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 expa-
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
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 during 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 drowned 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 cattle, 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 diagnosed 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 everyday 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 m³/sec 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>
<thead>
<tr>
<th>Occupational group</th>
<th>Intensity of intestinal bilharzia infection in eggs per gram of faeces</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canal cleaners</td>
<td>1700 to 2200</td>
</tr>
<tr>
<td>Sugar cane cutters</td>
<td>0 to 3800</td>
</tr>
<tr>
<td>Other villagers</td>
<td>0 to 1400</td>
</tr>
</tbody>
</table>

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 disap-
peared. 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 esheens 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 asterisks are villages in 'core stratum', and small asterisks 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 con-
taminated 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 severe-
ly 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 conta-
minted 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](image-url)
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 Government’s 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

![prevalence of diarrheal disease in children, cases per two weeks in %](image)

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 develop 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.
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

<table>
<thead>
<tr>
<th>Item</th>
<th>GRP Budget in million U.S. dollars</th>
<th>Diseases(^*)</th>
<th>Portion allocated to health in %</th>
<th>Amount for health in million U.S. dollars</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Improved irrigation structures</td>
<td>14.3</td>
<td>M</td>
<td>10</td>
<td>1.43</td>
</tr>
<tr>
<td>2. Canal maintenance weeding Research</td>
<td>7.3</td>
<td>M/B</td>
<td>50</td>
<td>3.65</td>
</tr>
<tr>
<td>3. Improved drainage system</td>
<td>23.0</td>
<td>M</td>
<td>50</td>
<td>11.50</td>
</tr>
<tr>
<td>4. Telecommunications – water control</td>
<td>11.8</td>
<td>M</td>
<td>10</td>
<td>1.18</td>
</tr>
<tr>
<td>5. Bilharzia program</td>
<td>6.0</td>
<td>B</td>
<td>100</td>
<td>6.00</td>
</tr>
<tr>
<td>6. Rural water supply</td>
<td>15.3</td>
<td>B/D</td>
<td>67</td>
<td>10.25</td>
</tr>
<tr>
<td>7. Water and sanitation – housing</td>
<td>4.3</td>
<td>B/D</td>
<td>50</td>
<td>2.15</td>
</tr>
<tr>
<td>8. Agricultural and irrigation research</td>
<td>3.8</td>
<td>M/B</td>
<td>10</td>
<td>0.38</td>
</tr>
</tbody>
</table>

Total: 36.54
Contingencies of 30%: 10.96

TOTAL FOR HEALTH: 47.50

\(^*\) M = Malaria, B = Bilharzia, D = Diarrhoea

Campaigns 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 unnecessary. 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.
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 prevalence 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
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 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 outskirts 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
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 cm², 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 develop 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.
<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Patillas</td>
<td>Guayama</td>
<td>Guanica</td>
<td>Cabo Rojo</td>
<td>Aibonito</td>
<td>San German</td>
<td>Salinas</td>
<td>Yabucoa</td>
<td>Las Piedras</td>
<td>Luquillo</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arroyo</td>
<td>Vieques</td>
<td>Lakes and reservoirs</td>
<td>Lajas</td>
<td>Sabana Grande</td>
<td>Maunabo</td>
<td>Barranquitas</td>
<td>Humacao</td>
<td>Juncos</td>
<td>Comerio</td>
<td>Cidra</td>
<td>Cayey</td>
<td></td>
</tr>
</tbody>
</table>

**Control Methods**

- Fuadin*
- Sodium pentachlorphenate
- Ditching and drainage
- 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

|------|------|------|------|------|------|------|------|------|------|------|------|------|

* 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).

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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
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 m³ of water when full, has a surface area of 4000 m² 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 impor-
tant 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 ponds**

<table>
<thead>
<tr>
<th>Pond</th>
<th>Municipality</th>
<th>At spillway elevation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Maximum depth in m</td>
</tr>
<tr>
<td>B</td>
<td>Aguas Buenas</td>
<td>4.5</td>
</tr>
<tr>
<td>C</td>
<td>Aibonito</td>
<td>6.5</td>
</tr>
<tr>
<td>D</td>
<td>Aibonito</td>
<td>2.6</td>
</tr>
<tr>
<td>E</td>
<td>Cayey</td>
<td>1.7</td>
</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th>Item</th>
<th>Pond D</th>
<th>Pond E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emergency spillway elevation (m)</td>
<td>4.1</td>
<td>1.6</td>
</tr>
<tr>
<td>Proposed draw-down (m)</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Average shore slope in draw-down zone, horizontal:vertical</td>
<td>1.6:1</td>
<td>13:1</td>
</tr>
<tr>
<td>Maximum water temperature in °C</td>
<td>27</td>
<td>28</td>
</tr>
<tr>
<td>Pond area at spillway elevation (m²)</td>
<td>2400</td>
<td>568</td>
</tr>
<tr>
<td>Water volume in fluctuation zone (m³)</td>
<td>1200</td>
<td>280</td>
</tr>
<tr>
<td>Required draw-down rate (cm/hour)</td>
<td>Night 27</td>
<td>Day 5.8</td>
</tr>
<tr>
<td>Proposed siphon discharge (l/s)</td>
<td>180</td>
<td>9</td>
</tr>
<tr>
<td>Maximum static head on siphon (m)</td>
<td>3.5</td>
<td>0.6</td>
</tr>
<tr>
<td>Siphon diameter (cm)</td>
<td>15</td>
<td>10</td>
</tr>
<tr>
<td>Measured discharge coefficient</td>
<td></td>
<td>0.6</td>
</tr>
<tr>
<td>Total cost of siphon in place in $</td>
<td>791.00</td>
<td>254.00</td>
</tr>
<tr>
<td>Cost of materials in $</td>
<td>300.00</td>
<td>116.00</td>
</tr>
</tbody>
</table>

**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.

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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](image-url)
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 reinfection. 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 nighttime 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-
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 10000 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

<table>
<thead>
<tr>
<th>System</th>
<th>Turbidity in standard units</th>
<th>Phosphates in mg/l (ppm)</th>
<th>Hardness as MgSO$_4$ in mg/l (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patillas System</td>
<td>9.0</td>
<td>0.01</td>
<td>45</td>
</tr>
<tr>
<td>Guajataca System</td>
<td>1.4</td>
<td>0.01</td>
<td>149.5</td>
</tr>
<tr>
<td>Juana Diaz System</td>
<td>4.0</td>
<td>0.06</td>
<td>21</td>
</tr>
<tr>
<td>Lajas Valley System</td>
<td>16</td>
<td>0.03</td>
<td>140</td>
</tr>
</tbody>
</table>

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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*

<table>
<thead>
<tr>
<th>Canal</th>
<th>Length in kms</th>
<th>Discharge at head end in m³/sec</th>
<th>Mean Velocity in m/sec</th>
<th>Type of lining</th>
<th>Prevalence of silt in canal</th>
<th>Biomphalaria glabrata population</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patillas</td>
<td>42</td>
<td>3.6</td>
<td>0.6</td>
<td>earth</td>
<td>no</td>
<td>abundant prior to control</td>
</tr>
<tr>
<td>Guayama East Guamani</td>
<td>10</td>
<td>1.0</td>
<td>0.6</td>
<td>earth</td>
<td>no</td>
<td>abundant prior to control</td>
</tr>
<tr>
<td>Guayama West Guamani</td>
<td>20</td>
<td>1.5</td>
<td>0.6</td>
<td>earth</td>
<td>no</td>
<td>abundant prior to control</td>
</tr>
<tr>
<td>Juana Diaz</td>
<td>–</td>
<td>3.6</td>
<td>0.6</td>
<td>earth</td>
<td>yes</td>
<td>not studied</td>
</tr>
<tr>
<td>Guajataca</td>
<td>58</td>
<td>2.8</td>
<td>0.4-1.2</td>
<td>concrete</td>
<td>no</td>
<td>rare</td>
</tr>
<tr>
<td>Lajas Valley</td>
<td>36</td>
<td>8.6</td>
<td>1.7</td>
<td>concrete</td>
<td>no</td>
<td>absent</td>
</tr>
</tbody>
</table>

*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 $\Delta ST$ the decrease in positive reactors to the skin test from 1963 to 1976 and $\Delta W$ 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 ($r^2$). Clearly the major factor operating in the non-controlled municipalities.

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

This simple equation $\Delta ST = 1.6 \Delta W$ 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 $21.1\% \times 1.6$, 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 km², thus
### Table 4.7 Calculated allocations of observed decreases in skin test positivity for Caguas, Guayama, and Arroyo, Puerto Rico

<table>
<thead>
<tr>
<th>Municipality</th>
<th>Proportion of households with piped water</th>
<th>Proportion of positive reactors to skin test</th>
<th>Decrease in positive reactors to skin test calculated from improved water supply</th>
<th>Residual decrease in positive reactors not explained by improved water supply</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1960</td>
<td>1970</td>
<td>ΔW</td>
<td>1973</td>
</tr>
<tr>
<td>Caguas</td>
<td>0.721</td>
<td>0.932</td>
<td>0.211</td>
<td>0.429</td>
</tr>
<tr>
<td>No snail control</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Guayama</td>
<td>0.814</td>
<td>0.878</td>
<td>0.062</td>
<td>0.463</td>
</tr>
<tr>
<td>Snail control</td>
<td>1953-1978</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arroyo</td>
<td>0.737</td>
<td>0.831</td>
<td>0.094</td>
<td>0.343</td>
</tr>
<tr>
<td>Snail control</td>
<td>1953-1978</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The cost for Guayama and Arroyo was 207 km² 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/km². As the scheme progressed the people were regrouped 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 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.
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 con-
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

<table>
<thead>
<tr>
<th>Reclaimed Area</th>
<th>Annual costs per ha</th>
<th>Crops</th>
<th>Annual benefits per ha</th>
<th>Benefit/cost ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>US$ Total</td>
<td>US$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>4.5</td>
<td>683</td>
<td>152 wheat</td>
<td>1151</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>rice</td>
<td>3238</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>alfalfa</td>
<td>6884</td>
</tr>
<tr>
<td>2</td>
<td>5.5</td>
<td>1415</td>
<td>257 rice</td>
<td>5037</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>alfalfa</td>
<td>10707</td>
</tr>
<tr>
<td>3</td>
<td>14.5</td>
<td>2217</td>
<td>157 wheat</td>
<td>4217</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>alfalfa</td>
<td>25240</td>
</tr>
</tbody>
</table>

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 reinstated. 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
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 bilharzia 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\%; after sanitation 22\%.

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

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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.

![Mortality curve during a malaria epidemic in Brengkok, East-Java, wet season 1933](image)

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. *sundaiica*).

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

<table>
<thead>
<tr>
<th></th>
<th>No. of An. mosquitoes collected</th>
<th>No. of An. mosquitoes infected</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>from cow-shed in period total</td>
<td>from houses storage gland</td>
</tr>
<tr>
<td>An.subpictus</td>
<td>43 971 1014</td>
<td>964 – – –</td>
</tr>
<tr>
<td>An.ludlowi</td>
<td>– 157 157</td>
<td>146 44 36 68</td>
</tr>
<tr>
<td>An.aconitus</td>
<td>1 1 2</td>
<td>2 – – –</td>
</tr>
</tbody>
</table>

*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 ricelands. 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

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*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.-ludlowii 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.ludlowii near the village Brengkuk, East Java, Indonesia](image-url)
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.

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* 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

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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.
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