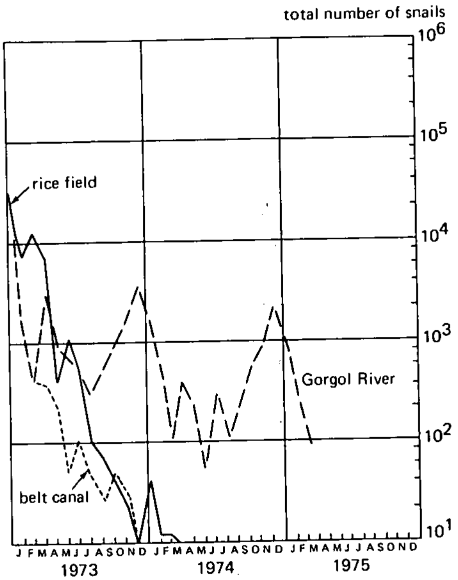


Figure 2.2 Predicted populations of *Bulinus guernei* in the proposed Gorgol Project

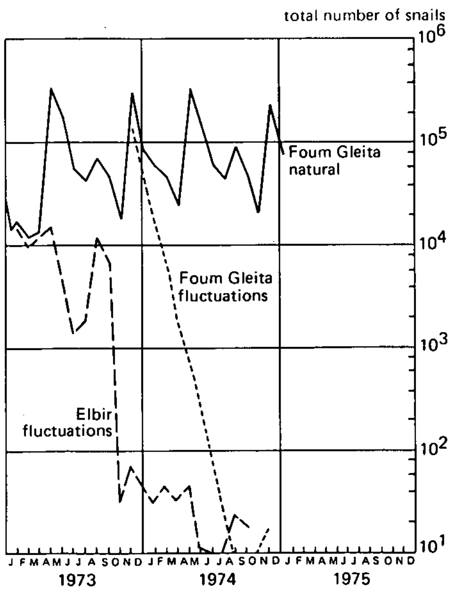


Figure 2.3 Predicted populations of *Bulinus guernei* in the proposed reservoirs

2.4 Proposed modifications to Gorgol Project preliminary design

The Gorgol Irrigation Scheme as initially designed would undoubtedly have created a stronger focus of schistosomiasis than that which already existed, particularly near M'Bout and Kaedi. The primary cause of the increase in disease transmission would be the large amount of standing water in the reservoirs and drainage system and the fact that two rice crops would be grown each year. Water would always be present and the effects of the annual drought would be eliminated. In addition, there would be a great deal of human contact with the water since rice is the main crop and it was originally planned to locate new villages among the rice fields.

2.4.1 General aspects of proposed modifications

Despite potential difficulties, it seemed possible that certain features of the irrigation system's design and operation could be changed and so minimize the problems of schistosomiasis. The changes suggested are detailed in this section. In addition to preventive measures, a continuous control program was seen as necessary to monitor and reduce transmission. This control program was conceived as operating for a five year period and would be integrated into the basic agricultural program.

2.4.2 Protection of the farming population

An outline was made of modifications designed to protect farmers and their families living near the irrigated zone. The rate at which people become infected depend on the amount of time they spend in water containing infected snails. Thus the original design, locating new housing facilities inside the irrigated perimeter would have caused high rates of infection amongst the agricultural workers. They would be surrounded by fields, canals, and drains containing snails. The children would play in the water and wives would wash clothes and utensils in the canals. In order to avoid a high incidence of disease, the new housing for agricultural workers had to be located outside the irrigated perimeter and at a considerable distance from the main canal. The distance would have to be more than 500 metres from the Outer Belt Canal and more than one kilometre from the existing bed of the Gorgol River since the Gorgol River would be the most important transmission site. The sites would also have to be outside the flood area. If existing villages were closer than these prescribed distances, canals and the river bed would have to be fenced off or otherwise protected from human access. Kaedi was the most important settlement which would have to be fenced off in this way.

In the new villages, a reliable and safe water supply provided close to the homes of agricultural workers would be of critical importance. Otherwise people would be forced to use the irrigation system or natural water bodies for drinking and bathing. Wells would have to be provided which could give a yield of at least 50 litres per person per day, even during drought years. Well construction would have to be extremely simple, with a well-curb at ground-level to prevent water becoming contaminated. If a pump had to be installed to lift the water to the surface, it would have to be a simple manual pump which could be repaired using local materials. Provisions for a bucket to be lowered to get water if the pump failed was essential. The most important design feature was that the well would provide a sufficient supply of water at all times. These wells would be the key sanitary features in preventing schistosomiasis transmission.

Agricultural workers travelling from their homes to their fields would cross the Outer Belt Canal at least twice a day. This canal could easily be a transmission site and foot bridges had to be provided across it on all main routes, particularly near new villages. In addition foot bridges had to be provided over those sections of the Gorgol River within the irrigated perimeter. The major considerations in designing these foot bridges had to be that they were conveniently placed and that it would be less effort to use a bridge than to wade through the water.

Certain portions of the planned drainage system would, of necessity, be much more hazardous than others. These potentially dangerous portions had to be isolated from the surrounding human population by physical barriers. It was seen as especially important to prevent children playing at these sites and to prevent casual use by adults. Only dangerous areas were to be isolated or restricted. Human contact with water could not be completely limitely in such an arid climate, and some water had to be available for recreational purposes.

The single most hazardous portion of the proposed system was the natural bed of the Gorgol River, from its confluence with the Senegal River near Kaedi, upstream to the point where the Gorgol River entered the irrigated perimeter. This portion of the river would contain water for most of the year and would receive fertilizer drained from rice fields. It would therefore have heavy vegetation and many snails. It would be too expensive to fence the area entirely and it was suggested that only the section of river within two kilometres of existing or proposed settlements should be fenced. The fence would be a two metre chain-link fence with two strands of barbed wire on top, and would run along the bank above the river's high-water line. At the end of the fence, the barbed wire would be run across the river and connected with the fence on the opposite bank. This would prevent people from wading or boating along the hazardous portion of the river. The second portion of the irrigation system presenting serious health risks was the Outer Belt Canal near the villages. These areas would also have to be fenced to within a two kilometre radius of the villages, an example being the settlement of Mafoundou.

Because of the large number of cattle in the region, it was inevitable that the Outer Belt Canal would be used by herdsmen watering their animals. In order to minimize human contact with the water at these sites, long concrete watering troughs were planned outside the Outer Belt Canal. The troughs would be connected by ten-centimetre diameter pipes through the bank of the canal and built at an elevation where the water level in the trough would be the same as the level in the canal. Thus cattle would continue to have access to water but the banks of the canal would be protected from damage by cattle. The local herdsmen would be consulted about the design and placing of these troughs. The canal was to be fenced to within 500 metres on either side of the troughs and they would be placed at all the major points were cattle herds or cattle trails had contact with the canal.

2.4.3 Protecting Kaedi's inhabitants

The greatest human contact with water in this region is in the Senegal River at Kaedi immediately below its confluence with the Gorgol River. This area could easily become a major source of new infections, particularly amongst children in Kaedi. If the Gorgol River inside the irrigated perimeter became a habitat for infected snails, they would release cercariae here. The amount of water contact observed here in a nine hour period in the hot dry season involved about 25 people at any one time. The average time in the water was thirteen minutes, indicating that a total of 1000 people entered the water each day. Of these contacts 38% or 380 lasted longer than ten minutes. This would give adequate time for infection by the cercariae. Almost all of the contact was by children.

Given the amount of water contact at the Gorgol-Senegal confluence, it was probable that the presence of infected snails in the portion of the Gorgol River within the irrigated perimeter would cause at least hundred new infections per day. The number of infected people in Kaedi at present is about 15%. Within a few years after opening of the Scheme, this percentage could be expected to rise to 90, giving an increase of some 10 000 recently infected people.

There were three possible ways of dealing with this potentially dangerous locality. The snails could be eliminated from the Gorgol River above Kaedi; the infected people could be treated and then re-treated with drugs; or the amount of water contact by the local population could be reduced. Because of the limitations of each approach, it was suggested that they should be combined in a series of joint measures. Two elements would therefore be included in the project's initial construction phase. Chemical dispensers for snail control were to be built into the gate and pump structures at the two points where the Gorgol River crosses the main canal and an improved public water supply system would have to be made for the people of Kaedi, Ganki, and Mafoundou. This water supply would have to include public outlets for every ten families and clothes washing and bathing or shower facilities. The design would have to be adapted to local customs and water had to come from wells, not from the river.

2.4.4 Modifications to reservoirs

The proposed reservoir at Foum Gleita posed a special transmission hazard because it would be very close to the town of M'Bout. There was already a high level of infection amongst children in M'Bout and the increase in water contact would cause more. The present light infections would increase in intensity causing severe disease. The methods outlined in this section were intended to prevent transmission amongst the population of the settlement, and also prevent infection amongst the nomadic herdsmen, who would undoubtedly congregate near the reservoir during the dry season.

Three environmental alternations were seen as necessary in order to make the reservoir an unfavorable habitat for snails. Amongst the measures suggested was a fast lowering of the water level in the reservoir, stranding the snails and their eggs on the shore. This rapid drop would have to occur periodically throughout the year, particularly during the snail breeding season. Hydrological conditions made this feasible in the Foum Gleita Reservoir only when it was full or when the level was gradually being lowered as water was released downstream. Rapid drops could take place from December to April and the water dumped at these times could be retained in El Bir Reservoir. The recommended recession pattern included one week of rapid drop, followed by one week of constant pool level. The recession rate must always exceed 1.2 centimetres per day of vertical draw-down. In a normal year, the reservoir level dropped 300 centimetres in 150 days, that is a mean rate of two centimetres per day. The vertical recession rate should be raised to four centimetres per day during the rapid recession phase. This pattern would then cause a similar cycle in the lower Gorgol Reservoir at El Bir, stranding the snails and killing their eggs. If the vertical recession rate could not be raised above two centimetres per day in Foum Gleita Reservoir, then an additional fluctuation system would have to be established for El Bir Reservoir and provisions would have to be made to retain the water discharged there.

The outlet works in the dam would have to be designed to allow for rapid drops in level. The vertical rate of drop in the water level would be determined by the shore slope and should be between 0.01 centimetres per hour (cm/hr) and 0.10 cm/hr. These provisions were made using data on *Biomphalaria* behaviour under laboratory conditions. Thus, as an absolute minimum, the outlet gate would have to be large enough to allow a discharge causing the reservoir level to drop as much as 0.1 cm/hr or 2.4 cm/day when the reservoir was at maximum volume. These figures were based on an assumed shore slope of 0.01 or 100 horizontal units to a vertical unit. Topographical map measurements indicated that the slopes were actually flatter and a slight safety margin had been included. In the portion of the reservoir near M'Bout, the shore slopes were about 0.001.

The snail habitat potential of the reservoir could further be reduced by straightening the shoreline and making it so steep that wave action would cause erosion and prevent vegetation and snails establishing themselves there. This measure would be implemented to within five kilometres of M'Bout. If the reservoir became a transmission focus, the shoreline would have to be improved wherever there was human contact. Improvements in the M'Bout area had to be included in the initial construction phase of the dam. Modifications to other sites would be on a continual operational basis and guided by epidemiological studies which would locate transmission sites around the reservoir. The most likely sites could be expected on the eastern shore near M'Bout and the northern shore. These shorelines were protected from the effect of the *harmattan* wind blowing from the North.

In flat shore areas, small depressions capable of holding water would have to be filled with earth or provided with outlet drainage ditches. The snail habitat could further be destroyed by removing trees and vegetation from these areas.

Human access to the reservoir would definitely have to be restricted. The sheltered portion of the shoreline within five kilometres of M'Bout could be fenced and an adequate water supply provided. Where new settlements develop around the reservoir, wells would have to be made. The best areas for these wells would be near the more exposed wind-swept shores of the reservoir. People would have to be encouraged to settle around these well sites.

In general, the problems expected at El Bir Reservoir were not as severe as those expected at Foum Gleita. The nearest human settlement was Lexeiba, lying some distance below the Reservoir. The yearly cycle of operation here included complete drying during the month of June and shore slopes were flatter at El Bir than at Foum Gleita.

Thus snails were more readily stranded. If the recommended fluctuation schedule was followed in the upstream reservoir at Foum Gleita, a similar cycle of fluctuation would occur in El Bir Reservoir and no further measures should then be necessary.

2.4.5 Facilities for an operational schistosomiasis control program

Laboratory and outpost

Because a continuous monitoring of snails and schistosomiasis transmission would be required, a base laboratory near Kaedi was planned to house the five-person control team. In addition, facilities would be needed near Foum Gleita and El Bir to store boats and equipment for snail control on the reservoirs. The base laboratory would have to include a parasitology laboratory, eight metres by eight metres. It would have to have air-conditioning so that sensitive microscopic work could be done with windows closed and dust excluded. The laboratory would need workbenches along three walls, each bench having a sink with hot and cold water. The benches must also have convenient outlets for electricity, a vacuum line for filtration purposes, and a vacuum pump. The laboratory would need a centrifuge for processing urine and faecal samples, filters for processing urine samples, a refrigerator for storing samples, and about ten aquaria of ten litres each for raising snails. One compound microscope and one dissecting microscope would also be needed.

The office on the Kaedi site was intended for data analysis and for examining and treating infected persons. A nurse's station with desk, two chairs, couch, storage cabinet for medicine, and six extra chairs for waiting persons would be made in the front half of the office. The rear half of the office would not have to be air-conditioned and it should include two desks and chairs and two filing cabinets. An adding machine for the snail-control and diagnostic personnel would also be required here. A storage room was included for drums of snail control chemicals, boats, and other minor equipment.

An outpost at Foum Gleita, close to the dam and accessible at all times by Land Rover, would be needed for the storage of a boat, chemicals, and equipment. It would have to include a sleeping area for three persons since the snail control crews would often have to spend two or three days on the reservoir before going back to Kaedi. A smaller outpost would also be needed near the dam at El Bir. This should be similar to the one at Foum Gleita, but did not have to include a sleeping area.

Vehicles and boats

The schistosomiasis control group would need two Land Rovers: one small model which could be used by the nurse for examinations and drug treatment in the Project Area, and one large enclosed Land Rover for the snail control crew to carry personnel, boat, chemicals, and equipment for snail control operations and transmission monitoring. The vehicles would be housed and maintained at the Gorgol Project Base garage near Kaedi. Three small aluminium boats four metres long would be required, one for each reservoir and one for the base laboratory near Kaedi. All boats would be equipped with oars. Five-horse-power outboard motors were planned for the boats on the reservoirs.

2.4.6 Periodic drying of rice fields and canals

The intention of the irrigation system designers was that the rice fields should be dry both at harvest and for a short time afterwards. The irrigation canal system would also be dry during these periods because no water was needed in the rice fields. Computer model calculations had suggested that snail populations would not establish themselves permanently in these sites. If, however, the canals and fields did not dry out completely twice a year, they would undoubtedly become snail habitats and transmission sites. It was particularly important that the original design of the canals and rice fields provided adequate slopes and outlets to ensure that they could be dried quickly and thoroughly when water was no longer being fed to the rice.

2.4.7 Preventive measures during construction

Construction workers involved in building the dam and irrigation system must receive clear information about the risks of bilharzia. Boots would have to be provided for workers in prolonged contact with water, and safe drinking water would also have to be readily available. Bathing water would have to be stored for one day before use and water containers would have to be designed for easy snail inspection. All workers coming from other parts of Africa would have to be examined for infection, both faeces and urine being checked for the presence of schistosome eggs. Infected persons would have to be treated immediately. *Metrifonate* was suggested for urinary bilharzia and *Ambilhar* for intestinal bilharzia. *Praziquantal* is at the moment the preferred treatment for both types of bilharzia. A physician and laboratory technician would be needed for testing, prescribing/providing treatments, and checking the efficacy of cures. It was hoped that, if these measures were carried out, even construction workers would have some degree of protection against infection.

References

Jobin, W.R. 1966. The Operation of Reservoirs for Control of Aquatic Snails. Doctoral thesis, Harvard School of Public Health, Boston, Massachusetts, U.S.A.

Jobin, W.R. and E.H. Michelson 1969. Operation of Irrigation Reservoirs for the Control of Snails. American Journal of Tropical Medicine and Hygiene 18: 297-304.

Jobin, W.R., H. Negron-Aponte, and E.H. Michelson 1976. Schistosomiasis in the Gorgol Valley of Mauritania. American Journal of Tropical Medicine and Hygiene 25: 587-594.

Annex 3

3.1 The Tennessee Valley Authority, U.S.A.

3.1.1 Introduction

The TVA program (TVA 1974; Mills 1984) has often been cited as an example of a successful, integrated mosquito control program in a major water resource development project. The TVA was created in 1933 as a government-owned corporation with responsibility for a series of functions in the Tennessee River Basin. Amongst these were flood control, the development of navigation, the generation of electric power, agricultural and industrial development, and the economic and social well-being of the people. The latter included malaria control. A water control system of dams and reservoirs has been the focal point of the TVA program. It includes nine main river reservoirs (see Figure 3.1) and 21 tributary reservoirs with a total surface area of 264 000 hectares and 15 600 kilometers of shore-line.

No two dam and reservoir projects are exactly alike. Each project has its own distinctive characteristics determined by physiography, site location, design features, and operating schedules. For any specific project a mosquito control problem is affected by several factors. These include the climatology of the region in which the project is located, the size and topography of the reservoir area, and the condition of the area to be flooded with regard to drainage and vegetation. An additional factor is the expected water level schedules to be followed (operating rule curves) in order to meet project requirements. If due attention is given to mosquito control in the earliest stages of project planning, it is possible through design, proper pre-impoundage preparation of the area to be flooded, and judicious planning of reservoir operating schedules, to mitigate the potential mosquito problem. The need for special post-impoundage mosquito control operations, such as larviciding can be reduced.

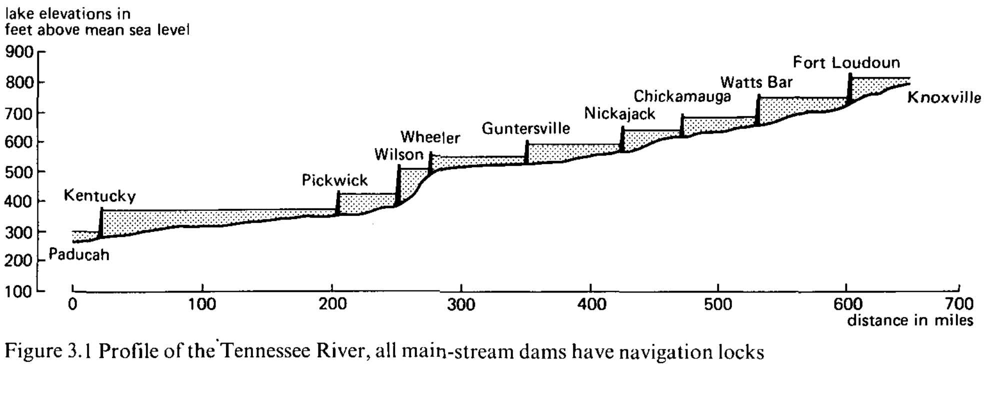


Figure 3.1 Profile of the Tennessee River, all main-stream dams have navigation locks

3.1.2 Water level management

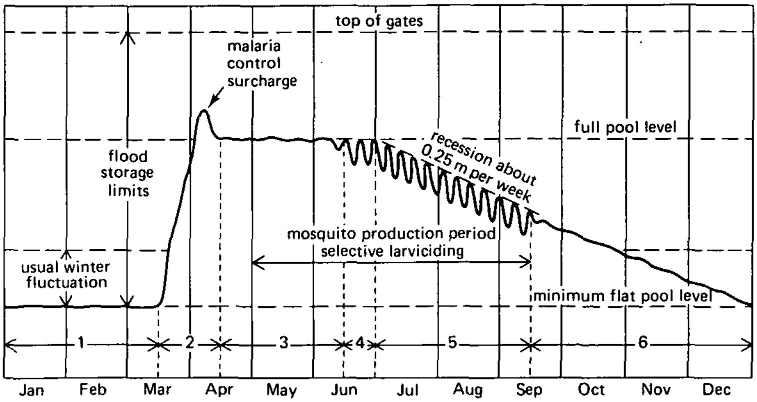
Water level management is the most important single measure available for mosquito control on reservoir projects. Its effectiveness, however, depends to a great extent upon proper pre-impoundage reservoir preparation and reasonable shore-line maintenance later.

Early in the planning of a reservoir project patterns of operation, or 'rule curve' of water levels to be anticipated throughout a normal water year, are developed. The water year coincides with the annual cycle of rains and run off, contributing to the stream flow at the dam site. The operational 'rule curve' developed to meet project requirements may or may not permit water level management of the reservoir adequate enough for mosquito control. Where the 'rule curve' is not favourable for malaria control, the possibility of modification should be investigated and project planning and adjustments made if necessary. Properly prepared reservoirs with a wide range, i.e between three to five metres or more of water level fluctuation usually present minimal problems, except when filling occurs during the mosquito breeding season. Storage reservoirs, used for flood control, irrigation, and hydro-electric power generation are examples of these. Difficult mosquito control problems are most likely to be associated with reservoir projects that are located in areas of flat topography and where there is a restricted range of water level fluctuation. Water level schedules providing constant or nearly constant pool elevations are the most objectionable from a mosquito control point of view. These should be avoided. For projects where this type of 'rule curve' operation might be envisaged it is important to make design provisions capable of wider ranges of fluctuation, should the need arise. A minimum range of approximately two metres is suggested.

Multi-use systems of reservoirs such as the TVA system with highly developed water control offer the maximum opportunity for utilizing water level management for mosquito control. Figure 3.2 shows those features of water level management schedules developed by TVA's main reservoirs and which are particularly important for mosquito control.

The mosquito control features of water level management schedules for TVA reservoirs were developed after extensive biological investigation and field research. They operate to control the malaria mosquito vector and the marginal vegetation which supports its reproduction. The schedules illustrated in Figure 3.2 when applied to specific reservoirs reflect integration and balancing of mosquito control requirements with total reservoir use. For navigation purposes each reservoir must be kept high enough to provide navigation depths to the next dam upstream. For flood control the reservoirs are operated at lower levels during the winter to maintain capacity for flood storage when needed.

Within these requirements, stream flow is utilized optimally for electric power generation. Management of water levels for these functions include special provisions for mosquito control with modifications to meet individual reservoir characteristics and primary operating requirements. As the lakes reach normal high level in the spring most are 'surcharged' briefly in order to strand floatage above normal operating level. If this were not done conditions would remain favourable for mosquito reproduction later. The stable high water level maintained during the early spring retards the growth of certain shore-line vegetation and is timed to help the reproduction of nest building



1 LOW WINTER FLOOD CONTROL LEVELS
Control growth of submerged aquatics. Permits marginal drainage and herbicidal operations.

2 EARLY SPRING FILLING
Retards plant growth.
Surcharge – strands drift above full pool level.

3 CONSTANT LEVEL POOL
Provides long – range plant growth.

4 CYCLIDAL FLUCTUATION
Destroys mosquito eggs and larvae.

5 FLUCTUATION AND RECESSION
Destroys eggs and larvae.
Reduces breeding areas.
Provides clean shoreline.

6 RECESSION TO WINTER LEVELS
Permits full shoreline maintenance and improvement operations.

Figure 3.2 Desirable phases of water level management for mosquito control on the TVA main river reservoirs

fish such as bass and crappie which spawn in the warm spring water temperatures. The weekly fluctuations serve to bring the water out of the marginal band of vegetation thus temporarily eliminating or greatly disturbing mosquito producing habitat. The gradual drop in water level during the latter part of the mosquito breeding season serves to ensure that the low point of the weekly cycle will draw the water sufficiently far away from the advancing marginal vegetation to control mosquito reproduction.

Aquatic plants are a continuing problem in TVA lakes and control by water level management has only limited effectiveness, except where reservoirs have deep winter time draw-downs. Plants are then exposed to drying and freezing. This provides a reasonable degree of control in the fluctuation zone.

3.1.3 Type of reservoir and water level management

The opportunity for applying the type of water management phases schedule outlined above varies with the nature of the reservoir. For large reservoirs weekly cyclical fluctuation requirements cannot be fulfilled because of the very large flows involved. For mosquito control they must rely on regulated recession over longer periods. A seasonal storage reservoir, such as that used in the Tennessee River system, can seldom follow the indicated phases schedule because its situation at the head of a tributary stream makes it subject to an annual rhythm of fill and draw. Filling takes place during the winter and early spring and, after a short storage period, water is released to maintain downstream flow as the summer progresses. Water level recession without periodic fluctuation would be the principal feature of water level management for mosquito control in the average, seasonal storage reservoir.

Some reservoirs are neither provided with flood storage nor operated to give wide seasonal recessions. These are run at a nearly constant level as is the case with some hydro-electric projects. Where in-flow is not scarce, cyclical fluctuation coordinated with maximum and minimum weekly power factors is best for mosquito control.

On small reservoirs, that is those ranging in size from a one to 40 ha, constant level and seasonal recession phases are applicable. A flood surcharge of between thirty and sixty centimetres used for only a day or so will effectively strand floatage. Implementing the constant level phase should give no problem. If fluctuation is possible it should have the same scope and period as that for the 'standard reservoir' of Figure 3.2, inflow being a variable. From a practical standpoint, water level fluctuation can be best achieved by manipulating stop-logs or flashboards installed in the spillway or control structure. The procedure commonly used to effect fluctuation is the removal and replacement, alternately, of the flashboards at four or five day intervals. If inflow is such that a sufficiently regular frequency can be obtained, an automatic siphon may be used to control the periodic fluctuation.

Recession can be practised on ponds with insufficient flow, and this also creates fluctuations. It is most effective on impoundages with steep shore lines. The effective recession rate must be determined for each reservoir taking into consideration the inflow, capacity and use of the reservoir as well as the rate of plant invasion and mosquito production. Assuming that the reservoir has been properly prepared and adequately maintained, a recession of three to nine centimetres a week should be initiated at the beginning of the mosquito breeding season. If this is used in combination with fluctuation the procedure can be started a little later. It can be generally assumed that it is not so much the dimensions of a reservoir that restricts water level management in any of the four phases as its hydrologic characteristics.

3.1.4 Applicability for the tropics

The 'phases' schedule is the ideal management technique for temperate zone climates where advantage can be taken of a winter period. It is based on the assumption that flood stages will normally occur in late winter or early spring. The question of how to adapt water level management to tropical zones, where a winter does not interrupt vegetation growth and mosquito propagation, is more problematic.

The storage surcharge phase is the most undesirable feature of the tropical regime. The problem lies in the rate at which refilling occurs and the promptness of the drawdown which will ensure a stranded floatage. If the water level rises slowly, over several months in margins covered with vegetation, emergency larviciding has to be carried out. With a rapidly rising water level, the danger may be insignificant because of the latency period required for the maturation of the new larval habitat.

Most tropical reservoirs are located on large rivers fed by high torrential rainfall, often 80% of the annual flow occuring in two to three months of the year. Reservoirs usually have large storage volumes designed to carry water in dry years. Turnover rates vary from once in five years on the Volta, for example, to once in nine years on Lake Kariba in Zambia. At the beginning of the flood period, the reservoir is likely to be quite low and much of the flood flow will be over barren shore-line. When the rising water level reaches the vegetation band the weather will usually be clear with cool nights. This may retard mosquito development from egg to adult by as much as two to three weeks, depending on the altitude. When the water level has reached its peak, it starts its annual recession, at first slowly, then later gathering greater momentum. The de-watered shore-line will be progressively exposed to hot dry weather and the highest evaporation rates. Mosquito control must be achieved by water level recession, a good shore-line maintenance and, if dry season inflow permits, fluctuation.

The Damodar Valley Corporation (DVC)

The DVC, known as 'India's TVA' is a governmental corporation created in 1948 and is located in West Bengal and Bihar (see Figure 3.3). Its greatest single function is flood control but hydro-electric production, irrigation, and navigation have also been developed on a large scale and are important. Malaria control has been cited as the scheme's fourth major priority (Henderson 1955). In 1953 the DVC system consisted of four multi-purpose main reservoirs and two barrage ponds. Most Indian plains rivers are dry for several months every year but become flooded torrents during the south-west monsoon months. The combination of flood control and irrigation functions of the reservoirs give long sustained drawdowns and sharp refill characteristics in the four main reservoirs. There appeared to be little danger of mosquito production in the reservoirs, and clearing the shore-line and draining residual pools were considered to be sufficient safeguards.

However, the possibility of production existed where the main pools of the two constant level barrage ponds were concerned. Use requirements and dam design prohibited incorporating water level recession in the water management plans of these shal-

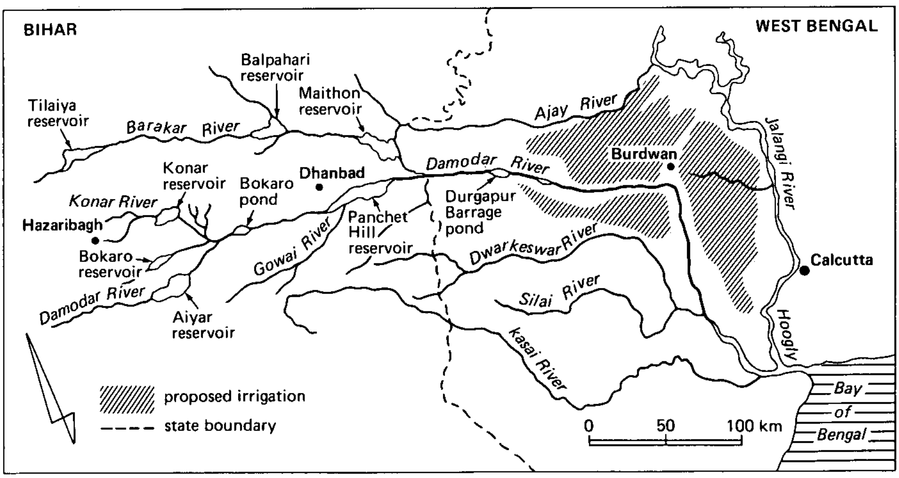


Figure 3.3 The Damodar Valley Corporation (DVC)

low ponds. A plan of weekly water level fluctuation was developed which fitted in with other water use requirements.

In Durgapur Pond, an area of some 1400 ha, it was necessary to integrate the water management plans of five upstream hydro-electric and cooling water impoundments as well as the requirements of downstream irrigation, navigation, and municipal water supply into a periodic fluctuation scheme. A draw-down of forty to eighty centimetres in 24 hours was possible with no wastage of usable water. An equivalent rise in water level was spread over the other six days of the week. It was possible to adjust the inflow because of the high proportion of electric energy scheduled for potential industrial use. This involved a prolonged off-peak period during the weekend. Further flexibility was given by the presence of a 200 000 km thermal plant. The Bokaro Pond, an area of some 100 ha, had very limited live storage capacity in the upstream reservoir. The development of a feasible draw-down refill cycle was made possible by recirculating the 11.5 m^3 of cooling water required by the thermal plant during the six-day refill period, and by discharging it on the weekly draw-down day.

3.2 Lake Volta, Ghana

In the 1970's, scientists in a UNDP/WHO project on the Lake Volta hydro-electric reservoir investigated the epidemiology of bilharzia among the 120 000 Krobo farmers and Ewe fishermen who live around the lake. Conventional control methods were tested but the cost of these measures was too high for government resources. Lake Volta is an outstanding example of the need to control bilharzia using biological methods rather than the more conventional use of drugs and pesticides. Environmental engineering or manipulation of water levels in the lake are impractical because of the size and single function of the reservoir.

Human prevalence surveys around Lake Volta showed that almost the entire population was infected with the heavy worm burdens of urinary bilharzia. The parasite is spread by the snail *Bulinus truncatus rohlfsi* and transmission is seasonally and geographically specific. Most of the transmission occurs in small shore-line foci near the villages and it is usually most intense after high water level has been reached on the lake in November. The lake fluctuates from between three to five metres vertically during a three month rising period between August and October. After November, there is a slow decline.

Lake Volta was created with the building of Akosombo Dam, a rock-fill structure 113 metres high which can pass a flood discharge of 34 000 m^3 second. The dam impounds 148 000 million m^3 of water at spill-way level. The surface of the lake at high water covers some 9000 km^2 and the shore-line is over 5300 km long. The contributing watershed extends into Upper Volta and includes an area of 400 000 km^2 with an average rainfall of one meter. 80 000 people were displaced when the lake was formed and resettlement has caused considerable hardship.

Soon after it had filled in 1966, the lake began to harbour an enormous fish population, and coastal Ewe fishermen, and their families migrated there. A seasonal migration back to the coast takes place every year when the fishing season ends. Fishermen stay on the coast until the fishing on Lake Volta improves again with rising water (see Figure 3.4). With the fish came a great deal of vegetation and the intermediate

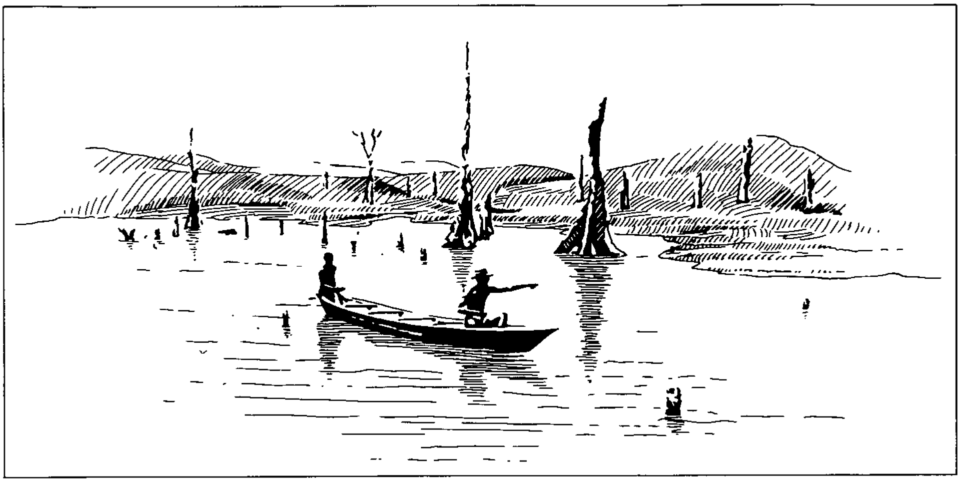


Figure 3.4 Shore of Lake Volta, 1978. Inundated trees die but trunks persist for decades causing problems of access and navigation. Fishing activities and accumulation of debris can support snail and mosquito breeding

snail host of *Schistosoma haematobium.* Unfortunately some of the Ewe fishermen were infected with a strain of *S. haematobium*. This was rapidly transmitted throughout the communities on the lake shore. In 1971 the World Health Organization, with UNDP support, began a program investigating methods of controlling disease in the lake area. It was hoped that the experience gained in dealing with other large hydro-electric reservoirs such as the High Dam Lake in Egypt, Lake Kainji in Nigeria, and Lake Kariba in Zambia, would be useful.

Two methods were given careful and long-term evaluations. The repeated treatment of people living along the lake with the inexpensive drug, metrifonate, and secondly chemically controlling the snails in the small foci where transmission occurred. Pre-control research indicated that infected snails were found in small predictable sites at the lake's edge, near paths leading to the villages. Furthermore, the months from December to April, the falling level stage, were more important for transmission than other months of the year. This indicated that snail control efforts could be effectively concentrated both geographically and seasonally (Chu and Vanderburg 1976; Chu et al. 1981; Chu et al. 1981; Klump and Chu 1977).

Those infected were treated annually with metrifonate. Snail control was also carried out and some villages received new water supply systems. Health education was emphasized. The cost and extent of these efforts have not been published but per capita cost of the snail control effort has been estimated at around US $1.20 (at 1987 prices). Probably the combined cost of chemotherapy and other methods would give a total of nearer US $ 2.50 per capita. Although this seems fairly modest, the government did not continue the control program when outside support ended.

One can understand the reluctance of the government to continue this program when the increasing cost of chemicals is examined. The control effort relied on two chemicals purchased overseas: the drug metrifonate and the pesticide bayluscide.

In 1977, when the Ghanaian cedi was worth 0.275 dollars, a kilogram of bayluscide cost US $14 or 50 cedis on the open market. By 1984 the cedi was worth only 0.007 dollars, and a kiloghram of bayluscide cost the government US $17 or 2429 cedi's.
It is possible that bilharzia in the Lake Volta area has been held in check by the drought years of the early 1980's. It can be expected, however, that when the lake is full again, another severe urinary bilharzia epidemic will occur.

Another difficulty in extending this type of control method in large lakes is illustrated by the estimated cost of expanding the control program to cover the entire western shore-line of the lake where most transmission occurs. This extension would have been necessary for a more permanent solution to urinary bilharzia along the lake. At least 2000 kilometres of shoreline required control. A pilot study set the cost of partially controlling 32 kilometres of shore at about US $18 200 (at 1987 prices) or an estimated annual cost of US $1 million for snail control and probably another US $1 million for drugs and other measures. This expenditure would have had to be maintained indefinitely and be locally financed, despite constant devaluation in local currency.

This brief analysis shows the disadvantages of conventional bilharzia control methods over long periods in large reservoirs. A more rational approach would be the development of low cost biological methods such as the *Marisa* used in Puerto Rico reservoirs.

3.3 Brazil; north-east coast reservoirs

The small reservoirs built by individual farmers or small agricultural communities in central Brazil have been a source of serious bilharzia infections. Snail control with the chemical bayluscide has been successful in these reservoirs. The long range economics of the method, however, did not lead to its being developed beyond the initial pilot studies. One problem was the high cost of chemical control. The snails always came back and chemicals needed to be applied indefinitely.

A computer simulation was used to decrease the cost of chemical control by indicating ways in which its effectiveness could be increased. The simulation estimated the snail populations in typical reservoirs and calculated the relative effect of chemical applications at different times in the year.

A strategy of 'safeguards' for Brazilian lakes and reservoirs was urgently needed since Brazil has the most extensive schistosomiasis problem of any country in the western hemisphere. Data were obtained from typical reservoirs along the north-east coast of Brazil near Recife and in Minas Gerais near Belo Horizonte. The climates are quite different in the two areas and so are the abilities of the local strains of snails to resist desiccation. Because there are great differences in the normal population histories of reservoirs, the optimum timing of control measures would not be the same.

3.3.1 Reservoir in the north-east

A description of snail habitats near the city of Recife was used as the basis for understanding natural environmental conditions in the area. There is a four month period from December to March when the habitat is dry. The snails survive by aestivation and they have a very high resistance to desiccation. The rains begin in April and the reservoir is full of water by May. The volume gradually diminishes from July to November with decreasing rains. The amount of vegetation increases from April to August, and from August it stays at a high density until the dry season. Water temperatures are always about 25°C and can rise to as high as 35 or 40°C as the habitat gets drier. In this typical climate a maximum number of snails are produced between August and October. There is a low in production during April and May. The snail breeding period is roughly between May/June and October.

The optimum time of year for application of molluscicides in a reservoir in the north-east was determined by simulating 99% mortalities from chemical treatment, one month at a time: for April, May, June, July, August, September, and October. A double application of molluscicides during each month was assumed at application intervals of 20 days. Only 99% mortalities were simulated in order to show the population recovery which could be expected after chemical treatment.

The effect of the molluscicides was least pronounced if the chemical was applied during the breeding season. This was due primarily to the high reproductive rate of snails. If the applications were made in May, the lowest number of snails recorded during the year was 111, this total being recorded immediately following the first chemical application. The next week there was a burst of egg-laying due to changed environmental conditions and the uncrowded habitat. The number of snails rose to 2251 with 23 000 eggs being laid. 1982 snails remained alive after the second chemical application. The reservoir was now full and contained 9000 m^3 of water. For the remainder of the breeding season the number of snails increased steadily. In contrast chemicals applied in November when the reservoir was low with only 50 m^3 of water, caused snail population to drop to ten by April. There was no population recovery following the application of molluscicides because the water temperatures were too high for oviposition, and the habitat had dried out completely by December. This forced the 48 survivors to aestivate.

By tabulating monthly predictions of the minimum number of snails left after the molluscicide application, it became clear that November was the best month for treatment and caused snail populations to drop to their lowest level. Other months in which chemical treatment would have optimum effect were April, May, and September.
Although the precise numbers developed in the analysis have little significance, it is clear that the best time to apply molluscicides in the north-east is immediately before October/November.

3.3.2 Reservoir in Minas Gerais

With the exception of the north-east, the only other area where a great deal of data was available on the population dynamics of *B. glabrata* was near Belo Horizonte, in Minas Gerais. A typical, small reservoir environment was simulated for Minas Gerais including water temperature, volume, and amount of food. This was done using data from two existing lakes. Water temperatures fell below 20°C between May and July, restricting the breeding season to nine months of the year. Even during the warmer season the mean monthly temperatures of the water did not exceed 25°C.

This was much cooler than in the north-east.

Although there is not a severe dry season in Minas Gerais the water levels do recede during the cold season and are lowest before the rains start in October. During the hot rainy season, October to April, heavy rains fill the lakes and produce high levels of turbidity. This is due to the fine silt carried in by flood waters and it restricts the growth of algae, retarding the amount of food available to the snails, until April, when the rainfall decreases. During the dry season the water becomes clearer and aquatic growths increase again. Under these conditions the model predicted a maximum snail population in September, with a minimum in July and August. This complemented in general terms, observation for lakes in Minas Gerais. The reservoir simulated for Minas Gerais had a maximum volume of 9000 m^3, the same as the reservoir simulated for the north-east, and it made it possible to compare treatment costs.

A double application of molluscicides was simulated for each month. It was assumed that the applications occurred on the 1st and 21st days of the month and that each application caused 99% mortality. This was the same treatment regime which had been simulated for the reservoir in the north-east. Under these conditions the snails were completely eliminated if the molluscicide was applied during May, June, or July. Since this made it impossible to rank the months comparatively, the mollusciciding was resimulated assuming only 90% mortality.

The fact that the mollusciciding in Minas Gerais had a greater effect on the snail population than did the mollusciciding in the north-east indicated that snail control programs are more likely to succeed in Minas Gerais. This was because of the nature of the environment, lower temperatures causing a lower average oviposition rate. Snail population required more time to recover from the catastrophe.

In Minas Gerais the best month for applying molluscicide was July. May and June were also suitable. The other months were too cold for oviposition. Chemicals applied during the breeding season had markedly less effect on the number of snails. As well as being more effective when applied during the cold months, the cost of chemical application would also be slightly lower because the reservoir, although far from dry, would have less water than normal.

Comparative analysis showed that mollusciciding would be more effective in Minas Gerais than in the north-east, primarily because temperatures were more favourable for snail reproduction in the north-east. In addition the analysis shows that molluscicides should be applied just before the dry season in the north-east and in Minas Gerais they should be administered during the dry season.

Calculating the best times for molluscicide operations was the result of a general procedure which can be applied for other control methods, in other regions, and with other snail species. It can also be applied without the use of the computer model although this would be very time consuming.

References

Chu, K.Y. and J.A. Vanderburg 1976. Techniques for Estimating Densities of Bulinus Truncatus Rohlfsi and its Horizontal Distribution in Lake Volta, Ghana. Bulletin of World Health Organization. Vol. 54, pp. 411-415.

Chu, K.Y., R.K. Klumpp and D.Y. Kofi 1981. Results of Three Years of Cercarial Transmission Control in the Lake Volta. Bulletin of the World Health Organization. Vol. 59, No. 4, pp. 549-554.

Chu, K.Y., J.A. Vanderburg and R.K. Klumpp 1981. Transmission Dynamics of Miracidia of Schistosoma Haematobium in the Lake Volta. Bulletin of the World Health Organization. Vol. 54, No. 4, pp. 555-560.

Henderson, J.M. 1955. Water Management Planning for Malaria Prevention in the Damodar Valley, India. American Journal of Tropical Medicine.

Klumpp, R.K. and K.Y. Chu 1977. Ecological Studies of Bulinus Rohlfsi, the Intermediate Host of Schistosoma Haematobium in the Lake Volta. Bulletin of the World Health Organization. Vol. 55, No. 6, pp. 715-730.

Mills, D.B. 1984. TVA Handbook, (Revised) Tennessee Valley Authority, Knoxville, Tennessee.

TVA 1974. Vector Control Program, Environmental Statement. Tennessee Valley Authority Technical Report, TVA, Knoxville, Tennessee.

Figure 4.1 Seasonal cotton pickers working in the Gezira-Managil irrigation scheme

Annex 4

4.1 The Gezira-Managil Irrigation Scheme, Central Sudan

4.1.1 Introduction

Of the 2.5 million people living in the Gezira-Managil Scheme in 1985, about one million were immigrants into the area. These temporary and seasonal workers lived either in permanent camps, small villages or made use of temporary camp sites. The population concentration in this area is heaviest between December and April when the cotton is ready for picking (Figure 4.1). The Gezira Scheme is documented in major textbooks: e.g. Gaitskell 1959, Barnett 1977 and Fakki 1982. Figure 4.2 gives the general setting of the Scheme and indicates the lay-out pattern of the irrigation canals.

A gradual expansion program began in Gezira-Managil in 1950 and the scheme grew from 400 000 hectares, to its present size of 840 000 hectares. The largest expan-

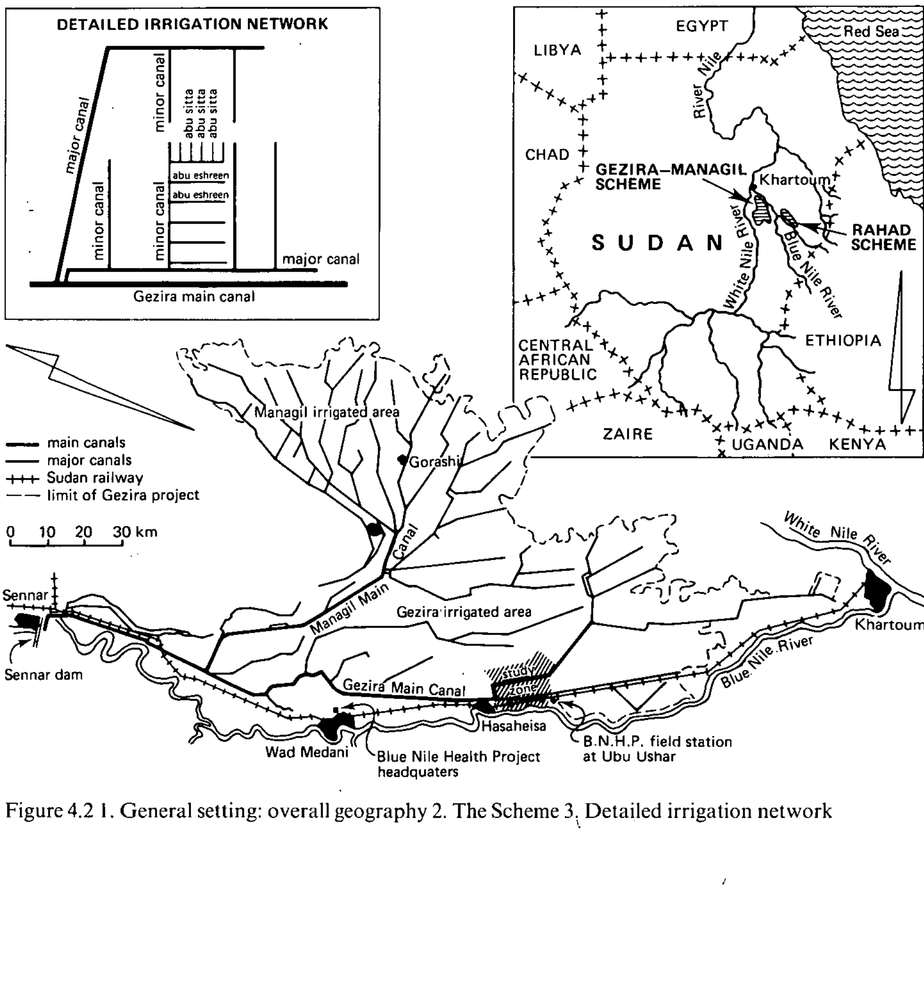


Figure 4.2 1. General setting: overall geography 2. The Scheme 3. Detailed irrigation network

sion occurred after 1966 with the completion of the Roseires Reservoir. This resulted not only in an increased area, but in a major intensification of cropping, and in an overall increase in agricultural activity. With this growth came complications: the original system deteriorated, cotton pests caused problems, and there have been increasing numbers of complaints about ill-health. If these problems can be dealt with, the scheme should be a major asset to the economic future of the Sudan.

4.1.2 Use of synthetic chemicals

Cotton and Whitefly

It is important to begin with a brief reference to Whitefly because of its stunning impact on agriculture in the Gezira, and because the strategies used to control it have a more general relevance. Whitefly is a major cotton pest in the Gezira fields. A serious disaster occurred in the 1980/81 season when the cotton yield dropped to its lowest level in 20 years. This was despite record expenditures on spraying Whitefly and other cotton insect pests. By 1980 the annual cost of cotton pest control per tenant had exceeded U.S. $150.00. This was more than the net return of even the most successful tenants. 1980 was the third, and worst year, a historic low-point in the productivity of the scheme. The history behind the 1980 cotton failure is complex (Eveleens 1983), but a major factor was the abandonment of overall responsibility for pest control by the Gezira Board. They handed the problem over to commercial chemical companies, who relied entirely on control through pesticides.

Fortunately the downward trend of cotton yield has reversed since 1981 partly due to the withdrawal of the chemical companies and to a return to an integrated program of pest control, based on a rational combination of all available methods. These included restraints on the timing and amount of insecticides applied (Bindra 1983; Bindra and Abdelrahman 1983). Intensive field research complemented this program. It aimed at developing cotton varieties resistant to Whitefly, strengthening natural biological control mechanisms, and manipulating the irrigation regime to create conditions unfavourable to the pest.

Wheat irrigation and malaria

A too heavy reliance on synthetic chemicals also characterized the health sector, particularly the use of pesticides and drugs to control malaria, diarrhoeal diseases and bilharzia. The malaria crisis of the early 1970's in the Gezira had many features in common with the whitefly tragedy.

Malaria has been closely linked to agricultural development in the Gezira ever since the Gezira Irrigation Scheme began in 1924. During the scheme's first 25 years reasonable malaria control was possible through good water management and larviciding. After 1950 improved malaria control using new chlorinated hydrocarbons for house-spraying was slowly offset by agricultural expansion. There was a gradual trend towards pesticide resistance because of large-scale chemical applications in the agricultural and health programs (Figure 4.3). The occurrence of complete resistance in 1970

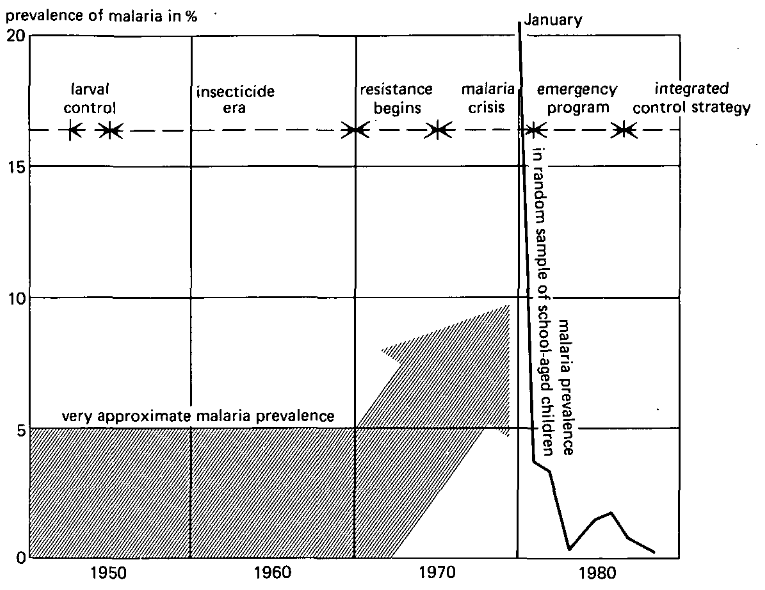


Figure 4.3 Pesticide resistance and prevalence of malaria

produced a health crisis among the agricultural population. The crisis coincided with an agricultural expansion and intensification program which had created new mosquito habitats. A second seasonal peak in malaria was caused by irrigated wheat during the winter months. Attempts at control by a return to larviciding were unsuccessful, and severe malaria outbreaks occurred in 1973 and 1974.

Adding winter wheat was a critical element in the increase in malaria transmission. Wheat cultivation meant heavy irrigation requirements from mid-October to the end of March, on land that had in the past been left fallow, or planted with cattle fodder. Now irrigation flow was almost doubled during the winter months. The irrigation of wheat added water to the larvae-producing 'abu-eshreens' at a time of year when air temperatures particularly favoured long life in the adult insects. This allowed the malaria parasite an increased chance of completing the extrinsic cycle and being passed on to a second human carrier before the mosquitoes died.

The malaria situation in the Gezira in the mid 1970's was dangerous. An extremely efficient vector, *Anopheles arabiensis*, could find ideal breeding conditions through most of the year, and housing, and human behaviour made malaria transmission easy. Under these circumstances the control program was constantly active and covered the greater part of the endemic area every year. The dominant form of the disease was *falciparum* malaria, a particularly serious health threat especially among children.

The main mosquito breeding grounds were in the small 'abu eshreen', irrigation ditches, drains, swamps, and those lands flooded due to excess irrigation water. The small water accumulations near breaks in canals or around community water taps were also good breeding places. The main vector in the Gezira preferred clear, stagnant water with very little shade or with emergent, vertical vegetation, such as grasses or reeds. Villages were widely dispersed in the area and every village was close to such a breeding site. Malaria was found throughout the million or so hectares of irrigated land, although there was slightly higher transmission in the upstream, southern portion of the scheme, where rainfall was heavier.

The severe and localized nature of the small thunder storms which occur in the Gezira area has meant that rapid communication and careful control and balancing of flows in the canal network is necessary, otherwise young cotton plants drown in flooded areas. When the communication and control system broke down in the 1970's canal overflows became frequent, and fields, and drains were often saturated. Breeding areas also increased. The overflow of canals was further aggravated by heavier aquatic weed growth than normal. This meant that canals had to be fuller in order to deliver water to crops and less margin was left for controlling discharge errors.

Special problems in the long-range planning of malaria control were created by the large numbers of seasonal agricultural workers migrating from malarious areas outside the Gezira. They lived in primitive shelters in the fields whilst picking cotton, herding cattlet, or performing other, seasonal activities such as weeding. These people were exposed to large numbers of mosquitoes, were outside the normal health programs, and could easily bring infections into the scheme from outside.

The health service system operating in the Gezira included a malaria control unit, as well as numerous health posts offering rudimentary diagnosis and treatment for common diseases. Almost all fevers, general malaise, even respiratory, and gastrointestinal infections were considered to be malaria by the general population and were treated with chloroquine. Malaria and other problems were diagnozed by symptoms and blood slides were seldom taken. Despite policies to strengthen these basic health units and repeated attempts to improve their performance and their acceptance by the communities, their contribution to malaria control was less significant than the work of the centralized malaria control unit based in Wad Medani, the regional capital.

The malaria control unit carried out an annual house spray with residual insecticides at the end of the rainy season, larviciding near the large towns during the dry season, and attempted mass treatment of seasonal labourers with chloroquine during the cotton picking season. They also monitored malaria prevalence. Blood slides from a randomly selected sample of children were examined annually and data submitted by hospitals on blood slides found malarial positive were also analyzed. Mosquito populations were monitored seasonally and new control methods were tested before they were introduced on a large scale.

A change to organophosphorous chemicals produced a rapid drop in malaria prevalence after 1975. However, the possibility of resistance to this new class of compounds, the increased costs of the new chemicals, the deteriorating agricultural situation and the economic problems of the late 1970's, made the future of malaria control in the Gezira uncertain. In 1978 a comprehensive approach to malaria control was planned. This coincided with an agricultural and irrigation rehabilitation program. Reliance on chemicals was reduced and environmental, biological, and educational measures were re-emphasized. Such anti-malaria measures do not require the continuous expenditures of hard currencies on foreign products and have more chance of a permanent place in every day life.

4.1.3 Aquatic weeds

The Gezira scheme in the early post-war period only produced cotton. Few other crops were grown and the scheme area had not increased significantly from its original design. In addition to cotton, sorghum was grown for food, and Lubia and Philipesara were grown as cattle fodder. By 1950 the total area under irrigation was 400 000 hectares with a mean irrigation flow of 93 m^3sec for the nine months between the end of July and March. The permanent population numbered about 550 000. An additional 100 000 seasonal migrants came in the cotton-picking season. Bilharzia had been identified as a problem at an early stage and a control program using drugs and molluscicides was developed in the 1950's. Urinary bilharzia and intestinal bilharzia seem to have been equal in prevalence.

The scheme gradually expanded after independence. The irrigation season was lengthened by the addition of wheat in 1970 and medium staple cotton in 1976. Intensification and increased flows occurred as the Managil Extension was added and as fallow was gradually taken over by wheat. Total acreage and population expanded. Population density was greatest at the time of peak labour requirement, October/November, when the cotton had to be weeded and the sorghum harvested, and between January and March when more labour was needed to pick cotton.

As water flow in minor canals increased because of the new crops and the reduced fallow, and as the irrigation season lengthened due to the addition of wheat and acala cotton, the number of minor canals remaining dry for anything more than a short time decreased. This allowed aquatic vegetation to grow for longer periods and extremely dense stands were produced. Manpower to clean the canals was lacking, water flow was hindered, and agricultural activities were interrupted. The canals became ideal snail habitats. Enormous snail populations were produced for most of the year and this provided ideal conditions for bilharzia transmission. Aquatic vegetation had to be removed and this meant that additional crews were employed year-round. These crews worked immersed in snail-infested waters. They became severely infected and were a major reason for the increasing transmission ratio. These crews had higher prevalences and intensities of infection than other occupational groups and the most severe of any age group in their own communities (Fenwick et al. 1982) (Table 4.1).

Table 4.1 Intestinal bilharzia in canal cleaners and other occupational groups in the Gèzira-Managil Irrigation Scheme, Sudan

Occupational group	Intensity of intestinal bilharzia infection in eggs per gram of faeces
Canal cleaners	1700 to 2200
Sugar cane cutters	0 to 3800
Other villagers	0 to 1400

Because of the dynamics of bilharzia transmission (see Chapter 4 on the Nile Shift) the intestinal form of bilharzia became most prevalent and gave rise to serious infections. The urinary form receded in importance and in some places practically disappeared. By 1980 hospital physicians in Wad Medani were seeing severe cases of bilharzia in increasing numbers, including infections in teenage boys. A prevalence survey in 1981, in a representative sample of villages showed a 51% prevalence of intestinal bilharzia and virtually no urinary bilharzia. The same sample repeated in 1982 gave a prevalence of 61%. A separate evaluation of uninfected persons identified in the first survey showed a 29% incidence of new infections in one year. This demonstrated an active and increasing transmission rate. The data indicated that the heaviest transmission was occurring in the Managil Extension.

Field studies showed that the geographical and seasonal patterns of transmission in the irrigation scheme was highly specific and restricted to minor canals near villages. Transmission occurred between October and July and particularly when the water was clear, vegetation dense, and snails numbers high. The minor canals, which also provided night storage, constituted the most stable snail habitat and the one closest to human settlements. The abu eshreens were dried frequently, mostly every two weeks, and did not support large numbers of snails. The main canals did not function as night-storage systems and did not trap as much silt, neither did they harbour as much vegetation. The snail populations were also not so dense there. Major canals were not as numerous or so close to villages and human contact and contamination was less frequent than in the minor canals.

The fundamental change in the ecology of the minor canals from 1950 to 1980 was the result of irrigation intensification and the reduction of fallow area. Wheat, medium-staple cotton, fruits, and vegetables requiring water in the normally dry months of April and May were gradually introduced. This resulted in a larger proportion of minor canals containing water throughout a lengthened irrigation season (Fenwick et al. 1981). There was also a larger number of 'summer' canals which never went dry and which supplied drinking water to the villages.

4.1.4 Village water supply

Social development programs placed considerable emphasis on village water supplies in the late 1950's. This resulted in the construction of over 1000 deep bore-well systems in Gezira and 125 gravity-sand filter systems in the Managil where canal water had to be used because of the salinity of the sub-surface waters. These systems were designed to supply about 100 litres per capita per day (l/c/d). They used windmills which were complemented, and then eventually replaced, by diesel engines. The cultivation of a wide variety of fruits and vegetables was encouraged and the people were taught the value of these items in a balanced diet.

An evaluation of village water supplies in 1982 (Study Zone Villages of Blue Nile Health Project, see Figure 4.4 and Section 4.1.5) showed that village populations were much larger than the original system had been designed for. Frequent shortages in fuel, electricity and spare parts had reduced the operating time of the system to 72%. This was of critical importance in bilharzia transmission. In these villages the prevalence of intestinal bilharzia was found to be in inverse proportion to the rate of water consumed at least up to a rate of 70 l/c/d (Figure 4.5). Bilharzia prevalence data were taken from a study of six 'core' villages and three unserved labour camps. Consumption beyond 70 litres showed no decrease in prevalence. It suggested that 70 litres

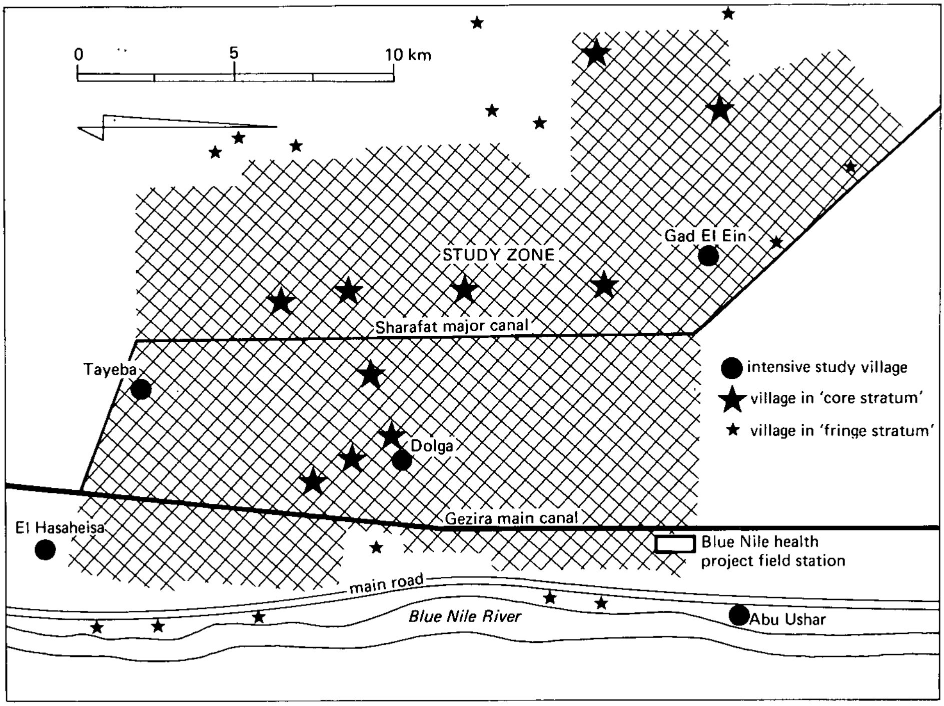


Figure 4.4 Location of study villages in Gezira-Managil Irrigation System. Black circles indicate intensive study villages, large asteriks are villages in 'core stratum', and small asteriks are villages in 'fringe stratum'

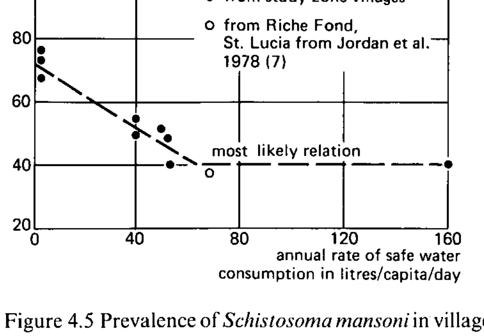


Figure 4.5 Prevalence of *Schistosoma mansoni* in villages in the 'Study Zone' versus their annual mean experience of safe water consumption, 1981 – 1982

was the daily per capita requirement for domestic purposes and that recourse to contaminated irrigation canals was virtually eliminated if this amount of water could be made permanently available. It appears that the residual prevalence of about 40% in those villages which consume more than 70 litres was due to non-domestic water contact such as water-play by children, agricultural activities, and daily bathing.

This causal relation of water consumption rate to bilharzia prevalence suggested by the data from the villages in the core stratum was confirmed in a later study on St. Lucia. Improvements were made in the water supply of St. Lucia, an island in the eastern Carribean, where *S.mansoni* infections were also endemic. Before water supply improvements, the prevalence of bilharzia in the village of Riche Fond was 56% (Jordan et al. 1982). A system providing 65 l/c/d was constructed. After five years this had resulted in a drop in prevalence to 38% (Figure 4.5).

Another important relationship was found between prevalence and the distance from the nearest minor canal in those villages which had only shallow open wells and no protected water supply. The bilharzia prevalence in these villages decreased inversely with distance, up to a minimum of 10% or 15% at 1700 metres. This indicated that at this distance people would prefer to use polluted water from shallow wells rather than walk two kilometres to the canals (Figure 4.6). The shallow wells were not contaminated with bilharzia, thus exposure to cercariae in these vilages was severely curtailed.

Other factors affecting the prevalence of bilharzia were the amount of water contact during play by children, casual crossings of canals, and a decrease in the amount of water used by everyone because of the extra time and labour needed to fetch it.

Village water supplies were constructed in the 1950's because of the obviously contaminated and turbid condition of canal water, previously the main source of drinking water. Water contamination from human and animal excreta was a major source of disease and a major cause of death amongst children. A village water supply system also meant that long journeys to the canal could be eliminated and water would be more freely available for use (Figure 4.7).

Deep borewells located near the villages were constructed in the 1950's to make at least 100 l/c/d available and to provide a safe, adequate and convenient water supply.

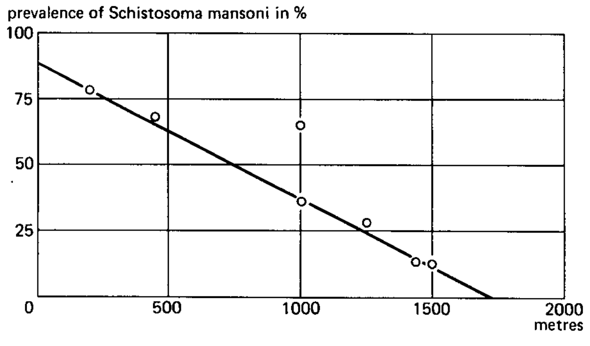


Figure 4.6 Prevalence of *Schistosoma mansoni* versus distance to nearest minor canal in small villages, without safe water supply, in 'Study Zone', 1981-1982, prior to intervention with comprehensive strategy

Figure 4.7 Original sources of domestic water. Irrigation canals were the only source of domestic water for villages without their own wells. Water carriers provided a minimum supply of highly contaminated water to these villages

When the Managil Extension was constructed, gravity sand filters were installed in the villages to treat canal water. They were not very successful.

The population in these villages had a 2% growth rate but the water supply systems had not expanded. After 1970 the Governments' deteriorating foreign exchange position resulted in shortages in spare parts, electricity, and fuel. This caused an increase in non-functioning time from an estimated 5% in 1960, 15% in 1970, to a measured 28% in 1982. The estimated daily per capita consumption in Gezira villages with bore-wells dropped from 95-100 litres in 1960, to 71 litres in 1970 and 50 litres in 1982. Projections for 1985 and 1990, given prevailing conditions, indicated an availability of 45 litres in 1985 and 38 litres in 1990.

The villagers had only two other sources of water if their deep bore-wells were inadequate: direct from the canals, or from shallow dug-wells. Both were heavily contaminated. The drop in safe water consumption was followed by an increase in both diarrhoeal disease and bilharzia. By 1982 the death rate for diarrhoeal diseases in Gezira children under five years was 49 per 1000 per year, slightly below the average for Africa.

Diarrhoea was treated with anti-biotics and, if the disease progressed to dehydration, the child would be hospitalized and given electrolytes and nutrients intravenously. Gezira had poor transport and communications, and there was a shortage of hospitals and medical resources. This treatment strategy therefore, had little impact and the death rate continued to climb. Respiratory disease was the only other cause of death of similar magnitude in infants.

When data from diarrhoeal disease surveys and the mean safe water consumption was evaluated for the three intensively studied villages in the core stratum of the 'Study Zone' a direct, inverse relationship was found between consumption and disease prevalence (see Figure 4.8). Although only three points were available to establish the line, this high correlation coefficient indicated a likely and quite logical relationship.

The correlations of disease with rate of water consumption and with distance to surface waters did not establish a cause and effect relationship. There was some evidence, however, to support the concept that increasing the quantity of water available would decrease disease. The village of Gad El Ein had the highest prevalence of bilharzia among the core villages studied. It also had the highest rate of diarrhoeal disease of the three intensively studied villages. Gad El Ein had the smallest pump and tank system: 49 l/c/d, even when operating 100% of the time. The people of Gad El Ein were extremely vocal and active in seeking improvements to their system, and it is unlikely that low levels of health consciousness could be blamed for the high prevalence of disease. Limited water supply seems the most likely cause, at least within the range of consumption evaluated.

4.1.5 The Blue Nile Health Project

Introduction

Severe disease, disability from bilharzia, and increasing death rate from diarrhoeal diseases were becoming major problems, particularly amongst the agricultural work

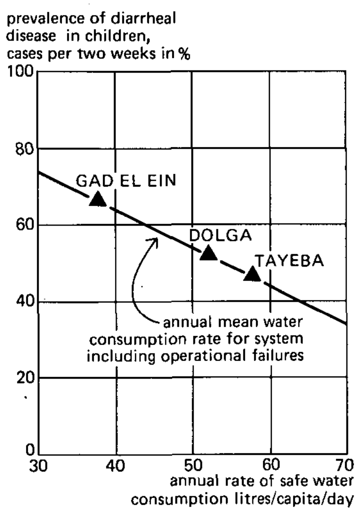


Figure 4.8 Relation of prevalence of diarrhoeal diseases and safe water consumption for intensive study villages, 1981

force who were most exposed to infection. Preliminary studies indicated that the labour available to tenant families, relying on family labour, was reduced by as much as 25% because of sickness. Canal cleaners needed two hours more sleep per day than other people, and families in which all members were infected had significantly lower income, less leisure time, poorer educational achievement, and less outside income than uninfected families. The bilharzia and diarrhoeal disease situation in the late 1970's was extremely unsatisfactory from a health, agricultural, and general community standpoint. Malaria was also a problem. This combination of factors was probably the reason why young people migrated away from the scheme, its declining agricultural productivity and the general economic malaise. A long-lasting, economically feasible health program was required to solve these problems and a program was developed that complemented plans to rehabilitate the agricultural scheme itself.

Control measures

The control measures in the Blue Nile Health Project were organized into a comprehensive program covering all major water associated diseases. The operations were integrated so scarce resources and technical personnel could be fully utilized. The strategy emphasized long-term measures which required a minimum of foreign exchange, had low environmental hazards, and could be operated indefinitely by normal government personnel. This integration and long-range planning would cover several years in the projects formative stage. It was emphasized in an attempt to avoid the failures which had occurred in many previous schemes. Long-term strategies are particularly important for endemic diseases such as malaria, bilharzia, river blindness, cholera and typhoid. Careful planning was required to develope a program that could be self-sustaining and which could survive once outside help was withdrawn.

Because of concern for the long-range impact of water-associated disease control, emphasis was placed on environmental, ecological and social change. Drugs and chemical pesticides were only to be used in the initial stages and their role would be progressively minimized. In many ways this strategy resembled the integrated Pest Control approach used against cotton Whitefly. Reliance on chemicals in the initial stages gives cultural and ecological measures time to become established and to create conditions unfavourable to the pests. Environmental strategies are emphasized in the following discussion on control measures and there is a brief description of drugs and chemicals used.

The major expenditures during the initial ten year phase of the Health Strategy Plan were for drainage, operation, and maintenance, improvements to irrigation canals, and village water supply development (Table 4.2). Villagers constructed diversion dikes and local drainage ditches to collect water from streets and areas near houses. They also provided an operator and fuel. The government installed concrete bases for pumps and kept pumps in storage during dry season and carried out preventive maintenance (Figure 4.9).

Development efforts were concentrated on initiating community work on sanitation and drainage and on increasing health awareness, showing for example how dehydration and fevers could be treated. Potential biological methods for vector control were also adapted for use under Gezira conditions.

Figure 4.9 Village drainage pumps installed during malaria transmission season.

Major purchases of anti-malaria and bilharzia drugs were made and pesticides to control mosquitoes and snails were ordered. The use of drugs and pesticides would be progressively reduced and gradually fewer people and smaller geographical areas would require drug treatment.

These health measures were designed to complement the agricultural and socio-economic improvements being planned. Some of the health measures would have direct benefits in terms of crop production. The improved drainage, the reduction in canal overflows, and better removal of aquatic vegetation proposed in the control of bilharzia snails and malaria mosquitoes would also have the effect of raising cotton yields and improving performance in other crops as well.

In the proposed Gezira agricultural rehabilitation program (GRP), eight items directly affected health (Table 4.2). The first four items come under the heading of improved water management. These include improved irrigation regulators and gates, a telecommunication system which ensures the rapid closing of gates during heavy rains, and an improved drainage system. The drainage system was scheduled to cost U.S. $23 million and half of that amount could be credited toward reducing malaria. Canal maintenance in minor canals where most bilharzia transmission occurred (Table 4.2) would decrease the amount of snail and mosquito habitats. U.S. $2.2 million was allocated for applied research into aquatic weed control. This includes studies on the Chinese Grass Carp, a fish which not only eliminates the vegetation which is the snails' food but consumed the snails themselves. The annual malaria spray cam-

Table 4.2 Items in Gezira rehabilitation program (GRP) which improved health and which are within the initial plan of Blue Nile Health Project

Item	GRP Budget in million 1984 U.S. dollars	Diseases*) affected	Portion allocated to health in %	Amount for health in million U.S. dollars
1. Improved irrigation structures	14.3	M	10	1.43
2. CanalmMaintenance weeding Research	7.3	M/B	50	3.65
3. Improved drainage system	23.0	M	50	11.50
4. Telecommunications – water control	11.8	M	10	1.18
5. Bilharzia program	6.0	B	100	6.00
6. Rural water supply	15.3	B/D	67	10.25
7. Water and sanitation – housing	4.3	B/D	50	2.15
8. Agricultural and irrigation research	3.8	M/B	10	0.38
		Total		36.54
		Contingencies of 30%		10.96
		TOTAL FOR HEALTH		47.50

* M = Malaria, B = Bilharzia, D = Diarrhoea

paigns would then only be necessary during exceptionally heavy rainfall years and spraying might possibly be reduced to intervals of every three to four years.

The bilharzia control program has a budget allowance for curative drugs and chemicals to kill snails. It is possible therefore to expand the initial phase of the control operations to most of the Gezira-Managil Scheme. Developments and improvements in village water supplies and in the water and sanitation facilities in the Gezira Board and Irrigation staff members' housing will result in reductions in both diarrhoeal disease and bilharzia. The cost of these two items in health efforts of the Blue Nile Health Project is about U.S. $12 million.

The final item in the table is agricultural research and the use of pilot farms to evaluate improvements introduced into irrigation and agriculture. An assessment of the effects of these improvements on health will be simultaneously carried out. A study will be made of the direct impact of snail and mosquito populations and the patterns of human contact with snail-infested waters. For example, if a new type of cotton were to be introduced it might need less water in the winter months, the period of the second malaria transmission peak when mosquitoes breed in the minor canals. A change in the night-storage system of irrigation might make the canals less suitable for bilharzia snails. This type of research has a budget of about U.S. $3.8 million, at least one-tenth to be used on health related research.

The Gezira Rehabilitation Program, including funds for contingencies, has a health component of about U.S. $50 million. It will be used over a five-year period. This supplements the existing work of the Blue Nile Health Project in the area, and the combined operations make-up an Interim Strategy. They include GRP activities and the malaria control efforts which have been underway in the Gezira – Managil Scheme since the late 1970's.

The bilharzia component of the GRP is a gradually expanding program treating infected people with a new drug and attempting to prevent re-infections by spraying snails near the villages with molluscicide.

Initial surveys have shown that the Gezira villages can be divided into two groups: the high-risk villages in the middle of the irrigated fields where 60 to 90% of the people are infected, and the low-risk villages along the main roads or on the outer edges of the irrigated area, and the large towns. In these low-risk communities only about 10% of the people are infected and infections are less severe than those in the high-risk villages.

Separate drug distribution approaches were developed for these different types of communities. For the high risk-villages everyone is treated without examination, with the exception of infants and pregnant women. The drug is comparatively safe and this mass treatment makes it possible to save almost U.S. $1 million in diagnostic surveys. Very little of the drug is wasted as virtually everyone in these villages except very small children are infected.

In the low-risk villages and towns the people will be examined before treatment. This represents a saving on drugs because 90% of this group is not infected. It is a slow process but much safer and cheaper than the mass treatment program. The gradually expanding chemotherapy campaign will be preceded by community education, snail control, improved water supply, and latrine distribution. The result should be an extremely effective first attack on the enormous bilharzia problem in the Gezira.

The cost of this comprehensive initial attack on bilharzia and diarrhoeal diseases will be about U.S. $18 million, that is about U.S. $9 per capita spread over five years. By the end of the initial phase it is hoped that a low-cost, permanent control program will be operational and make continued expenditures unneccessary. This comprehensive strategy is being simultaneously evaluated in study villages in the middle of the Gezira Scheme. The results of the first few years have been highly successful and maintaining the program appears to be within the financial and technical capabilities of Sudanese government agencies (Amin 1981).

4.2 Puerto Rico

4.2.1 Introduction

Puerto Rico is an island in the Caribbean Sea some sixty kilometres long and thirty kilometres wide. It receives heavy rainfall, carried in by north-east trade-winds. Rainfall distribution is affected by a central mountain range giving a low rainfall in the south and east, where major irrigation schemes feed sugar cane plantations. Many hydro-electric reservoirs are found on the north coast and in the central range and they make use of the heavy river discharges in the area. Towards the west of the island, in a region where dry years are frequent, more than three hundred small farm ponds have been constructed to store water for cattle. For overall geographical features of Puerto Rico see Figure 4.10.

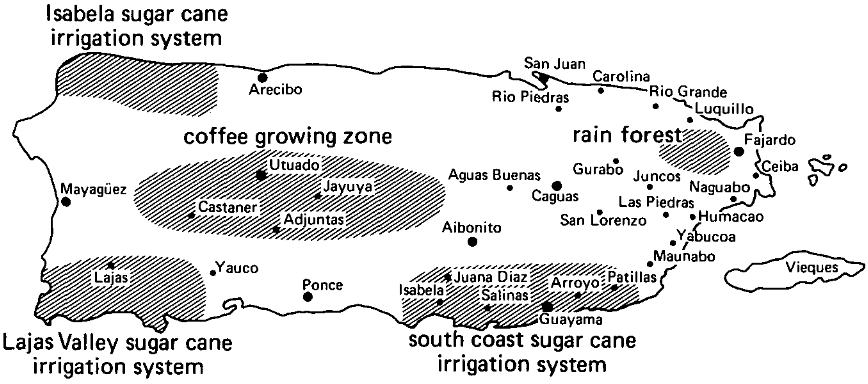


Figure 4.10 Major towns and other geographical features, Puerto Rico

4.2.2 A history of disease in Puerto Rico

General

The history of tropical diseases in the Caribbean has been unusually dynamic. Disastrous epidemics alternating with outstanding successes in disease control. Yellow fever and malaria outbreaks, bilharzia and hookworm infection and recently epidemics of dengue fever touched off by mosquitoes breeding in the trash of modern 'throw-away' societies are some examples.

Bilharzia is of exceptional interest because it appears to be nearing extinction in Puerto Rico. A wealth of epidemiological information has been available on the disease on the island since 1906 (Negron-Aponte and Jobin 1979). A great deal of information about bilharzia became available as a result of a hookworm control program developed in Puerto Rico at the beginning of the century. The program began in 1903 and included surveys in most population centres on the island. It uncovered much bilharzia infection at the same time. In the first decade of the twentieth century there was a low prevalence of bilharzia in the towns of Mayaguez, Utuado, Aibonito, and a higher prevelance on Vieques Island. The complete absence of bilharzia in Guayama, and many other towns indicated that the parasite was then quite limited in distribution.

In 1905, a major agricultural shift occurred in Puerto Rico. Coffee production was replaced by sugar-cane. This change was the result of shifts in world market conditions and increasing American intervention in the island's economy following the military invasion of 1898 (Figure 4.11). The shift in agriculture was made permanent by the construction of the South Coast Irrigation Systems which provided the water necessary to increase cane-field yields to highly profitable levels.

The work of the Anaemia Commission controlling hookworm was made easier by the decrease in coffee cultivation because transmission required the moist, shaded hillsides of the coffee plantation. Twenty years after the hookworm campaign had been completed a thorough study of bilharzia distribution was made. Surveys confirmed earlier findings but in addition a new, major endemic zone, the South Coast Irrigation

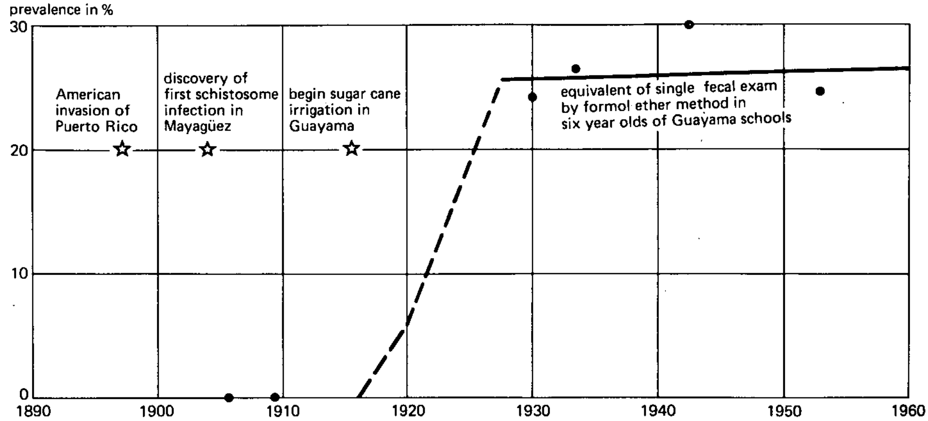


Figure 4.11 Early history of bilharzia in Guayama, Puerto Rico

System between Guayama and Patillas, was identified. Detailed investigations within this area showed that the disease was more severe than in other parts of the island and that it was closely linked to activities within the irrigation system, constructed in 1914.

Given the ecological link between sugar production and the presence of snails, it was not surprising that shortly after 1952, when sugar production reached a maximum of 1.4 million tons, bilharzia was an urgent problem. The Department of Health set up a control program in the irrigated zones between Guayama and Patillas. Besides the new endemic zone in the south, several other new foci had been found bordering on the urban centers of Rio Piedras and Caguas. In Utuado, a small zone of high prevalence was identified, and children living in the area had a prevalence of an almost 100%.

Diagnostic test results from the Guayama region

In order to clarify the changes in the prevalence of bilharzia infections in the South Coast Irrigation District the results of several diagnostic tests conducted on various age groups were correlated. The most common test was demonstrating the presence of eggs in a single stool taken from children of six years old. All subsequent surveys were interpreted using this standard. This interpretation required estimation of the ratio of prevalence among various age groups and the prevalence among six year olds. Although several different laboratory procedures had been used to locate the bilharzia eggs in faeces, the tests were calibrated, and it was then fairly easy to reduce the data to a common standard (Figure 4.11).

The composite result of the various prevalence surveys made after 1906 indicated that bilharzia, which had been almost non-existent in Guayama had been spread by the introduction of sugar-cane irrigation. Although outbreaks of Schistosoma haematobium have been reported from Africa, this outbreak is probably the first documented epidemic of *S. mansoni* in a water resource development scheme.

Post war trends

Several surveys were made in 1953 and 1954 before the control program began on the south coast. The combined results of these surveys indicated that two changes had occurred since 1944. The Utuado and Mayaguez foci had definitely diminished and new endemic areas were appearing in the eastern lowlands, probably due to the construction of rural communities known as parcelas. As in previous surveys the zone of highest prevalence was the irrigated coastal strip between Patillas and Guayama.

Why there had been a reduction in the prevalence of disease in the western part of the island cannot be explained exactly, but urban growth after the war caused a reduction in snail habitats, and the government-sponsored water-supply programs have probably played an important part. No control measures had been instituted in these areas except occasional individual chemotherapy.

The endemic foci in Aibonito and Caguas were not related to sugar-cane or coffee production. The specific transmission sites were small, extremely poor settlements, with bad sanitation, situated along streams on the outskirt of the cities. Probably the combination of large population centers and the flat topography of these two sites were enough to provide the mixture of snails and people necessary to support transmission.

The need for a bilharzia program: the original pilot programs and general measures applied

The snail studies and parasitological surveys of the early 1950's clearly showed that a schistosomiasis control program was necessary. The Health Department gave the endemic zones of the south coast highest priority and the first pilot projects were established in 1954 in Patillas, Arroyo, and Guayama.

In 1952 the Puerto Rico Department of Health and the San Juan Laboratories of the U.S. Public Health Service instituted a bilharzia control program. The history of the project can be divided into four phases. The exploratory phase 1952 and 1953, which included the initial prevalence surveys and attempts to control the snails using chemical measures. The control phase 1954 to 1960, organized on the bases of experiences gained in 1952, 1953, and based on five pilot projects: Vieques, Patillas, Guayama, and Arroyo with minor programs in Aibonito, and Naguabo, and a preventive operation was undertaken in the newer Lajas Irrigation System (Figure 4.12). By the end of 1960 efforts were concentrated on a third or maintenance phase of the initial pilot projects because of the scarcity of snail populations in the controlled zones. The fourth phase began after 1969, and included a major expansion of snail control activities from the original pilot projects to south-eastern areas of the island, eventually covering most of the endemic areas (Figure 4.13).

The control program was based primarily on two techniques: the control of snails with sodium pentachlorophenate and the treatment of infected persons with Fuadin. Field efforts to control *Biomphalaria glabrata*, the bilharzia snail, began with the survey and mapping of all water bodies. The streams, cane-field drains, swamps, irrigation canals, and reservoirs were numbered and the snail-infected areas marked on work maps at a scale of 1:20,000. The chemical used had previously been tested in Puerto

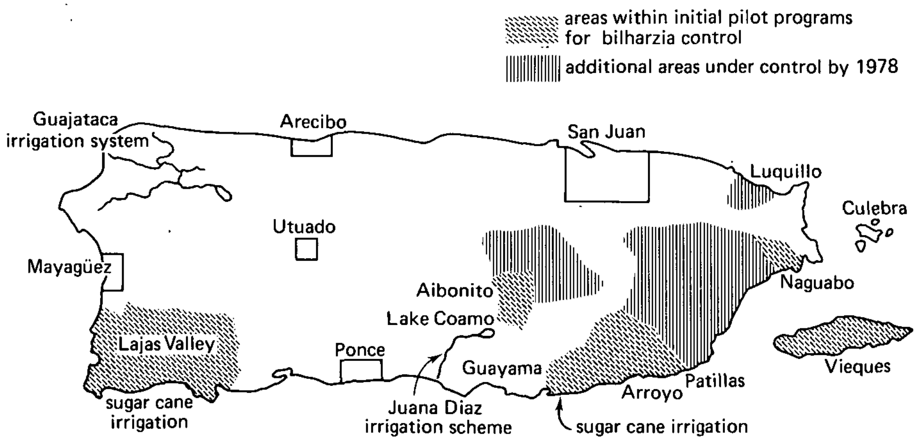


Figure 4.12 Puerto Rico pilot programs

Rico to determine proper dosages, and portable power sprayers were used for treating swamps. A solution of two grams per litre was sprayed at a pressure of ten kg per cm^2, with a final dose in the water of six to ten mg per litre. This process always began at the head-waters of each watershed and proceeded downstream. At first all snail inhabited streams were treated with six mg per litre for 24 hours, with manual adjustment of discharge from a simple dispenser. This method was discontinued after a two years period during which all habitats had been treated annually. The method was stopped because the snails had been reduced to isolated colonies and could be effectively treated with power sprayers. Using this method each habitat was treated monthly for three months, and retreated on a similar schedule whenever the snails reappeared. In addition to the main portion of the stream or swamp, a strip one and a half metre wide along their perimeter, was also sprayed to saturation. Small seepage areas and swamps were drained by constructing ditches. After 1956 biological control was used. A predatory snail, *Marisa cornuarietis,* was planted in reservoirs too large for chemical control and in the hundreds of night storage ponds of the irrigation systems.

4.2.3 Reports on control methods and results in the south-east region irrigation schemes

Vieques island

The history of snail control efforts on the tiny island of Vieques is of interest to those who would like to develope snail eradication programs. This off-shore island has so little natural surface water that drinking water has to be imported from the main island of Puerto Rico. Most of the coastal swamps are brackish so there are few good habitats for the bilharzia snail. Nonetheless, after 30 years of chemical applications, ditching and drainage works, biological control, and even burning of swampy habitats, the snail has not been eradicated from the island.

1953	1954	1956	1957	1958	1960	1963	1966	1969	1970	1976	1978
Municipalities added to the control program											
Patillas	Guayama Arroyo Vieques	Naguabo Lakes and reservoirs	Cabo Rojo Guanica Lajas Sabana Grande	Aibonito	Salinas	San German Maunabo Barranquitas		Yabucoa	Las Piedras Humacao Juncos Comerio Cidra Cayey		Luquillo
Control Methods											
		Fuadin*									
					Ditching and drainage						
		Sodium pentachloriphenate							Bayluscide		
							Acrolein in irrigation canals*				
					Latrine program*						
							Biological control				
					Rural water supply*						
Evaluation schemes											
			Annual fecal exams of first graders								
			Skin tests on fifth graders								
1953	1954	1956	1957	1958	1960	1963	1966	1969	1970	1976	1978

* These were activities independent of the snail control program

Figure 4.13 Chronology of the Bilharzia Control Program in Puerto Rico

Despite the difficulties with the snail, transmission of the bilharzia parasite was controlled over a seven years period by a program that emphasized snail control and treatment of infected persons. The effort began in 1954 when the prevalence of bilharzia was 7% among six-year old children. By 1958 transmission had stopped among children in high-risk schools and, by 1959, prevalence was down to zero.

The implications of the experience on Vieques island was twofold: it verified the theoretical analysis made by MacDonald that treatment of people and control of snails would result in a rapid drop in transmission and it also showed that it is not necessary to eradicate the snails in order to interrupt transmission (MacDonald 1965 and 1973).

Patillas

An irrigation canal taking off from the Patillas reservoir supplies water to cane fields in the area (Figure 4.14) and the control effort started here in 1952. Although snail control was the major method employed during the control phase, routine but unevaluated treatment with Fuadin was also given to more than 1500 persons. Health education was also offered in primary schools and rural communities. Drainage work was continued after 1960 when the project was put into the maintenance phase, and thereafter very little chemical was used for snail control. Fuadin therapy was also discontinued and health education efforts were gradually reduced. By 1962 the prevalence of bilharzia in seven-year old children had decreased to zero from an original 22% in 1952 and snail population had been reduced to one small area (Figure 4.15).

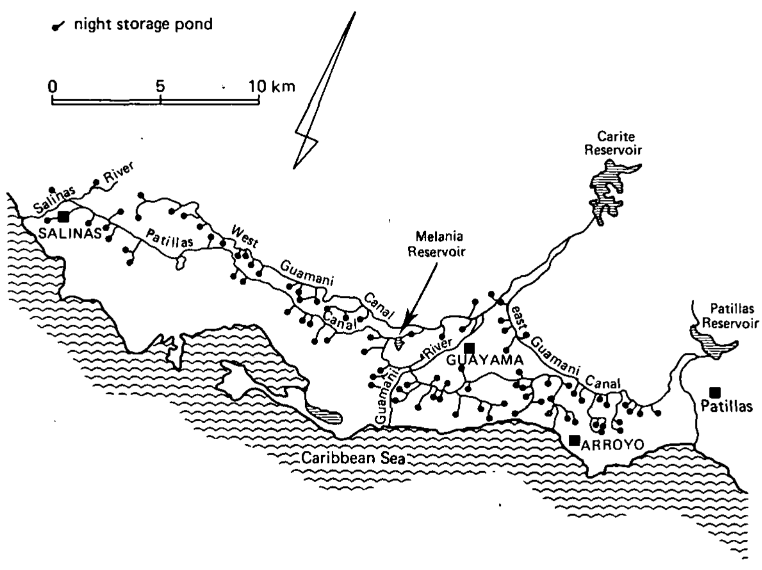


Figure 4.14 Guayama-Salinas irrigation system showing location of night storage ponds and main irrigation canals

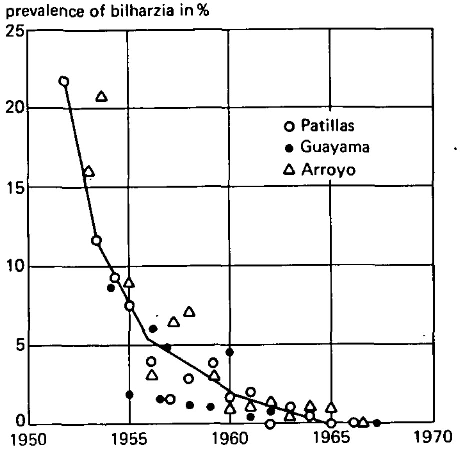


Figure 4.15 Prevalence of bilharzia on the south coast of Puerto Rico after the initiation of control measures, 1950–1966

Guayama and Arroyo

Guayama and Arroyo are municipalities on the south coast of Puerto Rico, west of Patillas. Their economies are based on sugar cane cultivation (Figure 4.14). The flat coastal areas are irrigated by the Patillas and Guayama canals which originate from the Patillas and Carite reservoirs in the north. The mollusciciding program in Guayama and Arroyo was as successful as that in Patillas, and the prevalence of bilharzia had been brought to zero by 1966 (Figure 4.15).

4.2.4 Reports on control methods and results from other parts of Puerto Rico

Aibonito

Aibonito was one of the first towns in Puerto Rico to consider bilharzia an important public health issue. The town is somewhat isolated on a high mesa in the central mountains. During the past few decades there has been considerable socio-economic change in Aibonito. Between 1960 and 1970 significant development occurred. Censuses taken in 1960 and 1970 showed that there had been significant improvements in sanitation during the decade and the percentage of households with piped water supply had increased from 58% to 89%, whilst the percentage of households with toilets or privies had increased from 88% to 95%.

The prevalence of bilharzia
Control activities began in 1957 when an annual survey of first-grade school children was set up in order to evaluate the program's impact.

Bilharzia prevalence in first-grade children showed large variations during the seven

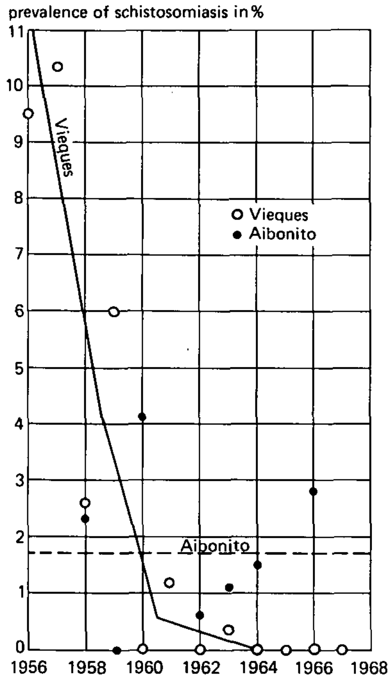


Figure 4.16 Prevalence of bilharzia identified by single fecal examination in first grade children of Aibonito and Vieques, Puerto Rico

years of measurement but did not differ significantly from the mean of 1.7% (Figure 4.16). By contrast, the prevalence among children from the control project in Vieques in the same period and using the same control methods, decreased rapidly to zero. There appeared to be an increase in prevalence in Llanos Adentro, while the rest of the municipality showed little or no infection. This increase may have been caused by the greater volume of discharge from the sewage treatment plant constructed in 1959. It discharged into the Aibonito River about one kilometre upstream of the Llanos Adentro area. In addition to the natural stream habitats in the river there were many snail populations in Aibonito. They were to be found in minor seepage areas along the edges of streams, in swampy areas, and especially in the increasing number of artificial ponds built by farmers to conserve water for cattle and for agricultural use.

Snail populations in farm ponds

Because Aibonito is located in an area of unreliable and low rainfall, some 600 mm per year, many farmers, assisted by agricultural agencies, have constructed farm ponds to provide water for cattle. The average pond contains 1000 m^3 of water when full, has a surface area of 4000 m^2 and a shoreline of some 300 metres. The final survey in 1977 recorded 33 ponds.

Since the control project was initiated in 1957, farm ponds were considered important snail habitats because they provided shelter for snails during the dry season and served to re-infest the streams below them when they overflowed during the rainy season. With so many ponds in the drainage system, the snail population could become inured to the seasonal half-yearly drought and its decimating effect.

Despite their obvious importance in protecting snail populations against drought, the direct role of these ponds in schistosome transmission is not clear. Most owners fence the ponds and discourage swimming but children are not completely thwarted by these measures.

Biological control of snails in farm ponds

Biological methods were used to control snails in the ponds and some chemical and engineering approaches were also used. The biological control snail *Marisa cornuarietis* was placed in several ponds and its effect on *B. glabrata* populations was studied.

Chapter 8 has further details about the introduction of *Marisa* into sugar-cane night storage ponds in Puerto Rico.

Aibonito farm ponds and the use of siphons for pond level fluctuation

The biological control snail was not effective in ponds with heavy vegetation so an environmental method of snail control was investigated. This involved the periodic dropping of pond levels and allowing them to fill again slowly from normal stream flow.

Small ponds were used to study this method. Siphon spillways were constructed on two ponds to cause periodic rapid drops in the pond levels, leaving the snails stranded. Some of the requirements for stranding bilharzia snails on the shores of habitats had been established during laboratory studies. The recession rates required on various shores were calculated from the observed speed of the snails on the slopes. The required periodicity of fluctuations was determined by the use of a mathematical simulation to predict snail population in a pond. The analysis had indicated that fluctuation periods of five to twenty days would cause the most rapid declines in snail populations if automatic siphons were used to effect these fluctuations.

Four ponds were studied. They originally contained stable populations of *B. glabrata*, the small snail which transmits bilharzia in the western hemisphere. The ponds were similar in construction and ecology and ranged in volume from 800 m^3 to 11 000 m^3 (see Table 4.3). The snail populations in all four ponds were studied in detail for one year or more prior to the construction of siphon spillways in ponds D and E, the two smaller ponds.

Table 4.3 Geometrical characteristics of four farm fonds

		At spillway elevation			
Pond	Municipality	Maximum depth in m	Perimeter, in m	Surface area, in m^2	Volume in m^3
B	Aguas Buenas	4.5	277	2,769	4,880
C	Aibonito	6.5	410	4,000	10,875
D	Aibonito	2.6	239	2,400	3,400
E	Cayey	1.7	114	568	776

Periodic measurements of the relative number of snails in each pond were made by taking 100 sweeps around the perimeter of each pond with a wooden-handled dipper. The dipper was made of a wire screen 20 x 20 cm.

The sampling program was timed to monitor the snail population for one year before and one year after the siphons began to prime.

Ponds B and C were not altered in any way and their snail populations served as untreated populations for comparisons with the snails in Ponds D and E. The first siphon was constructed on Pond E in November 1967 and the second on Pond D in December 1967. The design criteria for the siphons were the draw-down rates determined in previous laboratory studies for the specific shore slope and water temperature of each pond. Draw-down rates required for day-time stranding were used to design the siphon in Pond E and the rates required for night-time stranding were used in Pond D. Snails migrate down a slope more rapidly in the day-time apparently because of an aversion to strong sunlight. A faster draw-down is therefore required over day.

Water levels in the reservoirs were monitored with continuously recording gauges and weir boxes were constructed on the outlets of the siphons. The design data are given in Table 4.4.

The siphon on Pond D was designed to produce a vertical draw-down of 27 cm/hr in a 50 cm vertical zone, priming whenever the reservoir reached the elevation of the emergency spillway. The siphon on Pond E was designed to produce a draw-down rate of 5.8 cm/hr over a 50 cm zone. In both cases this design assumed a small inflow to the reservoir and could only be an approximation since the hydrological characteristics of the catchment areas were not known.

Table 4.4 Design data for siphon spillways on ponds D and E, 1968

Item	Pond D	Pond E
– Emergency spillway elevation (m)	4.1	1.6
– Proposed draw-down (m)	0.5	0.5
– Average shore slope in draw-down zone, horizontal:vertical	1.6:1	13:1
– Maximum water temperature in °C	27	28
– Pond area at spillway elevation (m^2)	2400	568
– Water volume in fluctuation zone (m^3)	1200	280
– Required draw-down rate (cm/hour)	Night 27	Day 5.8
– Proposed siphon discharge (l/s)	180	9
– Maximum static head on siphon (m)	3.5	0.6
– Siphon diameter (cm)	15	10
– Measured discharge coefficient	–	0.6
– Total cost of siphon in place in $	791.00	254.00
– Cost of materials in $	300.00	116.00

Ponds B and C

The number of snails in the two untreated ponds B and C fluctuated at fairly high levels throughout the study period 1967-1969. This meant that between ten and one hundred snails were recovered per 100 dips. This indicated that there were no major environmental events which might have caused permanent decreases in normal snail populations during the study period. The observed fluctuations in numbers are of the usual range for small ponds in Puerto Rico.

Pond D

Previous dipping surveys in Pond D during 1962 and 1963 had shown a strong population of *B. glabrata*, with a range of two to thirteen snails per 100 dips. When sampling began in March 1967 about two snails were recovered per 100 dips (See Figure 4.17).

After January 1968, the *B. glabrata* populations began to increase and reached a peak of 47 snails per 100 dips in April 1968. In June 1968 the population dropped to zero snails per 100 dips following the first recorded draw-down of the water level. Afterwards it fluctuated between zero and four snails per 100 dips.

The siphon was not primed until June because of lack of rain and reduced inflow into the pond (Figure 4.17). Siphon records indicated at least two rapid drops in the water level in November 1968, almost one year after the siphon had been installed. The snail population then disappeared, reappearing in April 1969. Five months had passed without the siphon being operated.

The low frequency of priming on Pond D was due to infrequent rainfall in the catchment area and thus infrequent flow into the reservoir. The average rate of draw-down during the two priming events in November 1968 was 7.6 cm/hr over a zone of about 100 cm. The large fluctuation in water level and the low draw-down rate indicated that the primings were initiated by fairly heavy rainfalls which caused considerable flooding of the pond. Because of the large inflow into the pond, the siphon discharge was not large enough to lower the water level in the reservoir at the design rate of 27 cm/hr. November is the hurricane season in Puerto Rico and rainfall is often heavy and brief.

The failure of the siphon to eliminate the snails from Pond D during the study

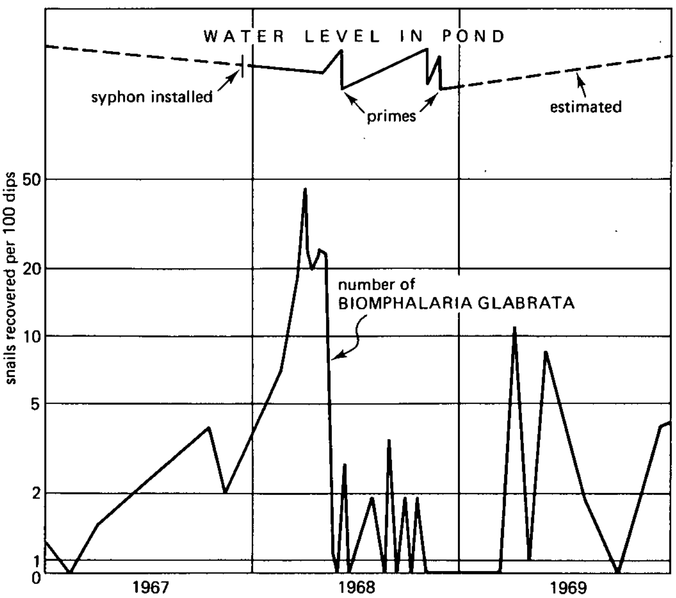


Figure 4.17 Water level record for Pond D and population history of *B. glabrata*, 1967-1969

period is clearly due to the low frequency of priming. The necessary frequency suggested by laboratory studies was about twice a month. The siphon primed only three times in the twelve months after its construction.

Pond E

In the year before the siphon was installed in Pond E, the snail population fluctuated at around an average of ten snails per 100 dips. The siphon first primed in June 1968 and after five more primes the snail counts dropped to zero (Figure 4.18). Although no snails reappeared in Pond E for several months there were always snails in the stream immediately above the pond. The pond was inspected regularly after June 1969 because of the continuous possibility of reinfestation. 1969 was in fact the nominal end of the first year of operation. In August 1969 the siphon was examined and found to be plugged with rags. The obstruction was removed but a temporary resurgence of the snail population was observed. The final observation in June 1970 showed the pond free of snails again, although they were found in great abundance immediately below the spillway.

The rapid control of the snails in Pond E with draw-down rates slightly below the design values, occurred at a time when the snails had favourable environmental conditions. Priming was carried out once a month during the first year of operation, fairly close to the frequency indicated as desirable by laboratory studies. This indicated that the siphon action caused the decreases in snail populations, suggesting that the draw-down rates and frequencies based upon laboratory studies were adequate so long as the siphon was functioning. A close examination of the priming records indicated that most of the priming was carried out towards evening on Pond E. Thus, the average observed draw-down rate of 2.5 cm/hr was greater than the values suggested for night-time stranding, about 1 cm/hour. In this respect there remains some uncertainty about the precise draw-down rates necessary for stranding snails, although any reasonable rate of draw-down is sufficient to strand snail eggs which are usually attached to vege-

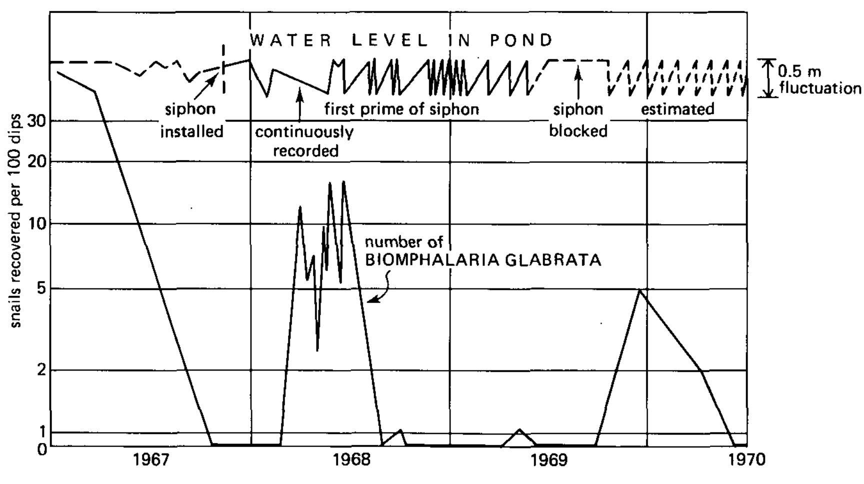


Figure 4.18 Water level record for Pond E and population history for *B. glabrata*, 1967-1970

tation. The greatest effect of the draw-down during the breeding seasons might be the destruction of snail eggs which are extremely susceptible to desiccation.

The recorded water levels in the pond and in the weir box indicated that a large volume of water was lost in the pre-priming phase of operation. The amount of water wasted prior to priming was 210 m^3, slightly more than the amount discharged during the draw-down.

The original cost of automatic siphon spillways was low when viewed as a 20 or 30 year investment (Table 4.4). A maintenance program was also required especially in view of operating difficulties. This would necessarily increase the annual cost of the siphon method. A careful analysis of the pond was also needed before trying this method of control because siphons only worked when there was sufficient inflow into the reservoir. Further research has to be carried out on the precise rates for lowering the water level and on ways of designing the siphons to reduce water wastage.

The Lajas Valley Project (South-West coast)

A preventive snail control program was started in the newly constructed Lajas Valley Irrigation Scheme in the hope of preventing an outbreak of bilharzia there. This goal was achieved and even the pre-construction endemic foci in Yauco were eliminated. The prevalence of infection in first-grade children was reduced to 0.5% by 1960, and continued to decrease. Thus in contrast to the South Coast Irrigation Systems, the beginning of irrigation in this large valley of some 10 000 people did not cause an increase in bilharzia transmission.

4.2.5 General comparison

One important question raised by the data available on snail populations is the following: why did the Patillas, Guayama, and Guajataca main canals support *B. glabrata* populations while the main canals in the Lajas Valley System did not. A survey carried out in 1976 showed that although there were some differences between the various groups of lakes which supplied these systems, this was insufficient to explain the absence of *B. glabrata* (Table 4.5).

Table 4.5 Water quality in lakes supplying various irrigation systems in Puerto Rico, 1976

System	Turbidity in standard units	Phosphates in mg/l (ppm)	Hardness as $MgSO_4$ in mg/l (ppm)
Patillas System	9.0	0.01	45
Guajataca System	1.4	0.01	149.5
Juana Diaz System	4.0	0.06	21
Lajas Valley System	16	0.03	140

A detailed analysis of these lakes and others in Puerto Rico confirmed the finding that the small variations found in water quality in the major reservoirs in Puerto Rico also did not seem to affect the distribution of *B. glabrata*. Furthermore the lack of *B. glabrata* in the main canals of the Lajas Valley could not be explained simply by their absence from upstream sources. The drainage basins and lakes supplying these canals all contained *B. glabrata* and thus provided potential colonizing snails for the main canals.

The most likely explanation then is the lower mean velocities in the Patillas, Guayama, and Guajataca main canals. In general, flow in canals not supporting populations of *B. glabrata* had mean velocities of above 1.2 m/sec. (Table 4.6).

Although the general conditions of the Juana Diaz System were similar to the Guayama and Patillas Systems there was evidence that relatively little bilharzia was found in the Juana Diaz System, except in the final downstream portions of the drainage system around Santa Isabel. The only major differences which could explain the lack of infection in the upstream portions of the Juana Diaz System was the high silt content of the water collected in Lake Coamo. This eventually filled the entire lake and prevented the growth of algae and other snail food. Silt had been noted as a cause of low snail populations in irrigation systems in Ethiopia and in portions of the Senegal and Niger Rivers in West Africa.

Table 4.6 Characteristics of main canals in irrigation systems in Puerto Rico*

Canal	Length in kms	Discharge at head end in m^3/sec	Mean Velocity in m/sec	Type of lining	Prevalence of silt in canal	Biomphalaria glabrata population
Patillas	42	3.6	0.6	earth	no	abundant prior to control
Guayama East Guamani	10	1.0	0.6	earth	no	abundant prior to control
Guayama West Guamani	20	1.5	0.6	earth	no	abundant prior to control
Juana Diaz	–	3.6	0.6	earth	yes	not studied
Guajataca	58	2.8	0.4–1.2	concrete	no	rare
Lajas Valley	36	8.6	1.7	concrete	no	absent

* From Water Resource Authority Irrigation Division, Engineer Giannoni and Chief Engineer Francisco Severa

4:2.6 Rural water supply and its effect on bilharzia prevalence

Since the Second World War significant socio-economic improvements have occurred in Puerto Rico. Improvements in domestic water supply has been one of these developments.

Bilharzia skin test surveys: overall results

Two statistical sources were used to estimate the impact of improved water supply on the distribution of bilharzia: the 1960 and 1970 federal census of socio-economic conditions which also recorded the percentage of households with piped water supply and the 1963 and 1976 skin test surveys for bilharzia. The skin tests, after adjustment, showed the proportion of people reacting positively to the bilharzia test. This skin reaction is a measure of previous exposure to bilharzia infection and is very sensitive (Figure 4.19).

When plotted, the decrease in positive reaction to the skin test and the increase in water supply shows a linear increase with good correlation ($r = 0.91$). The equation for a line passing through the origin was approximately

$$\Delta ST = 1.6 \Delta W$$

With Δ ST the decrease in positive reactors to the skin test from 1963 to 1976 and Δ W the increase in households with water supply from 1960 to 1970 (Figure 4.20). With a correlation coefficient of 0.91 the water supply improvement thus accounts for 84% of the variability observed (r). Clearly the major factor operating in the non-controlled municipalities.

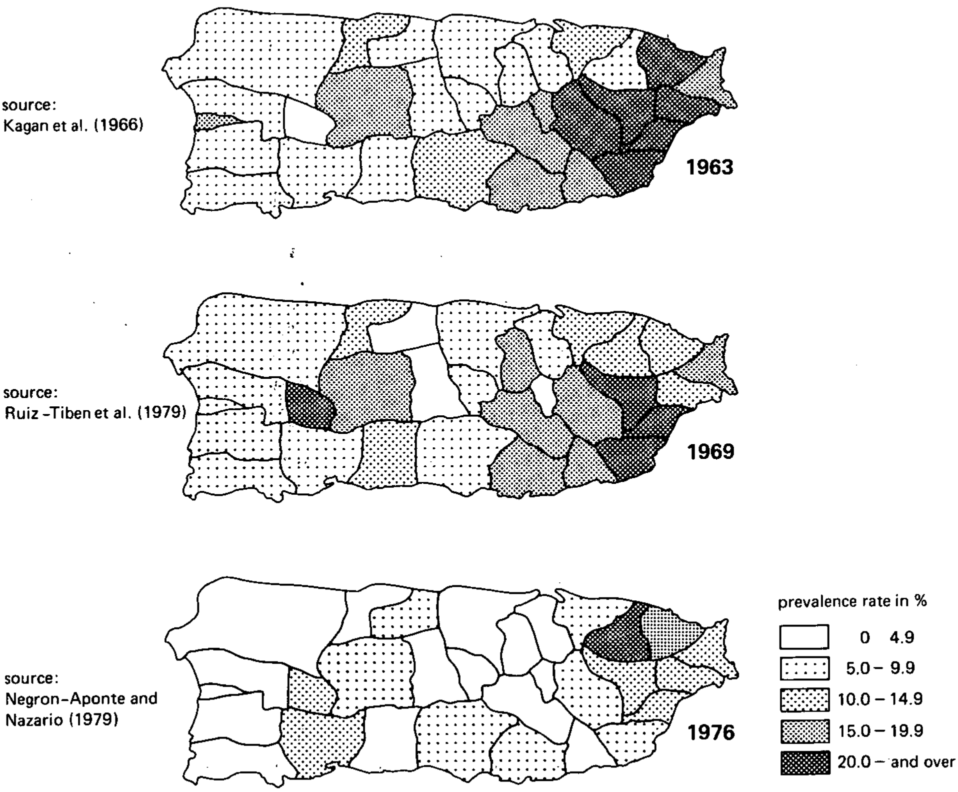


Figure 4.19 Positivity from bilharzia skin test surveys in Puerto Rico, 1963 – 1976

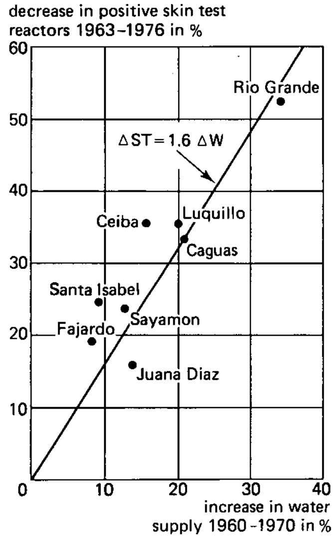


Figure 4.20 Increase water supply versus decrease positive skin test reactors

Additional investigations

This simple equation Δ ST = 1.6 Δ W can be further used to explore the cost and impact of water supply in conjunction with the skin test and water supply data for all 76 municipalities in Puerto Rico. One can estimate the comparative cost-effectiveness of water supply and snail control in municipalities such as Caguas which had no snail control operations but which did have a large decrease in skin test positivity. The ten year improvement in water supply was 21.1%, thus it was calculated that a consequent reduction would occur in skin test positivity of 21.1% x 1.6, or 33.8%, approximately the amount observed (Table 4.7). The improved water supply therefore explained 90% of the observed decrease in skin test positivity.

In two adjacent municipalities directly south of Caguas snail control programs were being operated by the Health Department but only minor improvements in water supply occurred: 0.062 in Guajama and 0.094 in Arroyo (Table 4.7). For these two snail control projects 76% and 96% of the decrease in skin positivity could therefore be attributed to snail control.

Cost of improved water supply and its impact when compared with direct snail control measures

The three municipalities thus experienced similar decreases in bilharzia between 1963 and 1976 with water supply being the critical factor in Caguas and snail control in Guayama and Arroyo. Since the effect was the same, costs were compared directly. The annual cost of snail control for Puerto Rico in 1976 was U.S. \$420 per km^2, thus

Table 4.7 Calculated allocations of observed decreases in skin test positivity for Caguas, Guayama, and Arroyo, Puerto Rico

Municipality	Proportion of households with piped water			Proportion of positive reactors to skin test			Decrease in positive reactors to skin test calculated from improved water	Residual decrease in positive reactors not explained by improved water supply
	1960	1970	Δ W	1973	1976	Δ ST	Δ ST = 1.6 Δ W	
Caguas No snail control	0.721	0.932	0.211	0.429	0.084	0.345	0.338	0.007 (2%)
Guayama Snail control 1953-1978	0.814	0.878	0.062	0.463	0.052	0.411	0.009	0.312 (76%)
Arroyo Snail control 1953-1978	0.737	0.831	0.094	0.343	0.002	0.341	0.015	0.326 (96%)

the cost for Guayama and Arroyo was 207 km^2 x U.S. \$420 = U.S. \$87000 or U.S. \$1.74 per capita annually.

For the water supply program in Caguas cost has been computed on the basis of the cost of water supplies by the Rural Aqueduct System and reduced by the ratio of daily per capita consumption in liters for a system sufficient to control bilharzia.

The 330 l/cap/day supplied in Puerto Rico was considerably in excess of the amount found necessary for bilharzia control in St. Lucia or the Sudan. In St. Lucia which has a climate comparable to Puerto Rico, 62 l/c/d was found to be sufficient to control bilharzia, indicating that the logical fraction of total cost to be apportioned toward bilharzia control in Puerto Rico should be 62/330.
Taking this fraction into account the total annual costs of water supply for Caguas comes to U.S. \$1.52 per capita, slightly cheaper than the U.S. \$1.74 per capita for a snail control program and it had the same effect.

4.3 Dez Pilot Irrigation Project Iran

4.3.1 Introduction

The Dez Pilot Irrigation Project is in Khuzestan Province, western Iran. The scheme extends from Dezful and runs southward along the Dez and Karkum Rivers to Ahwaz. It is only 100 km above Khoramshahr and the war-torn Abadan (Figure 4.21). In 1965 the new irrigation scheme was beginning to supply water to a 20000 ha area with the expectation that it would eventually service 125000 ha. During the first ten years of development the scheme expanded its cultivation of wheat, barley, and beans in the winter, and rice, sesame, and vegetables in the summer. Grasses were also grown for animal fodder and there was a large sugar cane plantation in the middle of the Project area. In 1960 the population affected by the initial Pilot Project was 14000.

The people lived in 57 villages which ranged in size from 60 to 600 inhabitants, a population density of 59 persons/km^2. As the scheme progressed the people were re-grouped into new villages in an attempt to encourage improvements in land use and agricultural practices.

The Khuzestan Water and Power Authority was created in 1960. It managed water delivery and levelling of land, as well as electric power production at a dam located 30 km upstream of Dezful. They also operate a second regulating dam at Dezful which controls water entering the 18 kilometres of main canal and the 34 kilometres of unlined branch canals.

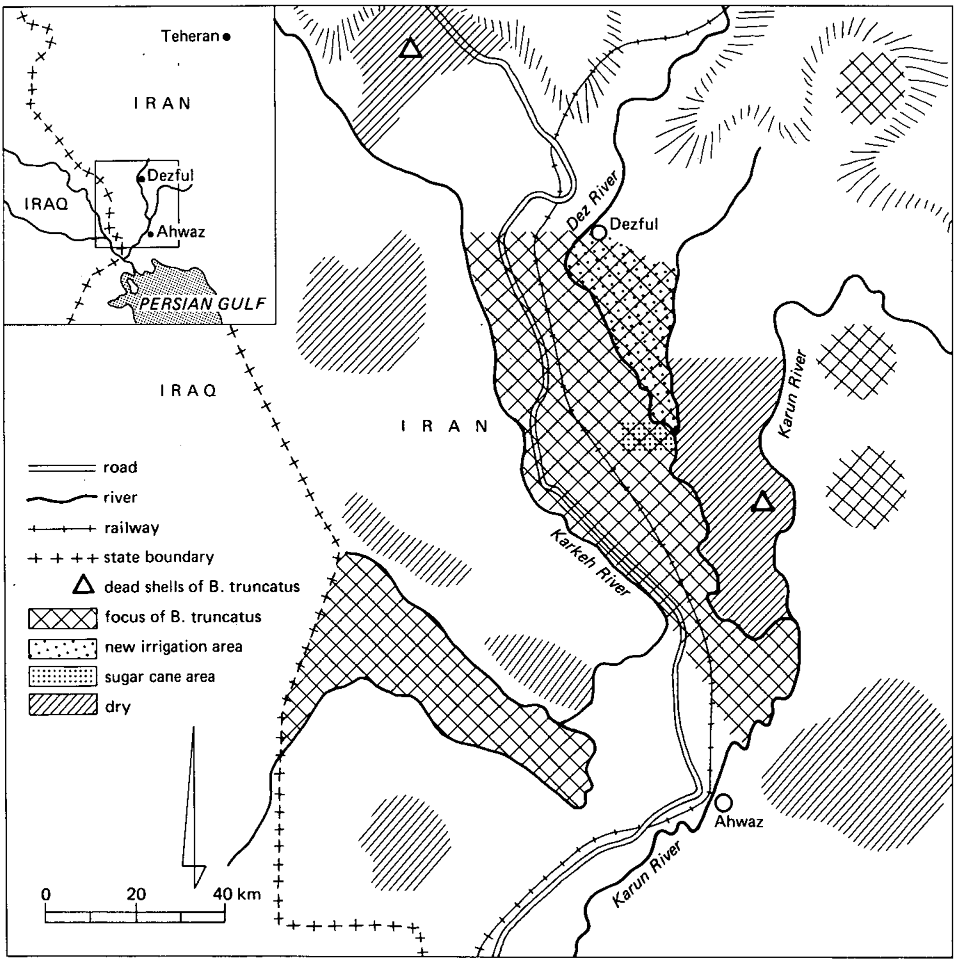


Figure 4.21 Map of south-western Iran and the Dez Irrigation Scheme (part of Khuzestan showing main endemic foci of *Bulinus truncatis* and the main river systems)

4.3.2 Bilharzia Control Program

Recognizing that any expansion in irrigation would also increase the likelihood of bilharzia, the government established a Bilharzia Control Program in 1959. This covered the Irrigation Project and adjoining areas and was set up to determine the best ways of controlling urinary bilharzia transmitted by the snail *Bulinus truncatus*. This snail was also a transmitter of parasites to cattle in the region.

A five-year study of the snail and its ecology showed that the snails lived primarily in the irrigation project but that they could survive in other places in the neighbourhood area. The patchy distribution of snails was related to the presence of surface waters and their salinity. With total salt concentrations of 1300 mg/l, the snails survived but with a concentration of 2000 mg/l they were usually eliminated.

The maximum number of snails were found in standing water during two seasons, May to July and then again from November to January. However the main seasons for transmission of bilharzia from snails to man were April-May and October-November.

Irrigation canals and drains were more important than village ponds for bilharzia transmission. The canals in which the highest number of snails were found varied from summer to winter. This anomaly was explained when further investigation revealed that the numbers of snails was related to the irrigation regimes in individual canals. The highest numbers of snails occurred when canals were in their season of lowest flow.

Geographical analysis of inhabited villages and their surrounding water-bodies showed a stronger link between bilharzia in villages which had canals nearby than in villages with ponds in their neighbourhood. This indicated that the irrigation system itself was more important in transmission than the numerous standing water habitats of snails. Standing water was important, however, in the transmission of parasites to cattle.

Bilharzia control measures began in 1967. Snails were killed using the chemical bayluscide. It was applied in the spring to all infested habitats and then re-applied, if necessary, at three months intervals during the summer. Engineering measures were also used to eliminate snail habitats: borrow-pits, small ponds, and large swampy areas around villages were drained or filled and banks of canals were repaired and the canals themselves dredged. The program of land levelling was also expanded to reduce snail habitats. If the prevalence of bilharzia remained above 10% after snails had been controlled around a village, drugs were used. Several new drugs were introduced on an experimental basis. Attempts to introduce health education, improved water supply, and latrines were largely unsuccessful in the beginning because agricultural communities were frequently being re-organized and there was a traditional resistance to changing sanitary habits.

Within eight years of initiating the bilharzia control program, the prevalence of urinary bilharzia had been brought to down to the 2% level (Figure 4.22). The fluctuations in prevalence from 1961 to 1967 can be accounted for in the following ways. Chemotherapy was added to the control strategy, new snail habitats were created by the expansion of irrigation, and these in turn were eliminated using engineering methods or by the application of chemicals. The early decline in prevalence, pre-1965, can be attributed entirely to the improvements made to agricultural land.

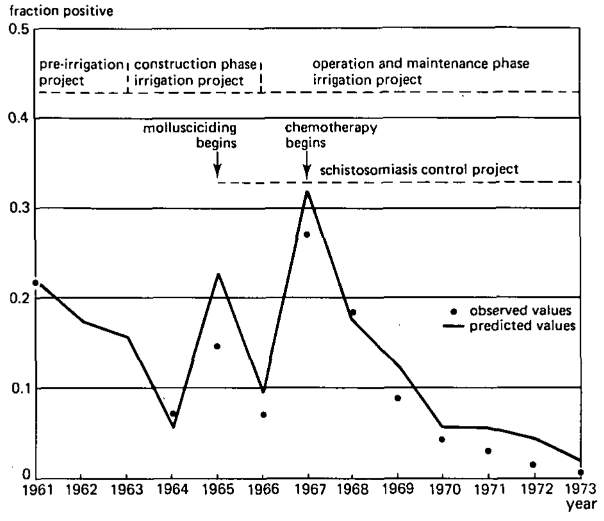


Figure 4.22 Bilharzia prevalence in the Dez Irrigation Scheme, 1961-1973

4.3.3 Swamp reclamation

Habitat modifications were analyzed in health and agricultural terms in an area 25 km south of Dezful. In 1973 three swampy habitats had been reclaimed in an area of traditional irrigation practices where the prevalence of bilharzia was unusually high. The swamps were thought to be sources of water contact by villagers. They were also considered important reservoirs from which snails could re-infect previously cleared areas.

The swamps were the results of inadequacies in the irrigation system, the methods of irrigation used, and of features in the natural landscape. They had proved too extensive to be handled effectively by chemical control.

Renovating the entire irrigation system and drastically changing irrigation and farming practices was of course not possible. It was decided that improving local drainage combined with filling and levelling low swampy areas would be the most feasible way to eliminate snails. It would also provide additional land for cultivation. Main drains were constructed by hand labour and field drains were constructed with a motor grader. Swamps were filled and levelled with heavy machinery including mechanical scrapers and bulldozers. This resulted in the desired improvements to the drainage system and gave considerable reclaimed land.

The average annual investment costs per hectare for drainage, reclamation and agriculture varied from U.S. $152 to U.S. $257 depending on the type of earthmoving equipment used (Table 4.8). Estimates of benefit/cost ratios for agriculture alone varied from 1.7 to 11.1 depending on the crops grown. Elimination of the costly requirement of chemical spraying to control snails could add annual benefits of over U.S. $2000 per ha, resulting in combined benefit/cost ratios uniformly above ten to one. This analysis of both agricultural and health benefits of land reclamation in snail control shows its undeniable value in areas where bilharzia control has been accepted as a necessity.

Table 4.8 Cost-benefit analysis of agricultural aspects of three reclaimed areas in the Dez project

Reclaimed		Annual costs US$		Crops	Annual benefits US$		Benefit/ cost
Area	ha	Total	per ha		Total	per ha	ratio
1	4.5	683	152	wheat	1151	256	1.7
				rice	3238	720	4.7
				alfalfa	6884	1530	10.1
2	5.5	1415	257	rice	5037	916	3.6
				alfalfa	10707	1947	7.6
3	14.5	2217	157	wheat	4217	291	1.9
				alfalfa	25240	1741	11.1

4.3.4 Long-term prospects

The primary impression from a review of the Iran experience is that the program was highly successful because of the broad approach taken to control bilharzia, that is the use of drugs, modification of habitats, and the chemical control of snails. Although sanitation efforts were initially unsuccessful, the combination of other measures were highly effective.

The subsequent revolution and war, however, gave the situation another perspective, and one important for long-range analysis. The economic problems which occurred after the revolution meant that hard currency was not available to the government, and drugs and chemicals could no longer be purchased. The war added a final blow to the health services insuring that many years would elapse before drugs and chemicals could be reinstituted. In the meantime the only restraints left to bilharzia transmission were the permanent modifications made to snail habitats by filling and drainage. There is a parallel to this in the experience of the Ghanaian Government bilharzia control program on Lake Volta. This ended when Ghana's currency lost its power to purchase necessary drugs and chemicals, and a carefully designed program was destroyed.

In a forward-looking cost-effectiveness analysis, the impact of the suspension of the Iranian program was simulated using a computer model developed in conjunction with the bilharzia control program some years before the war. This simulation was designed to compare the long-term value of the various elements in the control strategy by assessing the duration of their impact on transmission, if the activities of the control project had to be suspended for any reason. The technique might be called stability analysis, and it has particular relevance to countries where unstable conditions may cause interruptions in government programs.

The stability analysis involved computer simulation of three alternative activities all carried out at fairly high levels of expenditure. Intensive drug administration was

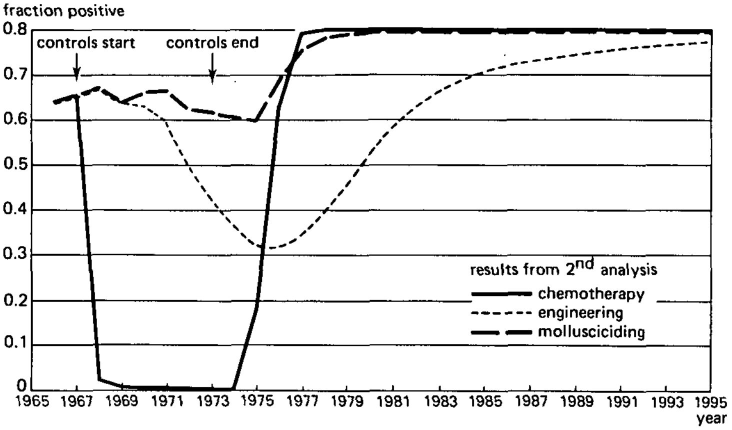


Figure 4.23 Predicted bilharzia prevalence in the Dez Irrigation Scheme

compared with heavy application of chemicals to snail habitats and these were compared with an extensive program of engineering modifications. Equal rates of expenditures over a seven year period were assumed (Figure 4.23). Thereafter the impacts of these interventions were deleted from the computer simulation and the computer model was allowed to calculate the resumption of bilhariza transmission.

The analysis indicated that within two years the positive impact of the drug program and chemical application would have virtually been destroyed by the rapid transmission rates inherent in the environment of the irrigation scheme.

However, engineering methods had produced a basic change in the environment. A return to the original high level of bilharzia transmission was considerably slower than in the other two cases. These years when the overall disease prevalence was low, meant healthier conditions for the human population in the Dez Scheme.

In the computer projection for the 22 years after the suspension of control operations, it was predicted that the impact of the engineering methods would be superior to that of drugs and chemicals, particularly in the first ten years. This is the innate advantage of environmental modifications over temporary intervention with drugs and chemicals.

4.4 Sanitation works, Java, Indonesia

4.4.1 Sanitation works

In the period 1920-1935 considerable sanitation work was done on Java as part of an effort to control malaria. Earthworks, elimination of dangerous pooling, attention to surface and groundwater drainage, sewerage works, and village improvement were all part of applying technical measures to malaria control. The fundamental principle in the 'technical fight against malaria' was the destruction of all the possible breeding places of anopheline mosquitoes. During this period sanitation works were clearly successful as can be seen by examining the death rate figures for Tegal, some 200 km east of Jakarta, on the north coast. Before sanitation the average monthly mortality was in the order of $33^0/_{00}$; after sanitation $22^0/_{00}$.

4.4.2 Species sanitation

Biological knowledge increased and the differences in the degrees of contagiousness of anophelines was documented. Consequently after 1935 sanitation works were directed to fighting the most dangerous carrier. Species sanitation involved the destruction of the breeding places of the most dangerous carrier. This method depends on knowing the local carrier with certainty and on it not occupying all possible breeding places in the area.

About 80 species of anophelines are known in the archipelago. Most of these are seldom or never infected and are therefore of no importance. Some species however show a high infection index.

An.ludlowi is the most dangerous carrier in the coastal areas of the Sunda Islands, whilst *An.aconitus* is found in the plains behind the coast and the hilly country. *An.maculatus* is prevalent in hilly and mountainous regions, *hyrcanus* in the marshes of South Sumatra and *punctulatus var. moluccensis* is found in the coastal plains of Irian Jaya.

Species sanitation had considerable importance in the approach taken towards malaria in the Sunda islands where *An.ludlowi* was the predominant carrier. It was noticed that two important biological processes characterised this species. Firstly, its larvae never occurred in the tidal forests on the low silt coast where the daily tide penetrates everywhere. The periodically closed river mouths of the steeper sand coasts, however, did produce a multitude of anophelines. This occurred only during the period when the river mouths were sanded up. When they were open and under influence of the tidal action they were absolutely harmless.

For this reason dangerous lakes and ponds shut off from the sea were brought into open connection with the tides by the construction of canals. This principle was carried out for the first time in 1921 with fish-ponds in East Java. It was not only the changing water level but also the absence of tube and filamentous algae which proved destructive to larvae production. Larvae could not find shelter against the *Kepala tima (Haplochilus panchax)* a small larvae eating fish. Adequate tidal action and periodic draining of pools destroys this vegetation. The method by which this draining has been systematically executed in specially constructed fish-pond complexes, is known as 'hygienic exploitation'.

4.4.3 Technical view of the malaria problem

The problem has been set out in a diagram (Figure 4.24) consisting of 16 items. 13 items concern a range of issues from 'mosquito breeding place' up to 'people who are ill' and other items concern safeguards against malaria: technical control, insecticiding, larviciding, and chemotherapy.

Knowledge is available on items 6-8-10-11-13 although a lot of investigation is still needed. An important issue being the increase/decrease in mosquito and larval density. Item 4 is a critical item and technical data necessary to obtain adequate insight into this issue involves knowledge of the nature of soil and water with particular attention to salt content, water-table behaviour in the area, the nature of surface water drainage, the characteristics of maritime influences, and the patterns associated with rainfall and evaporation.

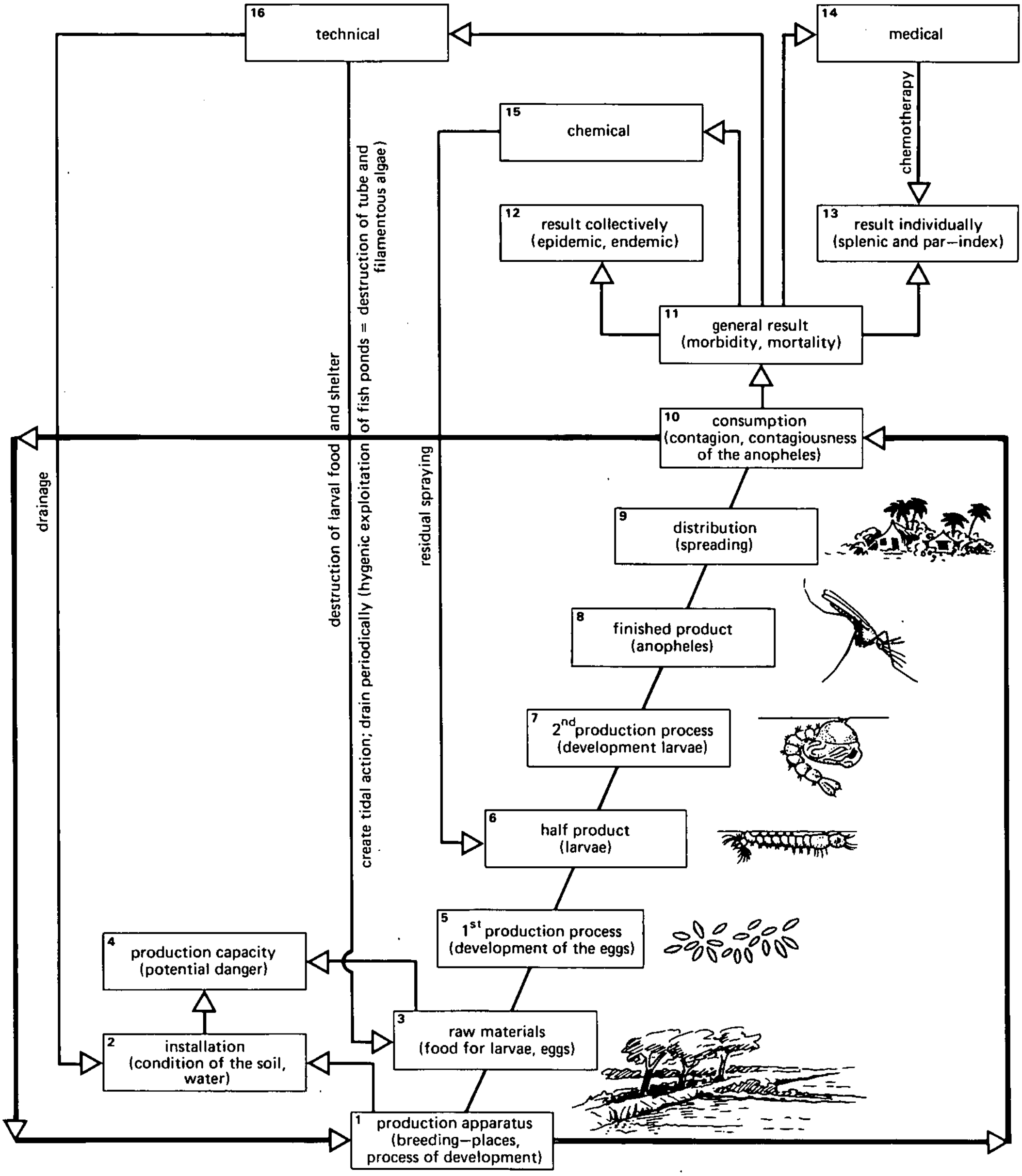


Figure 4.24 Diagram of the malaria problem

4.4.4 The 1933 East Java malaria epidemic

Important information about the relationship between the presence of potential danger spots (1), mosquito density (2), and mortality (3) comes from a discussion paper presented by W. Snellen (1987) 'A malaria epidemic caused by *Anopheles ludlowi* in East-Java, 1933'. This discussion paper presents a summary of a publication by J. Kuipers, Chief Engineer of the Provincial Sanitation Office for East Java, and W.J. Stoker, Government Physician for the Malaria Control Office in Surabaya. The original publication appeared in the Geneeskundig Tijdschrift voor Nederlandsch-Indië (Medical Journal for the Dutch East Indies), Part 74 (2) of 16 January 1934 (pp. 74-90).

Medical Report: Dr. Stoker

A severe malaria epidemic occurred in the village of Brengkok, population 5714, on the northern coast of East Java from June to August 1933. As usual in such cases the attention of the Provincial Health Service was attracted by the mortality rate levels. It rose from what was an expected figure of 20 per thousand in weeks 17 to 20, to a dramatic 100 per thousand in week 21.

A Government appointed assistant-physician was sent to collect blood samples from patients. It appeared that each sample contained malaria parasites, mostly malaria tropica and a sufficient quantity of quinine was immediately supplied to the village council.

In spite of the quinine the mortality rate remained high (Figure 4.25). The Provincial Health Service investigated and found that the drugs had not been properly distributed by the village council. A technical assistant from the Malaria Control Department was sent to Brengkok to ensure a systematic distribution of quinine. He stayed there from 24 July to 24 August. On 24 July a Government physician and the technical assistant conducted a medical survey of the village population. They made spleen examinations and ran blood tests, not specifically among the sick, but from a random group of people who attended a meeting at the home of the village head.

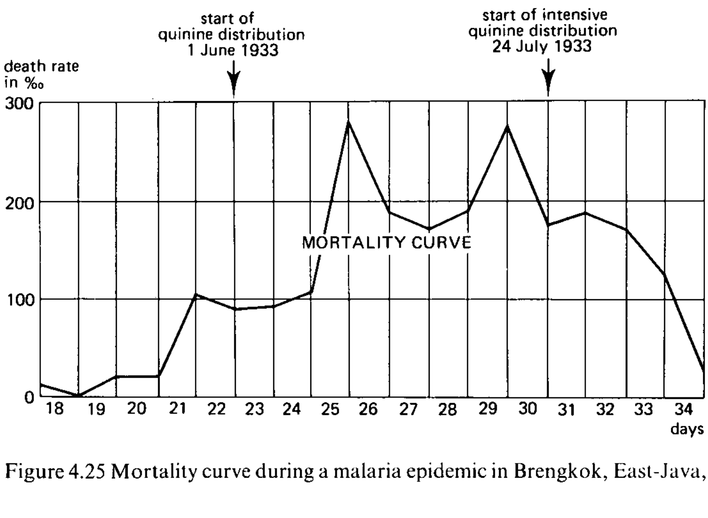


Figure 4.25 Mortality curve during a malaria epidemic in Brengkok, East-Java, wet season 1933

Data from the medical survey conformed to information already received from the Civil Administration and the local villagers who claimed that the disease and the high rate of mortality were quite unusual in Brengkok. It was mentioned, however, that malaria did occur regularly in the village of Manjaroeti, two kilometres west of Brengkok.

The technical assistant from the Malaria Control Department also collected and dissected Anopheline mosquitoes. The results are given here in Table 4.9. His examinations clearly indicate that the epidemic was caused by *Anopheles ludlowi (var. sundaica)*.

Table 4.9 Results of Anopheline mosquito collection and dissection in Brengkok, July/August 1933

	No. of An. mosquitoes collected			No. of An. mosquitoes infected			
	from cow-shed in one night	from houses in period 24/7-21/8	total	No. of An. dissected	stomach	salivary gland	total
An.subpictus	43	971	1014	964	–	–	–
An.ludlowi	–	157	157	146	44	36	68
An.aconitus	1	1	2	2	–	–	–

An.ludlowi breeds in sunlit, brackish pools. Figure 4.26 shows four zones around Brengkok where such breeding sites might have occurred. The first were the marine fish ponds extending from Brengkok to the coast, the second, the wasteland between the fish ponds and the village, the third the transition zone between the fishponds and the traditional riceland and fourthly the saline riceland itself.

After investigating these zones the authors concluded that the epidemic of 1933 could be attributed to the formation of brackish pools in the saline ricefields. These had not been planted with rice because of an abnormally low rainfall during the land preparation period. How the authors arrived at this conclusion even though the larvae they found in the remaining pools was that of *An.subpictus* is explained by Kuipers.

Technical report, Kuipers

Kuipers first considered the potential danger of each of the four areas. Marine fish ponds were regarded as safe because of what was termed 'hygienic exploitation'*, a process carried out under the inspection of the Fishery Department whereby the surface of the ponds was kept free of floating algae. Between the village and the fish ponds was an uncultivated area of two hectares with an irregular surface and saline

* Marine fishponds were notorious breeding sites for *An.ludlowi* and were considered the major contributor to coastal malaria. Large sums were spent filling in fish ponds and the Guidelines for Malaria Control for Government Officials, issued in 1924, warned strongly against the creation of new fish ponds in coastal areas. Later it was discovered that fish ponds kept clean of floating algae (hygienic exploitation) were perfectly safe.

groundwater. In the rainy season this wastelands's watertable would rise, filling small depressions and holes with brackish water. Although these sites were potentially dangerous, the author considered their collective surface area too small to sustain a heavy malaria epidemic. Between the marine fishponds and the traditional riceland was a transition zone that was subject to periodic flooding with brackish water from the fish-ponds. The zone consisted of uncultivated land, and some ricefields near the village of Majaroeti, irrigated by a small reservoir. Due to the high salt content of the soil, irrigation water or rainfall which remained standing in the field gradually became brackish. The irrigated ricefields themselves were not particularly dangerous, as *An.-ludlowi* did not breed in water shaded by rice plants.

A greater danger was the surface run-off or excess irrigation water from the ricefields which combined with imperfect drainage in adjacent uncultivated land might create sun-lit pools of brackish water. This explained the regular occurrence of malaria in Majaroeti. As a corrective measure the author proposed improving the drainage of this area by deepening the main ditch and lowering the water level in the feeder canal upstream of the dam (Figure 4.26).

The traditional rice growing area lay between the previous three areas and the lime-

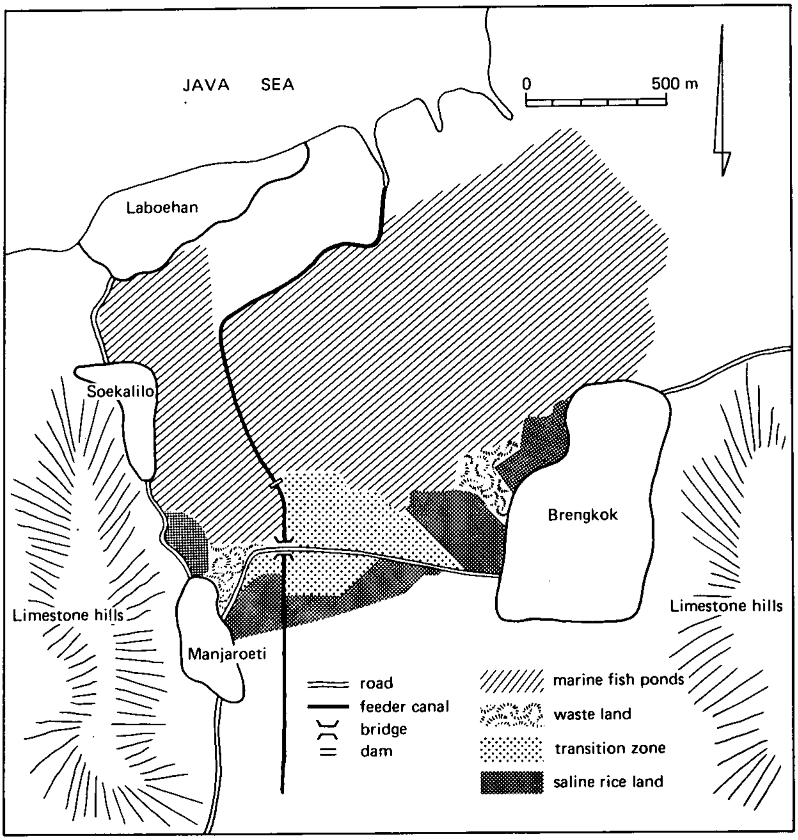


Figure 4.26 Potential breeding sites for *An.ludlowi* near the village Brengkok, East Java, Indonesia

stone hills. Rice cultivation here depended on rainfall alone. The ricefields close to Brengkok were highly saline because of inundation by sea-water long ago. The high salinity of these fields, despite their having been used as ricefields since living memory was explained by the very low permeability of the heavy clay soil. Water which remains standing on a saline ricefield will become brackish after a time but with adequate rainfall there are two factors that reduce the chances of these ricefields becoming breeding sites for *An.ludlowi*. Firstly *An.ludlowi* is a sun-loving species and will not breed in a field that is planted with rice. Secondly the time between two subsequent rainstorms is usually sufficiently short to prevent the water in the field from becoming brackish. With each rainstorm the water in the field is replaced or diluted by fresh water.

These two factors did not play a part in 1933 for a variety of reasons. There had been insufficient rainfall in December and January and the ricefields could not be prepared in time for planting. As a result most of them remained uncultivated. From March onwards ponding occurred in the uncultivated ricefields. The unusually low and infrequent rainfall allowed ponds to become brackish.

Because of the abnormal rainfall pattern of 1933 the brackish ponds which developed on these saline, uncultivated ricefields became excellent breeding sites for *An.ludlowi*. Kuipers used meteorological data including rainfall and evaporation, as well as soil moisture retention characteristics, to produce a ponding curve (Figure 4.27). From the ponding curve he derived a curve representing theoretical vector density*. The shape of this vector density curve very much resembles the mortality curve drawn up 35 days** later. The authors considered the resemblance between the vector density curve, derived from the ponding curve of the saline ricefields, as evidence that the epidemic was caused by prolific breeding of *An.ludlowi* in the uncultivated ricelands in that zone.

To remedy the situation, Kuipers simply proposed cutting the bunds of the ricefields when they remained uncultivated.

* Kuipers took a lot of trouble to explain how he derived the vector density curve from the ponding curve. To do this he divided the vector density curve into nine parts and discussed, for each period, how several factors had affected vector density. For example period end April to 13 May; occurrence of many small pools spread in regular pattern over the area with salt content increasing due to a relatively dry period and vector density increasing in similar fashion.

** Kuipers explained the time lag of 35 days between the vector density curve and the mortality curve as follows:

Day 0	*An.ludlowi* mosquito emerges
Day 1	*An.ludlowi* has its first blood meal and becomes infected
Day 14-16	The infected *An.ludlowi* bites another person
Day 21-30	The victim develops the first symptoms of malaria
Day 27-40	The victim dies

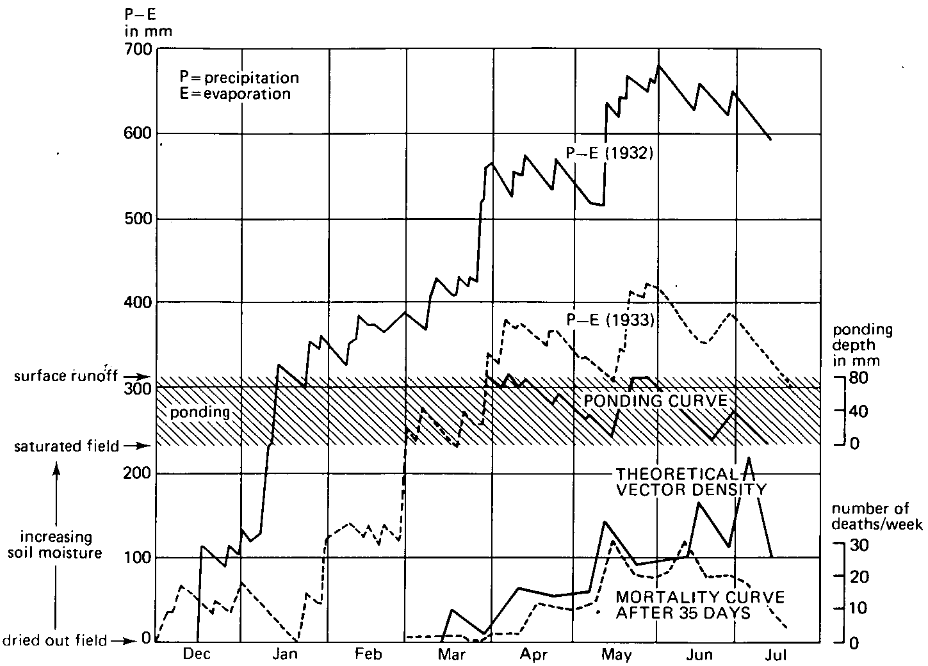


Figure 4.27 Mortality curve, theoretical vector density and the ponding curve in saline rice fields near Brengkok as derived from rainfall, evaporation and soil data

4.4.5 Conclusion

In Indonesia before World War II the identification of vector breeding sites was done by medical entomologists on the basis of larvae finds. A breeding place was considered dangerous when it contained sufficient quantities of the larvae of a malaria transmitting mosquito. With growing experience entomologists learned more about the specific breeding habits of dangerous vectors. This facilitated their search for larvae. There are breeding sites, however, that are dangerous only during certain periods of the year or, as was the case in the Brengkok epidemic, dangerous only under abnormal circumstances. In such cases an entomological approach based on larvae finds can easily fail to indicate potentially dangerous breeding habitats.

Kuipers tried to combine the information on specific breeding habits with meteorological and other readily available technical data so that he could predict when and where to expect a combination of environmental factors that would make a particular area a suitable breeding site for a suspected vector.

The Brengkok example is one of many examples from Indonesia during the period 1900 to 1940 showing the important role of environmental management in the control of malaria. For additional information about species sanitation, i.e. through improvement of field drainage systems in the framework of new plant and water regulations for rice cultivation, see Snellen, 1987.

References

Amin, M.A. 1981. The Assessment of a Large Scale snail Control Programme over a Three Year Period in the Gezira Irrigated Area of the Sudan. Annals of Tropical Medicine and Parasitology. Vol. 76, No. 4, pp. 415-424.

Bindra, O.S. 1983. Report on Host-Plan Resistance Work Done During 1982-83 in FAO/Sudan Project on integrated pest control. pp. 1-16. Gezira Agricultural Research Station. Wad Medani, Sudan.

Bindra, O.S. and A.A. Abdelrahman 1983. Integrated Pest Control for Cotton in the Sudan. pp. 1-43. Gezira Agricultural Research Station. Wad Medani, Sudan.

Doorenbos, W.M. 1925. Species Assanering en Afleiding op Dieren als Bestrijdingsmaatregel van Malaria in de Tropen, Leiden.

Eveleens, K.G. 1983. Cotton-Insect Control in the Sudan Gezira: Analysis of a Crisis. Crop Protection. Vol. 2, No. 3: pp. 273-287.

Fenwick, A., A.K. Cheesmond, and M.A. Amin 1981. The Role of Field Irrigation Canals in the Transmission of Schistosoma Mansoni in the Gezira Scheme, Sudan. Bulletin of the World Health Organization. Vol. 59, No. 5, pp. 777-786.

Fenwick, A., A.K. Cheesmond, M. Kardaman, M.A. Amin and B.K. Manjing 1982. Schistosomiasis among Labouring Communities in the Gezira Irrigated Area, Sudan. Journal of Tropical Medicine and Hygiene. Vol. 85, pp. 3-11.

Jordan, P. et al. 1978. Further Observations from St. Lucia on Control of Schistosoma Mansoni Transmission by Provision of Domestic Water Supply. Bull. WHO Geneva 56(6) 965-973.

Jordan, P.J. et al. 1982. Schistosoma Mansoni Control in Cul de Sac Valley, St. Lucia. Trans. Royal Soc. Tropical Medecine and Hygiene, London 74(4) 493-500.

Kotubu Bunsito. Sanitation Works in the Indian Archipelago.

Kuipers, J. 1937. Màthematisch-Statistisch Onderzoek van Waarnemingen over Anopheles in Nederland en op Java, Delft.

MacDonald, G. 1965. The Dynamics of Helminth Infections, with Special Reference to Schistosomiasis. Transactions of the Royal Society of Tropical Medecine and Hygiene, 59, 489-506.

MacDonald, G. 1973. Dynamics of Tropical Disease (collected papers, Ed. L.J. Bruce-Schwatt and V.J. Glanville), Oxford University Press, London.

Negron-Aponte, H. and W.R. Jobin 1979. Schistosomiasis Control in Puerto Rico. The American Journal of Tropical Medicine and Hygiene. Vol. 28, No. 3: pp. 515-525.

Smalt, F.H. 1937. Periodieke Drooglegging van Sawah's ter Bestrijding van Malaria. Med. D.V.G. XXVI (1937)4: p. 285-99.

Snellen, W.B. 1987. A Malaria Epidemic Caused by *Anopheles ludlowi* in East-Java, 1933. Discussion paper.

Swellengrebel, N.H. 1934. De Splitsing der Anophelessoorten. GTNI deel 74, Afl. 12(1934): p. 706-11.

Walch, E.W. en Dr. Soesilo 1926. Onderzoek van een Malaria-epidemie in Tegal in het Voorjaar van 1926. Overdruk uit de Mededelingen van den Dienst der Volksgezondheid in Nederlands-Indië. 98 pp.

Walch, E.W., M.L. van Breemen en E.J. Reyntjes 1930. De Assaineering der Zoutwatervischvijvers van Batavia. Bijdrage tot de 'hygiënische' exploitatie der bandeng-vijvers. Med. D.V.G. (1930), p. 547-80.

Walch, E.W. and R. Soesilo. Malària Control in The Netherlands Indies. Med. D.V.G. (1935)3, p. 86-94.

Tamein, O. et al. 1987. Water Supply Systems in Blue Nile Health Project.

Zout en brakwater Vischvijvers als Bron voor Malaria Gevaar. (Red. W.I.). De Waterstaatsingenieur No. 5 (1919), p. 223-5.

Annex 5

5.1 Rice cultivation on the Niger River

5.1.1 Introduction

Operation Riz in Central Mali is a project aimed at improving traditional rice cultivation along the Niger River between Segou and Mopti (Figure 5.1). The project did not have a health component but it was clear that agricultural improvements would have a definite impact on the established bilharzia transmission patterns on the flood plain. Over U.S.$ 3.4 million was spent on constructing dikes, gates, drains and land improvement. The remainder of the budget of U.S.$ 9.2 million was needed primarily for training, farm equipment, fertilizers, seed production, a credit system, and rice-handling facilities.

The entire project is located in the Fifth Region of Mali within the flood plain of the Niger River (Figure 5.1). Of the farmers on the flood plain near Bamako 30% are Bambara people and closer to Mopti 20% are Markas and Nonos. The area is

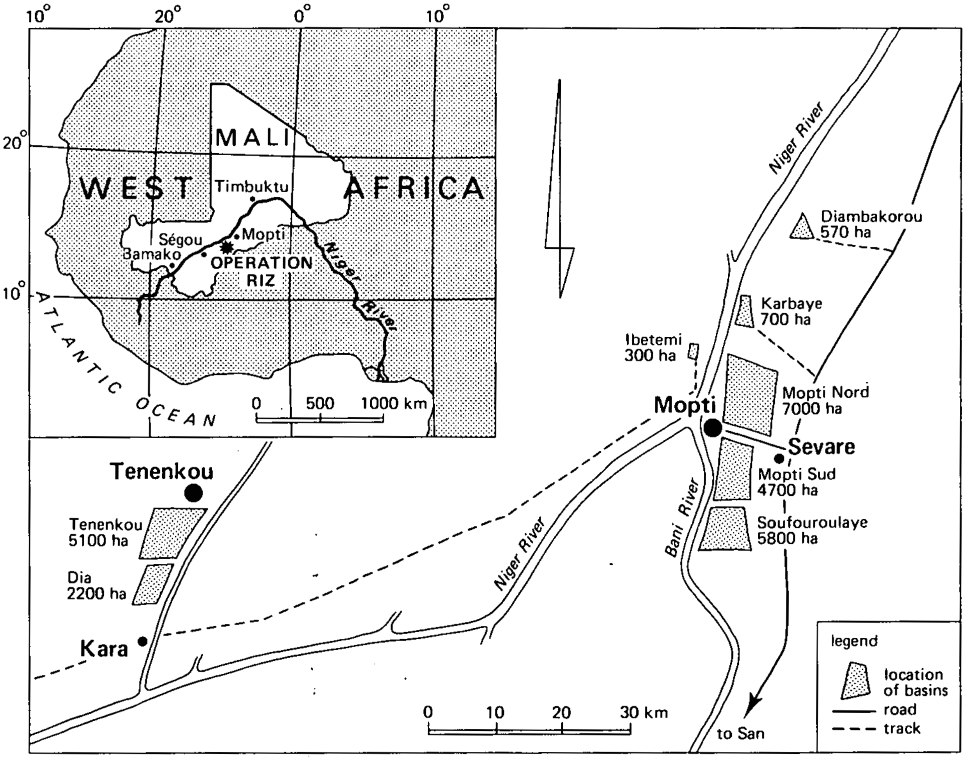


Figure 5.1 Operation Riz on the Niger River, Mali, West Africa. Location of casiers (bunded rice fields) near Mopti

also inhabited by itinerant fishermen, nomadic Peuhl herders who camp with their cattle on the flood plain in the dry season between October to June, Tuareg traders, and several other smaller ethnic groups.

The flood zone of the so-called island delta near Mopti is extremely flat. It includes many depressed plains or basins situated between natural levees. About 5% of this land is high enough to remain dry during the flood. The climate is generally of the northern sudan type, which changes to sahelian climate in the north. There is a dry winter from October to June and rains in the summer. These rains vary from 600 mm at Tenenkou in the south of the project zone, to 540 mm at Mopti, and 400 mm in the north.

Rainfall plays an essential role in the rice culture, from the preparation of the soil in July up to the the time of the arrival of the flood near the end of August. This is the first growth phase of the rice plant and it develops with rain as its sole source of water. The planting of rice is timed to coincide with the onset of the rains, which begin fairly predictably.

A good harvest is assured if the flood waters can be held off until the rice plant is sufficiently developed and if submersion is terminated when the rice is ready for harvest.

In the standard irrigation system, the main objective is to provide the required discharges. In this project, which consisted of controlling submersion, the main concern was the timing and the level of the flood. The delivery of water to the rice fields depends on the height of the river and rainfall is largely irrelevant once the flood arrives.

5.1.2 Bilharzia and snail infestation

The modest data available indicated that bilharzia was common among the inhabitants of the flood plains with a 35% prevalence of urinary bilharzia. The other form, intestinal bilharzia, was found further south in the Dogon Plateau but was not common near the river. Other water-borne diseases are common near Mopti and in population centres on the flood plain. Amongst these is cholera which occurs periodically in epidemic form.

The *Bulinus* snails which transmit urinary bilharzia must pass the several months of the dry season in the soil where they are left stranded every year by the receding flood. The broad flood plain is a major snail habitat, although a few snails are found in the shifting sand bed of the Niger River. In and around the lowest depressions in the rice fields, one finds other snails such as the amphibian *Lymnaea*. Bilharzia snails are seldom found here because they are apparently unable to survive the high water temperatures which develop as the ponds get shallow. These residual ponds are important sources of water and food for cattle at the end of the dry season. They are also sources of cattle parasites transmitted by the amphibious snail *Lymnaea*.

5.1.3 Vector control through environmental manipulation

Better water control and improved land preparation for rice cultivation were two of the basic physical improvements brought about by Operation Riz. The natural levees

Photo 5.1 A leaking concrete irrigation pipe crossing a major drain perpetuates breeding places for mosquitoes

were strengthened and raised to reduce over-topping. Control gates were installed to hold the flood out until the rice plants were ready and to hold the flood water on the rice fields during the period of maximum growth, that is after the flood wave in the river had subsided. The channels leading to the gates were made wider and deeper and improved so that flood water could be run off prior to harvest. All of these measures were designed to increase rice yield by allowing more precise control of rice development.

Although the agricultural measures were not intentionally designed for snail control, they would also have an important impact on the snail population. By delaying submersion as much as possible and providing for an earlier and more rapid drying of fields the snail habitat would be significantly altered. Field studies have not been made in the area but it is likely that the snail population followed the rice cultivation cycle fairly closely with the snails aestivating from the time the water is withdrawn from the fields in about December until the flood comes in at the end of August. Transmission of schistosomes from snail to man would begin about two months after flooding, perhaps in early November, after the snails and parasites had time to complete their first development cycle. This would last until the water was withdrawn for the harvest in December (Figure 5.2). Any delay in flooding or early draining for harvesting would produce a shortening of the snail reproduction season and a restrict schistosome transmission at the peak period. Under normal conditions these are short time-spans, with only four months for the snails to develop and two months for transmission. Even shortening the flooded period by one month would cut the transmission season in half.

Of equal importance was the rapidity of drainage prior to harvest. This was increased significantly by land levelling and drain improvement. The snails can adapt to very slow drying and easily survive several months without water. However, if the water disappears quickly, their survival is reduced to a matter of weeks. Improvements in the drainage would have a drastic impact on the snail and the number of habitats

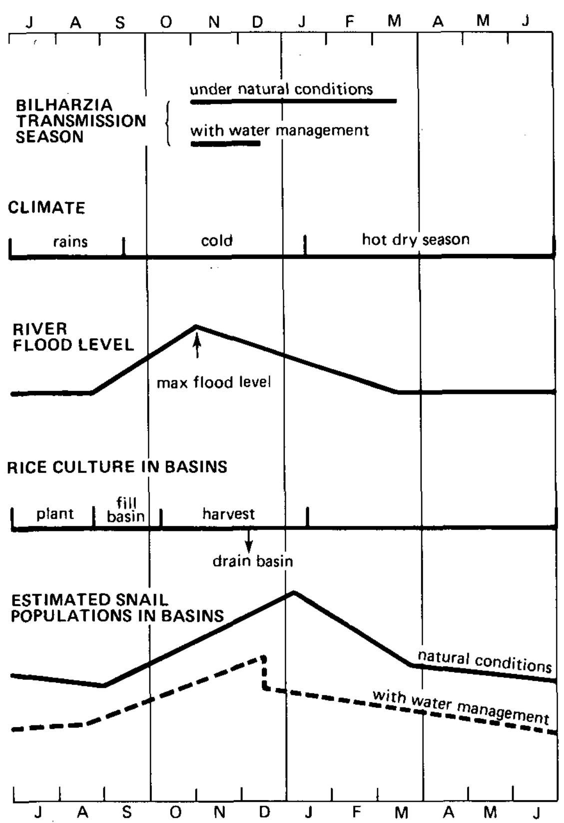


Figure 5.2 Annual calendar for agriculture and bilharzia in rice casiers near Mopti, Mali

where they could maintain populations for more than a few favourable seasons would be greatly decreased.

The overall evaluation of the hydro-agricultural improvements in rice cultivation can only be estimated but it seems certain that this type of improved water control and land levelling would be a health benefit. It decreases the number of snails and significantly shortens the natural bilharzia transmission season. This evaluation is substantiated by a study in rice fields in Burkina Faso where farmers in the improved rice irrigation scheme had a much lower prevalence of urinary bilharzia than those who cultivated crops around natural swamps in the traditional way.

5.2 Asian bilharzia and rice in the Philippines

5.2.1 The Asian bilharzia snail

One of the earliest bilharzia control projects in the Philippines was in the municipality of Palo, in eastern Leyte. It was sponsored by the World Health Organisation. Palo lay in an area of heavy rainfall and rice was cultivated in the lowlands using relatively primitive techniques. Bilharzia is transmitted in the Philippines by a small amphibious snail, *Oncomelania quadrasi*, which has ecological requirements quite different from those of the *Bulinus* and *Biomphalaria* species in Africa and the Americas. It transmits *Schistosoma japonicum* which is found only in the Orient. The characteristics of this Asian species of bilharzia and of the amphibian snail which transmits it gave the control programme in the Philippines a strong orientation towards ecological changes (Hairston and Santos 1961). It is important to recognize that Asian bilharzia cannot be controlled in the same way as the urinary and intestinal bilharzias in the rest of the tropics. Symptoms displayed may be similar to other bilharzias but Asian bilharzia is a special case with important epidemiological differences.

Field studies showed that newly hatched snails were strictly aquatic in their first two weeks of life and during this period they are extremely susceptible to drying. Furthermore, the snail populations need shade to survive and they do not propagate in deep, stagnant water such as is found in most fish ponds. Agricultural and engineering measures for snail control by habitat modification took careful account of these characteristics.

Exploratory studies in the early 1950's showed a close relation between primitive rice cultivation in the municipality of Palo and the transmission of Asian bilharzia. One of the principal measures developed was improved cultivation of rice, which involved levelling land, careful water management and efficient drainage. This practice resulted in increased yields as well as snail control.

5.2.2 Environmental management:

Drainage

Unused swampy areas close to housing were important transmission foci for the bilharzia. Not only humans, but rats, cattle, and other animals were are also infected in this way. These swamps were reclaimed for agricultural use by clearing vegetation, filling depressions and installing interceptor drains or sub-surface drainage systems. Normal surface drainage by ditching proved to be only temporarily effective in such swampy areas because of the high maintenance costs involved. In areas where drains could not be constructed because of lack of outlets, deep pools with steep sides were excavated to serve as fish ponds. Streams were channelized to reduce swampy margins and increase velocities. These measures were found to be highly effective in snail control giving general reductions of about 95% in the numbers of snails over large areas of the municipality. At the same time, previously unproductive land was reclaimed. The increased value of the land now available for agricultural use was usually enough to quickly compensate reclamation costs.

Impact evaluation

These measures were evaluated in a demonstration project conducted in three hectares of water-logged area overgrown with thick vegetation. The snail infested area was initially drained by an intercepting canal and a main drainage canal. The reclaimed area was subsequently diked and subdivided into rice paddies. Finally, irrigation pipelines from the irrigation canal to the diked paddies and a system of irrigation, drainage and intercepting canals was installed. When land preparation was complete two rice crops were planted during successive planting seasons using the masagna or margate method for 'wet' land, transplanted rice. The land was ploughed twice, harrowed, levelled, planted in rows, and weeded with rotary weeding machines. Orderly planting made weeding easier. The weeds which were pushed under the surface served as fertilizer. The periodic removal of irrigation water and weeding the fields up to three or four weeks before harvest when the irrigation water was no longer needed, all contributed to the increased yield in the paddy.

Snail densities before, during, and after planting were obtained using the tube method. This consisted of eight transects across the whole experimental rice field. An adjacent area which remained fallow throughout the experiment and in which snail densities were similarly calculated served as a control plot. In the initial snail sampling, base-line data of 231 snails per square metre were calculated in the experimental area and 196 per square metre in the untreated area. The snail density in the latter was lower because it was farther from the Main Irrigation Canal. After the system of drainage and irrigation canals had been completed there was an appreciable decrease in the snail density, that is to 91 per square metre. The density in the comparison areas remained almost the same. Results of sampling before planting revealed a further decrease to an average of 1.6 snails per square metre in the demonstration area. In the untreated comparison area, the snail density was 166 snails per square metre. After the first harvest another snail sampling conducted in the area gave an average of 0.7 snails per square metre. A subsequent sampling done after the second harvest showed that snails had been totally eradicated in the demonstration area. On the other hand, an increase in snail density was observed in the comparison area during samplings made after the first and second harvest.

It was observed that where drainage courses existed in the Palo municipality they were often dammed and used by the farmers in irrigating their lands. Removing these dams to control snails would be strongly opposed by the farmers. If any large-scale

Photo 5.2 Shallow, sunlit pools in the silted bed of a field channel

improvements were to be made in the area's drainage, an adequate and independent irrigation system would have to be designed.

Because of the overriding question of cost in controlling water and vegetation, measures that would result in benefits other than that of snail control had to be considered. In practically all the efforts to eradicate the snail host in Leyte, land reclamation and improved land use were important considerations (Blas 1976).

In this way substantial socio-economic development accompanied bilharzia control in this region.

5.3 Irrigation and vector-borne diseases: a case study in Sri Lanka

In 1977, the Accelerated Mahaweli Development Program was launched by the Sri Lanka Government. It was designed to ease the serious economic problems of the country and make it more self sufficient in rice production and power. At the same time jobs would be made available for the large numbers of unemployed. The program covered an area of 165 000 ha of sparsely populated land, partly natural forest and partly under traditional irrigated agriculture. Irrigation facilities would either be improved or constructed and a resettlement program implemented. The resettlement project involved massive human migration affecting some 150 000 families. This combination of ecological and demographic change had serious implications for the public health of the area. A particular danger was the possibility of an increase in vector-borne diseases amongst a population which was already exposed to malaria, filariasis, and various arboviral diseases.

A study was made by ILRI in one of the sub-systems of the Mahaweli Program, Zone 2 of System C. The investigation took some eight months and was designed to identify those features of irrigated agriculture which could lead either to the introduction of vector-borne disease or to an increase in its prevelance.

5.3.1 Introduction

In the wet season 1984/85, an initial inventory was made of potential breeding places for vector mosquitoes and changes which occurred in these breeding places were registered. An analysis was made of the technical and organizational features of the irrigation system and the possible relationships between irrigation engineering, water management, and the creation of potential breeding places were examined. For a full account of the case study see Annual Report ILRI 1985.

5.3.2 The Study Area

System C is located on the right bank of the Mahaweli Ganga River, an area of some 63 000 ha (Figure 5.3). The topography is sloping and irregular, and when this is combined with soils quality and other factors, the amount of land available for irrigation is limited.

Areas which are suitable for irrigation include the valley bottoms of small catchments, where soils are poorly drained Low Humic Gleys (LHG). These gradually change uphill through slopes of up to three per cent to imperfectly drained Reddish Brown Earth (RBE) soils. These are suitable for irrigation. The ridges and steepest slopes, four to six per cent, consist of well-drained RBE's or granite rock knobs. No irrigation can be done here (Hunting 1980). This means that only about 42 per cent of System C – or 26 000 ha – is regarded as being suitable for irrigation. Table 5.1 shows the land use in System C. Zone 2 is situated in an intermediate climatic zone which marks the transition between the Wet and Dry Zones. The mean yearly rainfall is 2100 mm, most of which falls in the wet season, or Maha, of the North-East Mon-

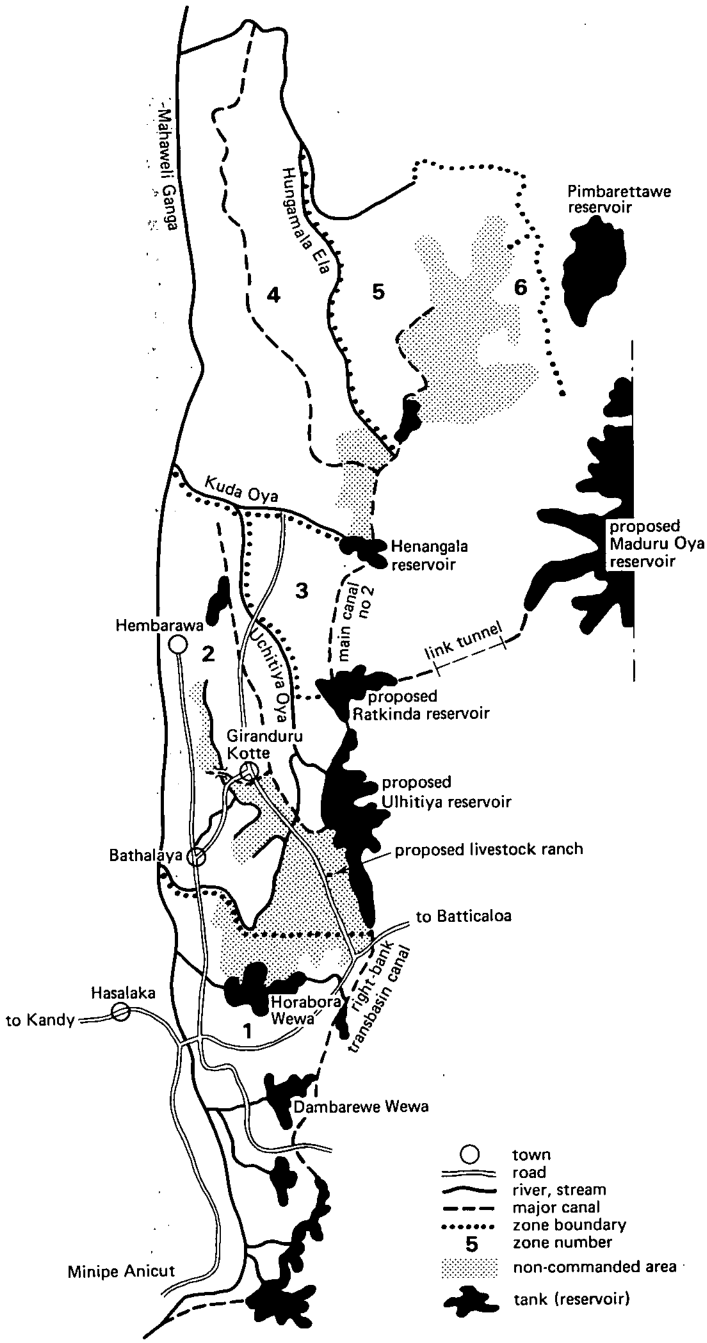


Figure 5.3 System C

soon between October and April. The dry season, or Yala, coincides with the South-East Monsoon and lasts from May to September.

The headworks in the Mahaweli River provide the necessary water storage and flow regulations to safeguard the water supply to System C's main reservoir, the Ulhitya, throughout the year. The irrigation system consists of a main canal taking off from Ulhitya, branch canals discharging into various buffer reservoirs, and distributary channels taking off from these reservoirs and conveying water to the minor irrigation units or turnouts. Every turnout has one field channel running downslope and serves between five and twenty farmers, each owning a one hectare allotment of paddy lowland. In addition each settler family gets a 0.5 hectare homestead where they can cultivate other rainfed food crops.

Table 5.1 Land use in System C

Net irrigable area	26 460 ha	(42%)
Settlement area	11 115 ha	(17.6%)
Forests	7 560 ha	(12%)
Grazing area	5 040 ha	(8%)
Residual areas of roads, canals and unutilized patches	10 305 ha	(16.4%)
Rocks and steep sloping land	2 520 ha	(4%)
	63 000 ha	(100%)

Roughly 2000 ha of the residual areas resorts under the turnout area bringing the gross irrigable area at some 28 500 ha or 45% of the total area.

5.3.3 Public health and vector-borne diseases in System C

In System C, the most prevalent ailments are those related to poor hygiene and sub-standard living conditions and they include malnutrition, water-borne diseases, respiratory diseases, and vector-borne diseases. The most serious vector-borne diseases are malaria, filariasis, dengue, and Japanese B-encephalitis. Schistomiasis has not yet occurred on the island and the reason for this remains unclear.

Country-wide figures show an average of 7% of the examined blood films to contain malaria parasites. There were higher incidences, 12%, in 1983 and 17% in 1984. In Sri Lanka the sole proven vector of malaria is *Anopheles culcifacies.* Six other species of the genus *Anopheles*, also present in Sri Lanka have been confirmed as malaria vectors in neighbouring countries. Research data in Sri Lanka shows these together with five other anopheline mosquitos present a potential danger as malaria vectors.

5.3.4 Health care

Three independently operating organizations provide health care in System C. They are the Mahaweli Authority, the Ministry of Health, and the Anti-Malaria Campaign. Each contributes to health services, hygiene education, and overall sanitary provisions

Photo 5.3 After the harvest when sluice gates have been closed mosquitoes proliferate in the attractive habitat of a drying up canal

around the settlers' homes. Vector-borne diseases are at present controlled by spraying houses with indoor insecticide and medical treatment of recognized cases particularly in the case of malaria.

5.3.5 Identifying vector habitats in Zone 2

Whether water forms a suitable breeding place for vectors depends on a variety of factors. In irrigated agriculture a relationship has to be established between observed water bodies, the practices that led to their creation, and whether they will cause the proliferation of specific vectors. To establish this relationship in Zone 2, three matrices were developed. They will be described below.

Matrix I

Matrix 1 (Figure 5.4) was obtained in the following way. Potential mosquito breeding places were classified by adapting the classification in the WHO *Manual on Environmental Management for Vector Control* to the local situation. The stagnant bodies of water encountered in Zone 2 were placed in one of seven categories, $A_{index} - G_{index}$, according to criteria such as organic pollution, exposure to sunlight, vegetation, freshness of the water, and the size of the pool. Details of this can be found in Table 5.2. Then the types of breeding places were related to the confirmed or potential vectors responsible for disease transmission in Zone 2.

In the absence of sufficient information adequately matching the specific ecological conditions in Zone 2, Matrix I could only be developed in a very simple form. Once more detailed information has been obtained about the main vectors in Zone 2, it will be possible to modify the matrix.

Disease	Mosquito species	Potential breeding place					
		A	B	C	D	F	G
Malaria	An. culicifacies						
	An. subpictus						
	An. vagus						
	An. varuna						
	An. annularis						
	An. nigerrimus						
	An. pallidus						
	An. barbirostris						
	An. aconitus						
	An. jamesi						
	An. tesselatus						
	An. maculatus						
	An. karwari						
Filariasis	Cx. quinquefasciatus						
	Mansonia sp.						
Dengue	Ae. aegypti						
	Ae. albopictus						
Jab. b.	Cx. tritaeniorhynchus						
Encephalitis	Cx. gelidus						

Figure 5.4 Matrix I, Identification/relation to mosquito species

Table 5.2 Classification of the most common potential breeding places in Zone 2, System C

Category	Description	Index
A	Large bodies of fresh water in full or partial sunlight Floating or emergent vegetation, especially near edges	1 Ulhitiya Reservoir, buffer reservoirs, large borrow pits, waterlogged pools behind bunds of distributary channels constructed in fill, large natural surface depressions. 2 Marshes
B	Small watercollections, stagnant and often muddy, but not polluted, full to partial sunlight 1 Vegetation present: scattered or at fringes 2 Vegetation absent	Marginal pockets along irrigation canals semi-permanent rain pools in natural or man-made surface depressions (e.g. in between road and canal bund), seepage pools behind buffer reservoir or canal bund, old borrow pits, clogged drainage ditches 2 Recent borrow pits, rock pools on excavation sites, new road ditches, wheel ruts, foot or hoof prints, rainwater pools
C	Marshy patches, often polluted with organic matter; mostly abundant vegetation (oily monolayers, iron-coloured water, smell of decomposition)	1 Seepage ponds/depressions along irrigation canals constructed in fill, poorly drained shallow but extensive surface depressions 2 Roads saturated with water from overtopped field channels bunds 3 Muddy broad sections of natural drains where the waterflow stagnates (mainly in upper parts of intermediate drains).
D	Paddy fields	1 Swampy and poorly drained fallow lowland paddy fields, prior to land preparation. 2 Recently tilled fields 3 Fields during seeding (levelled fields, no water layer, but small shallow pools) 4 Fields during transplanting (levelled fields, shallow water layer) 5 Fields during crop growth 6 Washing pits
E	Partially or heavily shaded water under abundant vegetation	1 Sluggish irrigation drainage streams (slow waterflow from one pool to another), pools at the interception of drains in distributary channels, ponds. 2 Stagnant pools in spillway drainage beds
F	Running water courses, clear fresh water, direct sunlight	1 Pools in drying stream beds (natural streams or irrigation canals), seepage pools from irrigation structures in canal beds, pools in stream-eroded canal depressions directly behind dropstructures, turnout structures and cross-regulators 2 Irrigation ditches and lowland grassy/weedy field-drainage ditches 3 Small side-pockets along embankments or irrigation canals (erosion gullies, bund breaches, etc.)
G	Man-made containers	1 Stilling basins of irrigation structures (turnouts, cross-regulators), silt catcher of reservoir spill 2 Wells, cisterns, discarded receptacles, old tyres, gutters

Matrix II

Matrix II (Figure 5.5) was developed in the following way. From direct observation of the irrigation system and agricultural practices, combined with other information, it was possible to determine where in the system (reservoir, main canal, field canal, fields or drainage system) and in which phase of the irrigation cycle (the pre-irrigation,

	Pre-irrigation	Land-preparation	Crop Establishment	Vegetative growth	Harvest	Post-irrigation
Reservoir	A1; G1	A1; G1	A1; G1	A1; G1	A1; G1	A1; G1
Main/Branch Canal	F1	F3	F3	F3	F3	F1
Level Crossing/Tanks	A2	A1; B1; C1	A1; B1; C1	A1; B1; C1	A1; B1; C1	A2
Distributory Channel	A1; C1 G1; F1	A1; B1; B2 F3; E1	A1; B1; B2 F3; E1	A1; B1; B2 F3; E1	A1; G1; C1; F1	A1; G1; C1; F1
Field Channel	C1; F1	B1; C1; C2	B1; C1; C2	B1; C1; C2	C1; F1	C1; F1
Field Ditch		F2	F2	F2		
Field	D1	D2; D6	D4;D6;D3;D6	D5; D6	D6	D1
Field Drainage		F2	B1; F2	B1; F2	B1; F2	
Natural Stream/Major Drainage	E1; F1	C3; E2	C3; E2	C3; E2	C2; E2	E1
Domestic Environment	G2	G2	G2	G2	G2	G2
Natural Environment	A1; B1; B2; C1	A1; B1; B2; C1	A1; B1; B2; C1	A1; B1; B2; C1	A1; B1; B2; C1	A1; B1; B2; C1

Figure 5.5 Matrix II, Phases of the irrigation and crop husbandry cycle and locations in the irrigation area proper and in the remaining area in relation to potential breeding places

land preparation, crop establishment, vegetative growth, harvest, or post-irrigation phase) the various breeding places would become a significant hazard to health. With this information and that provided by Matrix I the timing and location of vector breeding was established and Matrix II was obtained.

Matrix II indicates the relative importance of the irrigation system as a whole for potential vector breeding in the area. It singles out those elements of the irrigation system that give rise to the greatest risks.

Matrix III

Matrix III establishes the relationship between the location of breeding places and those features of water management and irrigation engineering that promote them. It focuses therefore on hydrology, design, construction, operation, maintenance, as well as on 'farm water management' and 'crop husbandry' (Figure 5.6).

Matrix III thus completes the cause-and-effect analysis which began with identifying the vector and ended with identifying the irrigation feature that influences the vector habitat. Although the matrices still need more information input from both irrigation and entomology, they do provide a schematic basis for the further study of the link between irrigation and vector ecology under specific environmental conditions in Zone 2.

5.3.6 Irrigation features related to vector-habitat creation

Matrix III directs attention to those features of the irrigation system which create a particular type of breeding place. A more general rule would also appear to apply and that is, the more carefully and minutely irrigation development is planned and executed, the less likely it is to encourage mosquito propagation. Some salient examples of the principles underlying this statement were observed in Zone 2. They will be discussed below.

Hydrology

The sloping and irregular topography of System C has imposed two major constraints on the drainage of the area. Firstly, draining the large area of land excluded from the irrigation scheme would have required a large number of culverts and other devices because newly constructed roads and canal bunds have cut off stretches of land from its natural drainage.

Secondly, there are numerous small unirrigable patches scattered within the irrigation system's boundaries. These contain natural and man-made surface depressions that do not drain into the drainage network laid out in the irrigation system. These depressions collect water from a variety of sources; blocked natural drainage, rainfall, surface runoff, and seepage. Bodies of stagnant water of various sizes are created and these are often brightly lit. They retain an overall breeding potential throughout all phases of the irrigation cycle.

	Irrigation feature					
	Hydrology	Farm water Management	Design	Construction	Operation	Maintenance
Reservoir	A1		G1		A1	A1
Main/Branch Canal				F3		F1; F3
Level Crossing/Tanks	A2; C1			B1	A1	A1
Distributory Channel			A1; E1; G1	A1;B1;B2;C1 E1;F1;F3	C1	B1;C1;F1 F3
Field Channel			F1	B1; C1; C2; F1	B1; C1; C2; F1	B1; C1; C2; F1
Field Ditch		F2		F2		F2
Field		D1; D6				
Field Drainage		F2				F2; B1
Natural Stream/ Major Drainage	A1; C3; E1 E2; F1			C3; E1; E2		C3; E1; E1
Domestic Environment				G2		G2
Natural Environment	A1; B1; C1		B1	B2		B2

Figure 5.6 Matrix III, Relationship between irrigation feature and breeding place

Design

A complicated network of reservoirs and major and minor canals was the result of trying to create a command area, as large as possible, in the undulating topography and varying soil conditions of System C. The control of water flows in all parts of this network is a complicated matter and places heavy demands on the staff operating the system. The situation is further complicated by the decision to leave the canals unlined. This has resulted in problems of erosion, canal seepage, and difficulties with guaranteeing proper water flows.

The design of the separate parts of the system may, in themselves, create public health hazards. Figure 5.7 gives an example of how the canal lay-out has been adapted to topography. Distributary canals are aligned along the lateral spurs of the main ridges, which means that the major part of every distributary runs through imperfectly to well-drained Reddish Brown Earths (RBE). Where these canals have been excavated in erodible RBE soils, serious forms of bund erosion have been observed. One effect of this erosion is deposition of eroded material. In the pre- and post-irrigation periods, this can lead to uneven canal beds with many shallow sunlit pools of stagnant water. As a result, conditions in the distributaries and branches before the first issue of irrigation water are particularly conducive to the development of mosquito larvae. After the first issue, a constant flow is maintained in the canals. Potential breeding areas remain, however, where eroded gullies in bunds permit pockets of standing water.

Two other effects of bund erosion occur in minor canals. Firstly over the full length of the field channels and at the tail end of distributaries, the deposition of a silt layer causes capacity problems. The subsequent overtopping of canal embankments leads

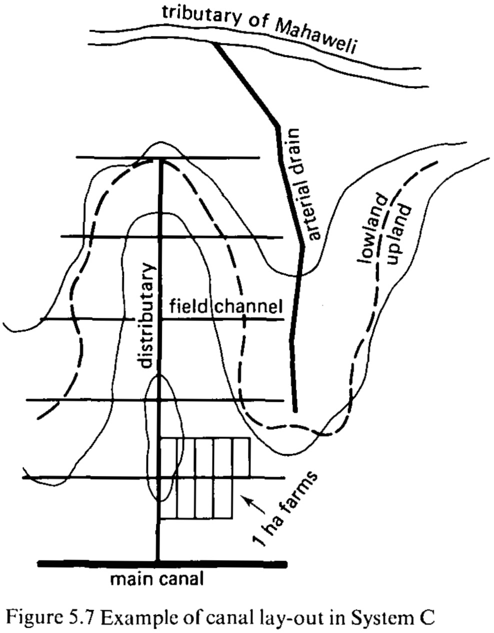


Figure 5.7 Example of canal lay-out in System C

to pool formation in adjoining surface depressions. Secondly, accelerated water flow and whirlpool action downstream of culverts, bridges, drop and check structures, and bends, cause bank erosion. This widens the canal cross-section, retards water flow, and creates breeding places in side pockets along the embankment.

In contrast the large Ulhitya Reservoir cannot be reckoned as a dangerous breeding place. The reservoir bund that is closest to the nearest settler hamlet is steep and well-lined whilst the distance between this bund and the hamlet exceeds the average flight range of most mosquito vectors, i.e. one to three kilometre. Unlike Ulhitya, many of the smaller irrigation reservoirs closer to human habitation may contribute considerably to the mechanisms of vector breeding. Often the embankments of small irrigation reservoirs are infested with emergent or floating vegetation of which *Salvinia natans* is a suspected breeding requisite for *Mansonia spp.*, the vector of Brugian filariasis.

These small reservoirs act to buffer the effects of any disproportion in the frequency of adjustments in major and minor canals. Water levels therefore, are subject to irregular fluctuations throughout the year and cause an exposed drawback zone suitable for mosquito breeding each time the water recedes. If the drawback zone has no isolated small depressions, the shallows will empty when the water recedes leaving the eggs, larvae, and pupae stranded.

Construction

Several observations were made during fieldwork concerning the construction of the system. It was noted that not all the canal beds and structures had been built at the proper elevations. The result was that incorrect water flows, stagnation of water flows in canal sections, and spilling of water over canal bunds occurred. This has led to the formation of pools in depressions adjoining the canals.

It was also clear that some canal sections had been constructed in fill. They had not been compacted, a process necessary to avoid seepage and leakage. This has led to the continuous presence of water-logged surface depressions next to these canal sections.

Complicated construction works such as large culverts, water-level regulating structures, aqueducts, and inverted syphons had not all been made with high-quality materials nor had they always been accurately installed. As a result the possibility of breeding places developing was greater and the efficiency of water delivery within the system was impaired.

Operation

In System C, the speedy implementation of a complicated design under difficult topographical conditions has resulted in complex operational procedures which have not been able to prevent excesses and shortages of water. According to Moore (1980) the cause of many of the problems in large-scale irrigation schemes in Sri Lanka, of which Zone 2 can also be said to be a part, lies largely in the operational procedures applied. These ranks low on formality, information, and control.

Formality

The 'formality' of operation in Zone 2 is characterized by an almost total lack of written technical procedures for the adjustment of control gates downstream of the main canal, the absence of explicit job descriptions for water management staff and the poor coordination of policies and activities. This has led to the haphazard implementation of rainfall corrections, rotation schedules, cropping calendars, and so on. In circumstances like this, alert and effective water management for an equitable distribution of irrigation water is impossible. The result is that farmers and water-management staff become alienated and less motivated.

Information

Flow measurements are imperative if one is to verify channel flow and locate faulty design or construction in the canal system. Flows in the main and branch canals of Zone 2 are measured with Parshall flumes and in the distributaries short-crested (hump) weirs are used. Only a minimum number of measuring devices have been incorporated in the canal network, however. Many of them cannot be used for accurate readings because of an improper construction elevation or the absence of a reading gauge. At present, the only records that are kept are those of the main sluice. Further down the system, unrecorded 'guestimates' from improvised methods are used for the adjustment of minor irrigation structures.

Control

Discrepancies between water requirements and actual amounts of water issued are inherent problems in irrigation. Some soils are more porous than others while differences in canal topography, length, and maintenance may mean that two adjacent canals require very different amounts of water at their head ends to ensure supplies at their tail ends. This can be hard to assess. Another factor is the degree of control it is possible to exercise over the water flows. In Zone 2, from distributary level down to the fields, the vertical sluice-gate inlet structures are adjustable, but they cannot be tuned precisely enough to guarantee the required flow (Hunting 1980). During rainstorms of more than eight centimetres for instance, the main flow is accurately cut back for one week to 50% of its initial flow. From the distributaries downwards, however, the adjustments can only be approximated. This can have the result of starving tail-end distributaries of water.

Rainfall is unevenly distributed over Zone 2 and may not reach all parts of it. Canals at the tail ends of the system sometimes fall dry because data is only available from one rain gauge.

At turnout level, farmers have difficulty in controlling the water issues. During land preparation the system operates at full capacity, delivering a continuous flow of roughly 30 l/sec to every turnout gate. But the number of farmers under one turnout varies widely, leading to over-irrigation at the smaller turnouts. This, when combined with local drainage problems can cause land to be inundated for several weeks at a time.

Along the field channels three farmers share the design flow using two outlet boxes, one of which remains half-closed. This is a discrepancy between design and rotational procedure and causes problems in achieving an equitable distribution of water within the turnout.

In the wet season of 1984 when 4000 ha of Zone 2 were being irrigated for the first time, too much water was issued as a palliative for these shortcomings. This disguised the need for urgently required reconstruction, reorganization, and maintenance within the system. In terms of 'overall irrigation efficiency' a very low value was estimated: < 20%. Other risks attendant on an over-generous supply of water are that farmers become wedded to lavish water use and lose their ability to handle water as a scare commodity or to manage rotational water deliveries. These can all in different ways lead to the creation of vector breeding places.

Once a vector habitat has been identified somewhere in the system it is difficult to determine whether its occurrence is related to one specific operational feature. Operational shortcomings tend to have a cumulative effect. This, however, does not detract from the general rule that the more carefully and minutely irrigation development is planned and executed the less likely it is to cause mosquito propagation.

Maintenance

Wherever maintenance of an irrigation system is neglected water flows will be retarded, areas will be inundated, and other processes favourable to the formation of pools of standing water are likely to take place. Maintenance work in Zone 2 is not well-organized mainly because of the lack of consensus on responsibilities at the institutional and turnout levels.

At the institutional level the construction of the system by one agency and the subsequent transfer of project management to another has not resulted in effective maintenance. For the first two years after construction, maintenance was the responsibility of the construction agency, but with construction still in progress in other parts of System C and in System B as well, this agency had difficulty in releasing the manpower and machinery needed for maintenance in Zone 2.

At turnout level the operation and maintenance of the infrastructure is left to the farmers who elect a farmer-leader to represent them and to see that works are executed according to agreed-upon procedures. The farmer leader, however, lacks the authority to enforce the rule that every farmer must clean the canal section adjoining his or her paddy plot, so not all farmers do their share of work. The result is excessive plant growth in the canals, damaged canal bunds, and silted canal beds. Another factor complicating cooperation at the turnout is hidden tenancy which can make the ownership of some plots unclear (Gunawardena 1983).

On-farm water management and crop husbandry

Two methods of rice cultivation are practised in Zone 2. One is the 'transplanting' method which uses plant material from a nursery, and the other is the 'direct seeding' method where rice seed is sown broadcast in the fields and no transplanting is done.

Farmers' activities in irrigated rice cultivation and the implications of these activities on vector breeding has received attention by FAO (1984). One important feature appears to be underestimated, however, and that is that a farmer's decisions on the sequence of his activities and the techniques he applies in cultivation and irrigation are not taken autonomously. To a large extent these decisions are influenced by constraints on when and how adequately the necessary inputs of water, labour, traction power, seed, and fertilizer will be available. Thus basic input provisions must be safeguarded before the farmers can employ cultivation techniques that will minimize the creation of vector breeding places.

Broadcasted paddy fields appear to provide more breeding grounds than transplanted fields because of the absence of a uniform water layer in the first two weeks after seeding and because there is a relatively slow closing of the crop canopy. Nevertheless, a potentially dangerous situation occurs with a transplanted rice crop when a second nursery proves necessary because the first did not provide enough usable plant material for the full one hectare. This leads to an extra three weeks of fallow for the still unplanted tilled fields.

During field observations it was found that each cultivation stage gave rise to certain typical breeding habitats. In the pre-cultivation period, the often water-logged, poorly drained, lowland fallow fields favour mosquito breeding. In the land preparation phase, the recently ploughed fields form a vast inundated area in which the chances for breeding depend, among other things, on the interval between successive activities. A rule of thumb is that if a ploughed basin is left untouched for ten days or longer in the climatic circumstances of Zone 2 it allows a high percentage of the larvae enough time to develop into adult mosquitoes.

During crop and canopy establishment the breeding danger is thought to lessen because the vegetative cover hinders the oviposition of female anopheline mosquitoes (FAO 1984). But other water bodies remain: borrow pits, undrained depressions along irrigation canals, seepage ponds and blocked drains amongst them. In the wet season of 1984/85, this situation was aggravated by the continuous over-supplies of irrigation water.

After the harvest when the sluice gates have been closed, the enormous lengths of drying-up canals are particularly attractive to the proliferation of mosquitoes and the marshy fallow fields constitute a favourable breeding habitat for *Culex tritaeniorhynchus*, particularly after the first rains have fallen on the decomposing stubble (WHO 1982).

5.3.7 Conclusion

Despite the complexity of relationships between irrigation engineering and the creation of vector breeding places, efficient water management can impede the creation of breeding places. It remains to be seen, however, whether a reduction in the breeding potential in Zone 2 will find expression in an actual reduced density in the vector populations. The large area that could not be incorporated into the irrigation system offers alternative breeding grounds that will certainly diminish the effectiveness of any environmental management measures incorporated into the engineering works.

An overall improvement in water management is nevertheless an important component in any irrigation project. It has a dual purpose: making a better control of vector breeding possible and leading to increased agricultural productivity. Once water management has been improved, thought can be given to more complicated environmental management measures for vector control (WHO 1982). Given the present technical and organizational level of water management in Zone 2, however, such measures are not yet relevant.

Some important environmental management measures which may have relevance in the future for Zone 2 when present management problems have been overcome, are summarized here. These should of course be seen in the light of an 'integrated control' program and stand in relation to the 'locations' and 'irrigation features' of Matrix III.

The canal network should be flushed weekly in the pre-/post-cultivation period in order to eliminate pools in the canal beds. Borrow pits should be filled with silt removed from the canal bed. Delay in beginning cultivation should be prevented as far as possible because it causes a prolonged land-preparation period as well as a longer period of irrigation water issue. Improved field drainage and improved drainage of the natural environment is particularly important as are preventive agricultural practices such as the transplanting technique. Over-issues of water should be avoided so farmers are not unable to adapt to a situations of water scarcity. The possibilities of introducing staggered cultivation should be studied with particular reference to the frequent delays in cultivation because of problems with the supply of draught power and other inputs in the one vital cultivation month.

The monitoring of flows in distributary and field channels should be intensified. This would give an insight into the quantity of water as well as identifying distribution at this level and the type of water use efficiencies that result.

Action has to be taken against erosion and silting in canals, tanks, and paddy fields and checks on the area rainfall distribution should also be made regularly, in order that irrigation inflow can be adjusted.

It is now being increasingly recognized in Sri Lanka that the medical profession cannot be held entirely responsible for providing remedial action for health risks introduced by engineers. What is needed for long-term control of vector-borne diseases is inter-sectoral collaboration between the engineering and the medical professions both at ministerial level and at project level. This is a prerequisite for incorporating preventive measures into the design and management of irrigation projects.

References

Anti-Filariasis Campaign 1978-83. Administration Reports. Ministry of Health, Mount Lavinia.

Anti-Malaria Campaign 1978-83. Administration Reports. Ministry of Health, Colombo.

Anti-Malaria Campaign 1984. Second Independent Assessment of the intensive Malaria Control Programme. Ministry of Health, Colombo.

Axtell, R.C. 1979. Principles of Integrated Pest Management (IPM) in Relation to Mosquito Control. Mosquito News, 39:709-718.

Blas, B.L. 1976. Agro-Engineering and Sanitation Improvement in the Control of Schistosoma Japonica in the Philippines; A Review. South-East Asian Journal of Tropical Medicine and Public Health. 7(22): 341-345.

Central Bank of Ceylon 1980. Review of the Economy. Central Bank of Ceylon, Colombo. 324 pp.

Fernando, M. (ed.) 1984. Human Population Movements and their Impact on Tropical Disease Transmission and Control in Sri Lanka. Proceedings of a Workshop. Faculty of Medicine, University of Peradeniya/UNDP/World Bank/WHO, Peradeniya. 180 pp.

Gunawardena, L. 1983. Analysis of Zone 2, System C. Mahaweli Economic Agency, Colombo.

Hairston, N.G. and B.C. Santos 1961. Ecological Control of the Snail Host of Schistosoma Japonicum in the Philippines. Bulletin of World Health Organization. 25: 603-610.

Hunting Technical Services Ltd. 1980. Feasibility Study, System C, Mahaweli Project. Borehamwood, United Kingdom.

Jayasekara, N. and K.S.P. Kalpage. Entomological and parasitological Field Study on the Transmission of Bancroftian filariasis in Sri Lanka. Medical Research Institute, Colombo (in preparation).

Mahaweli Economic Agency 1985. Statistical Bulletin, System C up to End December 1984. Mahaweli Authority of Sri Lanka, Colombo.

Mather, T.H. and Trink Than That 1984. Environmental management for vector control in rice fields. Irrigation and Drainage Paper 41, FAO, Rome.

Ministry of Health 1983. Annual Health Bulletin. Ministry of Health, Sri Lanka, Colombo.

Ministry of Mahaweli Development/MMD 1983. Mahaweli Project and Programmes. Ministry of Mahaweli Development, Colombo.

Moore, M.P. 1980. Approaches to Improving Water Management on Large-Scale Irrigation Schemes in Sri Lanka. Occasional Publication 20, Agrarian Research and Training Institute, Colombo. 47 pp.

People's Bank 1980. Economic Review. Research Department, People's Bank, Colombo. 6(3): 3-21.

Surtees, G. 1970. Effects of Irrigation on Mosquito Populations and Mosquito-Borne Diseases in Man, with particular reference to Rice Field Extension. International Journal of Environmental Studies. 1: 35-42.

TAMS (Tippets, Abbett, McCarthy, Stratton) 1980. Environmental Assessment, Accelerated Mahaweli Development Programme. For Ministry of Mahaweli Development. TAMS, New York.

World Health Organization 1982. Manual on Environmental Management for Mosquito Control. Offset Publication 66. WHO, Geneva. 281 pp.

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