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JESS INTERIM REPORT ON HEALTH IMPACTS OF DESIGN ALTERNATIVES FOR PROPOSED BAARDHEERE DAM

JESS Report No. 5

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CONTENTS

Section		Page
List of Tables		i
List of Figures		ii
Preface		iii
I.	Executive Summary	1
II.	Introduction	2
III.	Potential Diseases Around Dam and Reservoir	4
	A. Malaria	4
	B. Bilharzia (Schistosomiasis)	4
	C. River Blindness	6
	D. Other Diseases	6
IV.	Existing Patterns of Disease Transmission in the Jubba River Valley	7
V.	Predicted Extent of Aquatic Habitats Around Reservoir	10
VI.	Predicted Disease Transmission Around Reservoir	18
VII.	Need for Shoreline Modifications	20
VIII.	Required Discharge Rates from Dam to Control Mosquitoes	22
	A. Flood Surcharges	22
	B. Cyclic Fluctuations	23
	C. River Flushing	24
IX.	Required Discharge Rates from Dam to Control Bilharzia Snails in Reservoir	27
X.	Summary of Discharge Requirements for Dam	31
XI.	Economic Aspects of Increased Discharge Rates at Dam	32
XII.	Design Preference for Blackfly Control	35
XIII.	Need for Health Considerations in Dam Operation	38
IX.	Conclusions and Recommendations	39
	A. Operations Team to Control Dam Operation	40
	B. Discharge Capacity of Proposed Bottom Outlets	40
	C. Structural Aspects of Bottom Outlets	41
	D. Provision of Shoreline Improvements Around Reservoir	42
References		43

LIST OF TABLES

Table	Title	Page
1.	Calculation of Shore Slopes for Five Segments of Reservoir Behind Dam	11
2a.	Required Vertical Drawdown Rates to Strand Bilharzia Snails in Reservoir, According to Shore Slope	17
2b.	Expected Seasonal Recession Rates Determined from 32-Year Simulation of Reservoir Operation	17
3.	Required Outlet Discharges for Dam to Drop Flood Surcharge for Stranding Driftwood and Floating Vegetation as Mosquito Control Method in Reservoir	23
4.	Discharge Required from Dam for Mosquito Control at Steady High-Water Level, with 0.3-Meter Fluctuation on a Weekly Cycle	24
5.	Estimation of Extent of Impact Downstream on Mosquito Populations from Stream-Flushing Technique	26
6.	Estimated Secchi Disk Readings for Reservoir, and River Discharge Rates at Luuq, by Month	29
7.	Required Discharges at Dam to Draw Reservoir Level Down to Various Secchi Disk Depths	29
8.	Discharge at Dam Needed to Strand Snails at Maximum Reservoir Level for Various Fluctuations with Period of One Week	30
9.	Summary of Discharge Requirements for Dam to Control Mosquitoes and Snails in Reservoir	31
10.	Estimated Annual Costs of Alternative Disease Control Measures for Reservoir Behind Dam	33
11.	Optimization of Maximum Discharge Rate for Outlets in Dam, for Maximum Control of Malaria Mosquitoes and Bilharzia Snails in Reservoir	34

LIST OF FIGURES

Figure	Title	Page
1.	Map of Jubba Valley in Somalia.	3
2.	Anopheline mosquito, which spreads malaria in Somalia, and aquatic snails, which spread bilharzia.	5
3.	Seasonal disease transmission.	9
4.	Four views of Sector B of reservoir.	12
5.	Four views of Sector C of reservoir.	13
6.	Four views of Sector D of reservoir.	14
7.	Sketch of typical edge of reservoir.	16
8.	Predicted seasonal transmission of malaria and bilharzia.	19
9.	Amphibious lymnaeid snail which spreads parasites to cattle, sheep and goats.	28
10.	The blackfly, which spreads river blindness.	36

PREFACE

The Jubba Environmental and Socioeconomic Studies (JESS) (number 649-0134) are jointly funded by the government of the Somali Democratic Republic (GSDR) and U.S. Agency for International Development (USAID). JESS is part of a larger project funded by USAID and the GSDR, the Jubba Development Analytical Studies (JuDAS) project. Technical assistance and JESS management are being provided to the Ministry of Jubba Valley Development (MJVD) by Associates in Rural Development, Inc. (ARD) of Burlington, Vermont, under USAID contract number AFR-0134-C-00-5047-00. This report concerns analyses which occurred in the early part of Phase II of JESS, during a consultancy for ARD by Dr. William R. Jobin of Blue Nile Associates. The report was developed after a June 1986 consulting visit concerning water-quality and public health engineering aspects of the proposed Baardheere Dam on the Jubba River in southwestern Somalia.

I. EXECUTIVE SUMMARY

Precautions should be taken in the design and operation of the proposed Baardheere Dam in Somalia to prevent unnecessary outbreaks of waterborne diseases in nearby human and animal populations. Several important human and animal diseases may increase in prevalence and severity around the proposed reservoir on the Jubba River, because of the increased availability of water and aquatic habitats for the insects and snails which transmit malaria, bilharzia and other diseases.

Fortunately, these insect and snail populations can be reduced by careful fluctuation of the reservoir water level, stranding them on dry land, where they die. The ability to cause rapid recession of the water will be limited by the size of the bottom outlets in the dam. Thus the bottom outlets should be made large enough to minimize these health problems.

Analysis of records on river flows indicated that the bottom outlets should be designed to pass a maximum discharge of 1,050 cubic meters per second (cu m/s) for three to four days out of each week during certain seasons. This would make it possible to control mosquito and snail populations in the reservoir 31 years out of 32, and the intermittent nature of the flow would result in an averaged weekly discharge below 700 cu m/s by the time the flow reached Kamsuma Bridge, about 370 kilometers downstream.

Additional consideration should also be given to the detailed design of the control device for the bottom outlets. The original design of the outlet control device, using a valve of the Howell-Bunger type, would produce less potential for blackfly breeding than would the proposed alternate design of an under-flowing radial gate.

While providing financing for the dam, provision should be made to fund shoreline modifications of the proposed reservoir, aimed at straightening and leveling the shoreline in areas close to expected human settlements to further minimize health risks from a wide variety of diseases transmitted.

Finally it is recommended that an operations team control the dam, including a technical representative for health, responsible for coordinating the health requirements for operation with the requirements determined by the other members for power, irrigation and flood control.

II. INTRODUCTION

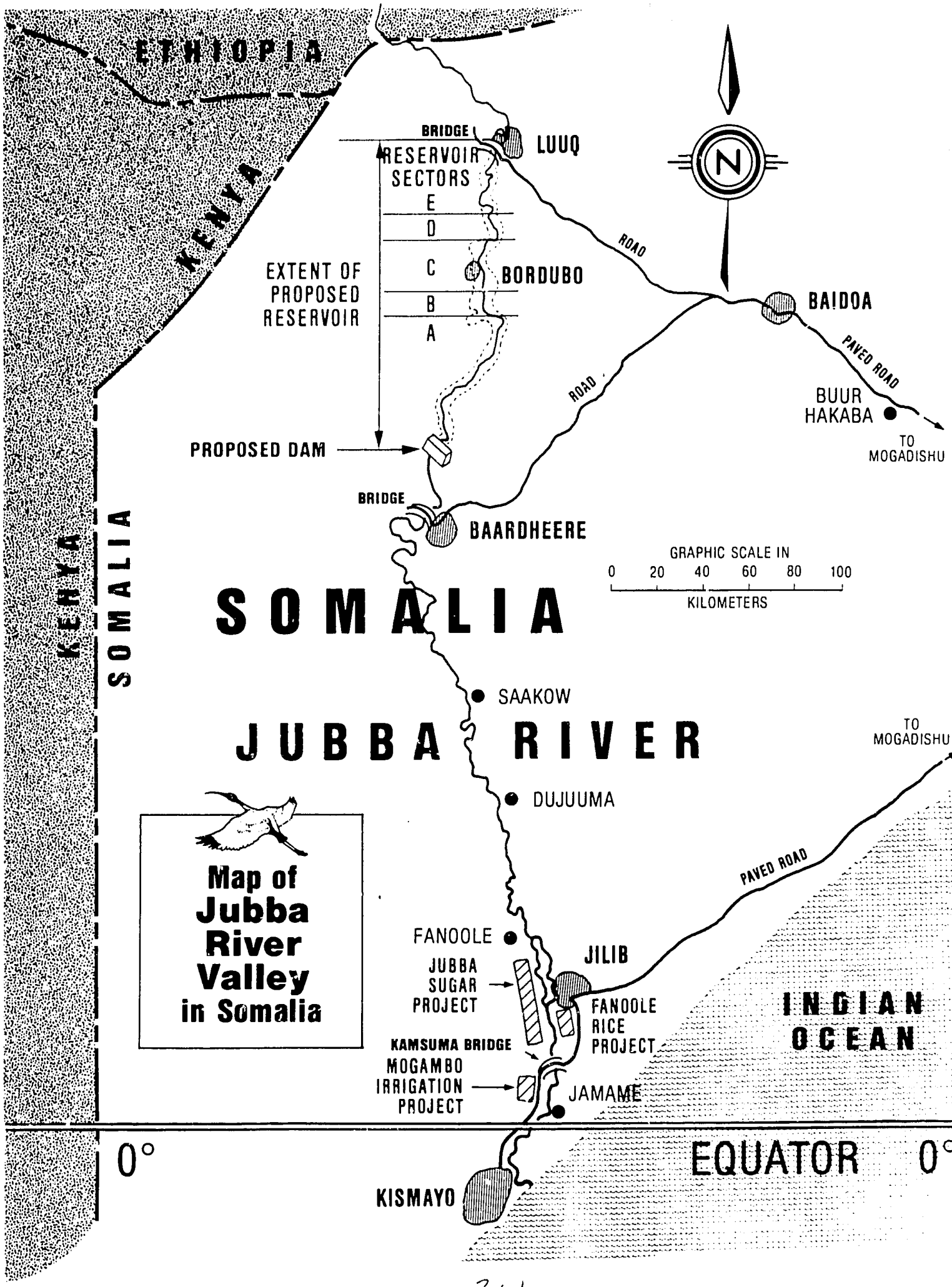
Completion of the proposed dam on the Jubba River near Baardheere, Somalia, will have the aim of balanced development of the resources of the Jubba River Valley, including protection of human and animal health (Figure 1). Optimization of the final design thus requires consideration of potential ecological and health impacts of the dam on the surrounding region, especially around the reservoir and downstream in the irrigated zones along the river. This interim report describes the first part of the ecological and health consideration, evaluating the health impact of alternative designs of the bottom outlets for the dam, features still under consideration at the time of completion of this report.

Malaria and bilharzia (schistosomiasis) are the major human diseases expected to increase around the reservoir with construction of the dam, with the possibility of increases in parasitic diseases of cattle, camels, sheep and goats. Shoreline populations of the mosquitoes and aquatic snails which transmit some of these diseases could be reduced by periodic fluctuations in the reservoir water level. Thus, analyses were directed at determining the impacts of the size of the bottom outlets in the proposed Baardheere Dam on the operational flexibility needed to produce the required fluctuations. The most important consideration was the maximum discharge which the outlets would pass, thus determining the maximum drawdown rate for the reservoir water level, an important parameter in mosquito and snail control. A secondary consideration was the detailed design of the outlets, as they might become sites for breeding of the blackflies which spread another disease called river blindness (onchocerciasis).

Although other diseases are also of concern for the human and animal populations which will congregrate around the reservoir, only malaria, bilharzia and river blindness were considered in this analysis, as the other diseases are not directly affected by the design of the outlets or other features of the dam. Prevention and control of the other diseases will be examined in later JESS reports, including proposals for shoreline alterations in the proposed reservoir to minimize health problems.

Figure 1. Map of Jubba River Valley in Somalia.

Map shows five geographical sectors of proposed reservoir behind Baardheere Dam.



Map of Jubba River Valley in Somalia

30)

III. POTENTIAL DISEASES AROUND DAM AND RESERVOIR

The creation of a large body of fresh water in a semiarid region, the expected result of construction of Baardheere Dam, will attract all kinds of animal and human populations drawn by the value of the water for domestic and agricultural uses. Unfortunately, the water is also conducive to populations of aquatic insects, snails and other small organisms which spread diseases among humans and domestic animals. Experience with major reservoirs and irrigation schemes throughout Africa and other tropical regions has shown that the spread of disease is almost an inevitable result of water resource development in the tropics. Major diseases are malaria and bilharzia, but many other human and animal diseases are also to be expected.

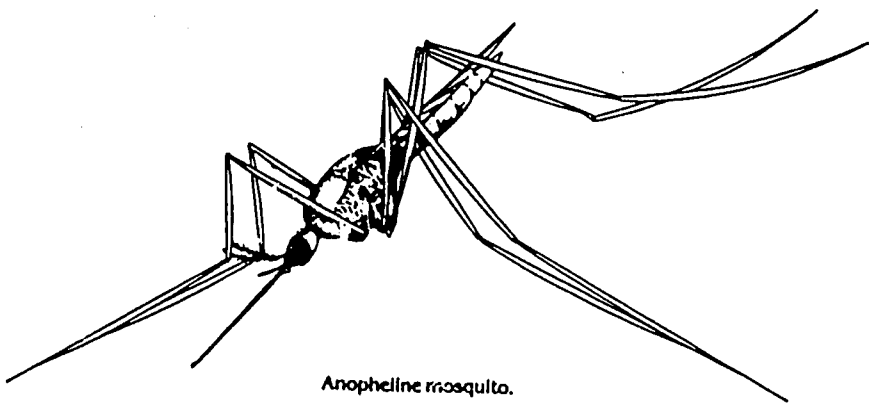
Both permanent and temporary congregations of people and their animals are highly likely around the proposed reservoir, based on experiences in other parts of Africa and the mobility of the Somali people. Prediction and control of the location and magnitude of these settlements, however, are extremely difficult. Perhaps the first necessary step is to consider the best land uses around the reservoir, given the character of the land and availability of such a large supply of water. From a land-use policy one could then establish guidelines for expected settlements and grazing patterns, and finally provide facilities to encourage development in the desired path. However, at the time of the health planning described in this report, it was only possible to assume that the reservoir would attract large populations of people and animals, and that provisions must be made for their protection.

A. Malaria

The most common of the tropical diseases related to water, malaria is transmitted throughout the tropics by anopheline mosquitoes whose eggs and immature forms are found infesting reservoirs, canals, drains, temporary rain pools and other flooded areas containing stagnant waters. In Somalia, there are two critical malaria seasons, shortly after each of the rainy seasons, due to the large areas of standing water where the mosquitoes lay their eggs, and to the high humidity which favors the survival of adult mosquitoes (Figure 2).

B. Bilharzia (Schistosomiasis)

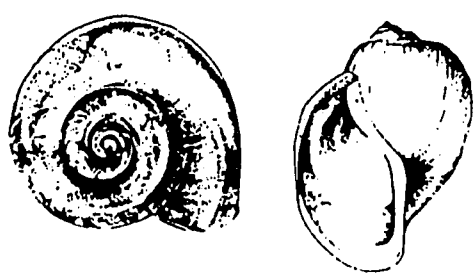
Bilharzia is a parasitic disease transmitted in a complex cycle through fresh water snails, an infection closely linked with irrigation in the tropics (Figure 2). It is also known as schistosomiasis and classically associated with the Nile Delta,



Anopheline mosquito.

MALARIA

The most common of the tropical diseases related to water, malaria is transmitted throughout the tropics by anopheline mosquitoes which are often found infesting reservoirs, irrigation canals and drains. Due to resistance to insecticides and drugs, prevention by environmental modification is becoming a necessity in water resource developments. These environmental control measures are best implemented in the design stages of a project.



Shells of planorbid snails.

BILHARZIA

Bilharzia is a parasitic disease transmitted in a complex cycle by fresh water snails, an infection closely linked with irrigation and classically associated with the Nile River. It is also found, however, in the Caribbean area and Brazil, in China, the Philippines and the Middle East. The disease is also known academically as schistosomiasis.

Figure 2. Anopheline mosquito, which spreads malaria in Somalia, and aquatic snails, which spread bilharzia.

The snail on the right is found in Somalia and spreads parasites to people and cattle.

the rivers of Mesopotamia, and nearly all other great tropical rivers. Bilharzia is concentrated in the regions of Somalia with the most surface water, the Shebelli and Jubba river valleys including the inter-riverine zone, and especially the lower Jubba Valley.

C. River Blindness

This disease, prevalent in Africa and tropical America, is spread through the bite of the blackfly, including various species of *Simulium*. The biting blackfly breeds in rapids or whitewater on spillways and water control structures, and is responsible for impeding agricultural development in many fertile river valleys in West Africa. Infested areas are also found in Ethiopia and North Yemen, as well as Uganda and possibly Kenya. There is also one report of these flies from Somalia, but apparently there are too few to present a health problem now.

D. Other Diseases

The same snails which transmit bilharzia to people can also transmit a similar parasite to cattle which causes reduced growth and milk production. Another small, amphibious snail transmits a parasitic liver fluke to sheep and goats. Mosquitoes and ticks also are the vectors of a number of serious diseases infecting camels, cattle, sheep and goats. The tsetse fly transmits a trypanosome parasite to wild and domestic animals as well. All of these insects and snails are attracted to water and the increased vegetation and humidity which large waterbodies provide.

IV. EXISTING PATTERNS OF DISEASE TRANSMISSION IN THE JUBBA RIVER VALLEY

Analysis of available information on weather (Entz, 1982) and water-associated diseases (Ministry of Health, 1986; World Health Organization, 1982) in Somalia showed that the present patterns of disease transmission were closely related to the four seasons of Jilaal (January-March), Gu (April-May), Xagaa (June-September) and Der (October-December). Understanding the existing seasonal patterns of disease transmission was necessary to estimate the effect of the proposed reservoir on these patterns. Reliable data were available for both malaria and bilharzia, primarily from the Shebelli River Valley and the lower Jubba Valley (Figure 3).

There were two peaks of malaria transmission, following the Xagaa and Der seasons (MOH, 1986). Mosquito breeding begins in pools of standing water created by the first rains in these two seasons. The mosquito population takes some time to increase due to a generation period of over two weeks. The mosquito which reproduces in the small flooded depressions in both the Shebelli and Jubba valleys is Anopheles gambiae, an extremely efficient transmitter of the malaria parasite, Plasmodium falciparum. The malaria parasite passed by these mosquitoes among humans also requires several days to reproduce inside the mosquitoes and people, so several weeks elapse before the number of infected people becomes significant. Thus the onset of large numbers of people coming down with malaria fevers is usually two months after the first rains.

The life span of adult mosquitoes, usually only a week or two, is prolonged during Xagaa due to the high humidity and relatively low temperatures (Figure 3). Transmission continues almost to the end of Xagaa, until that brood of mosquitoes has nearly disappeared. The next transmission period starts up after the onset of the Der rains, but is curtailed in late January by the rapid death of adult mosquitoes due to low humidity and higher temperatures. Under these conditions the mosquitoes only live four or five days, which prevents the malaria parasite from reproducing and infecting people. Thus malaria transmission during the extremely dry months of February and March is severely reduced, until the rains of the Gu season start the annual cycle again.

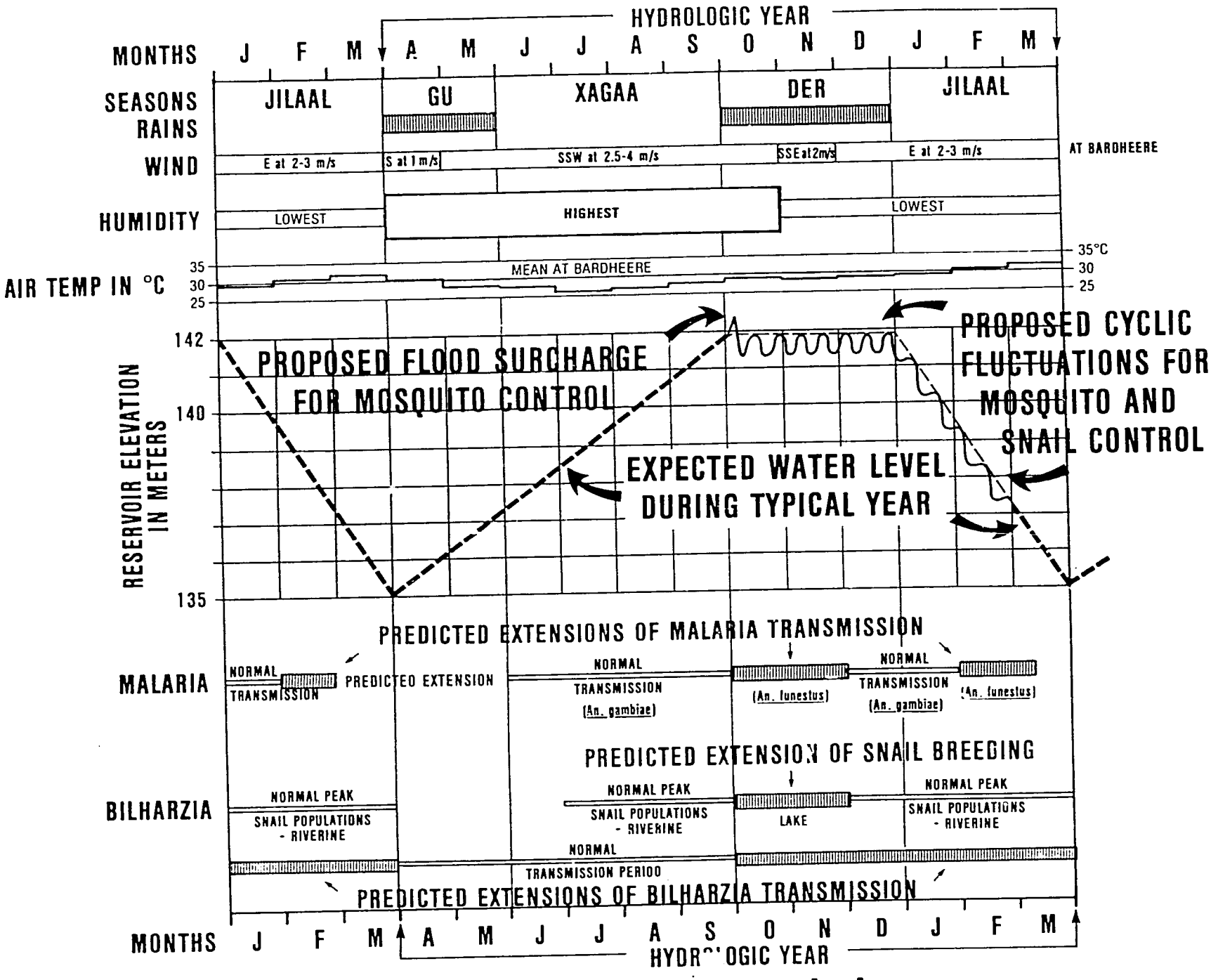
Bilharzia transmission has been studied in detail in the lower Shebelli Valley and there are considerable data on the snail populations as well. The snail species in Somalia is Bulinus abyssinicus, which lives in temporary pools, lakes and depressions, and transmits the urinary form of bilharzia caused by the parasite Schistosoma haematobium. Bilharzia snails live

in standing water away from the main river or canal systems (Upatham, 1981).

Bilharzia snail populations increase during the dry seasons, as the water clears, and decline rapidly during the rainy seasons when the high turbidity shuts out sunlight, preventing growth of algae and vegetation vital to survival of the young snails. These snails live only a few months, requiring continual reproduction to maintain a population. Thus the snail populations experience two peaks each year, roughly in phase with the malaria transmission season (Figure 3).

Transmission of bilharzia to people, is monitored by testing the water for the microscopic larvae of the bilharzia parasite, or by crushing snails to detect parasite forms. Such observations show that there is only one major bilharzia transmission season, in contrast to the two malaria seasons. This covers both the Gu and Xagaa, roughly April through September (Figure 3). Sporadic bursts of transmission are observed occasionally in January and February in the Shebelli studies, however, so there is still some risk of infection during the Jilaal (Upatham, 1981). It should be remembered that the malaria and bilharzia transmission patterns observed in the Shebelli River Valley are probably similar to those in the Jubba River Valley, at greatest intensity in the humid lower valley, and at a lesser intensity in the more arid upper valley.

Figure 3. Seasonal disease transmission.



Seasonal Disease Transmission

V. PREDICTED EXTENT OF AQUATIC HABITATS AROUND RESERVOIR

The initial step in evaluating the health risks around the proposed reservoir was estimation of the extent of aquatic habitats to be expected within and around the lake. It was then possible to predict the insect and snail populations and thus the potential for disease transmission for given conditions of the reservoir and human settlements. This process required a topographical map of the reservoir and information on seasonal wind patterns and weather, seasonal water temperature, clarity and quality, existing soil types and expected water-level fluctuation patterns. From this information the extent of shallow, marginal areas around the reservoir at different times of the year was estimated, an indication of habitat suitability for malaria mosquitoes and bilharzia snails.

Using the topographical map provided in the Electroconsult report of June 1985, the reservoir was divided into five geographically homogeneous sectors in order to simplify the analysis (Figure 1). The sectors were selected on the basis of similar shore slopes.

Mean shore slopes were determined for each sector, treating the west bank and the east bank separately. The horizontal distance from the centerline of the river to the shoreline at the maximum normal operational level was measured perpendicular to the river at the junction of each small tributary, to estimate the horizontal component of shore slope. In Sector B, which has a relatively large tributary entering from the west, these measurements were made perpendicular to that tributary (Figure 4). Thus, the 225:1 slope ratio for that portion of reservoir was not calculated directly from the measurements shown in Table 1, but from separate measurements along the tributary. Therefore, the slopes calculated for this western bank of Sector B are much flatter than they would have been had the measurements been made perpendicular to the mainstem of the Jubba River. However, this is the correct way to interpret the drawdown effect to be noticed by organisms along the shoreline in this area.

The horizontal width of each side of the reservoir was then divided by the vertical rise between the river and the high-water level to obtain the shore slope ratio for each sector. The slopes vary from 10:1 in Sector A to 225:1 in a small area on the west bank of Sector B where a large tributary comes in (Table 1). However, the largest and most important flat area is the west bank of Sector C, which has a slope of 148:1.

Table 1.

Calculation of Shore Slopes for
Five Segments of Reservoir Behind Dam (in meters)

Sector:	A		B		C		D		E*	
Bank:	East	West	East	West	East	West	East	West	East	West
Shore Width	427	330	500	1767	1650	2938	875	1314	186	357
River Elevation	110		121		122		128		135	
Vertical Rise	31.9		20.9		19.9		12.9		6.9	
Slope	E	W	E	W	E	W	E	W	E	W
Ratio	13:1	10:1	24:1	225:1	83:1	148:1	68:1	102:1	27:1	52:1

*Unstable, rapidly fluctuating area at upstream margin of reservoir.

Source: All measurements taken from Electroconsult map BRD 2004, June 1985.

In combination with the slope of the shore, the prevailing wind patterns which will cause waves and shore erosion will determine which portions of the shoreline are suitable for snail and mosquito habitats. There are two important seasonal wind directions for the Baardheere area, a south-southwest wind averaging 2.5-4.0 m/s from May to October, and an east wind at 2.0-2.9 m/s from December to March (Entz, 1982). For shorter periods, transitional winds blow from the south at about 1.4 m/s during April and from the south-southeast at 2.3 m/s during November.

Delineation of the portions of shoreline which are in the wind shadow--that is, the lee shore which is on the side of the reservoir from which the prevailing winds come--and therefore protected from waves and erosion, showed that large areas of the flat shores in Sector C will be protected throughout the entire year (Figure 5). Because of its extremely flat slope (148:1) and large length (about four kilometers), the area on the southwest perimeter of the Sector C shoreline may be the most important, although many other small areas may also harbor snails, on both sides of the reservoir.

Smaller protected and flat areas were also found by similar analysis of Sectors B and D (Figures 4 and 6). Sectors A and E, however, had such steep shores (10:1) that the areas suitable for

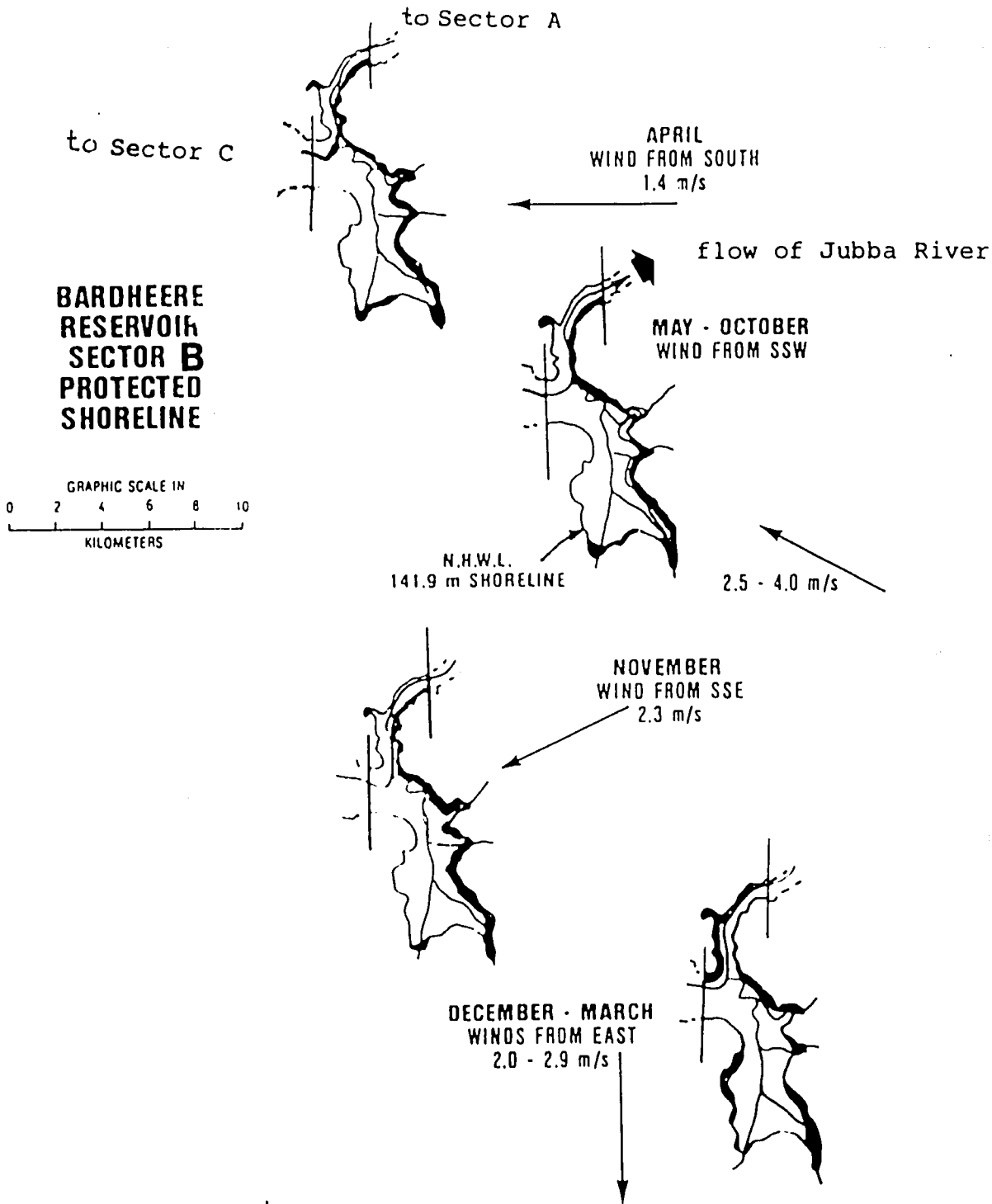
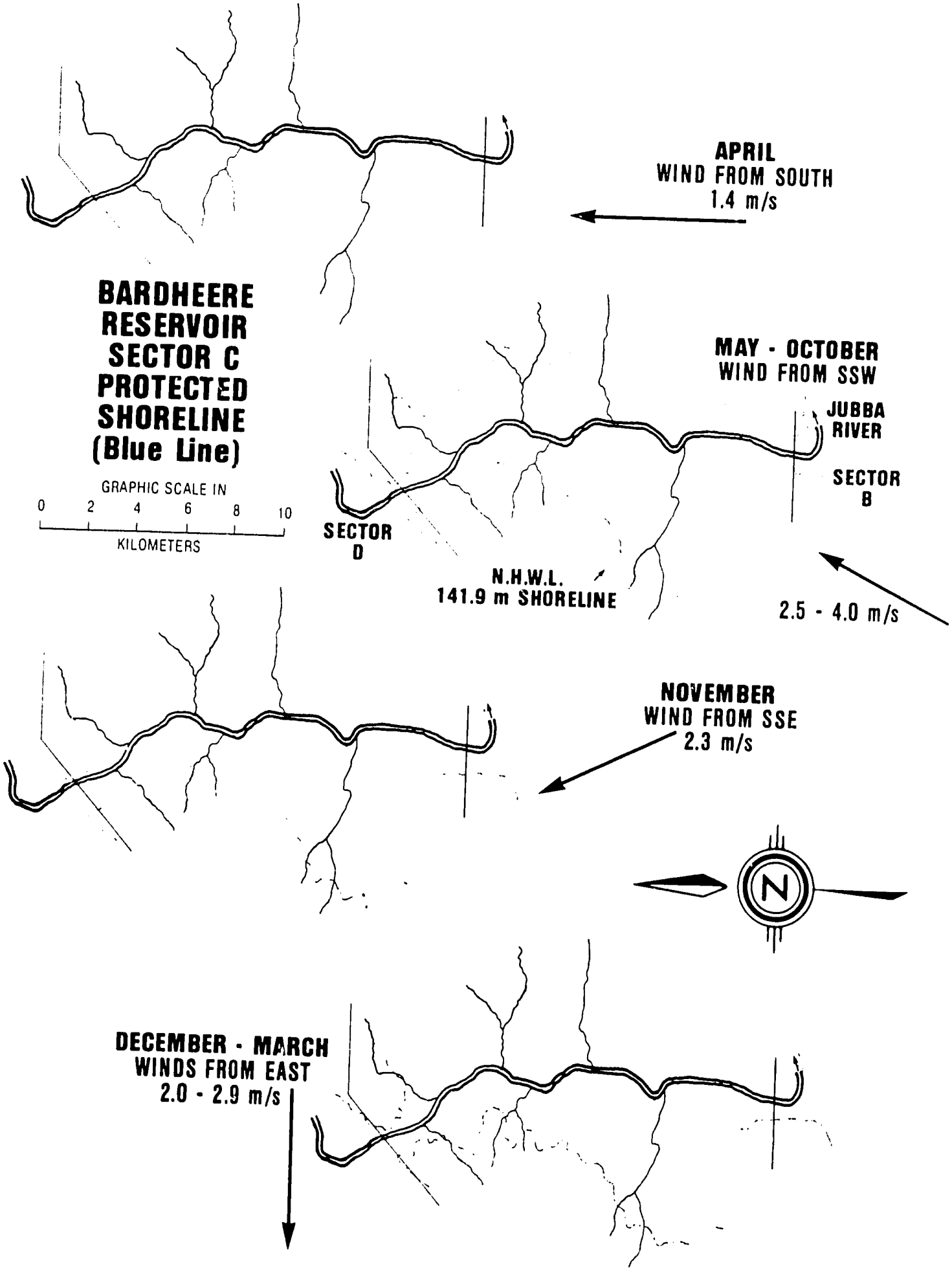


Figure 4. Four views of Sector B of reservoir.

Figure shows seasonal wind patterns. Dark lines represent shores protected from wind and waves.

Figure 5. Four views of Sector C of reservoir.

Figure shows seasonal wind patterns. Thick blue line indicates portions of shoreline protected from wave erosion for four different wind conditions expected in the area.


APRIL
WIND FROM SOUTH
1.4 m/s
BARDHEERE
RESERVOIR
SECTOR C
PROTECTED
SHORELINE
(Blue Line)
GRAPHIC SCALE IN
0 2 4 6 8 10
KILOMETERS
MAY - OCTOBER
WIND FROM SSW
JUBBA
RIVER
SECTOR
B
SECTOR
D
N.H.W.L.
141.9 m SHORELINE
2.5 - 4.0 m/s
NOVEMBER
WIND FROM SSE
2.3 m/s
N
DECEMBER - MARCH
WINDS FROM EAST
2.0 - 2.9 m/s

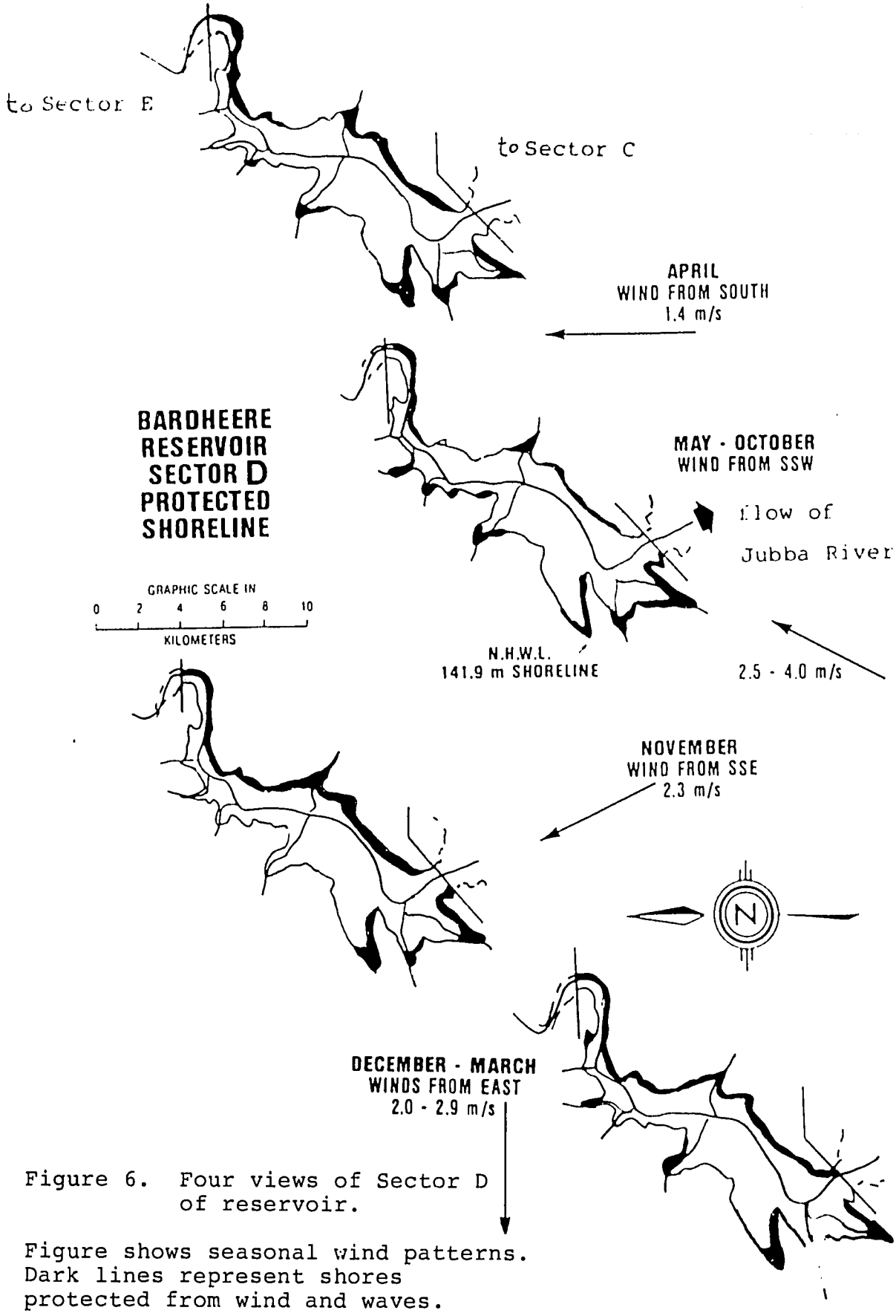


Figure 6. Four views of Sector D of reservoir.

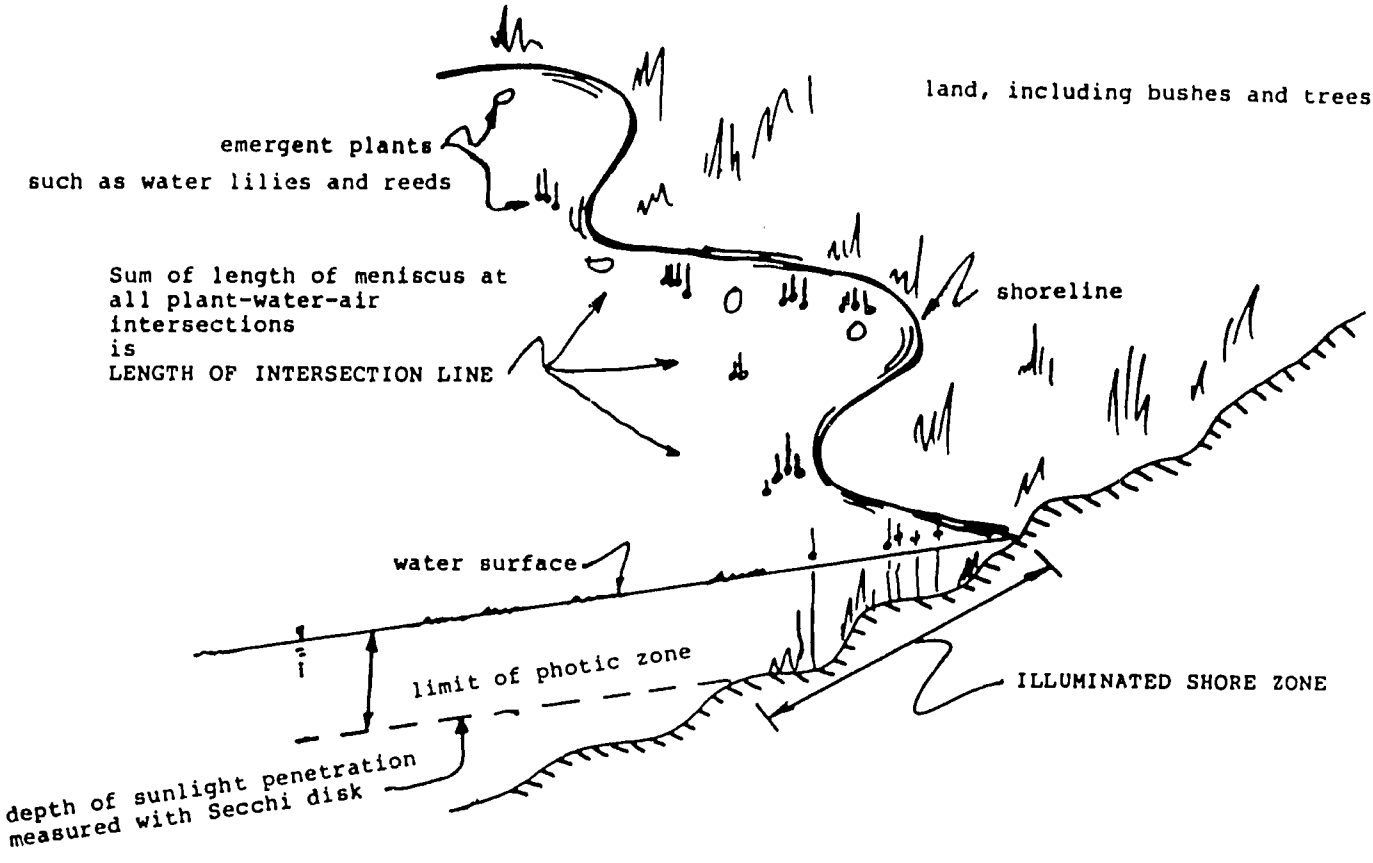
Figure shows seasonal wind patterns. Dark lines represent shores protected from wind and waves.

human settlement and animal grazing were almost nonexistent (Figure 1). Also, the width of the submerged shore illuminated by sunlight would only be a few meters in these two sectors, not sufficient for maintaining snail or mosquito populations.

Both malaria mosquitoes and bilharzia snails depend on aquatic vegetation for food, protection and breeding. This vegetation exists to the depth of sunlight penetration through the water and is usually only found in quiet, shallow portions of reservoirs. The quantity of mosquito breeding is proportional to a measurement related to this vegetation, known as the Intersection Line. The Intersection Line is the line surrounding a plant which marks the intersection of the edges of the plant with the water surface. Thus, it is the line which marks the intersection of the plant, water and air interfaces, recognized on close inspection as a meniscus or arc in the water surface where it wets the vegetation. The meniscus formed along the Intersection Line has peculiar properties of surface tension and refraction which allow attachment of mosquito larvae, an anchor for them against currents, and a hiding place for the larvae from predators such as fish (Figure 7). For bilharzia snails, the vegetation is important primarily as food, and the rate of reproduction is usually proportional to the mass of vegetation per unit volume, within the strip of submerged shore illuminated by sunlight and known as the Illuminated Shore Zone (Figure 7).

The width of the Illuminated Shore Zone can be calculated by multiplying the shore slope by the depth of sunlight penetration. A black and white Secchi disk is used to measure the penetration of sunlight by lowering the disk on a chain into the water until it is no longer visible, and then recording the depth of submergence of the disk. For a Secchi disk submergence of 0.5 meters and a shore slope of 148:1, the width of the Illuminated Shore Zone is calculated as 0.5 meters x 148 or 74 meters. Thus, the southwest portion of Sector C would have a stable Illuminated Shore Zone 74 meters wide by four kilometers long, almost 300,000 square meters of habitat suitable for aquatic vegetation, snails and mosquitoes. This would pose a significant health threat to any human or animal populations attracted to the flat, weeded shoreline of the reservoir for water or food. This is presently the location of the village of Bordubo and a large number of temporary refugee camps. New tropical reservoirs usually experience severe infestations of aquatic vegetation during the first decade after filling, with potential for causing serious problems at this site.

Previous laboratory investigations had shown that the bilharzia snails tended to migrate down slopes at a rate which increased with slope, during daylight hours (Jobin, 1966). This indicated the maximum required drawdown rate for stranding of the snails. Comparison of five sectors in Baardheere Reservoir showed that the typical seasonal recession rates to be expected



DEFINITION SKETCH FOR
ILLUMINATED SHORE ZONE
AND
LENGTH OF INTERSECTION LINE
ALONG SHORE OF TYPICAL RESERVOIR

Figure 7. Sketch of typical edge of reservoir, an ideal habitat for malaria mosquitoes and bilharzia snails.

in the proposed reservoir after the Der season would be adequate to strand the snails in the flat portions of the reservoir (Tables 2a and 2b). However, mosquito control would probably require periodic fluctuations in addition to this normal recession, as the rising water phase seems to be necessary to float the mosquito larvae out into the open where they are attacked by fish and other predators. In the steep portions of Sectors A, B and E, very high rates of vertical drawdown would be required to strand snails; however, such steep slopes are not usually suitable as snail habitats because of the narrow Illuminated Shore Zone and the consequent lack of vegetation for protection against waves.

Table 2a.

Required Vertical Drawdown Rates to Strand Bilharzia Snails in Reservoir, According to Shore Slope

	East Bank		West Bank	
Sector	Slope horiz:vert	Drawdown Rate cm/day	Slope horiz:vert	Drawdown Rate cm/day
A	13:1	148	10:1	188
B	24:1	50	225:1	1
C	83:1	4	148:1	2
D	68:1	6	102:1	2
E	27:1	40	52:1	10

Source: Jobin, 1966.

Table 2b.

Expected Seasonal Recession Rates Determined from 32-Year Simulation of Reservoir Operation

Maximum Recession Rate 1955 and 1965	5.8 cm/day
Minimum Recession Rate 1977	3.3 cm/day
Typical Year Recession Rate 1960, 1982	4.4 cm/day

Source: Electroconsult, BRD 1009, 1984.

VI. PREDICTED DISEASE TRANSMISSION AROUND RESERVOIR

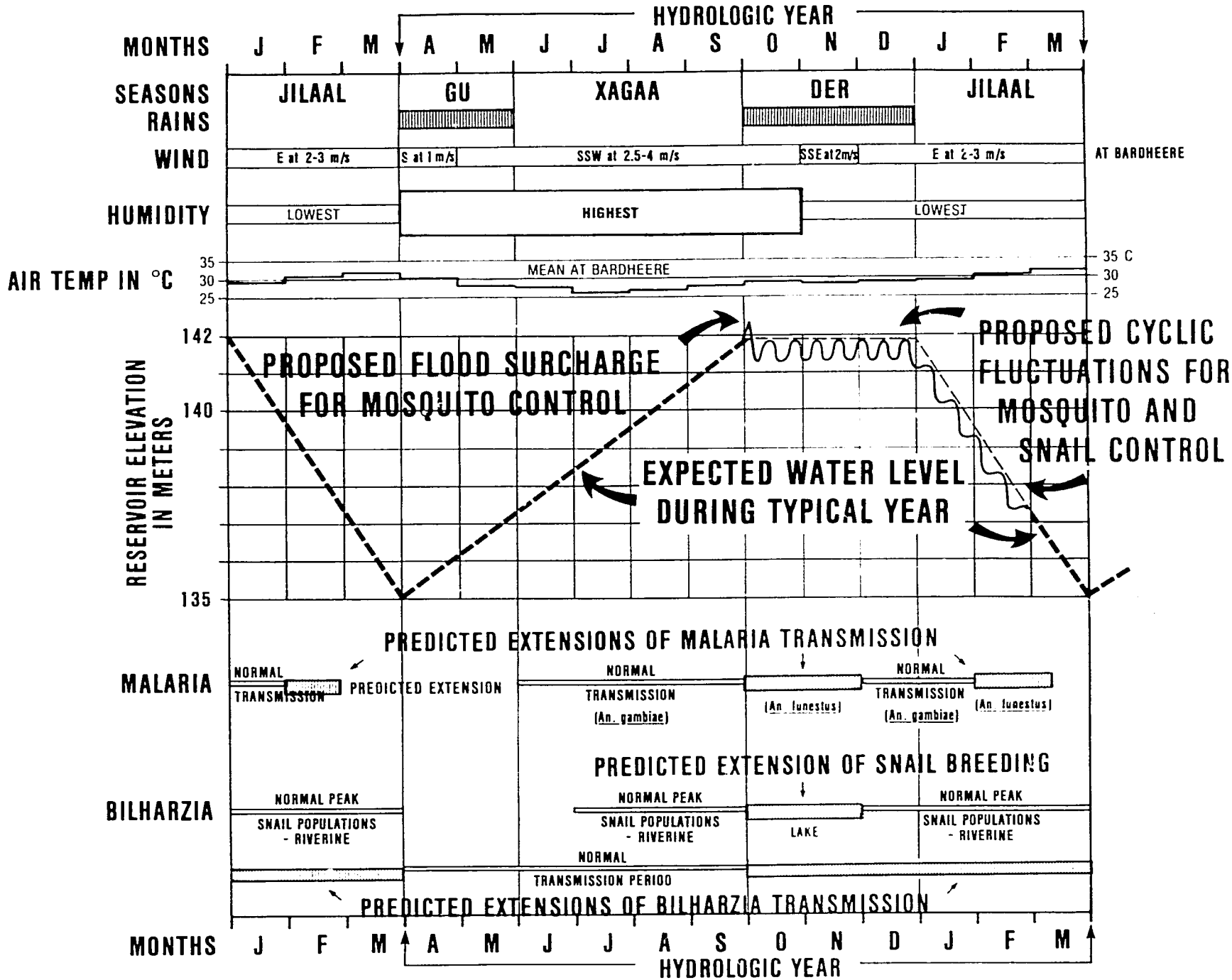
The preceding information gave a background for prediction of snail populations and bilharzia transmission in the reservoir during a typical year. Although the bilharzia snails would probably be stranded during the Jilaal stage of receding water level, small numbers would survive the several months of drying. The snail populations would recover a few months after the reservoir rose again and would rise to maximum numbers during the stable period of full reservoir during the late Der season, continuing into the Jilaal (Figure 8). It is thus estimated that snail populations will occur at their highest level during the Der, and that this will cause an extended period of bilharzia transmission during the Der and Jilaal.

Transmission along the lakeshore would terminate on or before the beginning of the Gu season as the last of the Der brood of snails are stranded. However, just as this area of bilharzia transmission was disappearing, new areas would be beginning in rain-fed pools outside the reservoir during the Gu. While this normal "riverine" transmission season is relatively unimportant in the upper Jubba Valley, it is clear that the addition of the reservoir in that region will severely increase the present rate and duration of bilharzia transmission.

The expected transmission patterns of malaria around the proposed reservoir can also be outlined, based on seasonal changes in weather and expected reservoir conditions (Figure 8). For full reservoir conditions, expected to occur during the Der season, it is likely that the malaria mosquito *Anopheles funestus*, which also transmits *Plasmodium falciparum*, will inhabit the lakeshore, causing a new period of malaria transmission during the Der. This will fill in the previous gap between the two seasons caused by *Anopheles gambiae*, and may also cause an extension of the season into mid-Jilaal (Figure 8). Although the normal (pre-construction) malaria transmission by *An. gambiae* is very slight due to the high porosity of the soil in the reservoir zone and the rapid disappearance of rain-fed pools, the combination of the two species of mosquitoes will surely lengthen and intensify the transmission season.

Figure 8. Predicted seasonal transmission of malaria and bilharzia.

Blue lines indicate predicted disease conditions, or in the case of the reservoir, proposed fluctuations in water level to counteract expected populations of malaria mosquitoes and bilharzia snails.



Seasonal Disease Transmission In Proposed Bardheere Reservoir

19a

VII. NEED FOR SHORELINE MODIFICATIONS

Improvements in the shoreline to be formed by the proposed reservoir can reduce disease transmission in nearby human and animal populations and have important advantages over other disease control methods. To limit the number of shoreline improvements and maximize their benefits, a management policy for the location and size of human and animal populations around the reservoir will be needed first. Shoreline improvements will certainly be an economical supplement to water-level fluctuations and would reduce the need for other operational activities to prevent outbreaks of malaria, bilharzia and other waterborne diseases of people, camels, cattle, sheep and goats.

The advantage of shoreline improvements, such as permanent elimination of swamps and flooded depressions by filling or drainage, is that they will reduce disease risks without requiring further attention, either in operation or maintenance. In the long run this is less expensive than any other method of control, and in places with similar climate and geography, such as the Dez Irrigation Project of southwestern Iran, such methods of bilharzia control have also produced agriculturally useful land (Hebert, 1975).

Elimination of small depressions within five kilometers of proposed human settlements may be an important adjunct to control of the existing vector of malaria, An. gambiae, which would not breed in the reservoir, but prefers small pools. Preliminary reconnaissance indicated that very porous soils near Bordubo would minimize this problem, at least in that area.

Straightening irregular shorelines causes direct reductions in such important biological parameters as the Intersection Line and the area of the Illuminated Shore Zone, thus directly reducing survival of An. funestus mosquito larvae and reproduction of aquatic snails (Figure 7). These improvements should be made at the time of dam construction when personnel and earth-moving equipment are in the area and can accomplish the work at the lowest costs. However, the design of these improvements--which may include diking large, low areas and filling small depressions--cannot be completed until land-use policies are established for the reservoir perimeter.

When land-use policies and patterns become more clearly established, after completion of the current socioeconomic and environmental studies, the design and cost estimations for these improvements should be completed, and their completion should be linked to the dam construction. The cost of these improvements should not be more than a few million dollars, but cannot be estimated until finalization of:

- the dam design and operational plans for the reservoir related to health considerations;

- a detailed plan for human settlements and nomad use around the reservoir; and

- more detailed topographical investigations in those areas near the reservoir proposed for human settlements or animal grazing.

Thus, during final decisions on construction of Baardheere Dam, it is important to recognize that additional costs for shoreline improvements will occur, and provisions should be made for funding and implementing them before construction of the dam is completed.

VIII. REQUIRED DISCHARGE RATES FROM DAM TO CONTROL MOSQUITOES

There are three techniques related to water-level fluctuations in the proposed reservoir which could be used to reduce malaria mosquito populations and thus malaria transmission. They are:

- a flood surcharge at the beginning of full reservoir phase;
- cyclic fluctuations during full reservoir and early recession phases; and
- downstream flushing to control mosquito breeding in the riverbed.

The flood surcharge and the cyclic fluctuations are the most important for the proposed reservoir, and could be imposed on the reservoir during most normal years of operation (Figure 8).

A. Flood Surcharges

Experience in several reservoirs of the Tennessee River Valley of the United States has shown that a flood surcharge of 0.3 meters over the normal full reservoir level will strand debris and floating vegetation and thus minimize the length of Intersection Line along the reservoir shoreline, proportionally minimizing breeding of An. funestus mosquitoes (World Health Organization, 1982). Previous simulation studies on the proposed Baardheere reservoir showed that this full pool situation will occur primarily during July, August or September (Electroconsult, 1985). The mean flow of the river is usually between 190 and 300 cu m/s during these months, adequate to achieve the rise within three to five days (Electroconsult, 1985).

Creation of the rapid drop (0.3 meters in one or two days) needed to strand floating materials will require discharging the volume of water contained in the change of reservoir level, plus the volume coming into the reservoir from the river. The reservoir area at normal high water level is expected to be 310 million square meters, thus the rate of discharge for a 0.3-meter drop over two days would be 540 cu m/s. Flow records from a gauging station at Luuq indicated that the maximum flows coming into the reservoir during this period were 510 cu m/s during August, with mean flows approaching 300 cu m/s for this three-month period (Table 3). Based on the 32 years of flow records, the maximum discharge required at the dam to cause this sudden drop would be the sum of 540 plus 510 or 1,050 cu m/s in August, and the mean required discharge would be the sum of 540 plus 300 or 840 cu m/s in September.

Table 3.

Required Outlet Discharges for Dam to Drop Flood Surcharge for Stranding Driftwood and Floating Vegetation as Mosquito Control Method in Reservoir

Height of Surcharge (in meters)	Time to Drop (in days)	Month	Flow Rates (in cu m/s) River Max	River Mean	Drop	Outlets Max	Outlets Mean
0.3	2	July	400	190	540	940	730
		August	510	270		1050*	810
		September	500	300		1040	840**

*Peak flow during maximum year of record.
**Peak flow during average year of record.

B. Cyclic Fluctuations

During the several months when the reservoir is expected to be full, cyclic fluctuations with periods of one week can be used to strand the mosquito larvae and wash them out into the main body of the lake, where they would be subject to predators. These weekly fluctuations would have to be created during the months from September through January, and possibly for a few months afterward into the receding phase of the reservoir, based on experience in the reservoirs of the Tennessee Valley Authority (Figure 8).

The river flow is high during this period due to the Der rains, sufficient to create the desired rise in reservoir level of 0.3 meters over 3.5 days. However, discharges from the dam sufficient to cause lowering of the reservoir level will have to offset the river flow into the reservoir, as well as cause the drop in level of 0.3 meters over 3.5 days. During this period the maximum river flow occurred during November, reaching about 1,110 cu m/s (Table 4). In an average year, however, the peak flow occurred in October, reaching 450 cu m/s for the 32 years of record. Thus the discharge required at the dam during an average year would be 750 cu m/s. During the wettest year it would be 1,410 cu m/s.

Table 4.

Discharge Required from Dam for Mosquito Control at Steady High-Water Level, with 0.3-Meter Fluctuation on a Weekly Cycle*

	Flows (in cu m/s)				
	In		Drop	Out	
Month	Max	Mean	in 3.5 Days	Max	Mean
August	510	270	300	810	570
September	500	300		800	600
October	790	450		1,090	750***
November	1,110	360		1,410**	660
December	480	120		780	420
January	120	40		420	340

*Area at high-water level is 310 million square meters.
**Peak discharge required for maximum year of record.
***Peak discharge required for average year of record.

If these cyclic fluctuations must be carried into the recession phase because of continued mosquito breeding, there occasionally may be difficulties in causing the 0.3-meter rise in the normal period of 3.5 days, due to declining river flows and continuing high discharge requirements for power generation. However, it would then be possible to slow the rising phase of the cycle to five to seven days, as long as the falling phase is maintained at 3.5 days or less. In drought years when the flow is insufficient even to produce this slower rise, operational decisions on the importance and cost of chemical spraying of the reservoir margins for control of mosquito larvae during that year will have to be balanced against the cost of alternative power generation methods. This situation will occur infrequently, however, as drought conditions also tend to minimize malaria transmission.

C. River Flushing

If mosquito breeding in the riverbed were important, the periodic drawdown of the reservoir level, which would produce flood waves in the river below the dam, would be an effective means of stranding and destroying the eggs and immature forms of the mosquitoes. Field surveys in June 1986 indicated that river conditions were not suitable for breeding during high-flow stages, probably extending from April through January. However, it remains to be investigated whether mosquitoes can breed in the river during the dry months of February and March. It would be during these months that weekly flushing could be used to control breeding downstream.

Prediction of the required rates of flushing and the extent of their downstream impact is very difficult in this situation, given the limited data on geometry of the riverbed. However, empirical data from flushing small rivers in the Philippines indicate that even extremely large waves produced by sudden discharges from the dam would not travel more than about 100 kilometers before their effects ended. Thus the river near Baardheere would be affected, but probably not Saakow (Figure 1).

Using the empirical equation developed from a large series of observations by Kruse and Lesaca (World Health Organization, 1982), it was estimated that the downstream effectiveness of such waves was

$$D = 213 \times [(Q \times V)/(W^2 \times S^{1/2})]^{1/3}$$

where D was the effective downstream distance in meters,
Q was the maximum discharge rate in cu m/s,
V was the total volume discharged in cubic meters,
W was the average bed width in meters, and
S was the average bed slope.

For the maximum flood which might be generated from Baardheere Dam of 1,000 cu m/s for a day, with an estimated bed width of 175 meters and a slope of 0.0003, the downstream effectiveness would be about 100 kilometers (Table 5). These are very crude estimates, but further calculations show that even a wide range in discharges, from 500 to 1,500 cu m/s, did not change the distance significantly. An extremely low flood wave of 100 cu m/s would reach about 50 kilometers downstream, affecting only Baardheere.

For control of mosquito breeding near Baardheere, the logical use of this technique would be to provide intermittent flow during the dry season, rather than a steady flow. Curtailing the flow for two to five days, then releasing it for a similar period of time at twice the desired average rate, has been shown on the Mahaweli project in Sri Lanka to be an effective measure for mosquito control. The average flow received at the irrigation systems in the lower Jubba River Valley would not change since this flow modification would even out within 100 kilometers below the dam.

A possible drawback of this technique, if not used carefully, would be the creation of breeding sites for An. gambiae downstream by over-bank flooding. The proper range of flood waves to be used would have to be determined experimentally after the dam is operating, carefully monitoring the populations near Baardheere, the town which clearly would be most affected.

Table 5.

Estimation of Extent of Impact Downstream on Mosquito Populations from Stream-Flushing Technique

Maximum Discharge from Dam (in cu m/s)	Downstream Distance Controlled (in kilometers)
1,500	133
1,000	116
700	103
500	92
100	53

Source: Equation by Kruse and Lesaca (World Health Organization, 1982).

IX. REQUIRED DISCHARGE RATES FROM DAM TO CONTROL BILHARZIA SNAILS IN RESERVOIR

During the Der season when the reservoir level is expected to remain steady near the normal high-water level, cyclic fluctuations would be an effective way to control the bilharzia snail populations, which would otherwise reach large numbers and could cause severe transmission of bilharzia in human settlements near the lake. These and other snails could spread similar parasites to cattle, sheep or goats grazing near the reservoir edge. Cattle can be infected by Schistosoma bovis from the bilharzia snail, and sheep and goats can be infected by the Fasciola parasite from the amphibious snail Lymnae, which inhabits flooded pasture (Figure 9). Fluctuations would be most effective against the bilharzia snails, but additional measures such as pasture management would have to be used against Lymnaea.

The height of the fluctuations necessary for control of snails is determined by the depth of sunlight penetration in the surface waters of the reservoir, most commonly measured as the Secchi disk depth. This determines how far down algae and other vegetation needed by the snails will be found, thus also determining the location of the snail populations. It is difficult to predict the Secchi disk readings to be expected in the reservoir, but it is likely that they will range from 0.1 to one meter during the high-water phase.

During the rainy season and in fast-flowing reaches of the river, Secchi disk readings were less than 0.1 meter due to suspended silt, even as late in the year as June, based on data collected in June 1986 (Jobin, 1986). Clarification of the water resulting from sedimentation in the quiescent lake will increase the Secchi disk reading somewhat. However, this clarification will be offset by the growth of algae due to the high level of dissolved nutrients in the river water.

Nitrates reached four milligrams per liter in the river at Baardheere during June 1986 and phosphates were extremely high, exceeding one milligram per liter. In the lower valley these nutrients, especially the phosphates, were also found, but primarily in organic form, probably incorporated in algae. This indicated that algae and vegetation growth in the proposed reservoir will be highly fertilized. The algae would reduce the clarity of the water severely, probably reducing the Secchi disk readings to 0.3 to 0.5 meters, even when the silt has settled. Thus, the subsequent analysis regarding snail control will assume maximum Secchi disk readings from 0.3 to 0.5 meters during the last six months of the year, when the reservoir is usually full (Table 6). It is also possible that higher values will be reached during the end of the Xagaa dry season, perhaps as much as one meter.

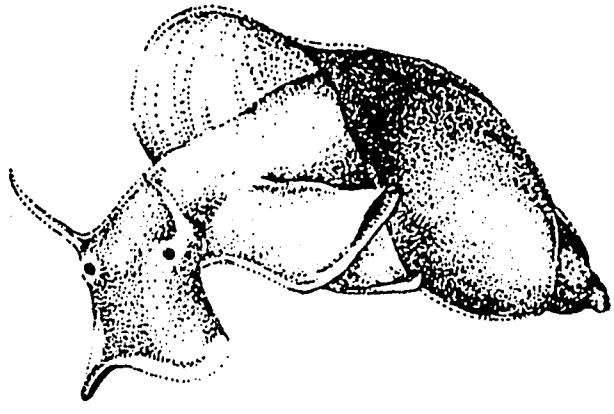


Figure 9. Amphibious lymnaeid snail, which spreads parasites to cattle, sheep and goats.

This snail is often found in damp pasture near lakes and swamps, spending part of its life cycle on land. The adult snails are about two centimeters long and can spread a parasite of the genus Fasciola.

Table 6.

Estimated Secchi Disk Readings for Reservoir, and River Discharge Rates at Luuq, by Month

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Secchi Disk Reading (in cm):	60	80	100	1	1	10	10	50	50	10	10	50
Flow (in cu m/s)*												
Max	120	180	420	800	600	670	400	510	500	790	1110	480
Mean	40	30	40	120	220	180	190	270	300	450	360	120

*Electroconsult, 1985.

The period of cyclic fluctuation for mosquito control was recommended as one week, due to the rapid hatching rates for eggs of malaria mosquitoes. For snail control this could be lengthened to 10 days, but analysis of the discharges needed for dropping the level 0.3 meters indicated that it could easily be accomplished in a one-week cycle, requiring an additional discharge of only 300 cu m/s (Table 7). To achieve a drawdown of 0.5 meters will require an additional discharge of 510 cu m/s. Thus, the normal period of fluctuations should be one week for control of both the malaria mosquitoes and the bilharzia snails.

Table 7.

Required Discharges at Dam to Draw Reservoir Level Down to Various Secchi Disk Depths

Depth of Transparency by Secchi Disk (in cm)	Additional Discharge Needed (in cu m/s) for Reservoir Level of 141.9 Meters, with Surface Area of 310 Million Square Meters for: 1 Day	3.5 Days	5 Days
10	360	100	70
30	1,080	300	210
50	1,800	510	360
100	3,590	1,020	720

The water clarity will vary seasonally, as will the river flow into the reservoir at Luuq, thus the requirements for discharge at Baardheere Dam will also show significant seasonal variation. In an average year, the required discharge at the dam

to expose the entire Illuminated Shore Zone will be 810 cu m/s in September (Table 8). During the maximum flow year on record, the maximum required discharge would be 1,210 cu m/s during November. This discharge rate would thus be adequate to strand the snails at any time during the year, during any of the years on record.

Table 8.

Discharge at Dam Needed to Strand Snails at Maximum Reservoir Level for Various Fluctuations with Period of One Week

	Discharge (in cu m/s)					
	Maximum*			Mean*		
Month	In	Drawdown**	Out	In	Drawdown**	Out
August	510	510	1,020	270	510	780
September	500	510	1,010	300	510	810#
October	790	100	890	450	100	550
November	1,110	100	1,210##	360	100	460
December	480	510	990	120	510	630
January	120	560	680	40	560	600

*From 32 years of records at Luuq.
**Dependent on Secchi disk reading for month, which thus specifies width of Illuminated Shore Zone and extent of snail population.
#Peak discharge requirement for average year of record.
##Peak discharge requirement for maximum year of record.

X. SUMMARY OF DISCHARGE REQUIREMENTS FOR DAM

The maximum required discharges for mosquito and snail control occur at various times during the year, and the fluctuation schedule should be tailored each year to the actual reservoir and disease conditions. However, an overall comparison of the requirements for mosquitoes and snails indicated that the maximum discharge required for mosquito control would probably be 1,410 cu m/s in November (Table 9). The maximum discharge for snail control would be slightly lower and would also occur during November, so both objectives would be achieved with a discharge rate of 1,410 cu m/s.

During an average year the discharge requirements would be significantly less, due to the lower river discharge at Luuq. The statistical pattern for the average year is slightly different, thus the maximum discharge required would be 840 cu m/s in September, during an average year (Table 9).

Table 9.

Summary of Discharge Requirements for Dam to Control Mosquitoes and Snails in Reservoir

Control Measure		Required Discharges (in cu m/s) Maximum Year		Mean Year	
Mosquitoes -	Flood surcharge	1,040	September	840**	September
	Fluctuations	1,410*	November	750	October
Snails -	Fluctuations	1,210	November	810	September

*Discharge required for control of both snails and mosquitoes in maximum flow year.
**Discharge required for control of both snails and mosquitoes in average flow year.

XI. ECONOMIC ASPECTS OF INCREASED DISCHARGE RATES AT DAM

The original discharge capacity of the proposed bottom outlets on Baardheere Dam was 700 cu m/s, and the maximum discharge rate of the combined turbine discharges was 300 cu m/s. Increases in the size of the bottom outlets for disease control may cause significantly higher construction costs for the dam, thus it is necessary to examine the economic value of the disease control effect of the larger outlets in order to determine their optimum size. These costs can be used in combination with an analysis of the 32 years of flow records for the river at Luuq to determine the savings for various sizes of bottom outlets smaller than the maximum of 1,410 cu m/s.

The alternative to using water-level fluctuations in the reservoir to control malaria and bilharzia would be the application of chemical or environmental methods for insect and snail control, as well as other public health measures aimed at disease control. The costs of integrated programs of disease control for similar situations are available from recent experience in the Sudan and Ghana and can be used to estimate expected costs for Baardheere Dam.

Estimated costs for malaria control were obtained from Blue Nile Health Project reports for the Gezira irrigation scheme in the Sudan, which indicated a per capita cost of US$0.60 annually in 1980 (El Gaddal, 1985). Assuming a human population around the reservoir of 50,000 people, an annual inflation rate of five percent would result in an estimated annual cost for Baardheere Dam of $40,000 in 1986 prices (Table 10). This figure is highly dependent on population sizes, which can only be crudely estimated at this time. The possibility of significantly larger populations would change this cost estimate considerably.

The estimated annual cost of bilharzia control around a large hydroelectric reservoir was $1 per capita or $320 per kilometer of shoreline, obtained from reports of a World Health Organization project on Volta Lake in Ghana and adjusted to 1986 prices (Chu, 1984). The critical shoreline involved in Sector C was 80 kilometers, thus the two parameters for estimation gave $50,000 based on population and $25,000 based on shoreline (Table 10). Since the fluctuations control both diseases and would be operated almost identically in the proposed Baardheere Reservoir, the alternative annual cost for controlling both diseases would be between $65,000 and $90,000 in 1986 prices (Table 10).

Table 10.

Estimated Annual Costs of Alternative Disease Control Measures for Reservoir Behind Dam

Disease	Estimated Annual Cost (in 1986 US$)
Malaria	$40,000
Bilharzia	$25,000 - $50,000
River Blindness	$3,000

Using the 32 years of monthly flow records at Luuq, a simple computer program and the monthly flow data presented by Electroconsult, the number of months and years when it would not be possible to achieve the desired drawdown rates for malaria and bilharzia control were calculated.

It was determined in the analysis that bottom outlets with the original discharge rate of 700 cu m/s would require supplemental disease control operations around the reservoir for 20 years out of 32 (Table 11). The optimum discharge for all outlets was 1,200 cu m/s, for which disease control operations would be needed only one year out of 32, based on the actual flow records. It did not appear advisable to increase the capacity beyond 1,200 cu m/s due to the small advantage provided--only one additional year of disease prevention. The discharge figure represents the average discharges over 3.5 days for all discharges from the dam, including the turbines. If the average discharge from the turbines is half their maximum capacity or 150 cu m/s, then the size of the bottom outlets should be 1,050 cu m/s, to give a total discharge of 1,200 cu m/s. During early stages of dam operation, this flow may be slightly lower if all the turbines are not installed. Thus, provisions should be made for using the empty conduits to bypass flow during these early stages.

Table 11.

Optimization of Maximum Discharge Rate for Outlets in Dam, for Maximum Control of Malaria Mosquitoes and Bilharzia Snails in Reservoir

Discharge (in cu m/s) Total*	Bottom Outlets	Years When Disease Control Could Not Be Achieved (out of 32 Years of Record)	Average Weekly Flow in River (in cu m/s)
700	550	29	425
850**	700**	20	450
1,000	850	7	575
1,200***	1,050***	1	675
1,400	1,250	1	775
1,500	1,350	0	825

*Including flow from bottom outlets, plus average flow from turbines assumed to be 150 cu m/s as a weekly average.
**Original design capacity.
***Recommended design capacity.

These high discharge rates would be sustained only 3.5 days, then the outlets would be closed to allow the reservoir to rise again. During the rising phase only the turbines would be discharging, at an average rate of about 150 cu m/s. Thus the flow rate in the lower valley, at Fanoole Barrage and at Kamsuma Bridge, would be the average of the two extremes. Previous estimates indicated that the flow variation would be smoothed out within 100 kilometers below the dam (Table 5). For the maximum discharge of 1,200 cu m/s this would produce a mean discharge at Fanoole Barrage or Kamsuma Bridge of about 675 cu m/s, below the safe limit for the bridge, which is presently estimated at 700 cu m/s.

In summary, the recommended maximum discharge from the bottom outlets of Baardheere Dam is 1,050 cu m/s, assuming that the weekly average discharge of the turbines would be 150 cu m/s. This capacity would make it possible to control mosquitoes and snails in the reservoir during 31 out of 32 years, and would not endanger the bridge at Kamsuma (Table 11).

XII. DESIGN PREFERENCE FOR BLACKFLY CONTROL

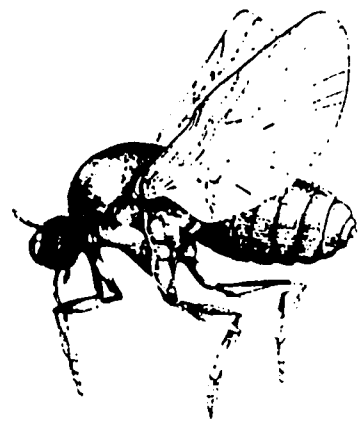
Blackflies would be attracted to the spillway and outlets of the Baardheere Dam due to the white-water areas, which would provide the flies with sites for depositing their eggs. If flow velocities near the surface are between 0.5 and two meters per second, the eggs can hatch in three to four days and continue their development to adulthood (Figure 10). Thus, the occurrence of stable flow at these velocities for three days, including a stable level of water surface, creates the potential for blackfly breeding.

Blackflies probably do not presently exist in the upper Jubba River Valley, but they have a considerable flight range and could come in from surrounding areas. Because of the small size of this potential breeding site, and the relatively long distances to the nearest surrounding sites, the likelihood of invasion is small, but it exists. There is one report of blackflies from the middle Shebelli River near Mogadishu, about 320 kilometers from the dam site (Zuretti, 1957). The maximum range of blackflies approaches 400 kilometers, with favorable winds. Since there are four months of the year when the easterly winds could transport the flies to the dam site, the risk of successful migration must be considered.

Existence of the flies does not in itself cause the disease; the female fly must achieve a high biting rate on humans to reproduce successfully and to transmit the parasite from one infected person to another. Further, the parasite must exist in the human population. The parasite could be imported by infected people from neighboring countries; for example, Ethiopians migrating from the Rift Valley at the upper perimeter of the Jubba River catchment basin. Again, this is unlikely , but possible.

The original proposal for Howell-Bunger valves on the bottom outlets would release a high-velocity spray into the stilling basin below the dam without providing suitable, stable sites on a solid surface for egg deposition. However, the alternative design, suggested for other reasons, was an under-flow gate which would discharge into a hydraulic jump in the stilling basin. The upstream, supercritical portion of the jump would probably create suitable sites for egg deposition along the walls of the channel. Thus, for health reasons, this alternative is less desirable than the original design.

If the original design were constructed, or if there were other suitable sites within the stilling basin or at the outlets for the turbines where the flies could deposit eggs, it would be possible to control the fly breeding by the application of an insecticide (e.g., Abate) at a modest cost. This can be



Blackfly.

RIVER BLINDNESS

This disease, prevalent in Africa and tropical America, is spread through the bite of the blackfly. The biting blackfly breeds in rapids or white-water on spillways and water control structures, and is responsible for impeding agricultural development in much of West Africa. The disease is also known as onchocerciasis to parasitologists.

Figure 10. The blackfly, which spreads river blindness in North Yemen, Ethiopia and other African countries.

This adult fly, about one centimeter long, has also been found in central Somalia.

estimated from experience in West Africa where blackfly control has been successfully practiced for over a decade. The Onchocerciasis Control Program (OCP) uses Abate at a dosage of 0.25 milligrams per liter for three hours during periods when the flow and water temperature are suitable for breeding (OCP, 1985). It is estimated that this would require six applications per year in cooler weather at Baardheere. Assuming an average flow of 200 cu m/s during these applications, six applications would cost $21,000 for chemicals, the principal expense.

Because of the small size of the breeding sites, repeated application of chemicals would locally eradicate the fly population. Several years might elapse before reinfestation occurs, thus chemical application would be needed only occasionally, perhaps every five to 10 years, depending on the frequency of reinfestation. Thus the average annual cost for chemical control should be about $3,000, assuming that reinfestation occurs in seven years (Table 10). This is significantly less than the alternative costs for malaria and bilharzia control.

XIII. NEED FOR HEALTH CONSIDERATIONS IN DAM OPERATION

An operations team, with one member responsible for health consequences of dam operation, will be needed to implement the required rapid recessions of the reservoir for health purposes. The timing and magnitude of these fluctuations will have to be determined periodically each year, depending on the reservoir level, climatic conditions, needs for power generation and irrigation, and flood control requirements. Quite often it will not be possible to satisfy all the competing demands for use of the reservoir, and compromises will have to be made among the various demands, requiring a balanced understanding of each of them.

Experience with malaria control around reservoirs of the Tennessee Valley Authority in the United States has shown that this is best accomplished with a cocperative team of technical members who understand the reasons for various operating requirements. Thus, it is recommended that a commitment be made at the time of final approval of the dam design to entrust operation of the dam to an operations team that will consider health needs in addition to the primary purposes for operating the dam.

The operations team should also oversee supplemental disease control operations around the dam and reservoir. Methods available to control these human and animal diseases include pasture management, tree and weed control, shoreline modifications, aquaculture and fish management, community sanitation measures, health education, drugs, biocides, and manipulation of the reservoir water level. To accomplish this, the operations team should establish a disease control unit to be stationed near the reservoir.

Based on experience with the disease control unit, the team member responsible for health should provide current cost figures to the operations team for alternative disease control measures to be implemented if the recommended water-level manipulations cannot be achieved. These costs will provide the operations team with the basis for deciding between the competing demands for water usage.

If such an operations team is not established, then the costs for required alternative control operations against malaria, bilharzia, river blindness and other diseases should be included in the financial analysis of feasibility of the Baardheere Dam project. When all of the human and animal diseases are considered, these recurrent costs may be as much as $100,000 annually in 1986 costs, mostly hard currency expenses (Table 10).

XIV. CONCLUSIONS AND RECOMMENDATIONS

Based on experiences elsewhere in Africa, it is expected that health problems will be created around the proposed Baardheere Dam project, and that provisions would best be made during the design of the dam and in planning its operations, in order to minimize these problems in the most cost-effective manner.

It is expected that human and animal populations will congregate around the perimeter of the reservoir created by Baardheere Dam, due to the attraction of the large, stable supply of water for domestic and agricultural uses. These human communities and animal herds will be difficult to regulate, as many will be nomadic or migrant groups in shifting settlements.

Because of relatively flat shore slopes and protection from prevailing winds, the portion of the proposed reservoir in the region near Bordubo and Garba Harrey may have extensive shoreline habitats suitable for the aquatic insects and snails which transmit bilharzia, malaria and parasites to domestic animals. Increased shoreline vegetation around the entire reservoir may also favor tsetse flies, which spread ngana in cattle, and encourage tick populations, which are responsible for camel diseases.

The physical structure of the bottom outlets in the dam may create favorable breeding sites for blackflies, which spread river blindness in people.

JESS field investigations in June 1986 showed that the main channel of the Jubba River below the proposed dam was not an important habitat for these insects and snails, but further studies are needed in February and March to determine whether the low-flow periods might provide suitable conditions. If so, periodic flushing of the river with discharges from the dam could eliminate riverine mosquito and snail habitats for about 100 kilometers downstream.

Based on these conclusions, four specific recommendations are made regarding finalization of the dam design. These recommendations were prepared early in the planning process in order to influence the dam design. Other aspects of Jubba River development will not be clarified for some time, thus recommendations (such as XIV.D, below) may be further refined later on, following additional JESS work by ARD.

A. Operations Team to Control Dam Operation

It is recommended that a commitment be made at the time of final dam design approval to entrust dam operation to an operations team that will consider health needs in addition to the dam's primary purposes. The required rapid recessions of the reservoir for health purposes will have to be determined periodically each year, and it will not always be possible to satisfy all the competing demands for use of the reservoir, thus compromises will have to be made. Experience with malaria control by the Tennessee Valley Authority in the United States has shown that this is best accomplished with a cooperative team including technical members who are well versed in the reasons for the various operating requirements. One member should be a biologist with special expertise in ecological aspects of mosquito and snail control.

The operations team should also oversee supplemental disease control operations around the dam and reservoir. Thus, they should be provided with funds to establish a disease control unit, stationed near the reservoir, to carry out these operations.

If an operations team is not established, then the costs for required alternative control operations against malaria, bilharzia, river blindness and other diseases should be included in the financial analysis of feasibility of the Baardheere Dam project. When all of the human and animal diseases are considered, these recurrent costs may be as much as $100,000 annually in 1986 costs, mostly hard currency expenses.

B. Discharge Capacity of Proposed Bottom Outlets

At the present stage of the Baardheere Dam project, it is recommended that major attention be given to those design features of the dam outlets which will allow maximum flexibility in manipulating the reservoir water level to control shoreline populations of vegetation, insects and snails.

Detailed analyses of the proposed reservoir and its expected operation resulted in recommendation of bottom outlets with a much larger discharge capacity than that of the original design.

Construction of the dam with the original bottom outlet capacity of only 700 cu m/s, combined with a weekly mean discharge rate from the turbines of 150 cu m/s, would restrict the ability to fluctuate the reservoir level and would result in a need for alternative disease control operations around the reservoir during 20 years out of 32, according to simulations conducted with data collected in June 1986. The cost of these alternative disease control operations would be about $80,000 per

year in 1986 U.S. dollars, mostly for hard currency purchases of chemicals and drugs. Thus the original design of the bottom outlets could cause considerable health problems and operating expenses in the future.

The maximum discharge rate required for complete mosquito and snail control in the reservoir was 1,410 cu m/s from all outlets, over twice the original design flow. However, a lower maximum discharge capacity is probably justifiable, based on analyses of the low frequency of such high flows in the Jubba River at Luuq.

Simulation of reservoir operation using available river-flow data for the 32 years of record indicated that a total discharge capability at the dam of 1,200 cu m/s would give satisfactory mosquito and snail control in 31 of the 32 years. Thus the recommended total capacity for discharge at the dam is 1,200 cu m/s, including discharges from the turbines.

Assuming the turbines would have an average weekly discharge of one-half their maximum capacity, or 150 cu m/s, this results in a recommended maximum capacity for the bottom outlets of 1,050 cu m/s. The recommended intermittent operation of the outlets to produce a weekly rise and fall in the reservoir would result in intermittent flow in the river, gradually averaging into a discharge downstream of 675 cu m/s, which is within the allowable limit for flooding at Kamsuma Bridge.

The difficulties and cost of supplemental measures for disease control by an operational health unit on the reservoir, which would require skilled manpower as well as $80,000 annually in hard currency, should be considered in selecting the final size of the bottom outlets for the dam, and in estimating costs and benefits for the Baardheere Dam project.

C. Structural Aspects of Bottom Outlets

A careful evaluation should be made of the design features that will determine velocities in the discharges from the turbines and bottom outlets.

Although the overall impact of the difference will probably be minor, the valve design for the bottom outlets would create less favorable conditions for blackflies, which spread river blindness in people, than would the under-flowing gate design. This is because the valve design discharges the flow into the air, whereas the gate allows the flow to reach the stilling basin with a high velocity, suitable for deposition of blackfly eggs.

In addition, care should be given to design of the turbine outlets and stilling basins to avoid high water velocities in

stable flow which encourage breeding of blackflies. In the absence of safe outlet structures, a control program for blackflies near the dam would cost about $3,000 a year.

D. Provision of Shoreline Improvements Around Reservoir

A management policy regarding the location and size of human and animal populations around the reservoir will be needed for protection of health and other environmental concerns. Shoreline improvements, in addition to water-level fluctuations, will be needed to control the insects and snails along the reservoir shoreline near these populations in order to economically prevent outbreaks of malaria and bilharzia as well as other waterborne diseases of people, camels, cattle, sheep and goats.

When land-use policies and patterns become more clearly established, it will then be advisable to provide for drainage and other shoreline improvements around the reservoir as supplemental measures for disease protection. These improvements may include filling small depressions and diking or straightening irregular shorelines, in those locations around the reservoir where human and animal populations are expected.

During final decisions on construction of Baardheere Dam it is thus important to recognize that additional costs for shoreline improvements will occur, and provisions should be made for funding and implementing them before construction is completed.

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