Annex 2
Case study: Gorgol Rice Irrigation System, Mauritania

2.1 Introduction

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

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

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

Figure 2.1 Proposed Gorgol Irrigation Project

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

The staff conducting the field surveys included a public health engineer, an entomologist, and an epidemiologist-physician. There was also a laboratory technician, who translated French and the local Peuhl language for the physician. Skin tests for bilharzia and blood-slide examinations for malaria and other parasites were made amongst school children in the two major towns of the project area. School children in several villages along the river were also tested. All water bodies were examined for snails and insects, and mosquitoes trapped in homes and other buildings were examined.

Human patterns of water contact were observed along the river and general information on water quality and temperature was collected from a pilot rice farm and from existing rice fields. The field data on snails and aquatic ecology made it possible to improve the snail population model and to better simulate conditions in the project's reservoirs and canals.

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

2.2 Summary and recommendations

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

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

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

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

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

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

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

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

### 2.3 Analysis and predictions

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

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

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

2.3.2 Prediction of snail populations in the original system design

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

2.3.3 Prediction of effects of water level fluctuations

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

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

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

Figure 2.3 Predicted populations of *Bulinus guernei* in the proposed reservoirs
2.4 Proposed modifications to Gorgol Project preliminary design

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

2.4.1 General aspects of proposed modifications

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

2.4.2 Protection of the farming population

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

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

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

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

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

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

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

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

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

2.4.4 Modifications to reservoirs

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

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

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

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

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

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

In general, the problems expected at El Bir Reservoir were not as severe as those expected at Foum Gleita. The nearest human settlement was Leixeiba, lying some distance below the Reservoir. The yearly cycle of operation here included complete drying during the month of June and shore slopes were flatter at El Bir than at Foum Gleita.
Thus snails were more readily stranded. If the recommended fluctuation schedule was followed in the upstream reservoir at Foum Gleita, a similar cycle of fluctuation would occur in El Bir Reservoir and no further measures should then be necessary.

2.4.5 Facilities for an operational schistosomiasis control program

Laboratory and outpost

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

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

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

Vehicles and boats

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

2.4.6 Periodic drying of rice fields and canals

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

2.4.7 Preventive measures during construction

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

References

3.1.2 Water level management

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

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

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

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

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

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

3 CONSTANT LEVEL POOL
Provides long-range plant growth.

4 CYCLIDAL FLUCTUATION
Destroys mosquito eggs and larvae.

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

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

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

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

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

3.1.3 Type of reservoir and water level management

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

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

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

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

3.1.4  Applicability for the tropics

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

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

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

The Damodar Valley Corporation (DVC)

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

However, the possibility of production existed where the main pools of the two constant level barrage ponds were concerned. Use requirements and dam design prohibited incorporating water level recession in the water management plans of these shal-
low ponds. A plan of weekly water level fluctuation was developed which fitted in with other water use requirements.

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

3.2 Lake Volta, Ghana

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

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

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

Soon after it had filled in 1966, the lake began to harbour an enormous fish population, and coastal Ewe fishermen, and their families migrated there. A seasonal migration back to the coast takes place every year when the fishing season ends. Fishermen stay on the coast until the fishing on Lake Volta improves again with rising water (see Figure 3.4). With the fish came a great deal of vegetation and the intermediate
Figure 3.4 Shore of Lake Volta, 1978. Inundated trees die but trunks persist for decades causing problems of access and navigation. Fishing activities and accumulation of debris can support snail and mosquito breeding.

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

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

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

One can understand the reluctance of the government to continue this program when the increasing cost of chemicals is examined. The control effort relied on two chemicals purchased overseas: the drug metrifonate and the pesticide bayluscide.
In 1977, when the Ghanaian cedi was worth 0.275 dollars, a kilogram of bayluscide cost US $14 or 50 cedis on the open market. By 1984 the cedi was worth only 0.007 dollars, and a kilogram of bayluscide cost the government US $17 or 2429 cedi's. It is possible that bilharzia in the Lake Volta area has been held in check by the drought years of the early 1980's. It can be expected, however, that when the lake is full again, another severe urinary bilharzia epidemic will occur.

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

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

3.3 Brazil; north-east coast reservoirs

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

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

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

3.3.1 Reservoir in the north-east

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

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

The effect of the molluscicides was least pronounced if the chemical was applied during the breeding season. This was due primarily to the high reproductive rate of snails. If the applications were made in May, the lowest number of snails recorded during the year was 111, this total being recorded immediately following the first chemical application. The next week there was a burst of egg-laying due to changed environmental conditions and the uncrowded habitat. The number of snails rose to 2251 with 23,000 eggs being laid. 1982 snails remained alive after the second chemical application. The reservoir was now full and contained 9000 m³ of water. For the remainder of the breeding season the number of snails increased steadily. In contrast chemicals applied in November when the reservoir was low with only 50 m³ of water, caused snail population to drop to ten by April. There was no population recovery following the application of molluscicides because the water temperatures were too high for oviposition, and the habitat had dried out completely by December. This forced the 48 survivors to aestivate.

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

3.3.2 Reservoir in Minas Gerais

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

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

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

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

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

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

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

References


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