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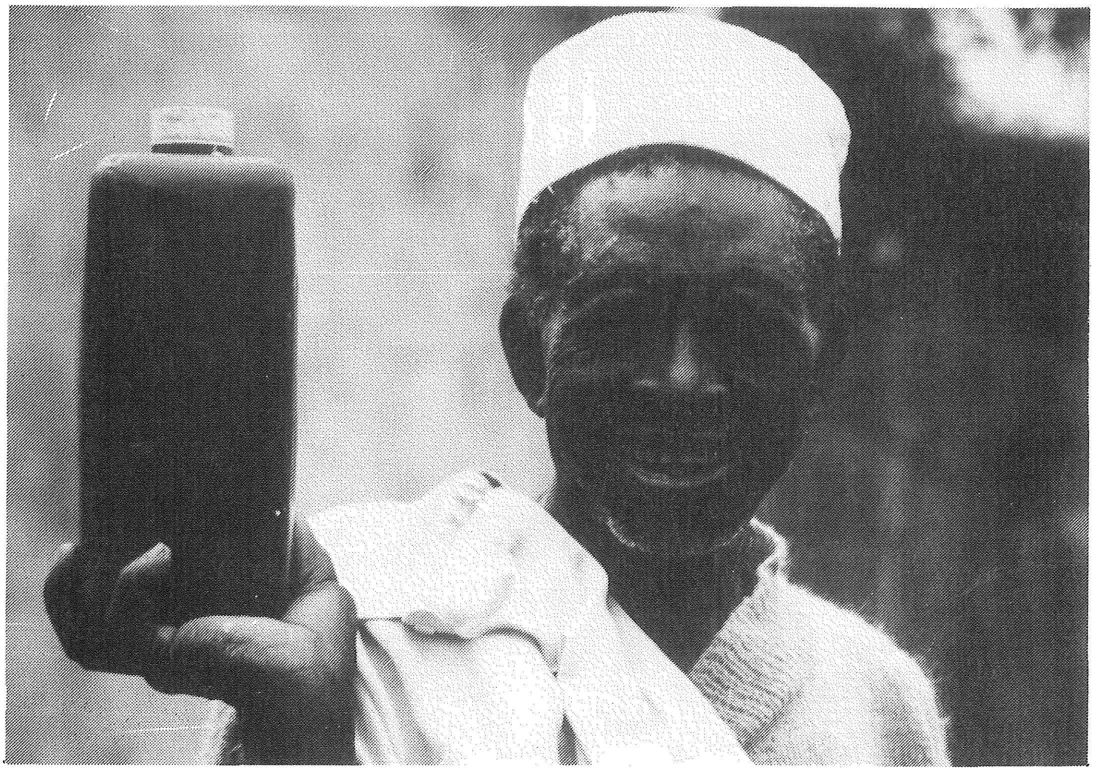
Chalmers Tekniska Högskola

Department of Hydraulics
Chalmers University of Technology



A STUDY OF WATER SUPPLY AT

NKINGA HOSPITAL

AND THREE VILLAGES IN IGUNGA DISTRICT, TANZANIA

Johan Anderson *Ronny Wahlström*

Master Thesis 1992:1

Göteborg Sweden 1992

A Study of Water Supply at Nkinga Hospital and three Villages in Igunga District, Tanzania

Johan Anderson
Ronny Wahlström

Master Thesis

Chalmers University of Technology
Department of Hydraulics
S-412 96 GÖTEBORG
Sweden

Cover photo shows a man at Nkinga village with a bottle of fresh water.

Photos:

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Hakuna matumaini, lakini yote inawezekana

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This report contains a distillation of knowledge and experience. Many people have contributed to it in various ways.

First of all, we wish to thank Ragnar and Carin Borell in Nacka for their great help. From their attic we borrowed the only complete Tabora Region Water Master Plan, that probably exists. Without their concern this Master Thesis would not be half as informative.

We are especially grateful for good advice provided by Kent Andersson, Karl Dunkers (Karl Dunkers Ingenjörsbyrå), Carl Christiansson (University of Stockholm), Bengt Eckebring, Steffen Häggström (Chalmers University of Technology) and Lennart Nolvall (PMU Stockholm).

For their help and advice in Tanzania we thank all the staff and missionaries at Nkinga Hospital and all friends all over the country. In particular, we wish to thank Igunga District Water Engineer, Mary Petro, Emanuel Nyström, Andrew Mathew and last but not least Adriano Ntinginya.

Finally, we are very grateful to our employers and families for their great encouragement, understanding and support.

Johan Anderson

Ronny Wahlström

Preface

THE ROYAL INSTITUTE OF TECHNOLOGY
INTERNATIONAL UNIT

This study has been carried out within the framework of the Minor Field Studies (MFS) scholarship programme, which is funded by the Swedish International Development Authority (SIDA).

The MFS scholarship programme offers Swedish undergraduate students or recent graduates an opportunity to carry out two months' field work in a third world country for their Masters theses or similar in-depth studies. The study should primarily be conducted in a country supported by the Swedish development aid programme.

The main purpose of the MFS programme is to create interest among Swedish university students to work in developing countries, providing them with initial experience of conditions in the third world. A further purpose is to attract students into professions suitable for this kind of work, thus supplying SIDA staff and widening the Swedish personnel resources for recruitment into international organisations.

The International Unit at the Royal Institute of Technology (KTH), Stockholm, administers the MFS programme for all faculties of engineering and natural sciences in Sweden.

Sigrun Santesson
Programme Officer
MFS Programme

Preface

Johan Anderson and Ronny Wahlström have been working for a long time with their master thesis. This is due to Ronny's accident just before they intended to go to Tanzania. The field work was thus delayed one and a half years.

I have followed Johan's and Ronny's preparations before the field work in Tanzania and the writing of the report afterwards. They have both been very enthusiastic and worked hard with a difficult problem — water resources management in some villages in the Tanzanian countryside.

They have investigated the resources and suggested solutions to the problems. In doing so they have been well aware of the local conditions and the presented solutions are realistic and possible to implement.

Their work has been very interesting to follow and I have seen few or no other students as enthusiastic about their work as Johan and Ronny. That may be the reason why they have worked so hard — far more than what is normal for a master thesis.

At last I hope that this master thesis helps to improve the water situation at Nkinga Hospital and the villages. I know that Johan and Ronny share this hope.

Göteborg, 1992

Steffen Häggström
Associate professor

Department of Hydraulics
Chalmers University of Technology

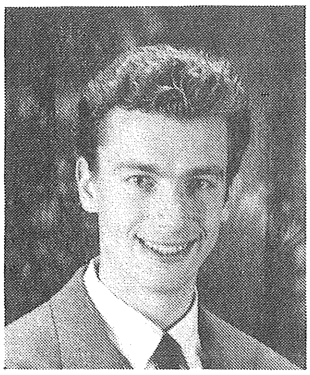
Preface by the authors

Searching for a Master Thesis theme, we wanted to find some interesting in one of the subjects that we have studied, for instance Hydraulics. Another idea was to work for an organization or company where the result could be directly used. A third thought was to find a theme abroad, learning new cultures at the same time.

We succeeded in combining the three ideas in one Master Thesis, working with the water supply at Nkinga Hospital and three villages in Tanzania.

It all started in the Autumn of 1989 when we contacted PMU, Pingstmissionens U-landshjälp, in Stockholm and understood the great need of solving the water supply problem at Nkinga Hospital in Tanzania.

We applied for a Minor Field Study Scholarship from SIDA, the Swedish International Development Authority, and got an approval in February 1990. In April we took part in a seminar about the situation and culture in developing countries at SIDA's Education Centre in Uppsala.



Johan Anderson

In two different countries, Ronny in Göteborg and Johan in Vienna, Austria, we got our vaccines, booked our tickets and started packing. Then it happened. Just three weeks before the departure, an accident occurred and destroyed the plan.

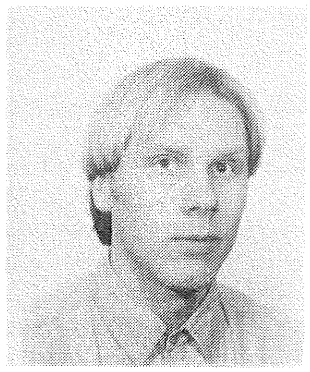
Ronny was riding a motorbike in Göteborg and was hit by a Norwegian car.

After about ten operations and several months at hospitals, Ronny began recovering. Almost one and a half year later than planned, we finally could start our field work.

The report is based on an intensive field study in the middle of Tanzania. The work took place during two months from October to December in the year of 1991.

Everybody from District Authorities to Regional Officers were very expectant and totally accommodating to us, but the resources were unfortunately very limited.

Right from the beginning we tried to explain and convince the rural people of our work and intentions. During the study of existing water supply systems in the villages, we were immediately surrounded by about 50 curious people. In poor Swahili we tried to explain who we were, who we worked for, what we were doing and in particular what the outcome would be. They helped us in all ways they could think of. They were astonished that we dared climb to the top of the water towers.



Ronny Wahlström

Our fieldwork mainly consisted of finding, making an inventory and analyzing all water supply systems in the area of Nkinga Hospital and the three villages Nkinga, Ulaya and Ndembezi. It included about 75 buildings with tin roofs and 69 rainwater reservoirs, four boreholes, three large rainwater dams, two rising main systems and four independent distribution systems, five water towers, ten shallow wells, water and sediment analysis and a large number of interviews with the maintenance people, the staff and the inhabitants.

We were often consulted by the inhabitants wherever we came. For instance we did a water supply study at Isanzu Dispensary and Clinic (appendix C), a study of water resources at the new Secondary School at Simbo and at the Clinic at Itanana, several water quality studies, a study of waste water problems at Nkinga Hospital and some education.

In particular we found the study of the water situation in Tasengwa, Tarangire, Tabora, Bahari and Matemwe exceedingly rewarding.

At our stay in Tanzania we tried to imbibe the Tanzanian art of living with open minds, a very pleasant way of living that has resulted in this open-hearted people. The wonderful beaches and the rich wildlife also contributed to the place in our hearts that Tanzania will have forever.

Stockholm and Göteborg, 1992

Johan Anderson

Ronny Wahlström

Introduction

The water supply has the highest priority for people in Africa. This is also true for Nkinga Hospital and the three villages in Igunga district in Tanzania.

The intentions were to help the people of Nkinga Hospital and the three villages with their water supply. The report contains an attempt to describe the system, how to improve it and how to increase the water supply outside the existing systems. Some of the improvements may be executed as aid development projects.

The report is written for a wide spectrum of readers, for example employees in the daily run, maintenance and planning, rural people and the Water Authorities of the district. The report is also for people who will make decisions about improvements, and then plan, run and execute them.

The major parts of this report are not specific for these three villages. The knowledge we have collected can hopefully be used to solve water supply problems in areas with similar problems in other parts of the world.

Abstract

Existing water supply systems

The water supply systems at Nkinga Hospital and the three villages in the neighbourhood have been steadily enlarged and rebuilt. Today, the water supply systems are very complex and very difficult to survey.

The largest water source is the Ulaya Dam, a 350 × 500 meter rainwater reservoir. It supplies the villages of Nkinga, Ulaya and Ndembezi, which means about 15 600 inhabitants. The second largest source is Borehole 1/79. It supplies Nkinga Hospital, adjacent Nkinga Nurses and Midwives Training School and staff houses. The hospital has 192 beds and more than 300 employees.

44 percent of the tin roofs of the hospital area are connected to rainwater reservoirs. This water is used as drinking-water all the year around. In the three villages and the surrounding rural area, there are about ten shallow wells and a number of small natural dams and dug holes.

Water supply systems in action

The Ulaya Dam has a high content of sediment and it is increasing. If no actions are taken to meet this problem, the dam will be filled with sediment in about 35 to 60 years. Today, the sediment causes serious wear in the pump, and bad water quality, especially in the rainy season. There is also a limited and insufficient amount of water pumped from the dam, because of insufficient financial resources and lack of interest from the authorities.

The water from the borehole is of good quality and sufficient for Nkinga Hospital. However, since there is a shortage of water from the dam, people from Nkinga village take water from the hospital's taps, thereby causing deficiency in the water supply for the hospital.

The rainwater harvesters at the hospital area are poorly developed and most of the reservoirs need repair. The water quality can also be improved.

A water quality improvement is generally needed.

Improvements of water supply systems

To solve the sediment problem, several methods can be used. The aim is to prevent the sediment yield and remove existing sediment from the Ulaya Dam, to prevent sediment in the rising main and to purify the water for the consumer. The work schedule for the employee running the Ulaya Dam system must be further regulated and more reliable. Reliability will increase the willingness of for example Nkinga Hospital to give financial support.

The generators at the borehole pumphouse should be replaced by electric wirings from the hospital.

The rainwater harvesters can be exploited more, and with rather small resources the water quality can be considerably improved.

Covers for the shallow wells should be built. They will not only improve the quality of the water, but also, through lesser evaporation, a steadier water supply.

A new cover at the Missionary Water Tower should be built when the reservoir is being repaired.

Future developments

An increased supply gives great opportunities. The Ulaya Dam can give about 500 cubic meters per day and even more when the dam is excavated. Today the extraction is about 60 cubic meters per day. The intake should be utilized with a sediment trap. The running costs can be payed by a new water supply organization.

Figure 1.1. Tanzanian Africans.

1 Tanzania

1.1 Introduction

The United Republic of Tanzania is, to most European people, the Serengeti National Park and Kilimanjaro, the highest mountain in Africa. But Tanzania is also a country full of facets. With its surface of 945 000 square kilometres, it is more than twice as big as Sweden (figure 1.2).

The population is about 23.2 million people (1988) and Dodoma, the capital, has a population of 203 833 (1988), [1].

The name Tanzania comes from the two former countries *Tan*ganyika and *Zan*zibar.

Tanzania has a variety of climatic regions, from the hot and wet zone along the Indian Ocean, to deserts and cold mountain regions and rain-forests.

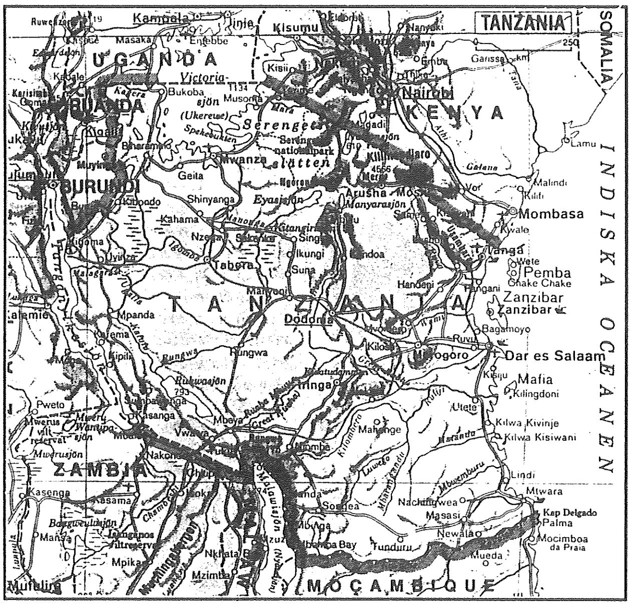


Figure 1.2. Tanzania.

1.2 Geography and climate

Tanzania is situated on the east coast of Africa, 120 kilometres south of the equator.

Most of the country consists of a plateau. Along the coast there is a narrow, flat shelf, which gradually rises to a central plateau, 1000—1500 meters in height. In the western part of the country, there are fault-fissures, which have created the second deepest lake in the world, Lake Tanganyika.

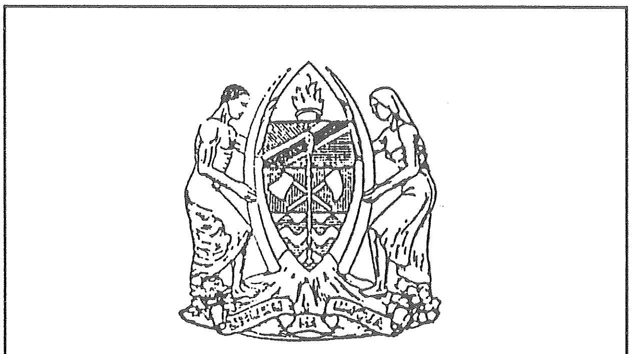


Figure 1.3. Symbol for Jamhuri ya Muungano wa Tanzania.

The climate along the coast is tropically hot, which makes it an appreciated holiday destination (figure 1.4).

There are no European traditional seasons, but two dry and two rainy seasons. The "cold", long and dry season lasts from June until October, and the "hot" dry season from December to February.

The two rainy seasons with short heavy pelting rains, consists of a short season from November to December and a longer one from March to May.

On the plateau it is warm and dry. The rainfall is rather irregular, which is a great disadvantage for the agriculture (figure 1.5).

On higher altitudes the temperature is lower and the top of Kilimanjaro is permanently snow-capped.

In the north, there is the third largest lake in the world, Lake Victoria, and the highest mountain of Africa, Mount Kilimanjaro, 5895 meters.

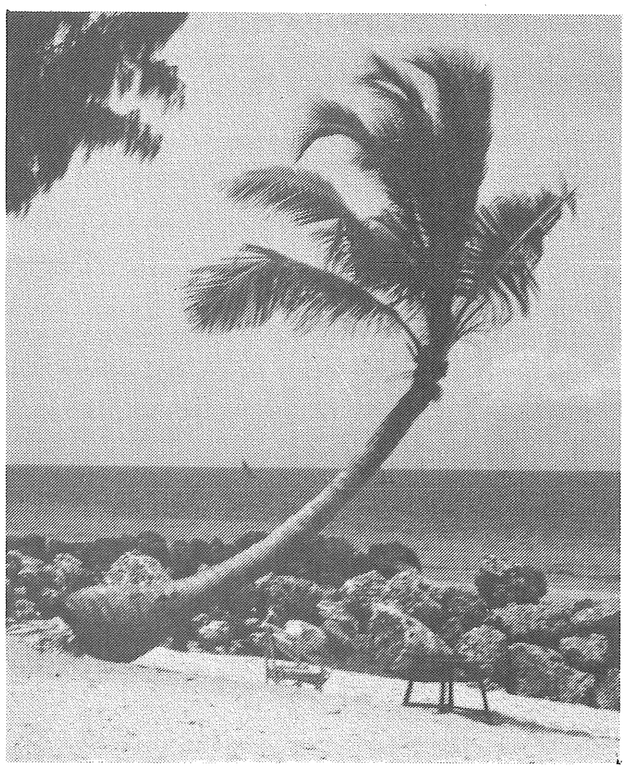


Figure 1.4. Bahari Beach, just north of Dar es Salaam.

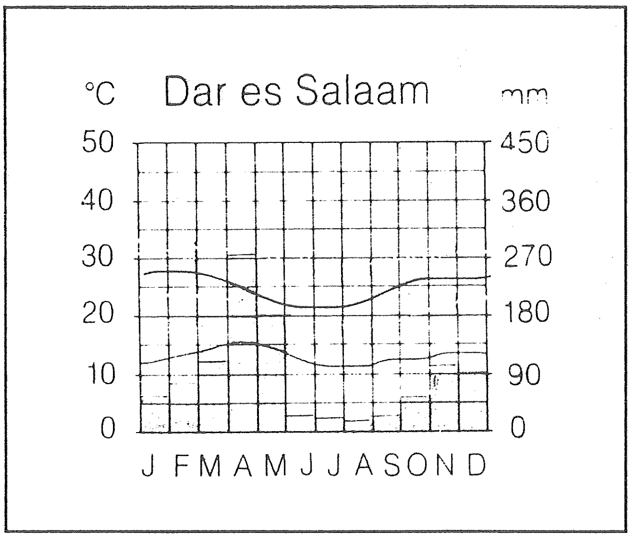


Figure 1.5. Average temperature and precipitation in Dar es Salaam.

1.3 Vegetation and fauna

Tanzania is a part of the great savanna-belt in Africa which is surrounded by the tropical rain-forests of western Africa and the Congo delta.

The savanna consists mainly of grass with a more or less dense number of trees. There are several types of a grassy plain with intermediate stages to other forms.

During the long dry season, the vegetation is sunburnt and dry, but at the beginning of the long rainy season luxuriant vegetation appears.

Where the dry seasons lasts seven and a half to ten months there are open thorn-bush-savanna. The grass surface is not continuous and the grass can reach knee-height. Trees suited to the arid climate are the acacia, the dum-palm and the baobab or monkey-bread-tree (figure 1.6).

The dry-savanna appears where the length of dry seasons are between five and seven and a half months. It is covered with grass, up to breast height, and open miombo-forest.

Where the east-african savanna belt has a duration between the dry seasons of two and a half to five months, for example the coastal inland, there is the damp-savanna. Leaving the savanna, dampish landscapes as the rain-forest can be found. Typically for that kind of forest is the large number of species for example liana and bamboo.

Near the coast there are Mangrove-marshes and open forests. Along the coastal waters there is a living coral reef.

Depending on the district and the season one can find fruits like bananas, oranges, mandarins, pineapples, mangos, papayas and passion fruits.

The savanna is especially rich in game. It is the natural habitat for elephant (figure 1.7), hippopotamus, rhinoceros, antelope, zebra, giraffe and buffalo. Among the big beasts of prey there are lion, leopard and cheetah. The world of birds is abundant and colourful, especially in the savanna and in the forests.

National parks in Tanzania includes the Serengeti, with its area of about 14 100 square kilometres and more than a million of large animals, Lake Manyara, Tarangire, Arusha, Mount Kilimanjaro, Rubondo, Katari Plains, Gombe Stream, Ruaha and Mikumi.

There are also the game reserves of Ngorongoro, Maswa, Nkomazi, Sadani, Biharamulo, Ugalla River, Rungwa and Selous.

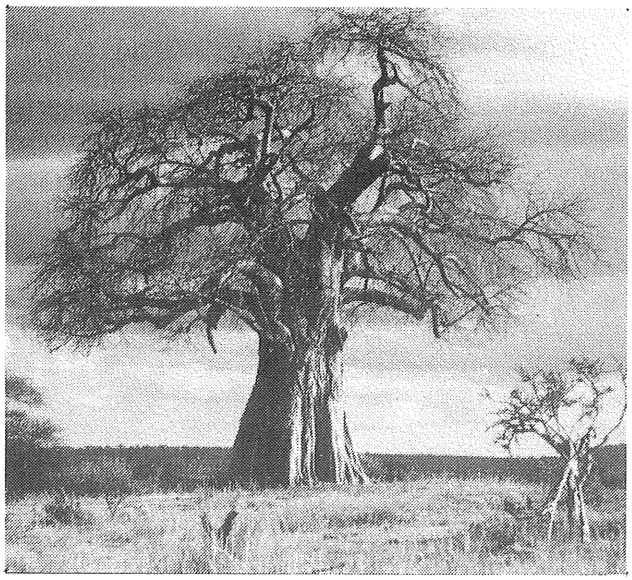


Figure 1.6. Dry-savanna with baobab in Tarangire National Park.

Figure 1.7. Elephants in Tarangire National Park.

1.4 The people

The African people of Tanzania can be devoted to a large number of tribes. None of them has been dominant though. The country has consequently avoided heart-rending tribal feuds. 99 percent of the Tanzanian population are Africans. Most of them belong to one of the 120 Bantu-tribes, of which Sukuma, Nyamwezi, Makonde, Haya and Shagga are the largest ones (figure 1.8). The well known Massai live in the north. The remaining population are Asians, Indians and Europeans.

The 23.2 million (1988) population is geographically very irregularly distributed. The most densely populated parts are around Lake Victoria, the high plateau, along the coast and on the two islands of Zanzibar and Pemba (figure 1.9).

The inland parts are sparsely populated. The reason of this is mainly the dread ravaging of the tse-tse-flies and the poor, dry soils.

The capital Dodoma had in 1988 a population of 203 833 inhabitants. The former capital (until 1973), Dar es Salaam, had in 1988 about 1 360 850 inhabitants, [1], and will at present, with its population growth of 8.5 percent, continue to grow rapidly.

The average life expectancy at birth is 52 years, and 60 percent of the population is younger than 20 years.

The official language in Tanzania is Swahili, a Bantu-language. It is spoken all over the country. The educated Africans also speak English.

While the traditional animistic religions are decreasing, Christianity and Islam are increasing. They have about one third of the population each.

1.5 History

According to prevalent scientific theories, eastern Africa is the origin of mankind. As an example 3.6 million years old human footprints has been found in the Ngorongoro Conservation Area in Tanzania.

In spite of the age, very little is known about eastern Africa before the eighth century when Omanian Arabs started to colonize the coast. Impressive ruins bear witnesses to the domination of the Arabs at that era.

In 1489 Vasco da Gama arrived at the coast of Tanganyika and till the end of the seventeenth century there was a Portuguese influence. With the new rulers, the Arabs from Oman, slavery began.

Many of the great expeditions during the eighteenth century in search for the source of the Nile started at the Tanganyika coast. Under a Mango-tree at the Lake Tanganyika near Ujiji the 28th of October 1871, Stanley said the famous words: "Dr Livingstone, I presume?", [2].

In 1884, the European countries were gathered in Berlin to divide Africa between themselves. Tanganyika became German, and in 1917, after the World War I, it became British.

After the liberation in 1961 of Tanganyika and Zanzibar, the two states founded a union the on 27th April of 1964, Jamhuri ya Muungano wa Tanzania, the United Republic of Tanzania.

At the end of 1978, Idi Amin's Ugandian troops invaded Tanzania and started a three-year war. The war, a decreasing agricultural productivity and the worldwide economical crisis caused a serious depression in Tanzania, with tremendous deficit in the balance of payments.

Today, in the early nineties, most of the necessary base products, which were absent a few years earlier, have returned to the stores.

1.6 Economy

The Tanzanian trade and industry show most of the common signs of an underdeveloped country. Agriculture and cattle-breeding are the foundation, the productivity per capita is low, the rate of unemployment is high and the income per inhabitant low.

In accordance with the Arusha-declaration 1967, banks, insurance companies and export- and import-firms were nationalized. In recent years, there has been a liberation and it is now possible to run a business in private regime.

The economy is very dependent on the aid-giving countries, where the Scandinavian countries contribute about one third of the total aid. Today Sweden annually gives economical aid to Tanzania in different forms worth 427 million SEK (1989).

The gross national product, GNP, totalled 240 US dollars per capita in 1984, of which agriculture were 52 percent. The aid was corresponding to approximately ten percent. For comparison the gross national product in Sweden was 26 690 US dollars per capita (1990).

1.6.1 Agriculture

Agriculture is the absolutely dominating sector and it occupies about 90 percent of the population. Almost

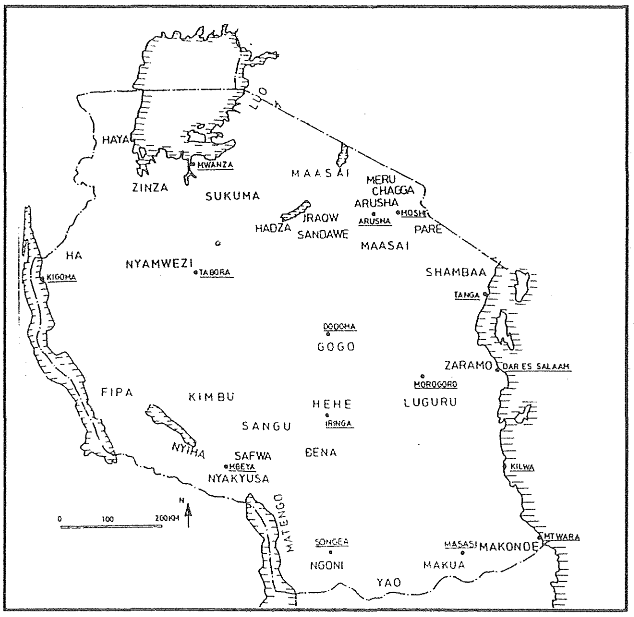


Figure 1.8. Tribes in Tanzania, [3].

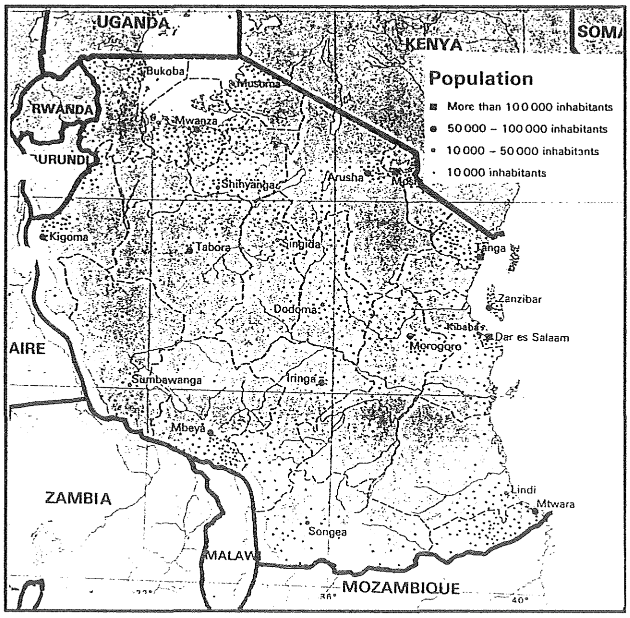


Figure 1.9. Population Density in Tanzania, [4].

everyone is a small farmer who works with archaic methods on small allotments. The aim of the farming is mainly to supply the needs for the family.

Corn is together with bananas, beans, rice, millet and cassava the most common products.

70 percent of the Tanzanian export comes from agriculture. One half of it is coffee-export and the other half is mainly cotton and tea, but also hemp, pyrethrum, cashew-nuts and meat.

Figure 1.10. Typical Swedish tourists.

1.6.2 Industry

The industrial sector is small and is dominated by nationalized and partly nationalized companies with low profitability. The utilization of the capacity is just about 20 percent.

The Government tries to direct the investments to the sugar, textile, cement, paper and local small-scale industry.

Almost the entire production is sold within the country.

1.6.3 Tourism

The tourism was during the seventies an important source of foreign exchange. However, during the eighties the number of tourists has rapidly decreased. The two most popular attractions, Serengeti National Park and Kilimanjaro, are available and more comfortable to reach from Kenya.

Figure 2.1. An average family outside their hut.

2 Nkinga Hospital and the three villages

2.1 Igunga district

Tanzania is divided into 25 regions (figure 2.2). One of them is the Tabora region. Each region is divided into districts and Igunga is one of the districts in the Tabora region. The district of Igunga 203 097 inhabitants (1988), [1], with Igunga as its district town (8478 inhabitants) (figure 2.3 and 2.4).

The landscape consists of mountains covered with soil in longish hills. Where there once was a dense forest there are now single trees of acacia and baobab with a bush-savanna.

The wild-life has diminished seriously since the forest disappeared. Previously, herds of elephant and lion could be seen. Nowadays, even zebra and monkey are seen rarely.

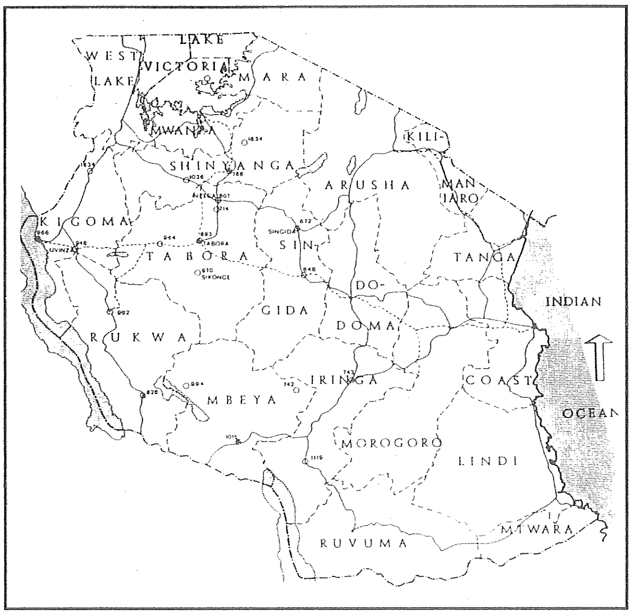


Figure 2.2. The regions of Tanzania, [5].

The dominating tribe in Igunga district is Wanyamwesi, speaking the Bantu-language Kinyamwesi. The nomadic Wataturu (the moon-people) are a cattle-herding people, in many ways alike the Massai, in spite of their black clothes compared to the Massai people's characteristic colourful clothing (figure 2.5).

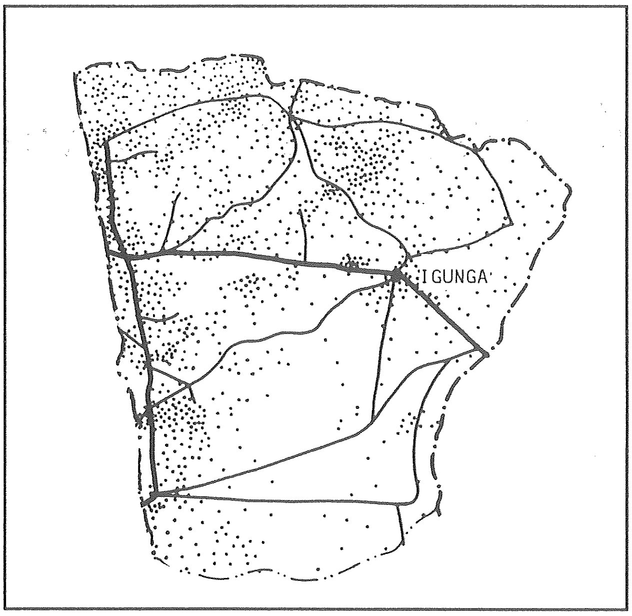


Figure 2.4. Population density in Igunga District, [6].

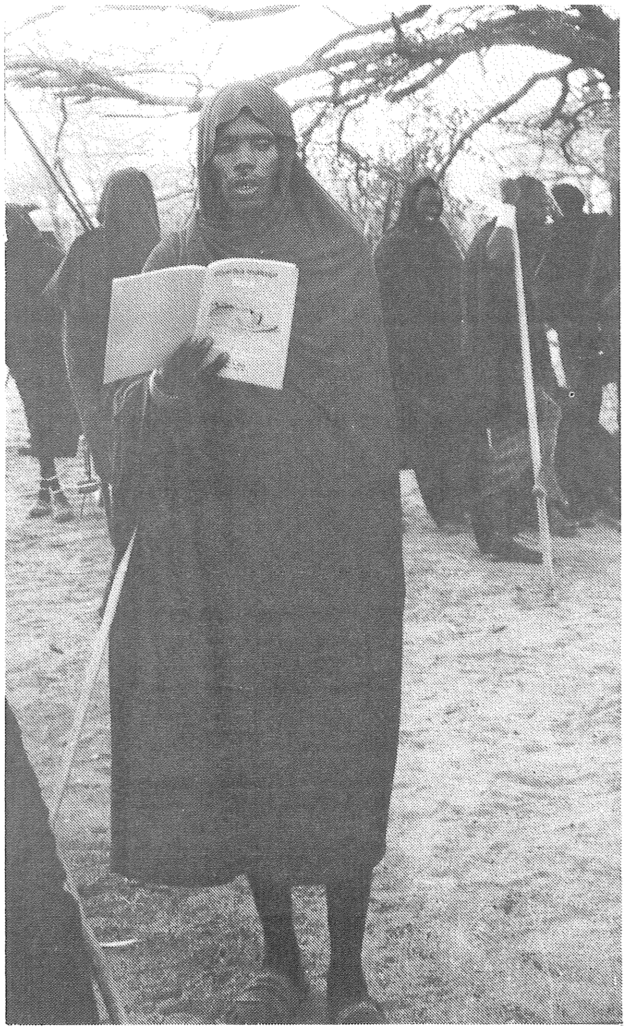


Figure 2.5. The Wataturu people.

The dominant occupation among the people in Igunga district is smallscale farming. An average family lives in a hut of clay with straw-roof, it consists of six persons and it has a little patch of cultivated ground, a "shamba" (figure 2.1).

The common crops are corn (ugali is the staple food, a porridge of maize meal), groundnuts, rice, millet, cassava and beans. Fruits are mainly bananas, papayas and mangos.

Telephones have recently been installed in the town Igunga, but electricity is still just a wish for the future. No large industry exists in the area.

The main roads are very bumpy gravel roads, often so bumpy that it is impossible to exceed an average speed of 50 kilometres per hour.

2.2 Nkinga Hospital

The story of Nkinga started in 1935. This year, Erland and Ester Jonsson from Örnsköldsvik, Sweden, cycled in the Tabora region to find a good location for a Pentecostal mission station.

From the King of Ulaya, they bought an uninhabited forest domain south of the Kings residence.

The Jonssons built a church and opened a clinic, that later became a hospital. Rather soon the place was given a new name by the people, Nkinga. That means "the place where sickness is prevented" (figure 2.6).

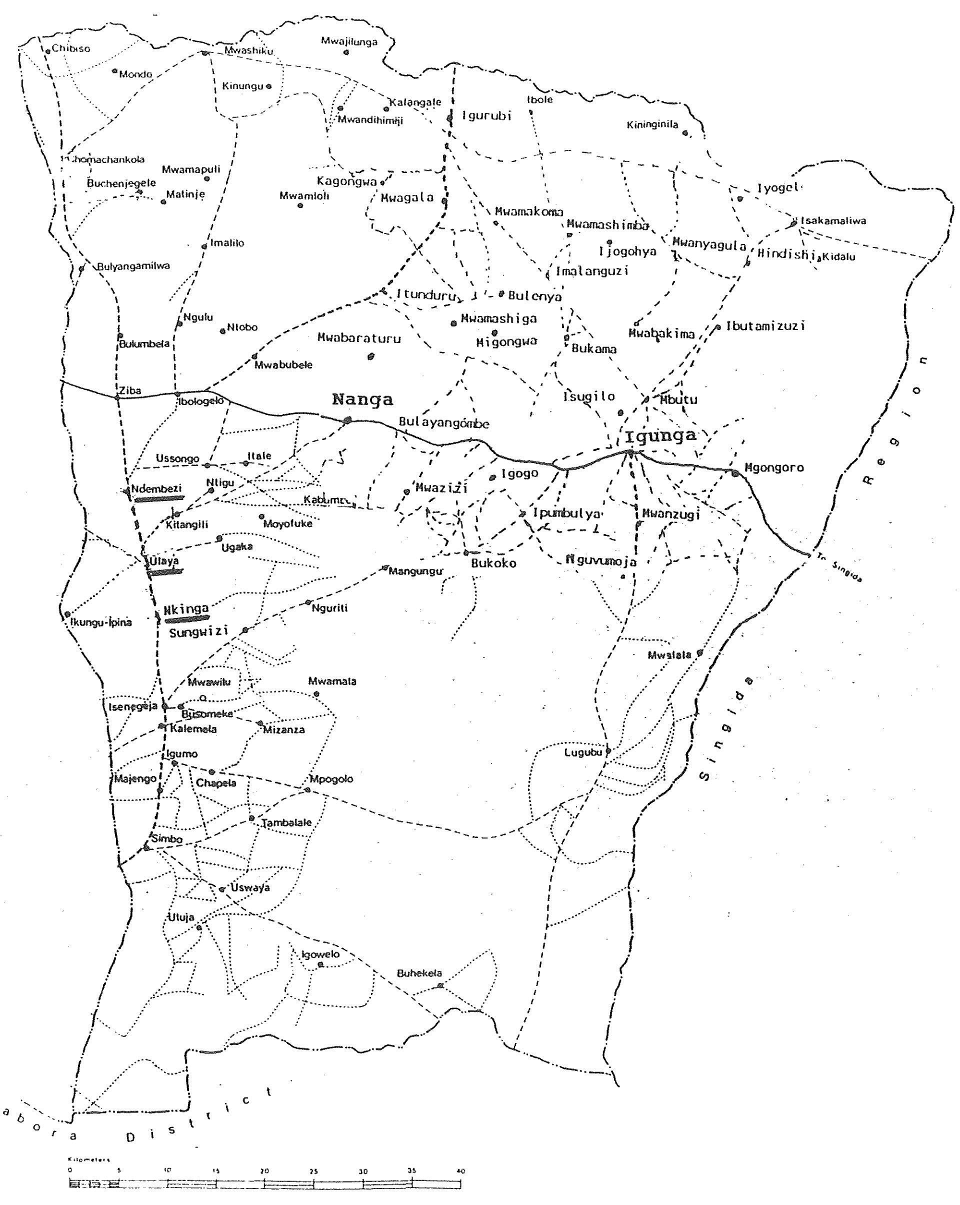


Figure 2.3. The Igunga district, [6].

Figure 2.6. Nkinga Hospital from above.

To satisfy the demand of nurses for the hospital, the Nkinga Nurses and Midwives Training School was started.

Today Nkinga Hospital is a Grant Aided Voluntary Agency Hospital, run by the Pentecostal Churches Association in Tanzania (PCAT). It is supported by PCAT's Swedish counterpart, Pingstmissionens U-landshjälp, PMU.

The catchment area is not restricted to Igunga district. Owing to the good reputation, 60 000 patients (1990) have come from all over Tanzania, including Dar es Salaam and Zanzibar.

The hospital can be divided into four wards, surgical, medical, children and maternity, and has totally 192 beds. The number of people in the staff exceeded 300 persons at the end of 1990. About 15 of them are Swedish missionaries, [7].

The Nkinga Pentecostal Church has about 2200 members (figure 2.7).

The village of Nkinga Hospital had in 1988 a population of 672 people (including patients, visitors and employees), [8] (figure 2.8).

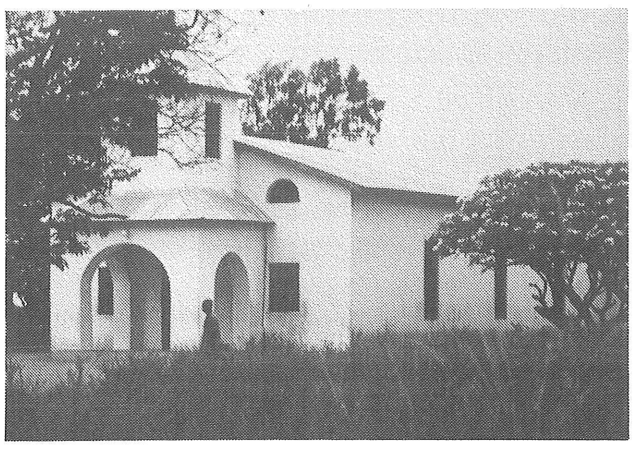


Figure 2.7. The Nkinga Pentecostal Church.

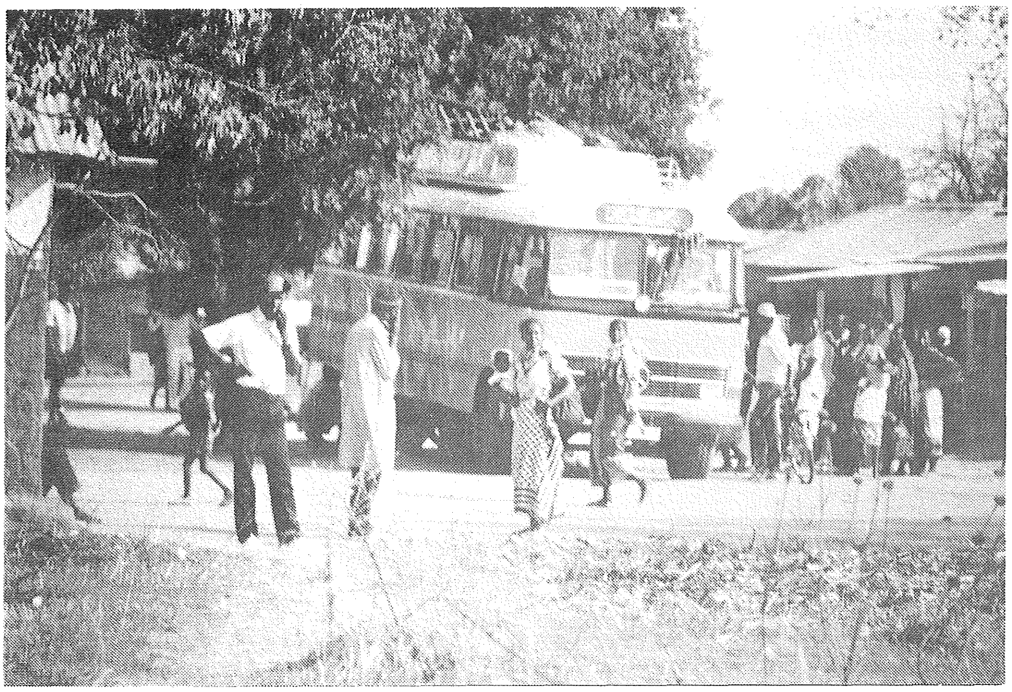


Figure 2.9. The main road through Nkinga village.

2.3 Nkinga village

Nkinga village is the houses situated around the hospital domain of Nkinga.

As a sick Tanzanian always brings his family with him, there were needs for lodging. The Ujamaa-program in 1972—1974, forced people to move to local centres with schools and hospitals. These two circumstances together with the function as a meeting and trading place (figure 2.9), made Nkinga grow from an uninhabited forest to one of the largest villages in the district.

In 1988, 4578 people lived at Nkinga, [8].

2.4 Ulaya village

Ulaya village is situated about three kilometres north of Nkinga. Ulaya means Europe in Swahili, but there are several stories about the reason why it is called "Europe". One of them tells the story of a Russian, who built his house at Ulaya during the Russian Revolution. Another story tells about the English two-storey hunting manor that was located near the Ulaya Dam in the late forties and the fifties. A third story tells about the landlord that kept his property in such good condition.

Today, Ulaya is a small village along the main-road and the dam, with 2011 inhabitants (1988), [8].

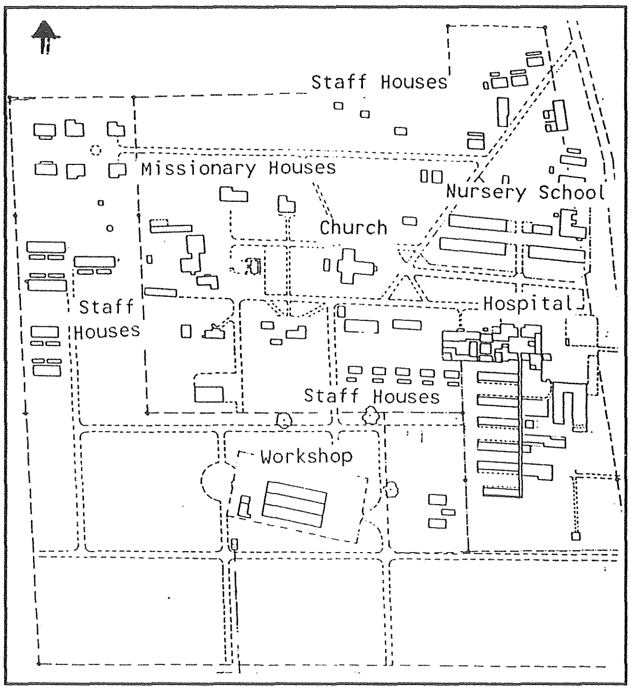


Figure 2.8. Site plan of Nkinga Hospital.

2.5 Ndembezi village

Ndembezi is situated about seven kilometres north of Ulaya. Perhaps most well-known because of its famous cemetery.

The houses are built along the road and in 1988 the village had 4383 inhabitants, [8].

Figure 3.1. The laterit is used to make sun-dried bricks.

3 Geology, hydrogeology and hydrology

3.1 Geology

The area of Nkinga Hospital and the three villages consists mainly of lateritic soil. The grain size varies from clay to gravel. It has mainly been formed by chemical weathering of the bedrock. The weathering process implies demolition and soaking of the rock. At the same time iron oxides are enriched, which give the soil its red colour. The contents of iron compounds and aluminum compounds, compared to the contents of quartz, is usually used as a measurement of the lateritic extent.

The laterit is a clayish soil with very high contents of iron and aluminum. It is used by the rural people to make bricks for house-building (figure 3.1). In latin the word *later* means brick.

The surface of lateritic soil is often very weathered and has a depth of a few meters. The transition to fresh not weathered rock occurs gradually and the material becomes coarser with depth.

The soil in the area is largely derived from granites. It is most sand to silty sand, and weathered granite. In some of the lower areas there is grey clay with contents of silt with or without sand.

In some parts of the area there are outcrops of granite. The granite is believed to be late precambrian, [9]. South and west of the Ulaya Dam there are big boulders of granite scattered in the terrain (figure 3.2). Boulders however do not always prove the presence of outcropping bedrock.

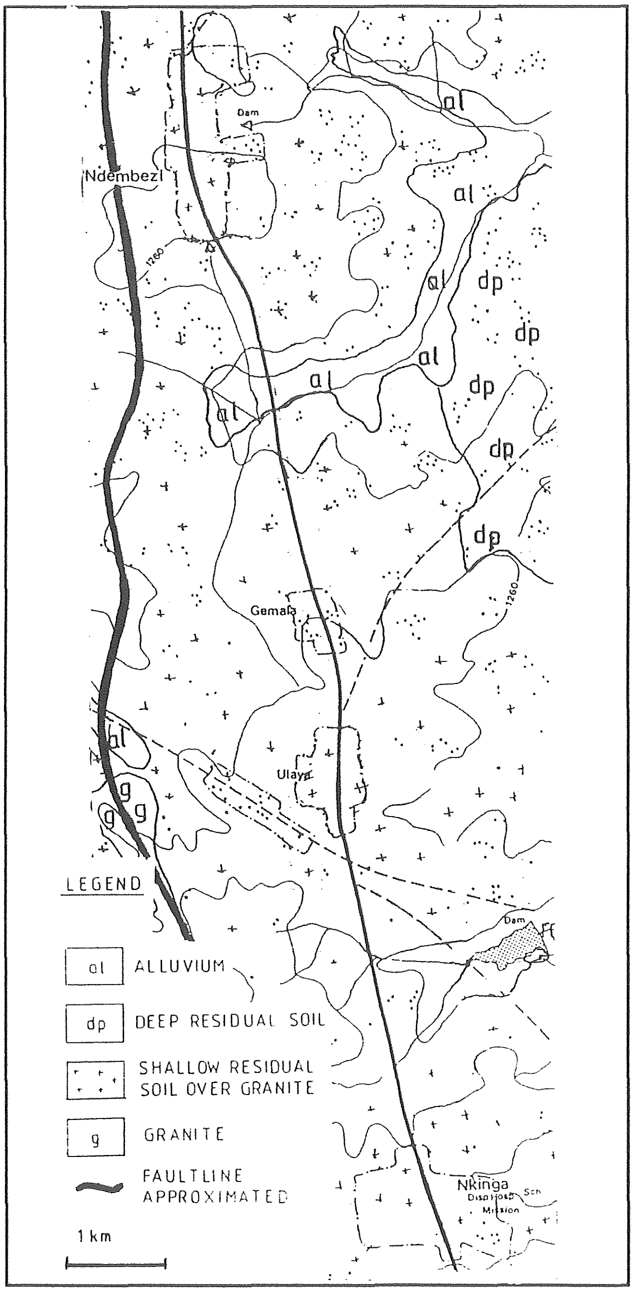


Figure 3.2. Geology in the area, [6].

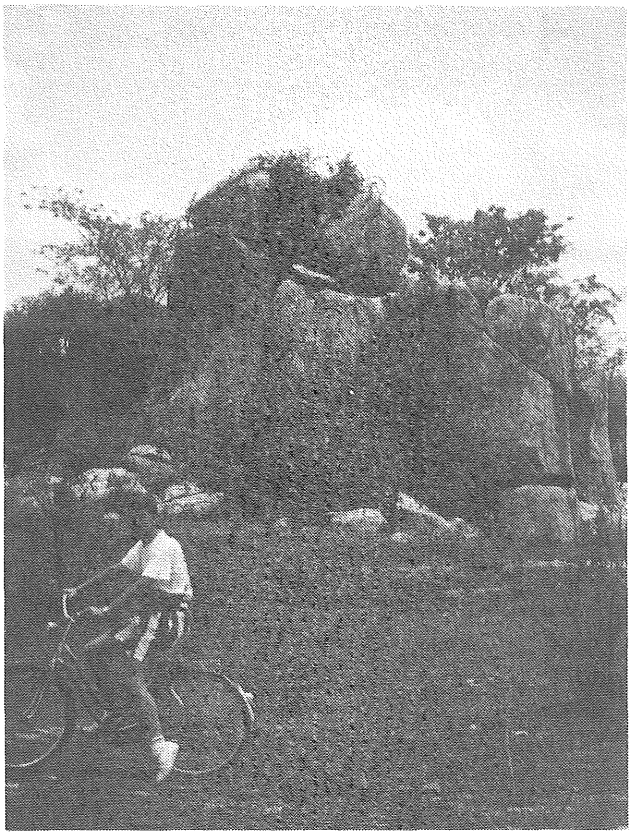


Figure 3.3. Big boulders near the Ulaya Dam.

Nzega Fault and Kogongho Basin

The Kogongho Basin is situated west of the Ulaya village along the road between Ulaya and Nzega. Kogongho is a river, which has its origin south-west of the basin. It flows north, flooding the entire basin during the rainy season. The river remains dry most of the year, [9].

The Nzega Fault, which has created the basin, cannot be exactly defined in the terrain. In the Ulaya area the fault zone seems to be located within the long slowly declining slope between the western parts of the village and the bottom of the basin. It is partly filled with water due to the rebuilding of the Idudumo Dam (figure 5.2).

In the upper parts of the slope some big boulders may mark the presence of bedrock (figure 3.3).

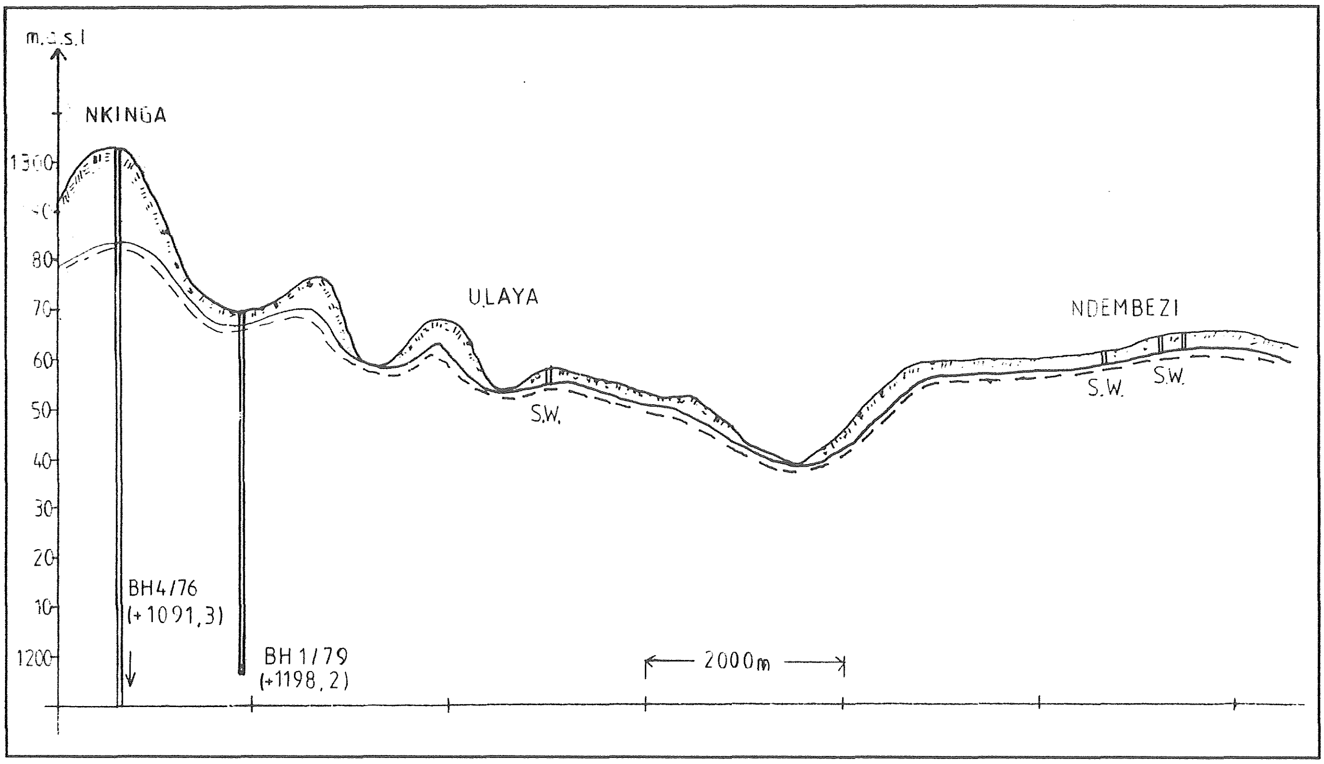


Figure 3.4. Profile along the road passing Nkinga, Ulaya and Ndembezi.

3.2 Hydrogeology

The main water bearing layers in the area are sand and gravel, weathered granites and fractured granites. Most water stored in this layers has an overpressure and this pressure increases with depth.

The recharge to the aquifers is mainly by precipitation. During the rainy season a considerable amount of rain-water percolates through the zone of evaporation and transpiration, and finds its way down to the aquifers. Recharge comes also from seepage from the Ulaya Dam and other dams in the area.

One question to be answered is how much water that can be extracted from the ground water reservoirs according to the relationship between precipitation, recharge and the possible amount of water that can be stored in the water bearing layers. Another interesting question is how much the groundwater level varies during the seasons.

The static groundwater level in the area varies with the topography. The studied area is characterized by several long slopes and hills along the road between Simbo and Ziba. The three villages are situated on the top of the hills and among them Nkinga has the highest altitude above sea level, between 1290 to 1310 meters. The ground level at Ulaya and Ndembezi varies between 1260 to 1275 meters (Figure 3.4).

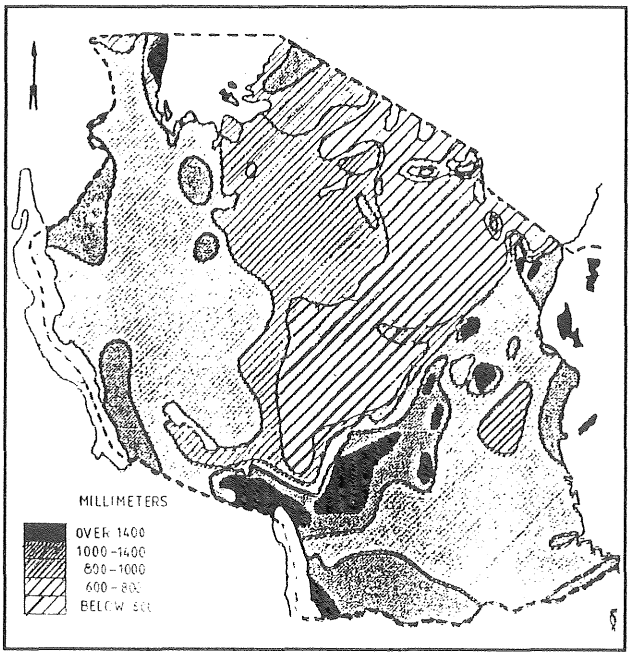


Figure 3.5. Tanzania. Mean annual rainfall, [11].

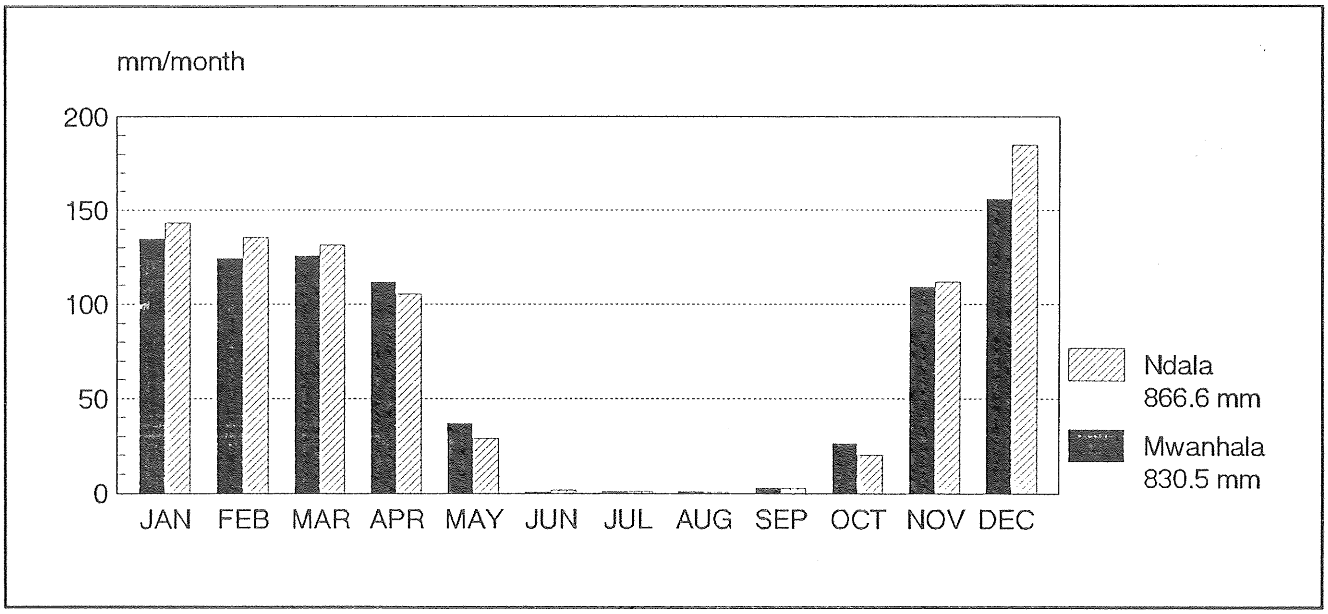


Figure 3.7. Average monthly precipitation at Ndala (1957—1989) and Mwanhala stations (1957—1989), [10].

The depth down to groundwater level is much deeper at Nkinga than at Ulaya and Ndembezi. The reason is mainly that Nkinga is situated on a higher altitude and that the ground at Nkinga slopes more steeply. Nkinga and the area around is also a part of the Ulaya Dam catchment area. A borehole drilled at Nkinga (appendix A) struck the water at 26.8 meters below ground level and the static water level was about 20 meters downwards.

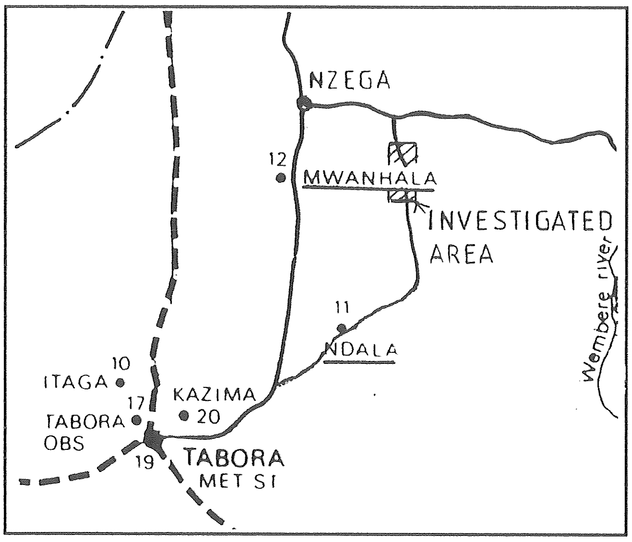


Figure 3.6. Rainfall stations near Nkinga.

The static groundwater level at Ulaya and Ndembezi varies, according to the water level measured in the shallow well inventory (chapter 8.2.1), from one to four meters below ground level. The water bearing layers are silty sand to sand and weathered granite.

In the first valley between Nkinga and Ulaya, the Borehole 1/79 is drilled at the lowest part (appendix A). The static groundwater level is about two to four meters below ground level. The first water bearing layer consists of gravelly sand and very weathered granite, between three to nine meters. The geophysical surveys done in the valley (appendix B), indicate a porous water bearing layer with a high water potential, between 9 and 26 meters below ground level. This layer is granitic and partly weathered. This depression probably corresponds to a second fault line of the Nzega Fault, striking west-northwest (chapter 3.1).

Along the dirt track from Ulaya to Nzega, the Borehole 181/78 has been drilled and geophysical surveys carried out (appendix B). Unfortunately, this borehole caved in when it was drilled during the rainy season. The road slopes from Ulaya down to the Kogongho Basin (chapter 3.1). The borehole is situated in the upper part of the slope, where the depth of the overburden is 41 to 50 meters deep and seems to penetrate a weakness zone. This probably corresponds to the earlier mentioned Nzega Fault. Water was struck three times in the lower part of the overburden, before it caved in.

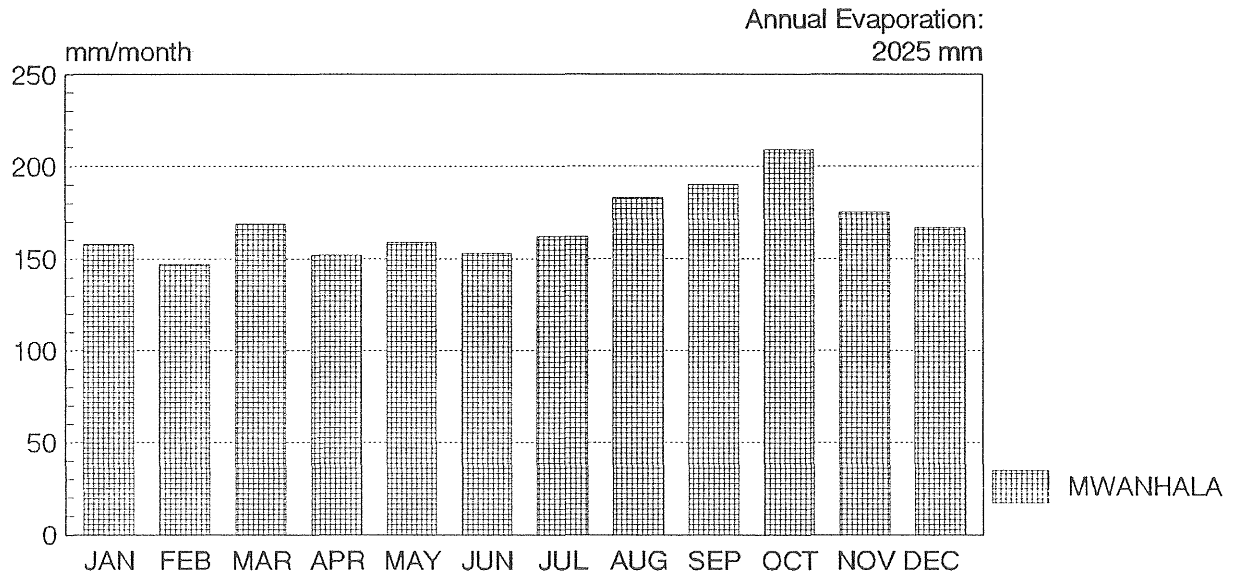


Figure 3.8. Average monthly evaporation at Mwanhala station (1969—1977), [6].

3.3 Hydrology

3.3.1 Precipitation

The rainy season lasts from November to April with one maxima in December and one in March (figure 3.5). The nearest rainfall stations are Ndala and Mwanhala (figure 3.6, table 3.1 and 3.2). The average yearly precipitation at Ndala is 866 millimetres and at Mwanhala 830 millimetres. The dry season from May to October is very dry with no or just very little precipitation.

The monthly variation is shown in figure 3.7.

3.3.2 Evaporation

The hot and dry climate causes a very high evaporation, in average 5.5 millimetres per day (Mwanhala, [5]), and varies monthly as shown in figure 3.8.

3.3.3 Other information

There are also other climatic factors, which effect the water supply situation. Shortwave radiation, temperature, vapour pressure and wind speed is shown in figure 3.9 (Mwanhala).

Table 3.2. Annual minimum precipitation (mm), [10].

Station	Return period in year		
	5	10	20
Ndala	719	657	610
Mwanhala	716	667	629

Table 3.1. Rainfall stations, [10].

Station	Number	Period	Latitude	Longitude	Altitude	Mean Annual Rainfall
Ndala	9433001	1957-1989	4:45'	33:16'	1372 m	866.6 mm
Mwanhala	9433002	1957-1989	4:24'	33:09'	1250 m	830.5 mm

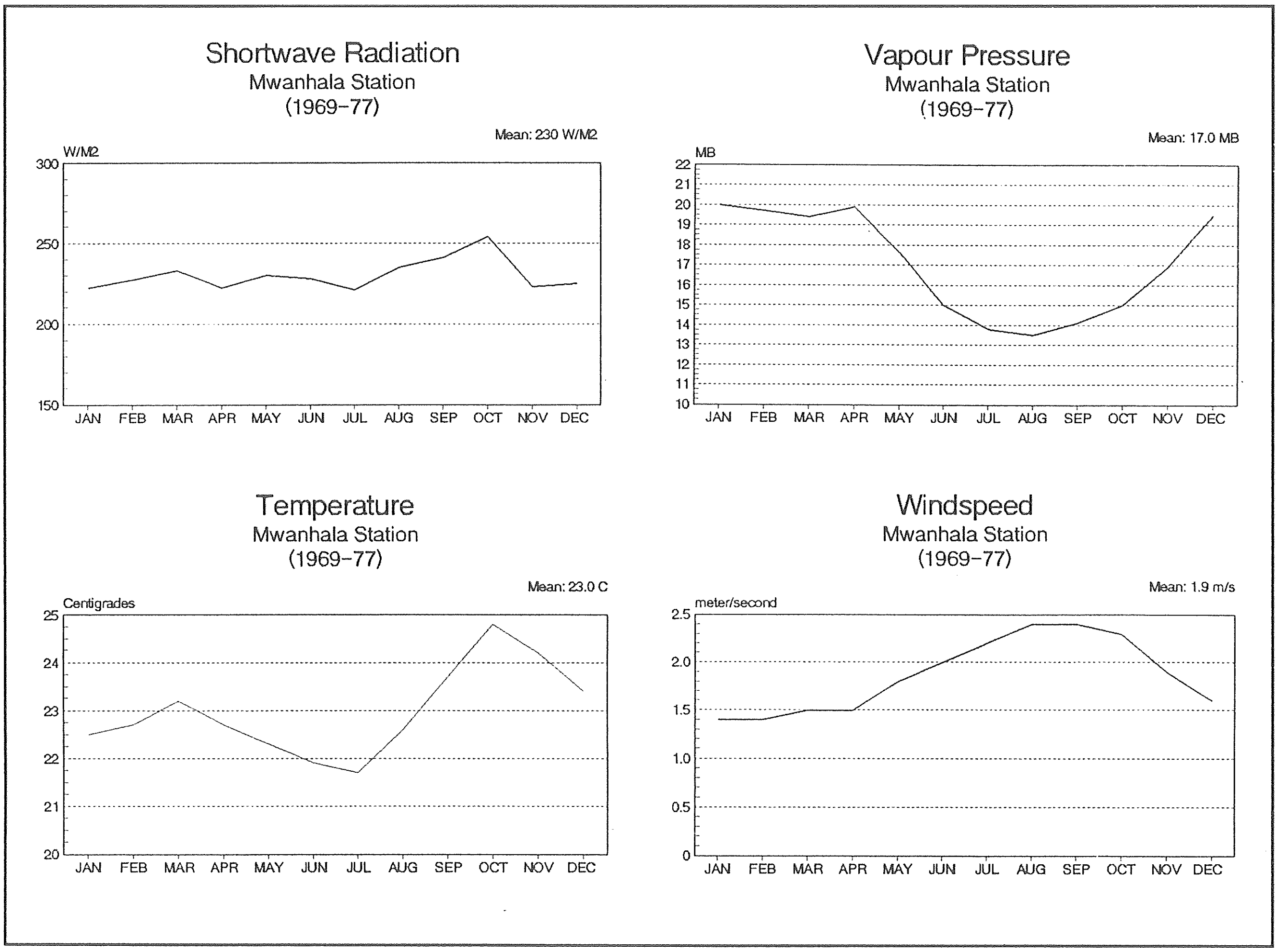


Figure 3.9. Shortwave radiation, temperature, vapour pressure and wind speed at Mwanhala station (1969–1977), [6].

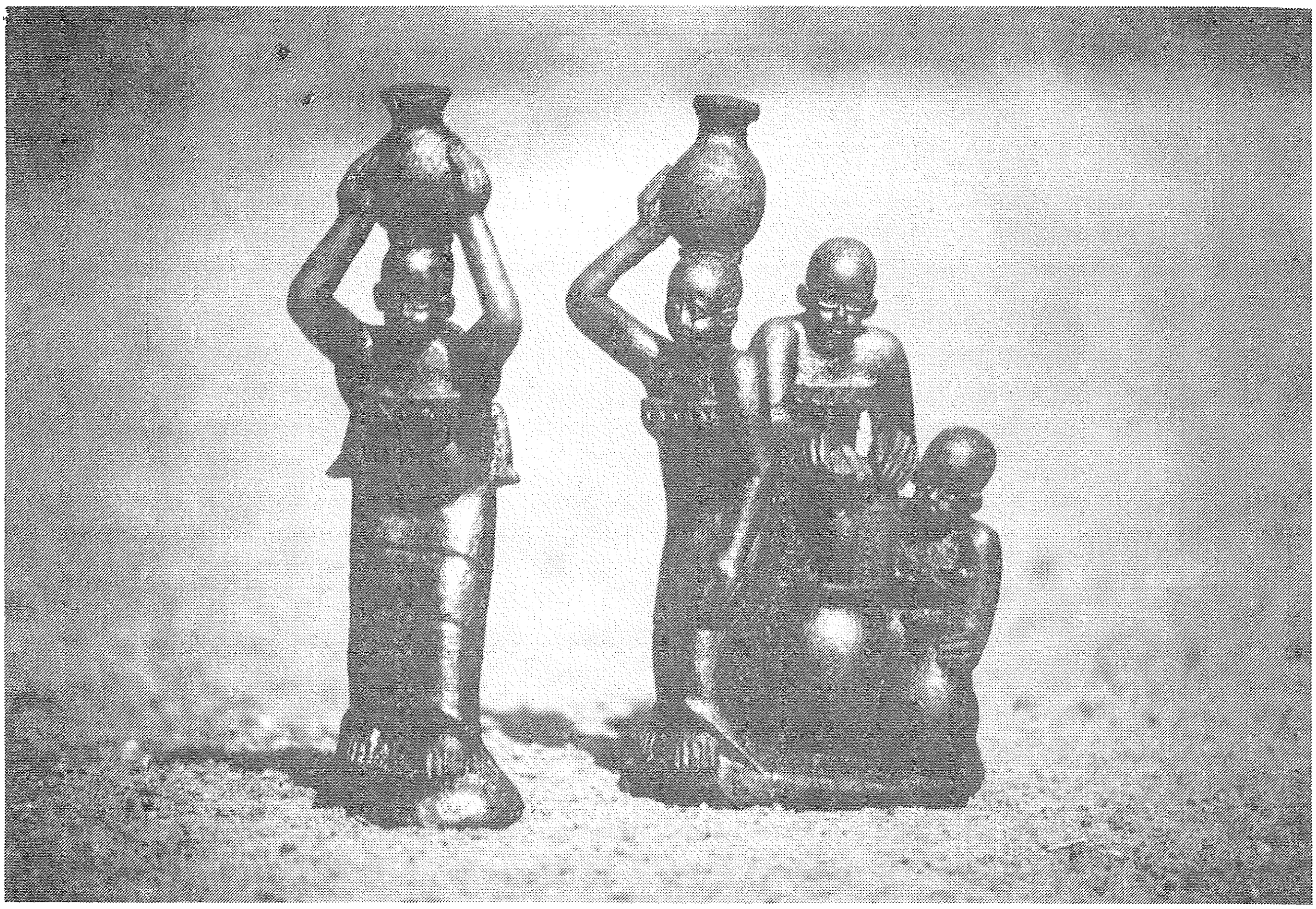


Figure 4.1. Women collecting water from a tap. Local handicraft pottery.

4 Survey of water supply systems

The existing water supply systems at Nkinga Hospital and the three villages Nkinga, Ulaya and Ndembezi, can roughly be described with three of the sources. They are the Ulaya Dam (a large rainwater reservoir), a deep-drilled borehole and rainwater harvesters (figure 4.2).

In the existing water supply systems at Nkinga Hospital and the three villages, there are a number of problems. Some of them are rather easy to remedy, other more expensive. The most expensive action is probably how to get the sediment out of the dam.

The main problem is that the need of water is much larger than the supply. There are however great opportunities to increase the supply. This is described in detail in the following chapters (table 4.1).

Table 4.1. Water sources.

Sorce	Extraction today (cbm/day)	After improvements (cbm/day)
Ulaya Dam	60	500
Borehole 1/79	30	70
New borehole	-	70
Rainwater harvesters	2,5	10
Other water sources	N A	N A

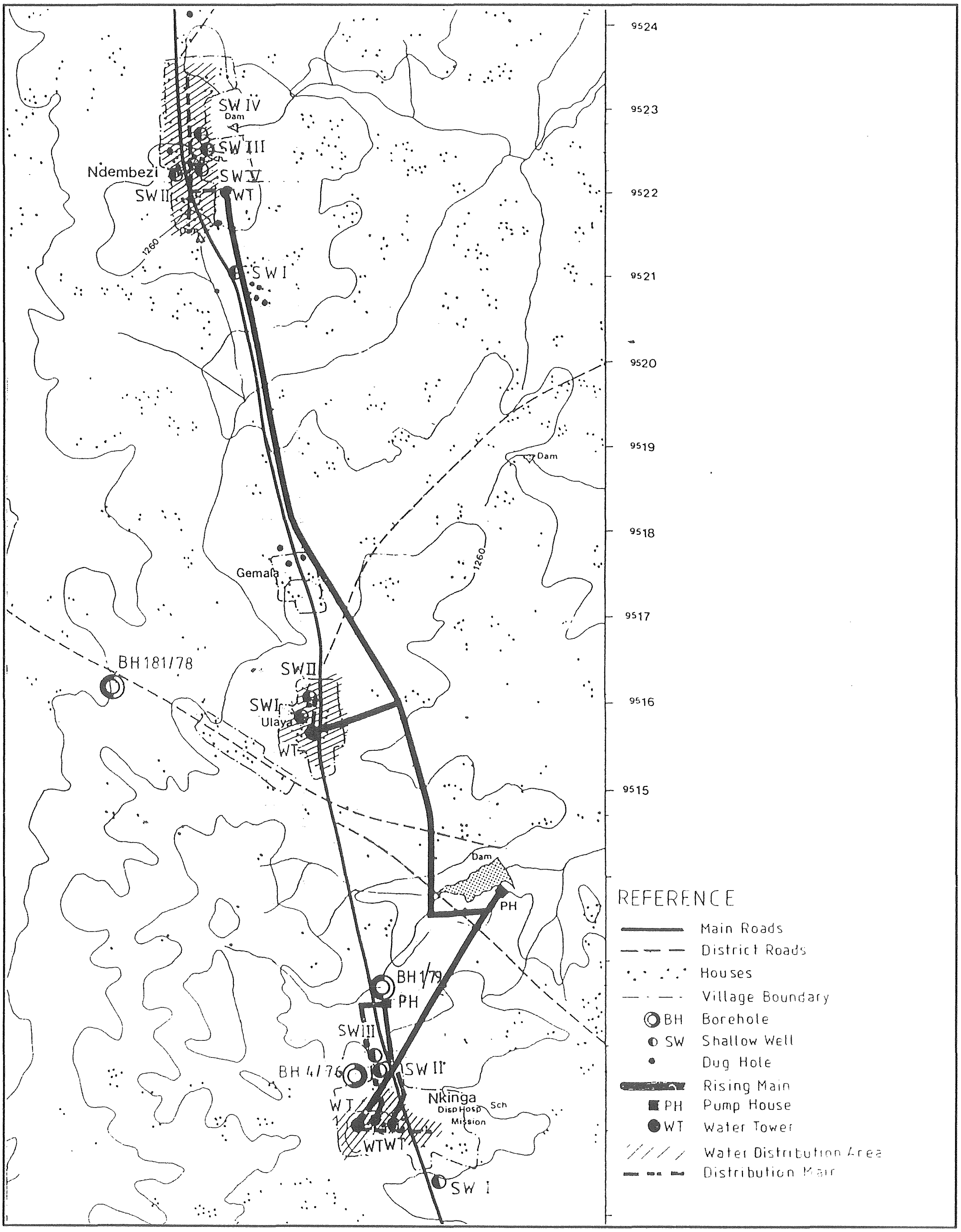


Figure 4.2. Water sources and distribution at Nkinga, Ulaya and Ndembezi.

Figure 5.1. The Ulaya Dam.

5 Ulaya Dam

5.1 Survey

The largest source in the area is the Ulaya Dam (figure 5.1). It supplies the villages of Nkinga, Ulaya and Ndembezi. Totally 15 627 people (1988) get their water directly from the reservoir, or via water towers in the three villages, [8].

The reservoir gives about 60 000 litres of water per day, or about 18 000 cubic meters per year. That means an average volume of 3.9 litres per person each day.

The water is of rather poor quality and has a high content of sediment, especially in the rainy season, giving the water a brownish colour. This has been an increasing problem the last years.

A rather small volume of water is pumped from the reservoir to the towers every day, depending on financial resources of Idara ya Maji to buy diesel for the pump motor. The Nkinga Village Water Tower is emptied in about one and a half hour, early in the morning.

The following chapters describe the capacity, sedimentation, water quality and actions that have to be taken to

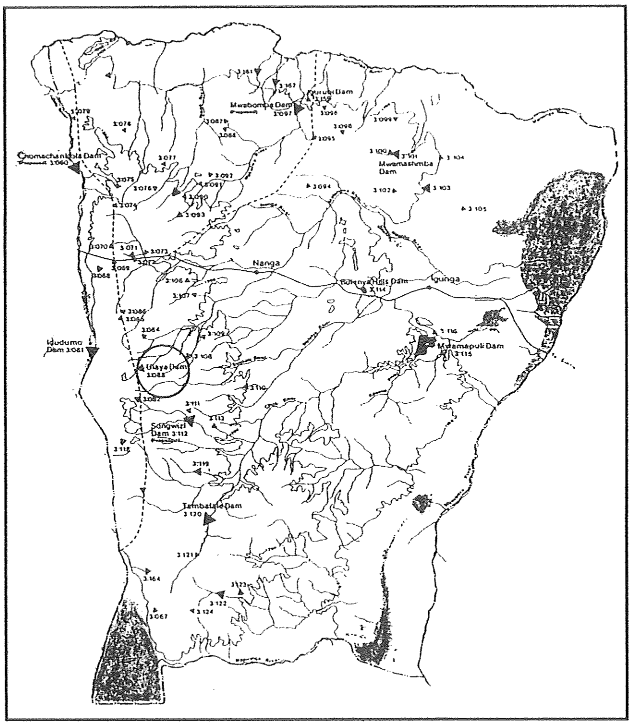


Figure 5.2. Dams in Igunga district, [6].

improve the system. Finally future developments are suggested.

5.2 Introduction

The Ulaya Dam is a rainwater reservoir. Reservoirs like this one are widely utilized in western Tanzania and in Tabora region in particular. They may look like small lakes, but they have an embankment on one side, (figure 5.2).

They are often used as good fishing-waters for the local people. The fish were initially planted to keep the malaria low.

The quality of the raw water taken from reservoirs is rather poor and treatment is usually required to reach an acceptable level of purity.

The widespread use of rainwater reservoirs for water supply is a result of the difficulties in exploiting groundwater. Thus, before there was a capability in the water organization to deal with deep-drilled boreholes, the reservoirs were the only solution.

5.3 Description

5.3.1 History

The Ulaya Dam is situated three kilometres north of Nkinga. The altitude is 1255 meters above sea level, and it was built in 1947 by the Englishmen.

The one and only time the reservoir has dried out, was in the extremely dry year of 1949. Considering that it was just a couple of years old, the water had not filled up the reservoir to full supply level at the start of the driest year in the history of the Ulaya Dam (1947—1991).

In the late forties, the Englishmen built a two-storey house near the reservoir. They used it on weekends, when they hunted birds near the reservoir.

In 1967 a distribution pipe to a storage tank at Nkinga village was designed. It was completed the following year with the Nkinga Village Water Tower. In 1974 a distribution pipe to storage tanks at Ulaya and Ndembezi was completed.

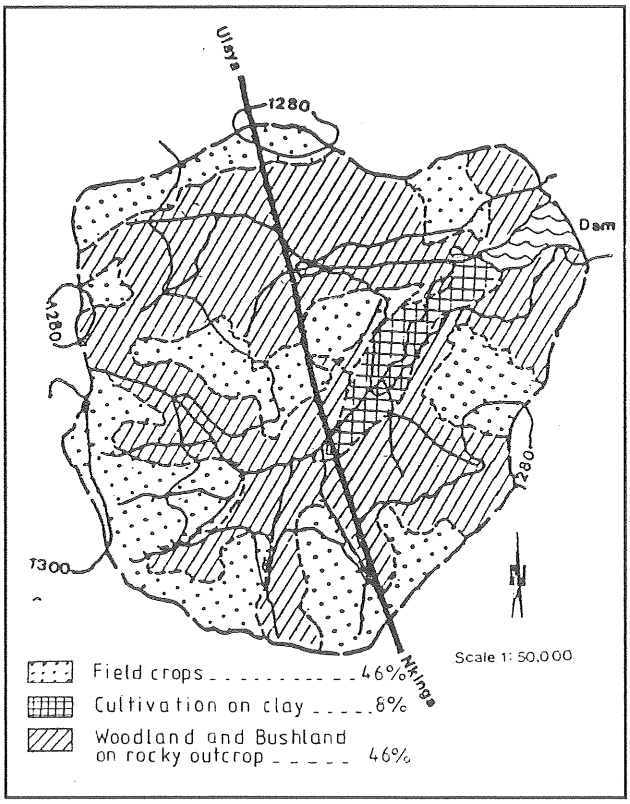


Figure 5.3. Catchment area for the Ulaya Dam. Scale 1:50 000.

5.3.2 Catchment area

The catchment area of the reservoir is 8.3 square kilometres and it is shaped like a balloon (figure 5.3). The average slope of this area is 1.7 percent. The landuse is divided between 46 percent of field crops, 46 percent of open woodland and bushland on rocky outcrops, and 8 percent of agriculture on clay.

One big stream from the west, branched in 16 smaller streams, supplies the reservoir with most of the water. The lengths of the streams are from 630 meters to 2.5 kilometres. From the north, some streams come along the cattle tracks down to the reservoir. At full supply level, the vegetation coverage in the reservoir is about five percent.

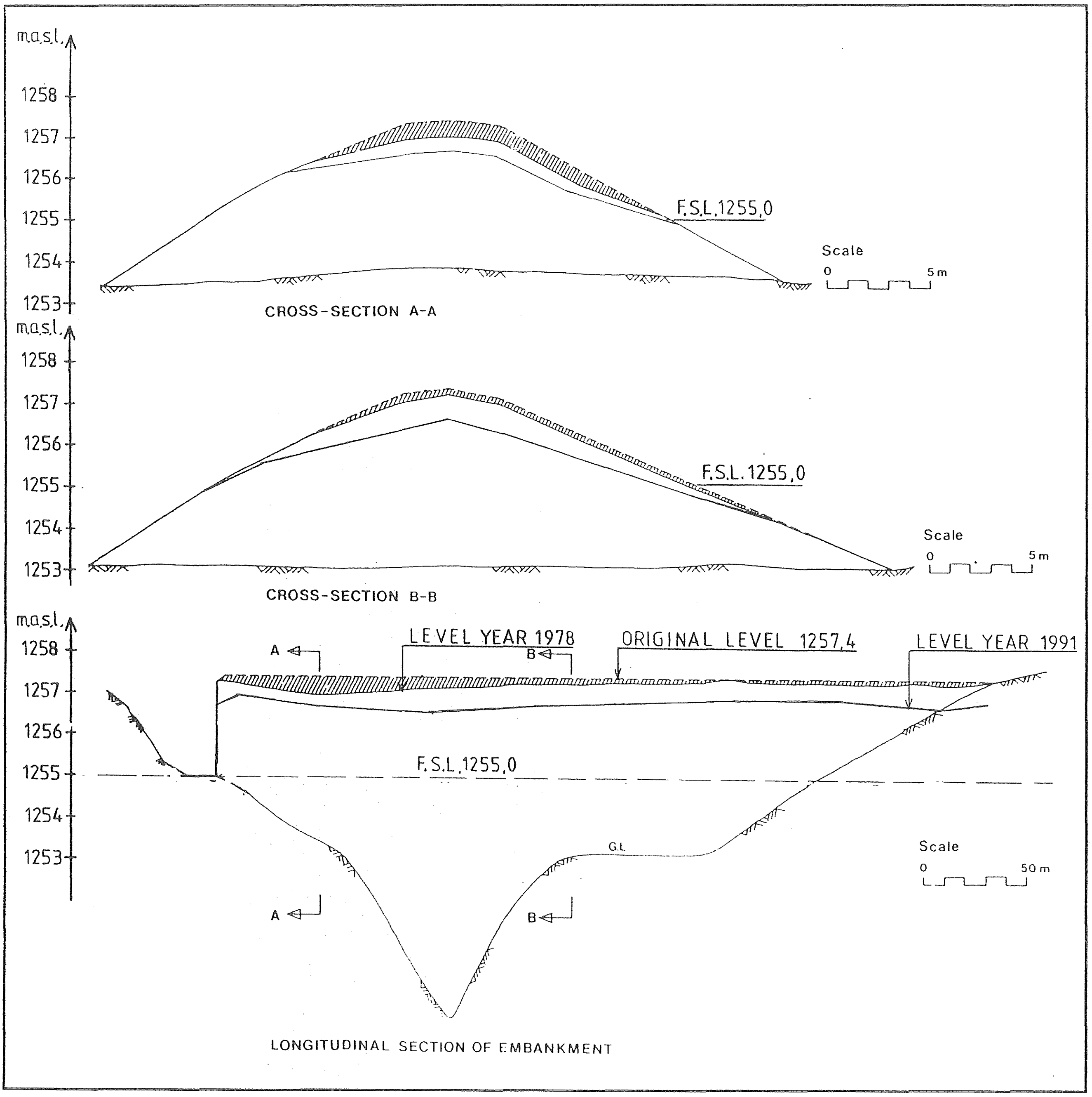


Figure 5.4. Site plan and longitudinal and cross sections. Embankment of the Ulaya Dam.

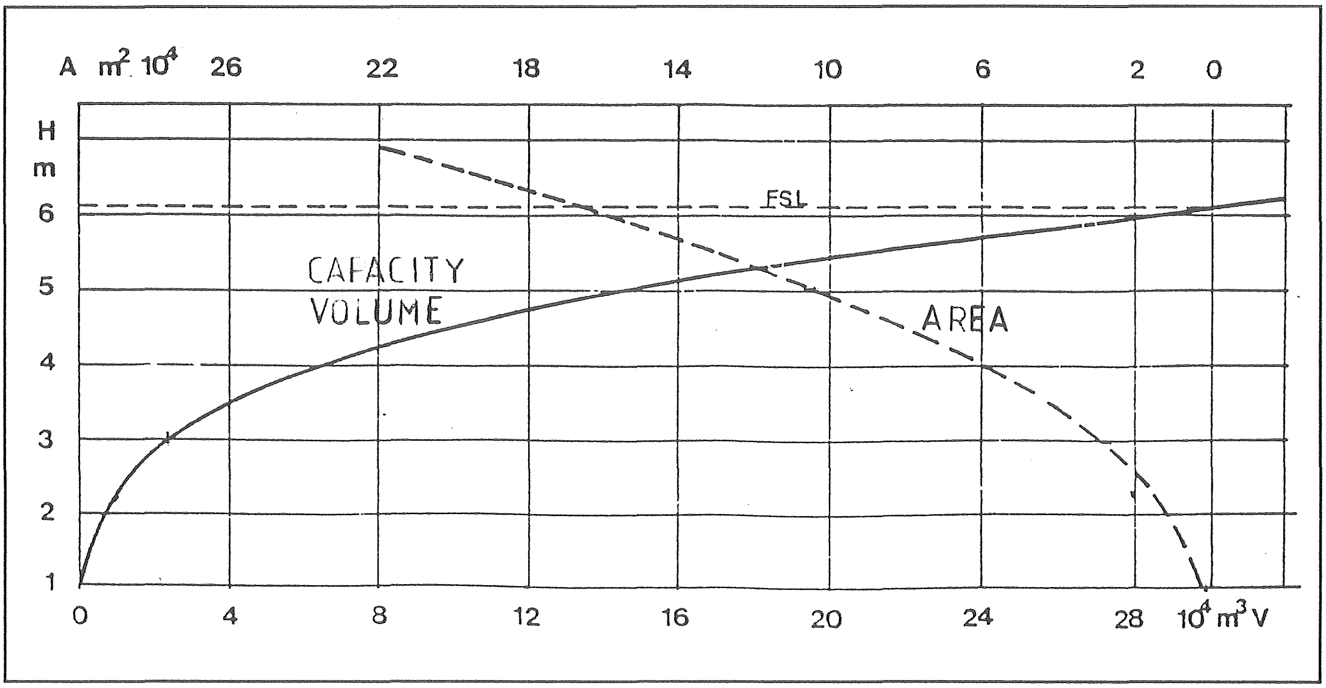


Figure 5.5. Fitted depth—capacity and depth—area function for the Ulaya Dam.

5.3.3 Design

The form of the reservoir is elliptic, measuring approximately 350 × 500 meters at full supply level. At the eastern short side, there is an embankment. It has an earth-volume of 56 000 cubic meters.

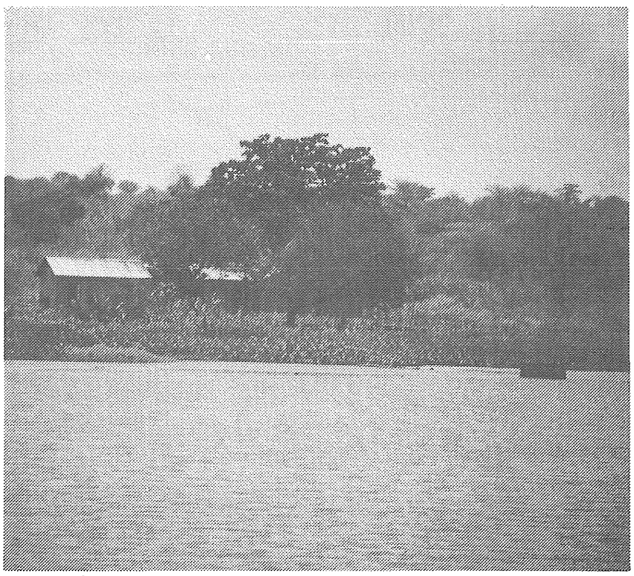


Figure 5.6. Intake at the Ulaya Dam.

The spill-way has a width of 24 meters with a crest made of concrete. The top level is estimated to be 1255 meters above the sea level, which is the full supply level of the reservoir (figure 5.4).

The utilizable volume at full supply level is 298 000 cubic meters and the area 168 000 square meters (figure 5.5). The deepest part of the reservoir is 7.1 meters.

The intake is situated 100 meters out in the reservoir at full supply level and a height of one meter above the bottom, 6.1 meters under full supply level (figure 5.6).

The reservoir is filled every year in the rainy season up to the full supply level.

5.4 Capacity

5.4.1 Landuse and population

The increasing number of people in the area around the villages, have implied a harder exploitation of the ground. More land is used for agriculture and many trees have been cut for fire-wood.

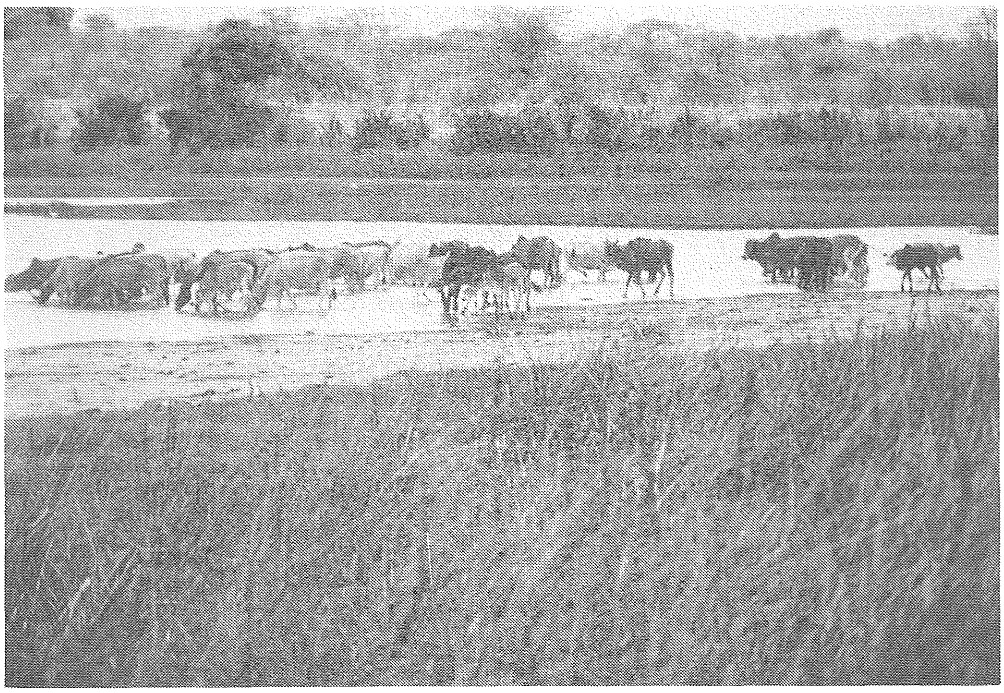


Figure 5.7. Watering of cattle in the Ulaya Dam.

Man-made grass, bush fires and burning of mulch and stubble after the harvest, also make the situation worse. They all further reduce the protective cover and they also cause a reduction in the humus content and in biological activity in the top soil.

There has also been an increased amount of cattle. The consequence of this is that a larger part of the area, especially the area west and north of the reservoir, has been overgrazed (figure 5.7).

The herds of cattle have made a lot of tracks to the reservoir when watering. The tracks have under the rainy season become rills, or in worse cases gullies.

5.4.2 Runoff

The percentage of runoff and the amount of soil loss depends on, [11]:

- ☐ Landuse
- ☐ Percentage of effective rainfall of the total precipitation
- ☐ Intensity of the rainfall
- ☐ Density of the catchment
- ☐ Condition of the catchment surface

The maximum percentage of the runoff occurs during consecutive days of heavy shower, which gives low ground absorption and low evaporation. The lowest percentage of runoff is under the growth period, when there is a high evapo-transpiration from bush canopy and in the beginning of the rainy season when the absorption by the soil is high.

This means that lack of continuous vegetation cover increases the runoff, which is positive in a water storage point of view, but at the same time gives a very high sediment yield to the reservoir.

Different studies of this problem have been done in Tanzania during the years. They all show that cultivated fields and areas of bare ground, such as overgrazed areas, have the heaviest runoff and the most severe soil losses. In table 5.1 some figures from different studies are presented.

Table 5.1. Runoff percentage of precipitation according to different studies, [11], [12].

Landuse	Runoff % of precipitation
Grass covered	5 %
Half grass covered, half cultivated	12 %
Cultivated	9 - 28,9 %
Bare uncultivated soil	30 - 50 %

In the Ulaya Dam catchment area (see figure 5.3), the dominating landuse is cultivated fields, bushes and trees on bare soil with scattered outcrops of granite (figure 5.8).

The runoff percentage of precipitation on this catchment is 5 to 10 percent (table 5.1).

5.4.3 Volume balance

To describe the volume variation in the Ulaya Dam the following formula is used:

$$V_{t+1} = V_t + V_p + V_r - V_{ev} - V_{ex} - V_{se} \qquad (5.1)$$

where

V_{t+1} = Storage at the end of month number t+1
V_t = Storage at the end of month number t
V_p = Direct precipitation on the reservoir
V_r = Runoff from catchment area
V_{ev} = Evaporation from the reservoir
V_{ex} = Required extraction
V_{se} = Seepage loss

For each month the calculations were made in ten iteration steps, with the inputs and outputs except V_t divided into ten equal amounts. This was made in order to reduce the errors caused by using discrete time steps and also to diminish the importance of the order of sequence among the included inputs and outputs in the model.

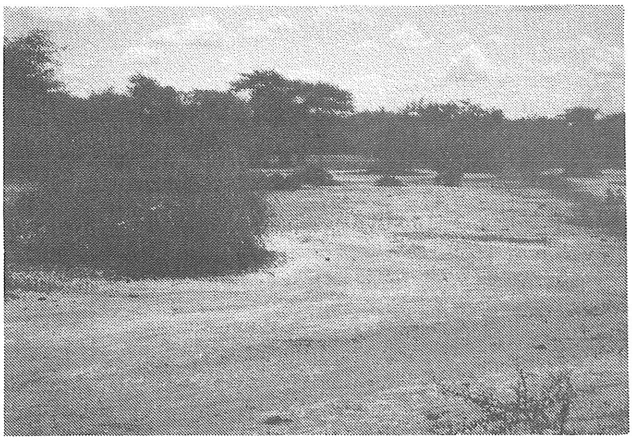


Figure 5.8. Bare sandy soil with bushes near the Ulaya Dam.

The equations that describe the relationship between area and volume in the reservoir were made by Brokonsult [6]:

$$H = (V/593)^{(1/3.44)} \qquad (5.2)$$

and

$$A = 2.04 \times 10^3 \times H^{2.44} \qquad (5.3)$$

where

H = Water depth in the reservoir (m), maximum 6.1 meters
A = Water surface area of the resevoir (m^2)
V = Water volume of the reservoir (m^3)

5.4.4 Results

According to interviews with the inhabitants, the reservoir is filled up to full supply level every year. The reservoir has this level in April at the end of the rainy season.

The values of precipitation, 830 millimetres per year, and evaporation, 5.5 millimetres per day, come from the average of the figures for each month at Mwanhala (figure 3.7 and 3.8).

The size of the catchment area is 8.3 square kilometres and the precipitation is multiplied with this area minus the reservoir area and then multiplied with the runoff factor:

$$V_r = (A_{catchment} - A_{reservoir}) \times K_R \times \text{Precipitation}$$

With a runoff factor between 5 and 10 percent, the runoff yield is about 350 000 to 700 000 cubic meters per year.

The extraction for the villages are about 60 cubic meters per day.

There are also a lot of cattle, drinking in the reservoir. One animal drinks about 30—80 litres per day depending on supply, weight and milk production, [14]. 500 heads of cattle, with a consumption of 40 litres per day, drink 20 cubic meters per day.

It is very difficult to estimate the seepage loss. It depends on bottom material, embankment material and surrounding groundwater level. A fair guess would be seepage

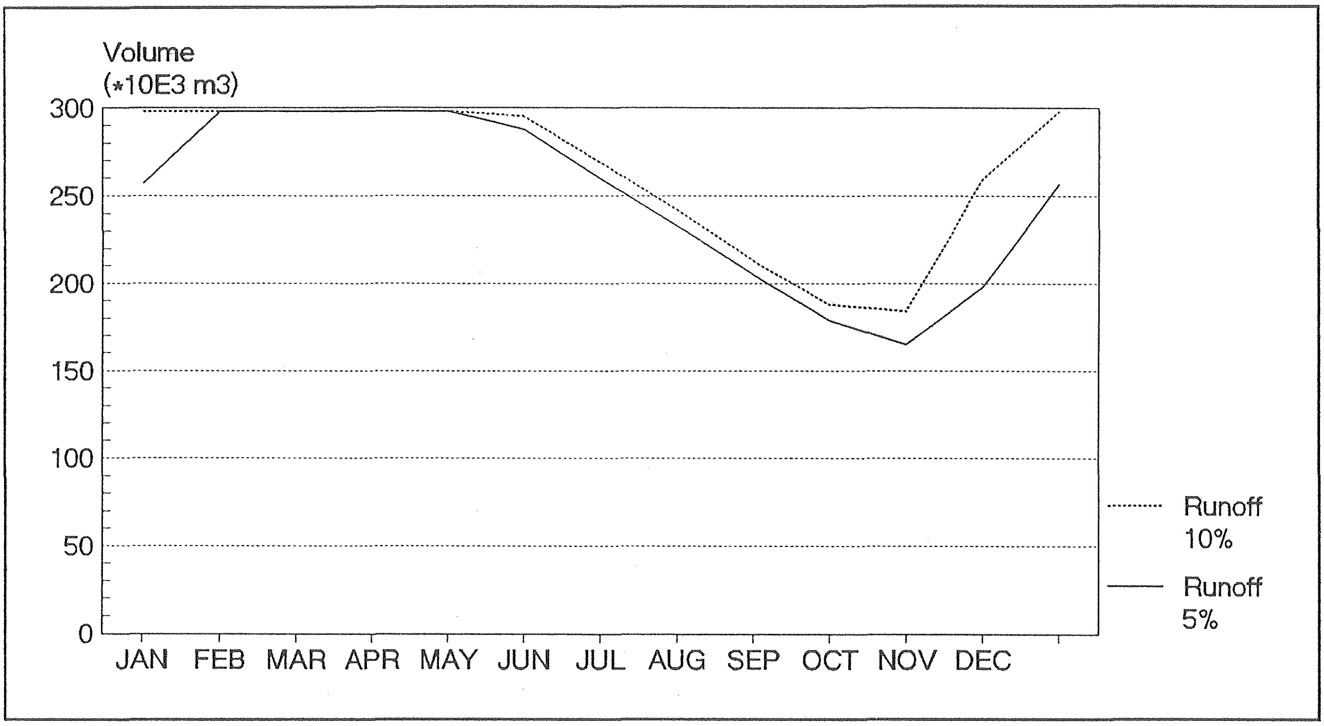


Figure 5.9. Water variation in the Ulaya Dam an average year.

equal to 10 millimetres per month over the whole water area.

The results for an average year are given in the figures 5.9 and 5.10. The runoff factors used is 5 and 10 percent of the rain falling in the reservoir catchment area.

5.5 Sedimentation

5.5.1 Survey

Since the reservoir was completed in 1947, there has been an increasing yield of sediment. In 1978 the sediment fill in the reservoir was estimated to 31 600 cubic meters, i e 10.6 percent of utilizable volume at full supply level, [6].

During the rainy season, a lot of sediments are transported by surface runoff and streams to the reservoir. At the same time, some of the finer grains of the existing sediment in the reservoir silts up and together with the transported sediment, give the water a brownish colour.

The main part of the deposition of material takes place at the deepest part of the reservoir and along the inlets of the streams. It implies that the relationship between water volume and water area decreases. This means that almost the same area is exposed for evaporation, but with an annually decreasing water volume.

During the rainy season the water pumped to the villages have a high content of sediment material. It has been an increasing problem in the last years. The situation is serious and even the population, used to water with changing quality, complains.

This problem is not unique for the Ulaya Dam. In semi-arid regions, the soil erosion is a very severe problem. Everyone of these reservoirs have problems with silting. If nothing is done, the reservoirs will have a limited length of life as water sources.

5.5.2 Eroding agencies

The eroding agencies are wind and water. In the Ulaya Dam catchment area, water are the dominating factor. There are four types of water erosion active on the area; splash, sheet wash, rilling and gullying, (definitions according to [15]).

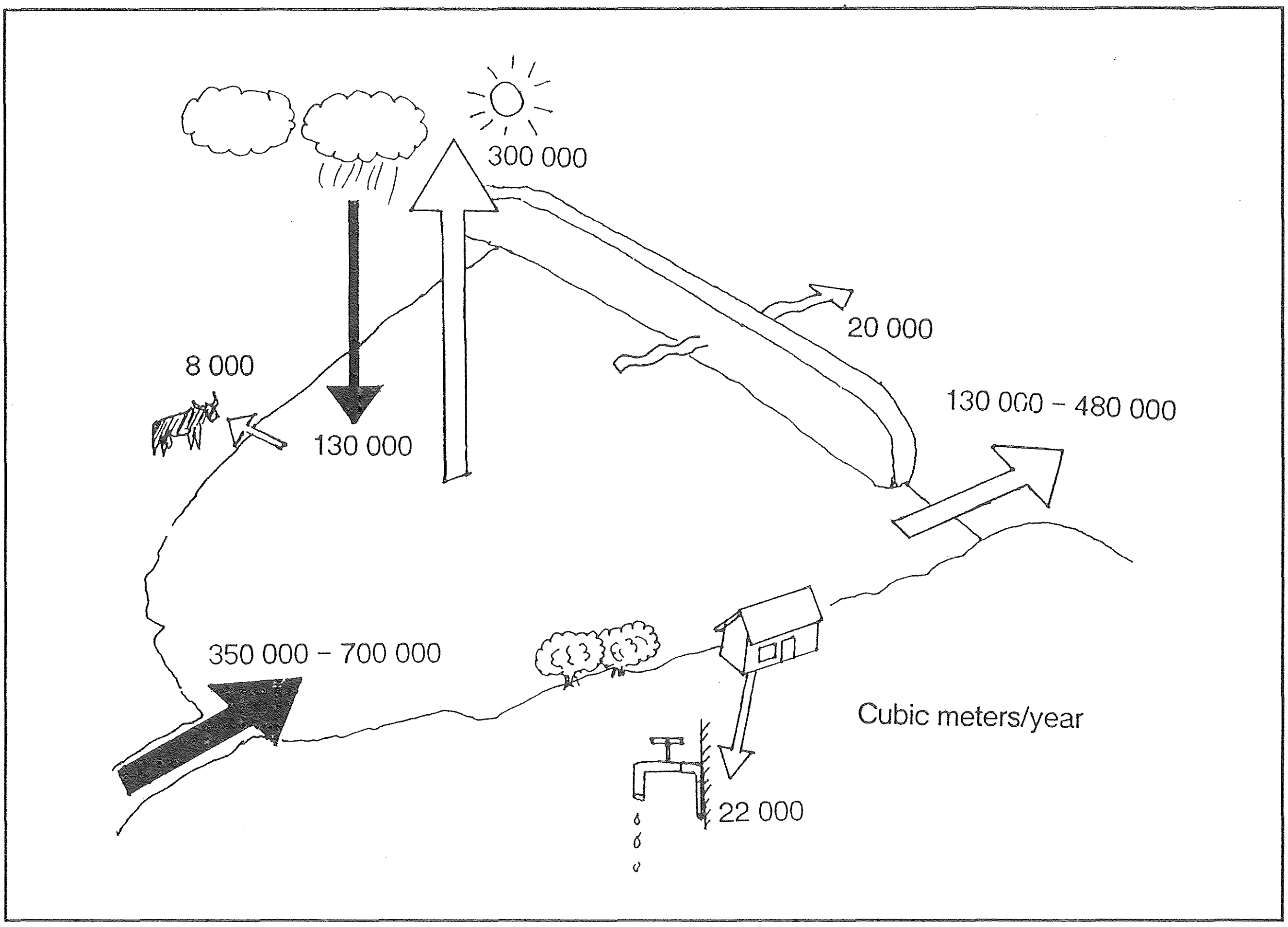


Figure 5.10. Water balance for the Ulaya Dam.

Splash erosion is caused by the direct impact of rain drops on the soil. The splash makes the tiny soil particles start moving. It also packs the soil surface and seals the pores, thus decreasing the infiltration rate and accordingly increasing the surface runoff.

Sheet erosion is a runoff erosion, which is the washing away of a thin surface layer of soil. Splash and sheet wash often work often in close connection. They detach, transport and redistribute top soil down slope. It generally operates selectivity, carrying away finer particles and lighter organic matter most valuable to plants.

Rill erosion and gully erosion are forms of channel erosion. Rill erosion occurs where surface runoff concentrates in minor natural or artificial depressions along the slope. It creates small furrows up to ten centimetres deep (figure 5.11).

Gully erosion is a later developing stage of rill erosion. When a rill channel erodes further it becomes a gully. It can have a depth of several meters.

5.5.3 Sediment yield

The most difficult figure to determine is the amount of sediment annualy deposited in the reservoir. The average figures for annual soil loss in small catchments in central Tanzania inselberg terrain is about 600 cubic meters per square kilometres, [11], and for the whole Africa it is 510 cubic meters per square kilometre, [16].

All the sediment is of course not deposited in the reservoirs. Depending on landuse, slope and the size of catchment area, more or less are trapped upstream in the area.

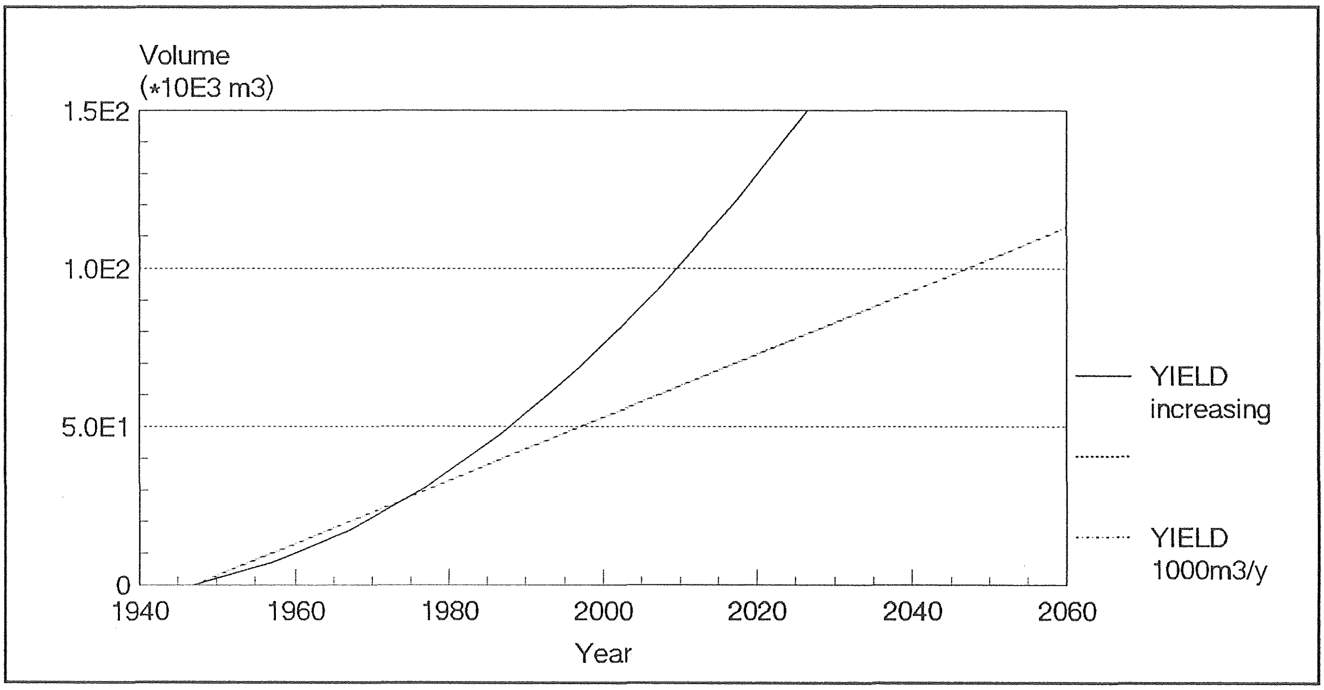


Figure 5.12. Estimated sediment fill in Ulaya Dam.

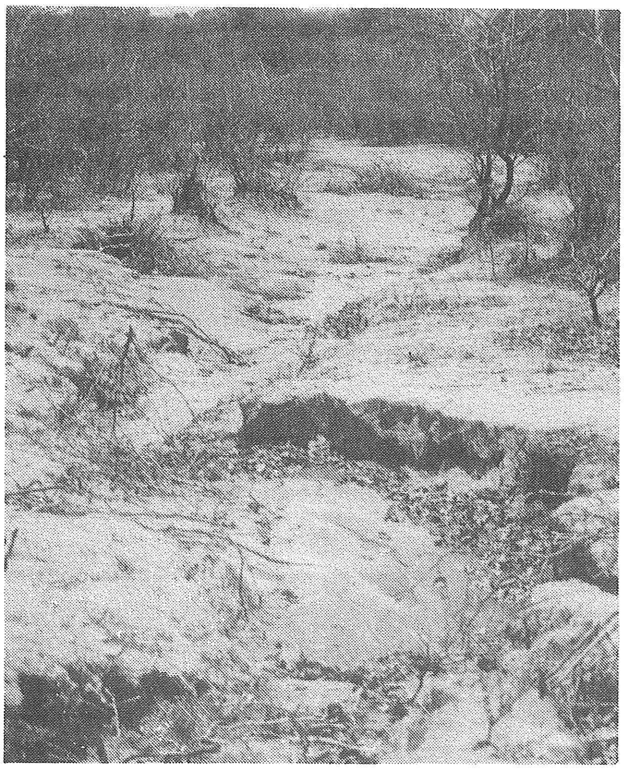


Figure 5.11. A rill on a cattle track to the Ulaya Dam.

In the Ulaya Dam catchment the average annual sediment yield was about 120 cubic meters per square kilometre, totally 1000 cubic meters (1947—1978). But this figure has increased, depending on a high population growth, changes in landuse with an intense agricultural use, deforesting and a high concentration of cattle causing overgrazing.

Considering the facts mentioned in this chapter, the annual sediment yield has probably increased every year. If the annual sediment yield was about 700 cubic meters in the first 10 years and then increased constantly every year, the curve of the sediment yield is as in figure 5.12. The sediment yield should be about 2000 cubic meters per year and the fill about 54 000 cubic meters today (1991).

The runoff volume has a content of about 0.3 to 0.6 volume percent (5 to 10 grams per litre) with an annual yield of 2000 cubic meters of sediment, depending on the runoff factor.

The maximum utilizing volume with the estimated sediment fill is about 100 000 to 150 000 cubic meters (figure 5.12).

Depending on the sediment yield, the economic lifetime for the reservoir is between 35 to 60 years (year 2026—2051). To determine the figure, a check of the real sediment fill compared to the calculated, can be done when the water is at its lowest level in the reservoir.

5.5.4 Sediment composition

According to test analysis done at Chalmers University of Technology, Göteborg, Sweden, the sediment consists of 83.5 percent inorganic materials. To determine all components, a complete elementary analysis should be done.

The materials are probably siliceous materials, with rather small particle sizes. The sediment therefore mainly consists of usual sand and silt. It is not dangerous to consume, but on the other hand not very tasty.

5.6 Actions to meet sediment problems

5.6.1 Survey

The problem can be divided into four steps, from the source to the consumers.

The first step describes how to prevent the sediment getting into the reservoir from feeder streams and surface runoff. The second step describes how to remove the sediment already in the reservoir. The third step describes how to prevent sediment from getting into the rising main where it wears the pump. Finally the fourth step describes how the rural family can clean the water with simply methods. This is described in chapter 5.8.2.

5.6.2 Prevention of sediment from entering the reservoir

The reservoir is supplied from the north by small streams. During the rainy season they find their ways down the slopes to the reservoir, mostly on cattle tracks. Many of those tracks have eroded and almost nothing is growing on them.

The largest and longest stream comes from the west. It dewaters the valley between Nkinga and Ulaya and many of smaller streams supply this mainstream along its way to Ulaya Dam. Most of the sediment is transported by this stream.

A technical solution to prevent sediment flowing into the reservoir is to build a sediment trap. A cheap type was constructed already in the thirties in Imagi Dam not far from Dodoma. It was built across the main stream with low walls of stone and small boulders, about 50 centimetre high. At an initial stage it was effective but after some time the trapped sediment had to be removed.

Another sediment trap is a concrete trap with several chambers. If the trap can prevent half of the sediment volume to reach the reservoir, the trapped sediment volume every year in the main stream would be about 900 cubic meters according to diagram and calculations in chapter 5.5.3.

The trapped sediment has to be deposited in an area that is not a runoff area to Ulaya Dam, for example down the embankment to the reservoir.

5.6.3 Removing sediment in the reservoir

There are a number of methods to remove sediment from the reservoir, but most of them are very expensive.

The volume of sediment in the reservoir is also remarkably large. The total sediment volume in the reservoir in 1991 is probably about 54 000 cubic meters; equal to 5400 trucks loads.

Excavator in emptied reservoir

The best time to remove the reservoir is at the end of the dry season when the water level is low. The sediment can be removed by an excavator and then transported by truck to the other side of the embankment.

During this period, the villages and the cattle need about 60 cubic meters of water each day. The Borehole 1/79 cannot supply more than the hospital and its employees and patients.

Another problem is that the resevoir bottom has to dry out sufficiently to bear heavy excavators. Finally, the filling of the reservoir will take one to two year until the full supply level is reached.

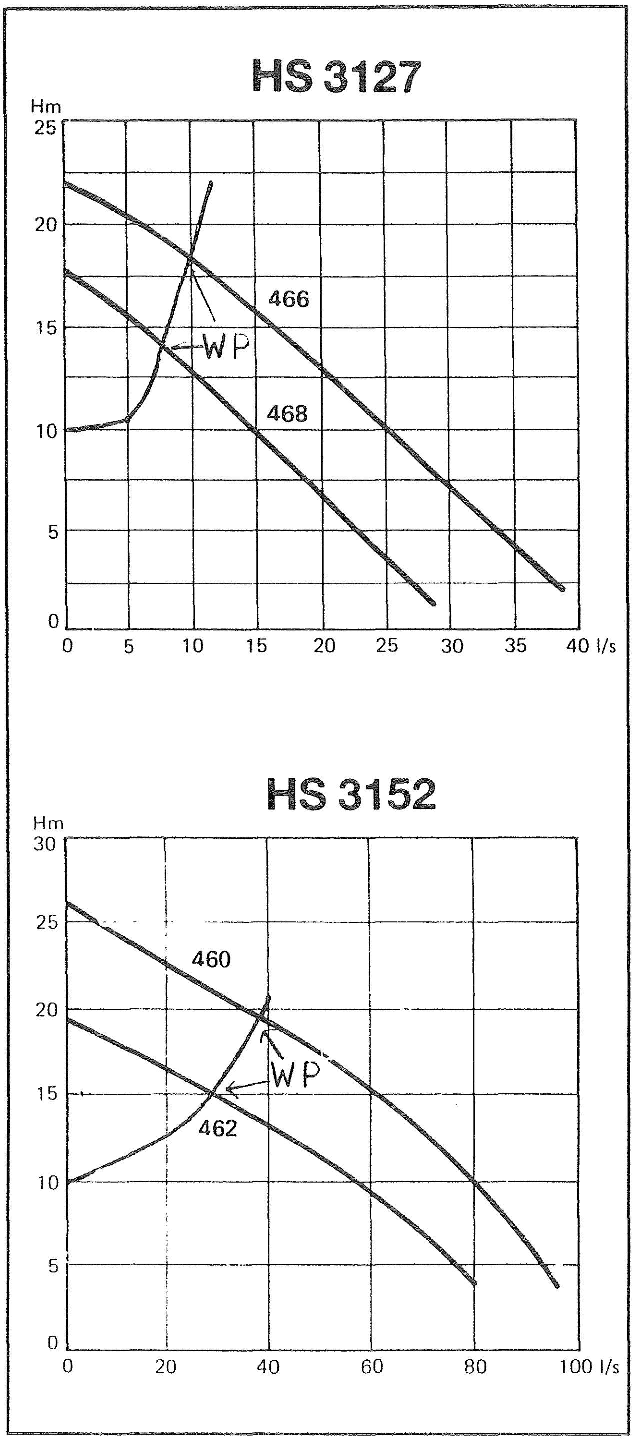


Figure 5.13. Capacity for the sludge pump type HS, ITT Flygt.

Dredger

There are a number of small dredgers on the market which can be transported by truck. The cost is about 150 000 US dollars (1992). At least one person must be trained in the running and maintenance of this machine.

Dredging gives a high sediment content in the reservoir during the whole period. Special sediment traps must be built around the intake to prevent sediment in the rising main.

If a dredger is bought to be used at many different reservoirs in Tanzania the cost would be more reasonable. There are several reservoirs with exactly the same problem. Spare parts must be bought and stored by the owner of the dredger.

Pumping

A cheaper solution is to use a sludge pump with an agitator. They are installed on a raft and the water is pumped to a basin on land. The water flows back to the reservoir after it has been separated from the sediment.

There are many different types and sizes of pumps on the market. One large manufacturer is ITT Flygt AB in Solna, Sweden. A reliable and heavy duty pump is needed, for instance the ones in the series HS (Heavy Duty).

The pump-motor must be run by a diesel generator on the raft, giving an effect of 4.7 to 22 kilowatts depending on pump type.

The height from the bottom of the reservoir up to the basin is approximately 10 meters and the longest pipe needed is about 300 meters. This data sets the working point for the pump (see figure 5.13). The working point varies between 7 and nearly 40 litres per second, depending on type of pump.

Assuming that the sludge content in the water varies between 0 and 30 percent with an average of 10 percent, between 20 and 115 cubic meters of sediment is removed from the reservoir in 8 hours. If about 50 percent of the sediment in the reservoir is to be removed, it will take the biggest pump more than six months of 8 hours of work each day.

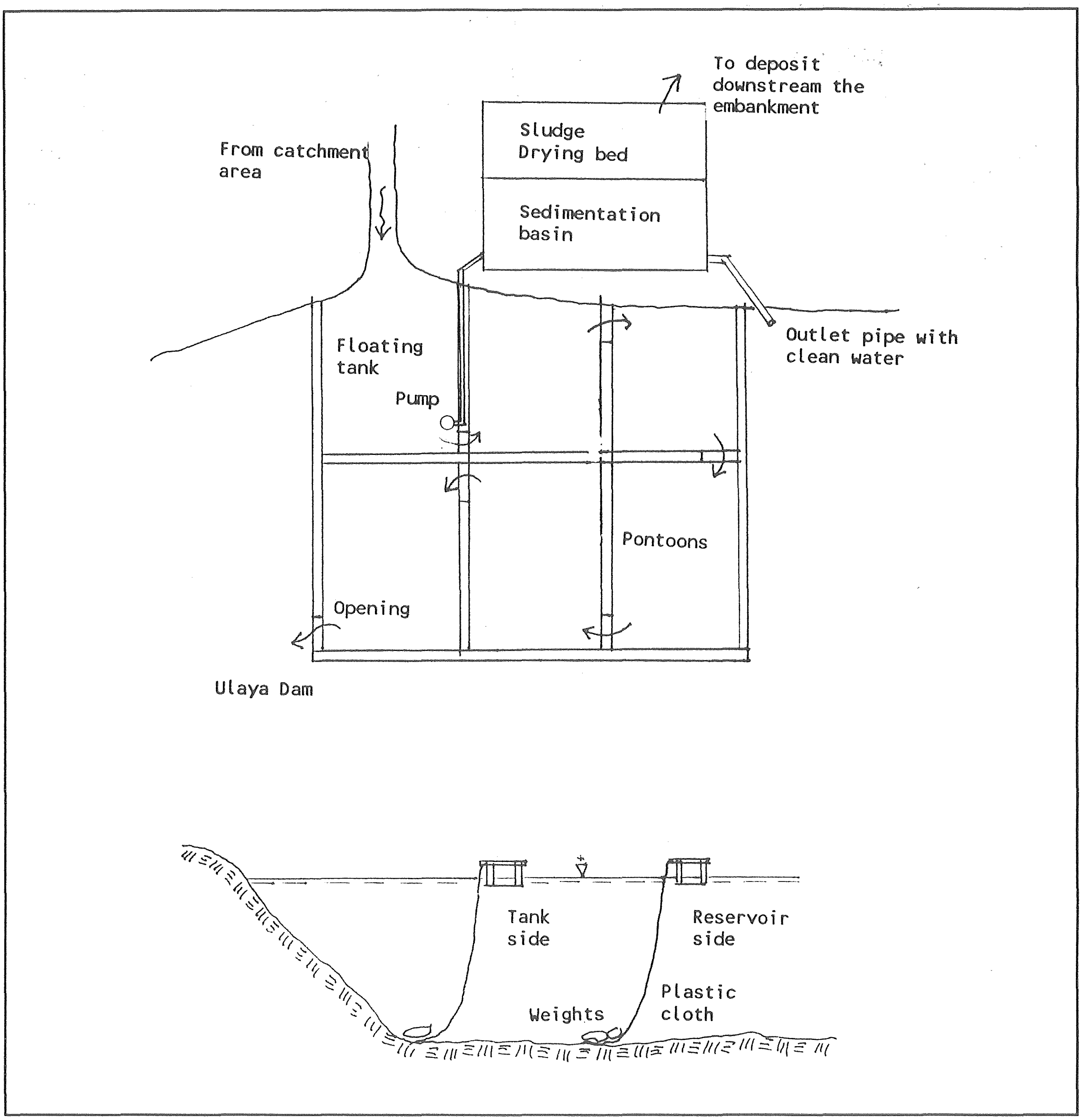


Figure 5.14. Sediment trap of pontoons using the flow balance method.

Flow balance method

Prevention against new sedimentation and removal of existing sediment can be combined. One successfully used method is a flow balance method invented, developed and world-wide patented by Karl Dunkers, Stockholm-Täby, Sweden.

A pontoon tank system is placed outside the inlet of the feeder stream to the reservoir is (figure 5.14). It is used because of the heavy flow variations from the stream. The flow from the stream is equalized in the pontoon tank system according to the plug flow principle. The tank is always filled up with water from the stream or with water from the reservoir. When it is raining, the water from the

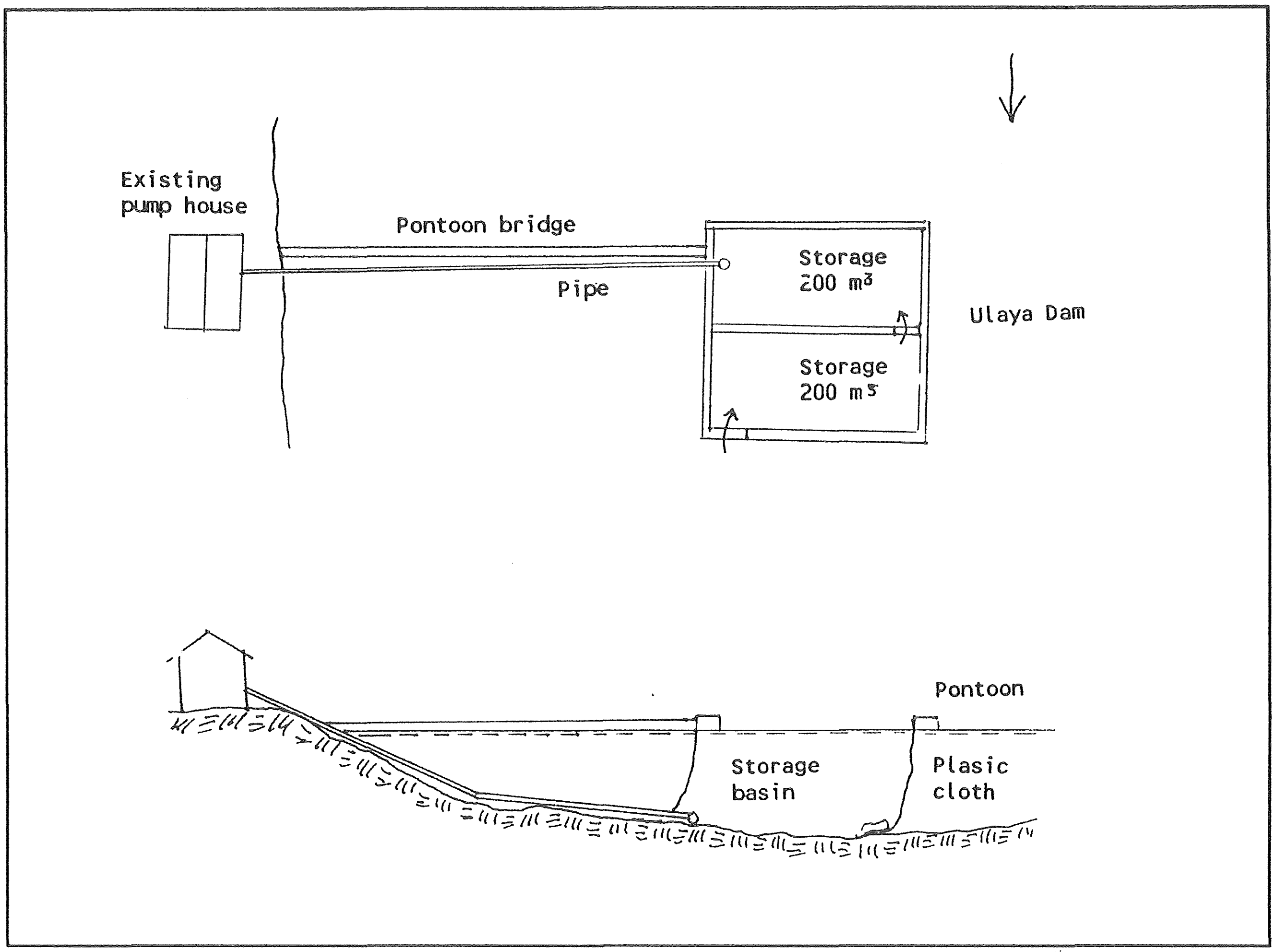


Figure 5.15. Intake with sedimentation chambers.

stream with a higher sediment content will "push" the reservoir water from one compartment to another. When it is not raining the reservoir water fills up the balance volume the same way, but in the opposite direction. Thus, the reservoir water is utilized as a flow balance medium.

A sludge pump is placed in the first floating tank compartment and it pumps the water to a sediment basin on land, where sediment is separated from the water. Between 350 000 and 700 000 cubic meters of water flows to the reservoir every year, with a runoff factor of 5 to 10 percent. If about 90 percent of the water to the reservoir flows by the main stream, 315 000 to 630 000 cubic meters will flow through the construction. This gives an average flow of 1575 to 3150 cubic meter per day, with peaks of about 10 times the average flow. The pump or pumps have to settle a flow of 77 to 154 litres per second with a working day of 8 hours, [17].

5.6.4 Prevention of sediment in the rising main

During the rainy season there is a serious problem of sediment in the rising main. Today, the intake has today no sediment prevention except a net at the intake pipe.

One solution is to build a basin of concrete or plastic covered with pontoons. It may consist of two chambers, one that is filled with water from the reservoir and one where the pump is placed. The intake is placed on the opposite side to the main stream comes. The storage chambers must be emptied from sediment at least once a year with a sludge pump (figure 5.15).

Another solution is to pump water from the reservoir to a sediment basin on land. After one to two days of stor-

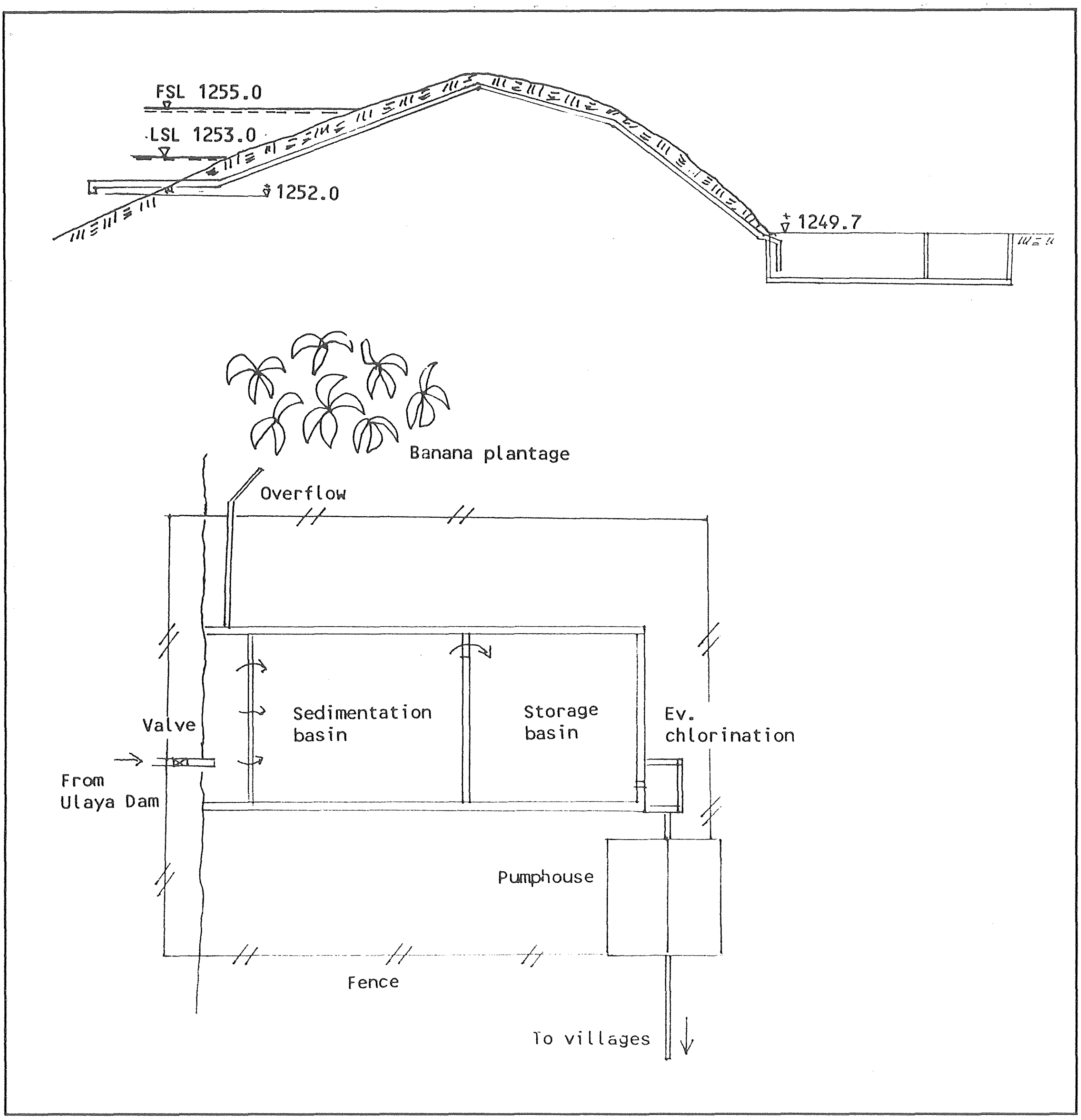


Figure 5.16. Siphon intake with sedimentation basins downstream the embankment.

age and sedimentation, it is pumped further to the villages.

A third way would be to build a concrete ring with a diameter of about 4 meters on the reservoir bottom. The top of the ring should be at a height above full supply level. Inside this ring another concrete ring with a diameter of about 2 meters is built. Gravel is filled between those rings and the water is taken from the inner ring. When the water penetrates through the gravel bed, it loses most of its sediment. The gravel has to be cleaned when the flow decreases, however it happens rather often.

A fourth solution is to replace the intake downstream the embankment (figure 5.16). The water flows to the basin on the downstream side with the help of a siphon. The water is separated from the sediment in a concrete basin. It is good for the water quality if the water is stored for about two days before use. Therefore the two basins of about 200 cubic meters have to be built. They are filled with water every second day right after the stored water has been pumped to the villages. Studies have showed that prolonged storage of water is a cheap and reliable technique to provide safe and clean water. Sand filter has shown bad results for large flows, [6]. To improve quality, chlorination can be done. The pipe has to be below the ground level. If the temperature is below 70°C, there is no siphon effect.

5.7 Water quality

5.7.1 Survey

Another problem is the breeding of malaria mosquitos and bilharzia in the reservoir. Many of the children in the area use the reservoir for fishing and bathing and become bearers of bilharzia. Approximately 500 animals are watered every day watered in the reservoir.

5.7.2 Water related infections

There are a number of diseases related to water. They are classified by four different transmission mechanisms.

Water-borne transmission occurs when the pathogen is in water drunk by a person or by any route which permits faecal material to pass into the mouth. Cholera, typhoid, infectious hepatitis, diarrhoea and dysenteries are examples of water-borne diseases.

Water-washed transmissions are related to cleaning of the body with water. Example of diseases are skin sepsis, scabies, louse-born typhus and the water-borne diseases mentioned above.

Water-based diseases are the ones where the pathogen spends a part of its life cycle in a water snail or other aquatic animal. All these diseases are due to infections by parasitic worms which depend on an aquatic intermediate host to complete their life cycles. The most common disease is bilharzia, also known as schistosomiasis.

Insector vector diseases are spread by insects breeding in or near the water. For instance malaria, yellow fever and onchocerciasis (river blindness) are transmitted by insects breeding in the water. Trypanosomiasis (Gambian sleeping sickness) is transmitted by the tse-tse-fly which bites near water.

Malaria

The greatest problems in the Ulaya Dam and for the people living nearby are the breeding of malaria mosquitos and bilharzia. At Nkinga Hospital malaria is the most common in-patient and out-patient diagnose and the third most common cause of death. Most of these cases were children, [7].

Fishes has been planted to keep the malaria mosquitos short in the Ulaya Dam.

Bilharzia

Bilharzia is a serious disease whose vector is an aquatic snail. There are four species of trematode worms, causing Bilharzia. The most common in the Ulaya Dam and the studied area is Scistosoma Haematobium. Their life cycle is illustrated in figure 5.17. Bilharzia is a worm that gets into the bloodstream through the skin. The worms settle in the blood vessels lining the bladder. They lay small eggs there and causes blood to appear in the

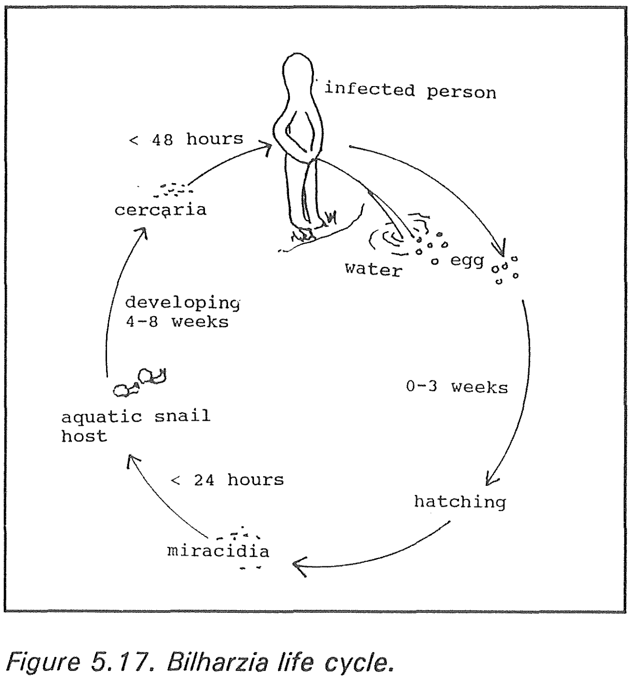


Figure 5.17. Bilharzia life cycle.

Table 5.2. Water analysis report of the Ulaya Dam from tap.

Analysis	Sample 1978.10.16	Sample 1991.11.20	WHO Int standards	Tanzania standards	Sweden standards
Conductivity mS/m	12,5				
Turbidity FTU	20		25		
Color mg Pt/l	50		50		
pH	7,93	7,2	6,5 - 9,2	6,5 - 9,2	7 - 9 (SL)
Total hardness meqv/l	0,8				
Calcium mg/l	9,6	29	75		100 (SL)
Magnesium mg/l	3,9		30		
Alkalinity meqv/l	0,88				
Sulphate mg/l	9		400	600	100 - 200
Chloride mg/l	7		600	800	100 - 300
Iron mg/l	0,21	0,4	1	1	0,5 (SL)
Manganese mg/l	0,6		0,5	0,5	
Nitrate mg/l	1,2		30	100	30
Fluoride mg/l	0,6		1,5	8	1,3 (SL)
Ammonia mg/l	0,488				
Permanganate mg/l	11				
Silicate mg/l	8,52	12			
			SL = Svensk Livsmedelsnorm		

urine. The eggs pass out of the body in the urine and must reach fresh water within three weeks to survive. Once in water they may not hatch for several days, so they can be carried long distances with the water flow.

After hatching, the free living larvae must find a suitable snail host within 24 hours. The worms are developed further in the snail during four to eight weeks and when they come out, they have to find a suitable host, such as Man, within 48 hours.

In the studied area bilharzia is most common among children. Examinations among school children at Nkinga Hospital have showed that about 70 percent are infected. Many of them have been infected when bathing in the Ulaya Dam. The majority of persons infected are apparently without symptoms. The symptoms arise, not from adult worms, but from eggs that fail to escape in the urine or faeces. At Nkinga Hospital bilharzia is the ninth most common out-patient diagnose, [7].

The risk of being infected by the water pumped from the Ulaya Dam via the water towers is however small.

5.7.3 Analysis

A water analysis has been done by Chalmers Univesity of Technology, Göteborg, Sweden (sample 91.11.20). The test of calcium and iron was done with Merck Quick Test, pH-number according to SS 028122, and silicate according to Standard Methods Colorimethric. The methods show rather high reability, but for a full test, more expensive methods has to be done (table 5.2).

The sediment in the water is not dangerous to consume (figure 5.18). Also the rather high content of iron, is not dangerous. The hardness of the water was 4°dH, according to Merck Quick Test.

5.8 Improvements of water quality

5.8.1 Survey

To improve the systems of today it is important to prevent sediment yield and to remove it from the Ulaya Dam. It is also important to prevent sedimentation in the rising main and to purify the water at the consumer end.

High concentrations of fluoride and nitrate are hazardous to health. Moderate concentrations of fluoride affects the enamel of the teeth while high concentrations causes skeleton fluorosis.

It is debated among medical experts which concentrations of fluoride that will cause skeleton fluorosis. The problem is complicated by the fact that it is the total intake of fluoride and not only the water concentration that matters. Thus other factors such as food are of importance.

In the case of nitrate, babies are most exposed. Babies bottlefed with milk powder in nitrate-rich water may have their milk affected. The haemoglobin is turned into a methaemoglobin, causing anaemia. The disease results in more or less pronounced cell suffocation and is often called blue baby disease.

An information program must be started at the schools to inform the children about water quality and the family sand filter.

5.8.2 The family sand filter

Sand has been used to purify water for over a thousand years, and it still remains one of the most dependable methods of making water fit for drinking. Water taken from sandy river beds is generally pure, because it has percolated through the sand grains where the bacteria harmful to man die out. The process that occurs in nature and if the conditions are right works.

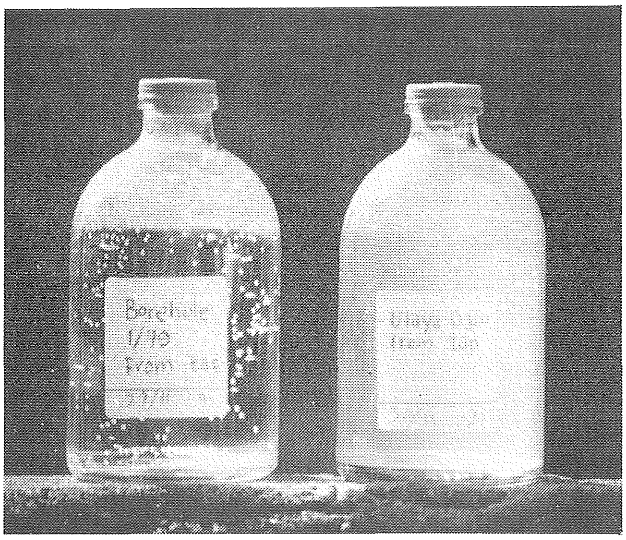


Figure 5.18. Water samples from the Ulaya Dam and the Borehole 1/79.

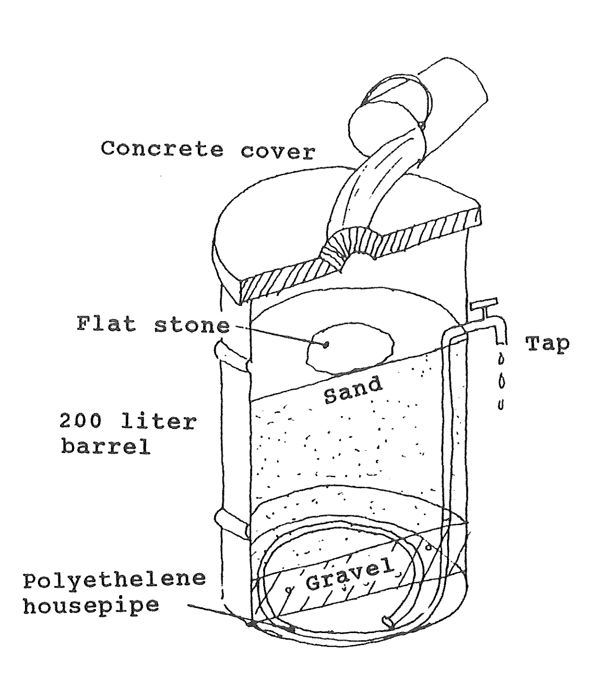


Figure 5.19. The family sand filter.

The effects of sand on water are complex and make use of several mechanisms. Many bacteria are consumed by the skin, made of algae, diatoms, protozoa and other organisms, on the surface of the sand. Water flowing through the ores in the sand, slows down and sediments out. As the depth from the surface increases, the quantity of organic matter decreases and the struggle between the various organisms becomes fiercer. The pathogenic bacteria cannot compete with other organisms more suitable to these conditions. Disease-carrying bacteria perish in such an environment.

This remarkable process can take place in a family sand filter contained in a 200-litre barrel, shown in figure 5.19. Such a unit is described below. The principle is of course equally applicable in a pot, cement jar or brick container.

A drum is a common fuel barrel, consisting 200 litres (45 gallons). It is cleaned out and a hole is made two thirds of the way up so that an outlet pipe can be fitted. For example a 12-millimetre tap can be used, and connected to a 12-millimetre polyethylene housepipe.The pipe is mounted downwards the drum wall, and placed in a circle on the bottom. The end is tightened, a number of saw cuts or drilled holes are made in the lower part of the pipe circle and the openings are faced downwards.

After the tap and pipe has been made, a layer of well-washed gravel, about 75 millimetres thickness is put at the bottom of the tank and levelled out. It is now necessary to find some good, sharp, very clean river sand to add to the drum tank. The sand is added to the gravel, in a 500-millimetre thick layer. The upper level of the sand should be just above the level of the outlet pipe.

In order to avoid erosion of the sand, a flat stone is put on the top of the sand, vertically under the inlet water hole. Some sort of cover is then put over the barrel, with a small inlet water hole.

When the family sand filter is complete, it has to be maintained in the right way. It is important never to allow the sand to dry out. The biologically active ingredients in the sand will die out. The best way to prevent this is to make a daily routine of adding water to the filter. Freshly washed sand will take a few weeks to ripen and to develop biologically active ingredients, but improvements in taste and colour will be noticed almost immediately.

When the delivery rate is too slow for convenience, 10 to 20 centimetres of sand should be moved, thoroughly washed and replaced in the filter. The lower the flow, the better the quality.

5.9 Future developments

5.9.1 Maximum extraction

The runoff factor from the catchment area is 5—10 percent, with an average of about 8 percent. The equations of the volume variation in the reservoir in chapter 5.4.4, show that with a runoff factor of 8 percent, up to 800 cubic meters per day can be extracted on average year.

In a year with little rain, 75 percent of the 800 cubic meters can be extracted. Still more than 500 cubic meters per day can be pumped to the villages. That is about eight times the extraction of today!

The above assumes action is taken to prevent sedimentation in the rising main (chapter 5.6.4).

5.9.2 Extraction after spillway rise

One way to increase the volume in the reservoir is to raise the spillway.

Today the volume at full supply level is about 300 000 cubic meters. If the spillway is raised for example 30 centimetres the new utilizing volume increases with about 50 000 cubic meters (equation 5.2). However, the bigger water surface exposed for evaporation results in larger losses. All the new 50 000 cubic meters will evaporate.

5.9.3 Extraction of sediment and soil

If 50 000 cubic meters of sediment and soil is excavated in the deeper part of the reservoir, it will imply 50 000 more cubic meters of water per year. It is possible to extract almost 140 cubic meters more per day .

5.9.4 Distribution organization

A new way to distribute and care for the water supply would be to found a water supply organization. It should be organized by the villagers and the hospital, employ one person for the daily maintenance and one for water sales.

Today the supply is so insufficient that it is impossible to water the cultivations. That depends on the deficient financial assets at the District Water Engineer.

The income will cover the running costs. It will make it possible for a farmer to expand. He can buy water to get a greater income from his farming. It will also give a much better participation.

The first 10 litres per household and day should be free, paid by the authorities, the following buckets should have a price of between one and three Tanzanian shillings (1 Tanzanian shilling = 0.025 SEK, 1991).

Figure 6.1. Pumphouse above the Borehole 1/79.

6 Boreholes

6.1 Survey

Most of the boreholes in Igunga district have been drilled by the Swedish company Brokonsult during 1978—1979 in the Water Master Plan program, [6]. The drilling was preceded by extensive geophysical investigations (see appendix B). Some wells were drilled near Nkinga Hospital and the three villages. They are here called 181/78, 1/79 and 48/79. The Borehole 1/79 is the second largest water source in the area (figure 6.1). The other boreholes in the area are not in use.

The Borehole 181/78 is situated west of Ulaya village along the dirt track between Ulaya and Nzega (figure 4.2). The area comprises a part of the so called Kogongho Basin (chapter 3.1). The borehole caved in when it was drilled in 1978. Because of very wet conditions, the drilling could not be finished.

The Borehole 1/79 is situated along the road between Simbo and Ziba in the valley just north of Nkinga (figure 4.2). The valley probably corresponds to a secondary fault line to the Nzega Fault, striking in west-north-west (chapter 3.1). The borehole supplies Nkinga Hospital, adjacent Nkinga Nurses and Midwives Training School (NNTS) and staff and missionary houses. Each day it

Table 6.1. Water analysis report of the Borehole 1/79 from tap.

Analysis	Sample	Sample	WHO Int	Tanzania	Sweden
	1979.03.23	1991.11.20	standards	standards	standards
Conductivity mS/m	90				
Turbidity FTU	10		25		
Color mg Pt/l	10		50		
pH	8	7,6	6,5 - 9,2	6,5 - 9,2	7 - 9 (SL)
Total hardness meqv/l	1,92				
Calcium mg/l	32	86	75		100 (SL)
Magnesium mg/l	3,9		30		
Alkalinity meqv/l	6				
Sulphate mg/l	11		400	600	100 - 200
Chloride mg/l	24		600	800	100 - 300
Iron mg/l		< 0,1	1	1	0,5 (SL)
Manganese mg/l			0,5	0,5	
Nitrate mg/l	0,03		30	100	30
Fluoride mg/l	5,6	1,8	1,5	8	1,3 (SL)
Ammonia mg/l	0,98				
Permanganate mg/l	7,2				
Silicate mg/l	160	100			
			SL = Svensk Livsmedelsnorm		

gives about 30 cubic meters. The water is pumped to two water towers in the hospital area.

The Borehole 48/79 was only drilled in order to get information about the well test carried out in the Borehole 1/79.

There is also a borehole situated just north of the Nkinga Hospital area. It was drilled in 1976 by Craelius Ltd, and it is called Borehole 4/76 (figure 4.2). The quality was however poor, the yield low and the pump head high, so the hole was only in use until 1982.

The borehole profiles are described in appendix A.

6.2 Introduction

The site of a new borehole depends on investigations made earlier.

Phase one includes a study of aerial photos, topographic and geological maps and a study of existing ground water sources, such as boreholes and shallow wells.

Using the results from this phase, the fieldwork, geophysical investigations could be planned and carried out.

The results should be used to choose the site for the exploration drilling.

There are basically three different approaches to this kind of drilling:

Alternative one is to construct the exploration hole directly as a well.

Another possibility is to drill the hole with a smaller dimension than a production well and with only formation stabilizing casing. If the borehole is to be used to produce water, it can be reamed to full diameter.

The third alternative is to drill a new production hole nearby. The exploration hole can then be used as an observation well.

When the well is drilled it has to be tested to determine yield and the surrounding variations of ground water level.

An investigation with a well log unit combined with the penetration rates, gives valuable information to determine the borehole profiles i e lithology, joint zones, water bearing zones etc.

Finally, checks of the ground water level has to be made regularly in order to see how the well acts during a longer period.

6.3 Water quality in the Borehole 1/79

6.3.1 Analysis

A water analysis has been done by Chalmers Univesity of Technology, Göteborg, Sweden (sample 91.11.20). The test of calcium and iron was done with Merck QuickTest, fluoride with Dr Lange Quick Test, pH-number according to SS 028122, and silicate according to Standard Methods Colorimethric. The methods show rather high reability, but for a full test, more expensive methods has to be done (table 6.1, figure 5.18).

The rather high content of iron, calcium and silicate in the water is not dangerous to consume. The hardness of the water was 12°dH, according to Merck Quick Test.

Calcium can give corrosion in pipes and at pots. If calciumrich water is used for washing-mashines, the pipes will fill in. If used for washing, the textilies can be damaged by the calcium.

The fluoride content can give spots at the enamel by children. If the content is higher than 6 milligram per litre, the water is not potable and the there are risks for osteofluoros, fluoride-storing in the skeleton.

6.3.2 Film at pots

When boiling the borehole water, the pots becomes a film of deposits. Thereby, the pots are useless for other things than to boil water. According to test analysis done at Chalmers University of Technology, Göteborg, Sweden, the sediment consists of 93.4 percent inorganic materials. To determine all components, a complete elementary analysis should be done.

The materials are probably SiO_2 and Calcium. That means very small sizes of sand or silt particles, and lime, the same content as in plaster or lime concrete. It is therefore not astonishing that it is so hard to chip the film off.

Test has been made at Chalmers University to dissolve the deposits in different heated acids. Citric and tartaric acids give a small effect. Acteic and hydrochloric acids (90 percent) give a better result, but not a complete dissolation.

It should be possible to prevent new deposits with an addition of citric or tartaric acid before the boiling.

There is nothing in the film that makes the water dangerous to consume, but on the other hand the pots and

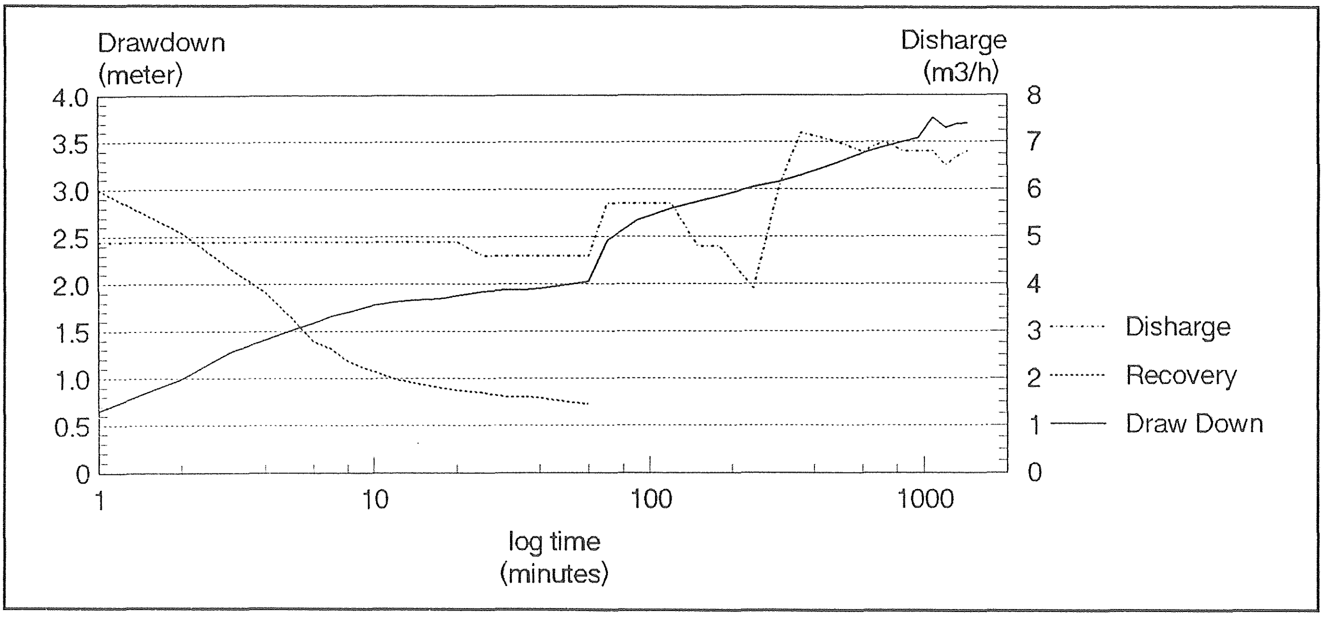


Figure 6.2. Constant discharge test of the Borehole 1/79.

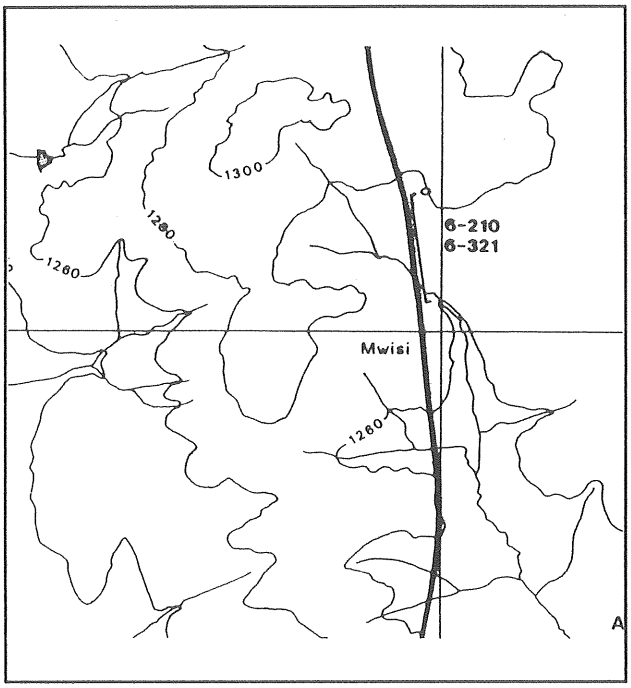


Figure 6.3. Location of investigation near Mwisi.

washing-mashines would not be damaged if the calcium content is neutralized.

6.4 Future developments

6.4.1 Maximum extraction

The Borehole 1/79 has a higher capacity than used today. According to the constant discharge test (figure 6.2), 6.8 cubic meters per hour were extracted and it did not cause any problems for the borehole to recover. This means that the extraction probably can increase to about 70 cubic meter per day without any problem. It can be compared with the extraction today of about 30 cubic meters.

A new borehole test during longer period is recommended before the extraction is increased.

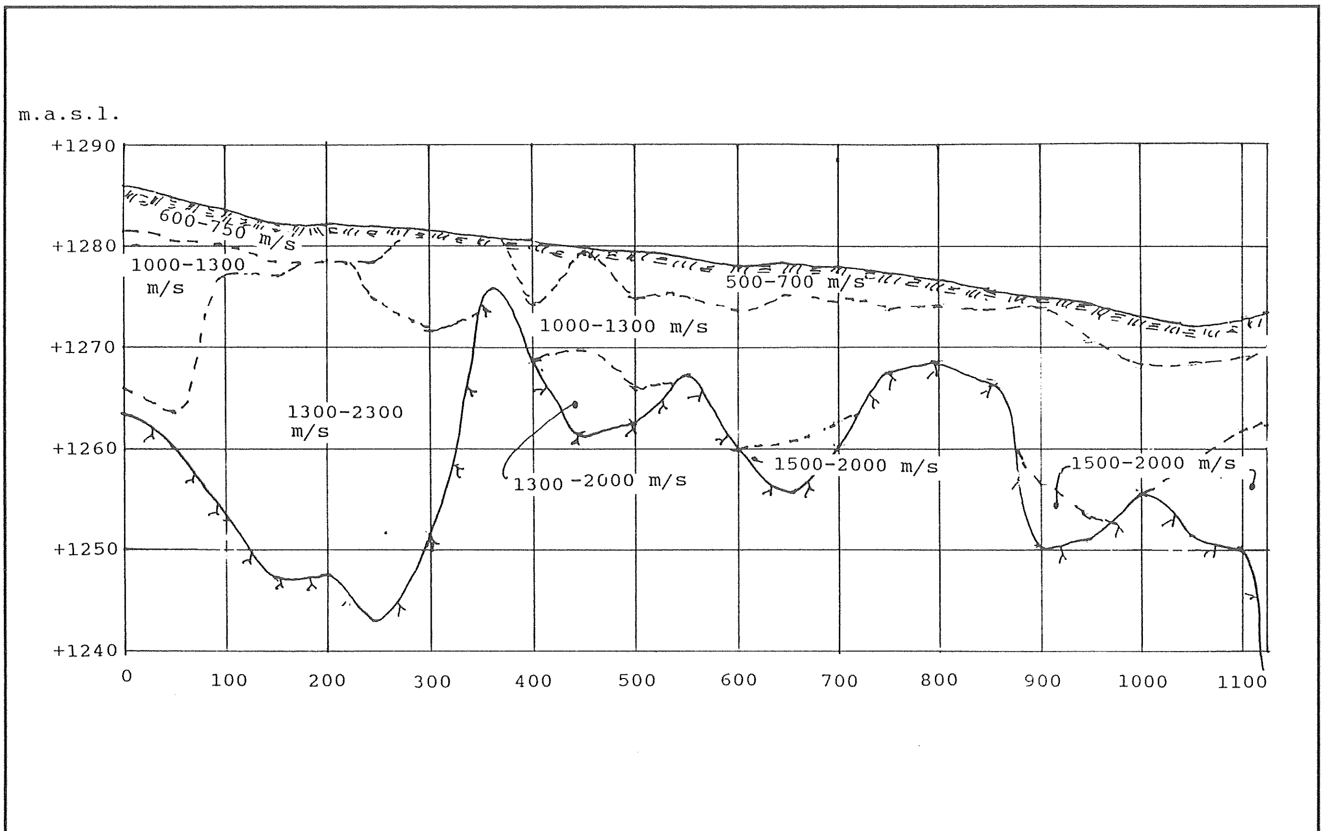


Figure 6.4. Result of the seismic profile 6-210.

6.4.2 New borehole south of Nkinga

Investigations has been made in a valley about one kilometre south of Nkinga along the road between Simbo and Ziba, near Mwisi, [6] (figure 6.3). The valley probably corresponds to a secondary fault line to the Nzega Fault on the east side of Kogongho Basin (chapter 3.1). The background and theory is the same as for the Borehole 1/79.

Geophysical investigations were made. The seismic profile 6-210 showed a weakness zone between 560 and 570 meters (figure 6.4) and the magnetic profile 6-321 showed a anomaly between 500 and 600 meters ranging from about 34 800 to 33 700 gammas (figure 6.5).

A promising site for a new borehole is between 560 and 600 meters. Brokonsult did not try to drill a borehole here due to the wet conditions when the drilling should have taken place.

The capacity and head for the new borehole will probably be about the same as for the Borehole 1/79, that is a possible flow of about 8 to 12 cubic meters per hour and a depth of about 60 to 70 meters.

However, to be more specific, requires a test hole. It will give possible flow and the static water level.

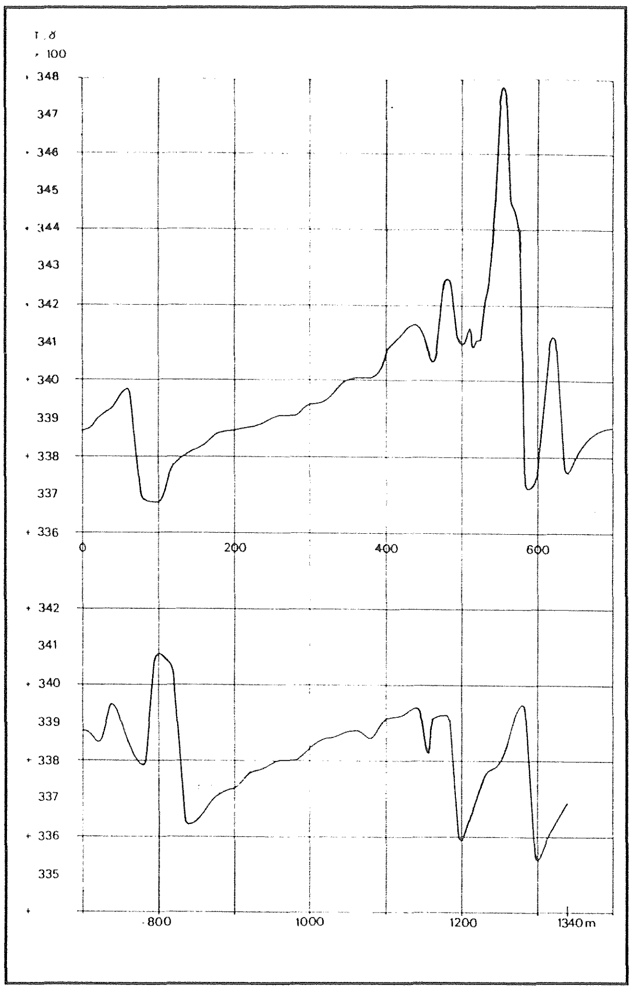


Figure 6.5. Result of the magnetic profile 6-321.

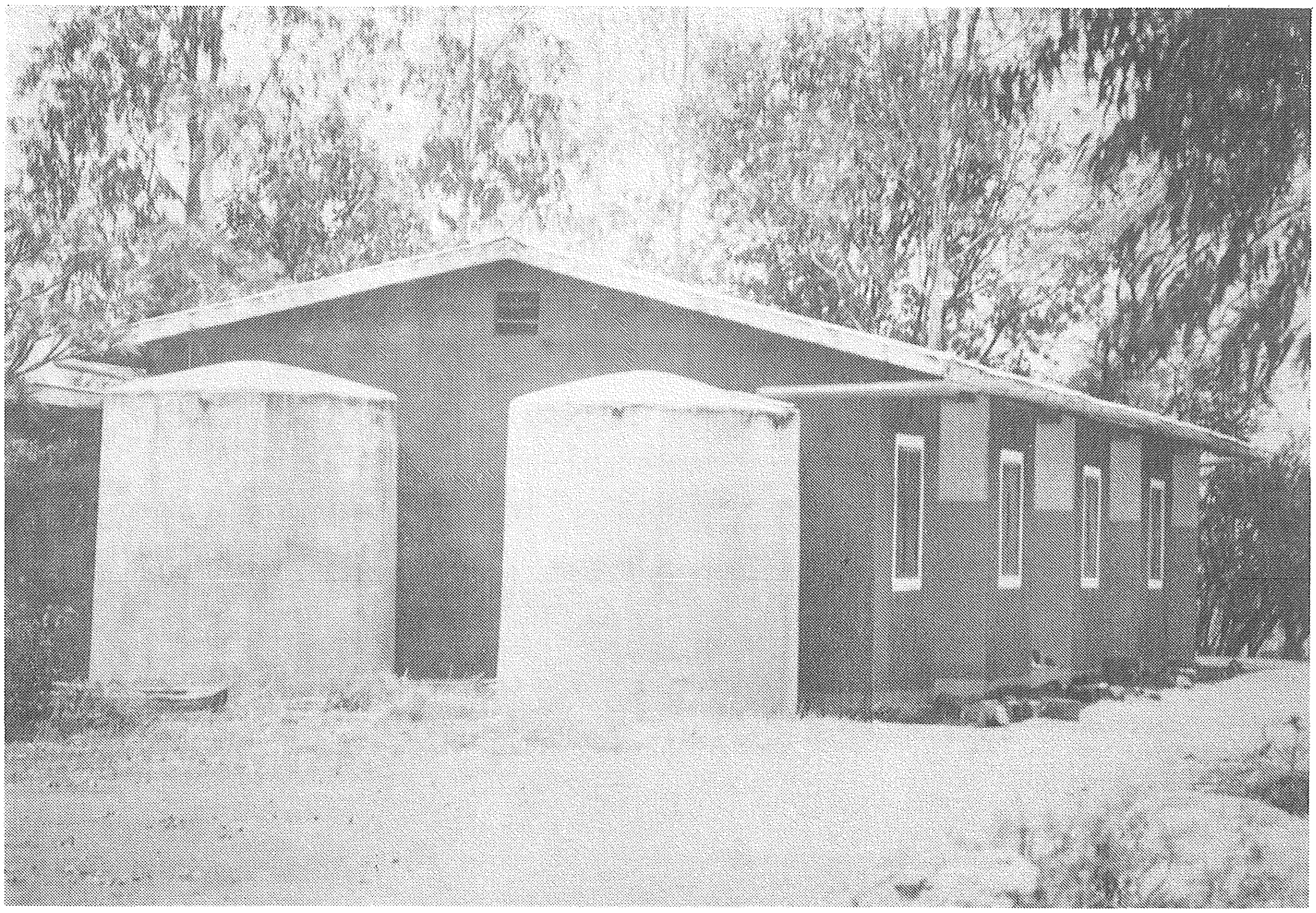


Figure 7.1. Rainwater harvester at Nkinga Hospital.

7 Rainwater harvesters

7.1 Survey

Rainwater harvesters have been used as the main source of water since Nkinga missionary station was founded in the late forties. Today, more than half a century later, it is still the main source of drinking-water and for manufacturing infusions and a number of medicine products (figure 7.1).

The harvesters consist of tin roofs and most of the tanks are mural concrete tanks above or below ground. The location and numeration of the houses at Nkinga Hospital and their tanks are given in figure 7.2.

Theoretically, 7 500 litres could be extracted in mean per day from the existing system, but in reality 2 500 litres is available, because of bad roofs and tanks.

A ground harvester, such as the one described in chapter 7.2.2, can be built by the rural family. With a consumption of 100 litres per day, the harvester has to be 6.0 × 9.0 meters and connected to a tank of about 20 cubic meters.

7.2 Design

7.2.1 Capacity and efficiency

The collection and storage of rainwater from run-off areas such as roofs, rocks and other surfaces has been practised by Man since ancient times. It is still widely used in the world and it is particularly suitable for areas where pumped or reticulate supplies of water are not available.

By careful design it is possible for a family to live for a year in areas with as little rainfall as 100 millimetres per

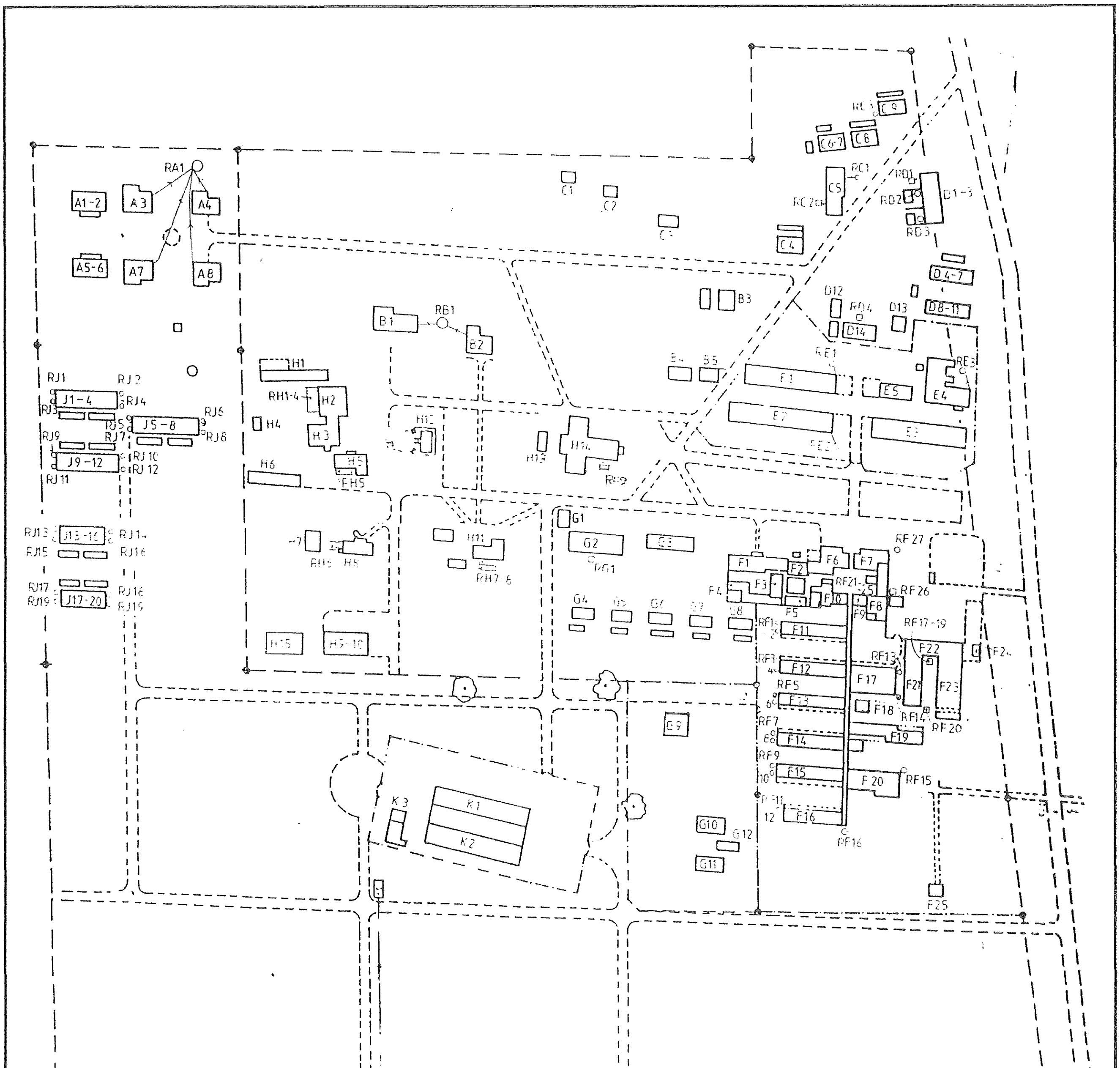


Figure 7.2. Location of houses and rainwater tanks at Nkinga Hospital.

year. Many observations, made in Zimbabwe, show that between 80 and 85 percent of all measurable rain can be collected from suitable catchment areas and stored. This includes light drizzle dew and condensation which may occur during the drier months, [18].

One millimetre of rain, falling on one square meter of the roof (measured horizontally) will therefor yield 0.80—0.85 litres of water.

7.2.2 Harvesters

Rocks

A good water catchment area often exists where rocks cover the surface. As an example a single granite dome covering one hectare, and rainfall of 830 millimetres, may yield 4 150 of storageable cubic meters water per year (with 50 percent efficiency). That is enough for more than 400 head of cattle for a period of six months.

Roofs

Modern roofing materials are more common in Tanzania now than ever. This also means that the rainwater can be led from the tile, asbestos or tin roof, to a water tank. Roof materials as lead, copper and straw are not advisable.

An average farm with sleeping, kitchen and cattle houses may have a horizontal roof area of up to 200 square meters. With 830 millimetres of rainfall per year and an efficiency of 80 percent, the yield will be 133 cubic meters. If adequate precautions are taken to prevent contamination, the water should be soft, potable and suitable for washing. 133 cubic meters per year is anormal consumption for an average family of six persons and up to five head of cattle.

The most useful place for the roof rainwater collection technique may be at the rural school. Usually, the schools are built with extensive roof coverage. Large quantities of rainwater can be collected through the season. Careful management of the water, essential to the success of the technique, can also be taught and performed at school.

Artificial harvesters

Where no roof or rocky outcrops is suitable for collection, the construction of an impervious surface can be undertaken directly on the ground. Reinforced concrete is perhaps the best kind of surface.

An alternative technique is to put a large plastic sheet in a hollowed-out and levelled ground area (figure 7.3). A layer of sand is laid over the bottom of the excavated area and then raked flat. The plastic edges have to be raised up against the side walls of the excavation. The water is drained away in a slotted PVC pipe and then in a pipe to the tank.

The area should be fenced off to prevent access to it for animals. If a family wishes to collect 36 cubic meters of water per year, the size of the harvester should be 54 square meters (with 830 millimetres rainfall and 80 percent efficiency). It will need a tank of 20 cubic meters and provide a daily water supply of 100 litres.

7.2.3 Gutters and drain pipes

The rainwater harvester system has to be optimized to utilize the rainfall to a great extent.

Roof harvesters are the most common collectors. The dimension of the gutter depends on the intensity of the rain, the length of the gutter, the gutter slope, the area, depth and slope of the roof. The dimension of the drain pipe depends on the flow from the gutter.

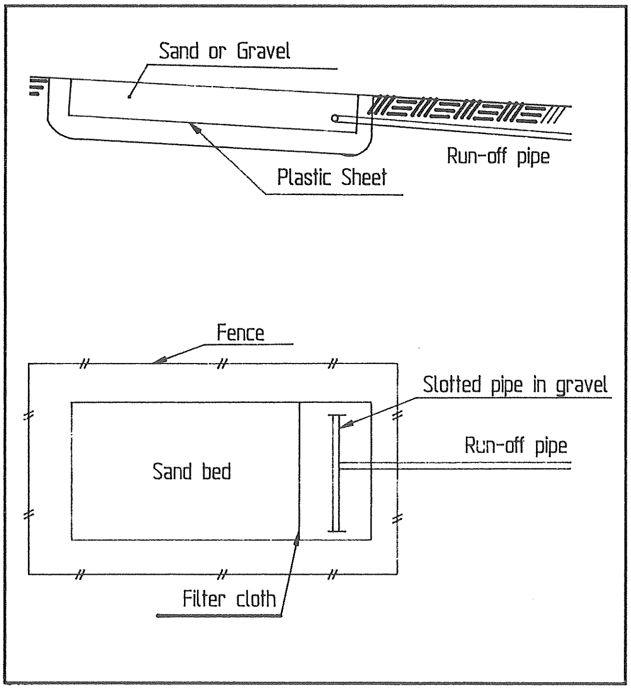


Figure 7.3. Rainwater harvester on the ground.

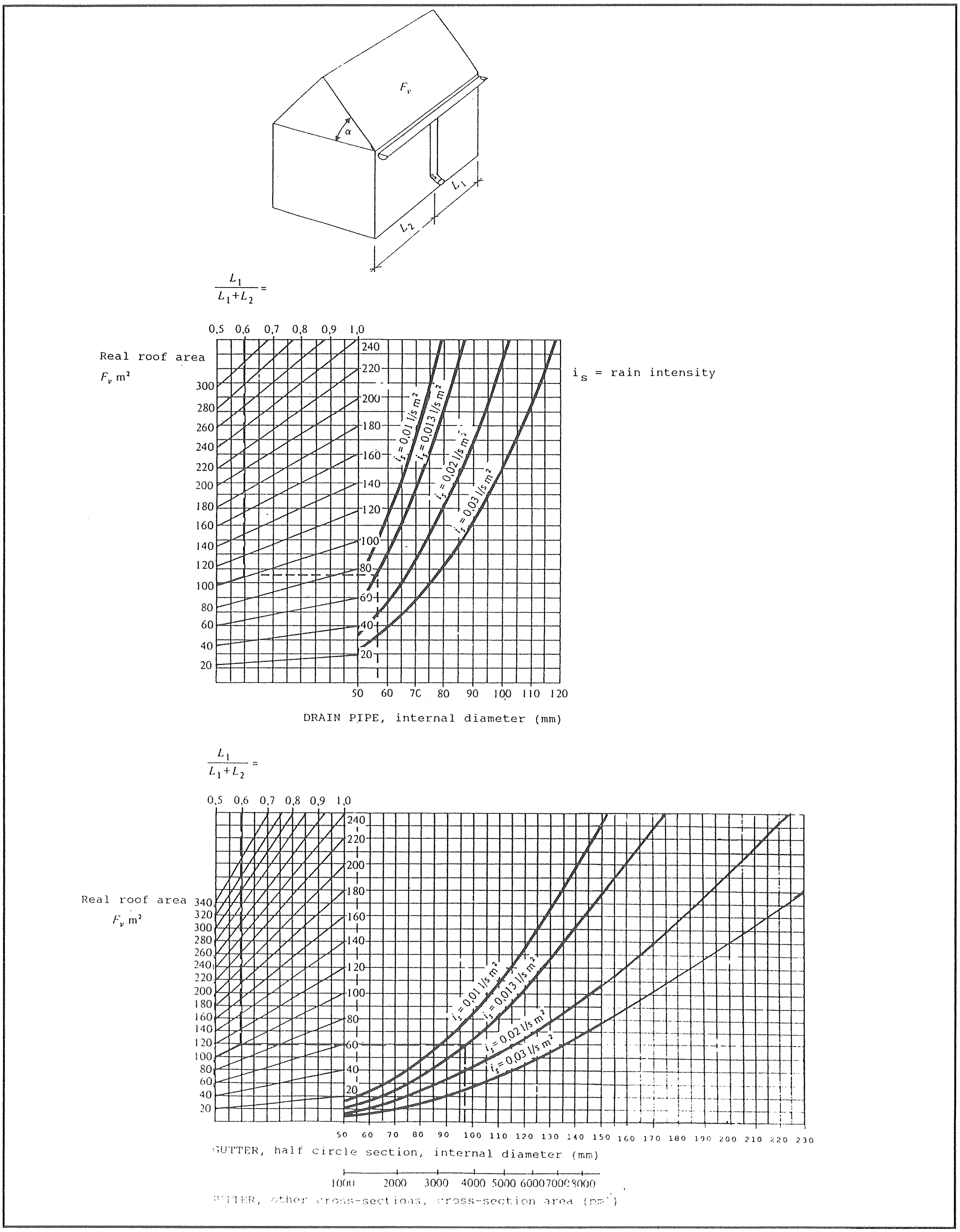


Figure 7.4. Design of gutters and drain pipes.

It is very hard to get information about rain intensity in Tanzania. Measurements done near Tabora in 1978—79 show an intensity of 34 millimetres during one hour, i e 0.0096 litres per second and square meter [6]. Another shower of 27 millimetres per hour (0.0075 litres per second and square meter), was measured the same year.

If assuming that one shower, with a frequency of one shower per year and a duration of one hour gives about 0.009 litres of water per second and square meter. That could be compared with one shower at the Swedish west coast with an intensity of 0.0031, once a year. The intensity in Tanzania is almost three times the intensity in Sweden.

The gutters and pipes in Sweden are designed for a shower with a duration of 10 minutes and a frequency of one shower per five years, but for areas smaller than 10 000 square meters the rain intensity 0.013 litres per second and square meter is used. This figure is about four times higher than the one hour shower with a frequency of one shower per year in Sweden, [19], [20].

If assuming that this relationship is the same in Tanzania, the gutters and pipes should be designed for four times 0.009, which means 0.036 litres per second and square meter. This figure would imply drain pipes of 20 to 30 centimetres.

A shower with a duration of 10 minutes and a frequency of one shower per year is about three times as high as the one hour shower in Sweden. If permitting the gutters to overflow sometimes it is sufficient to dimension them for 0.027 litres per second and square meter.

The figure 7.4 and 7.5 imply:
☐ The roof slope is greater than four degrees.
☐ The gutters have a minimum slope of 0.25 percent.

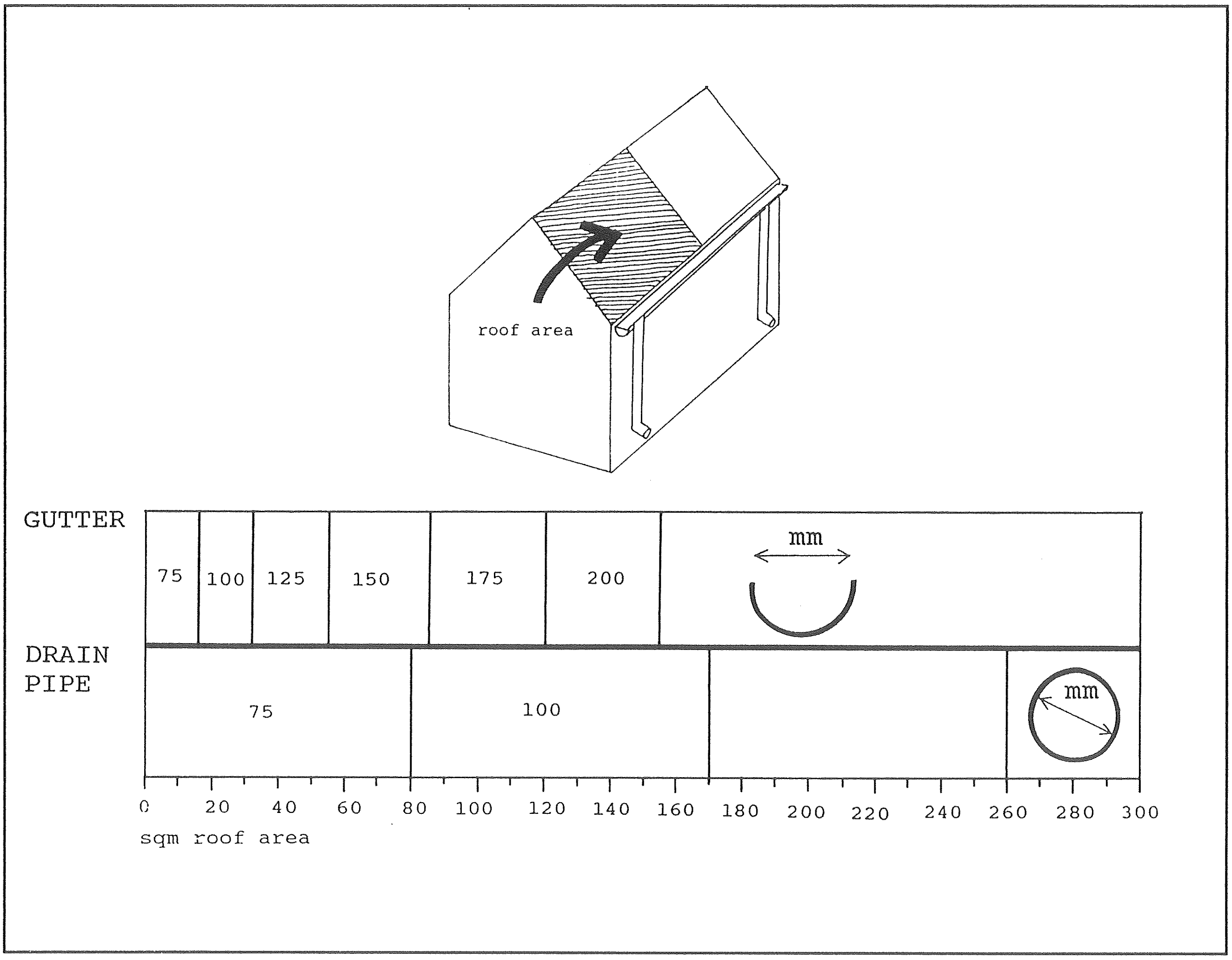


Figure 7.5. Minimum dimensions of gutter and drain pipe, with a rain intensity of 0.027 l/s,m² and the pipe at the gutter end.

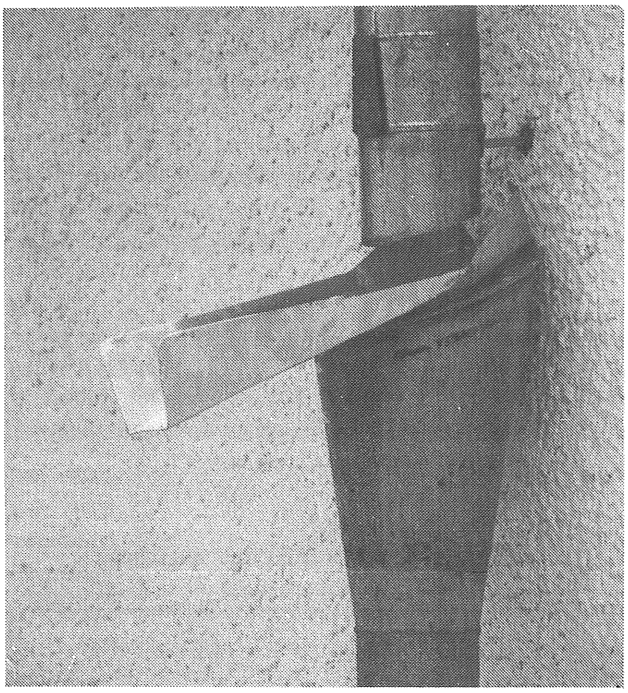


Figure 7.6. Well designed separator on a drain pipe.

With this shape of the roof, gutter and drain pipe will have losses below 10 percent of the measurable precipitation.

The tanks should be totally enclosed. With a good design, the losses in the tank caused by leakage and evaporation, can be reduced to less than 10 percent.

Together all losses will not exceed 20 percent. Therefore, the efficiency of a well designed and well maintained system will not be under 80 percent of the measurable precipitation.

One problem with the rainwater harvesters is where to separate the leaves, the branches and other strange particles. Yet another problem is how to design the connection between the gutter and the drain pipe.

The common way of solving the separating problem is to put a net in the gutter where the drain pipe starts. A cleaning box after the drain pipe, before the pipe that leads water to the tank.

There are some problems with this system. At first, the net is very easy getting tight of leaves and other particles. This net, that is situated at a height of about three meters, is hard to clean, but most important, it is hard to discover.

Secondly, the boxes have low efficiency and once again, it is difficult to discover when a cleaning is necessary. The losses of spill water and friction are also considerable. The boxes, situated in ground level, are also hard to make tight, which contributes to the contamination.

To get as small losses as possible, the connection between gutter and drain pipe could be shaped like the one illustrated in figure 7.6. This will result in a minimum of spill water and friction losses.

7.2.4 Tanks

When harvesters like roofs already exist, the biggest cost comes from the construction of suitable tanks. Where the potential for collecting large volumes of rainwater exists, tanks should be built large enough to cope with the volume. If they are built well, they will be a worthwhile investment.

The tanks should be covered to prevent the growth of algae, to reduce evaporation and to prevent contamination.

When roof harvesters are being used, tanks can be built above ground level. In other cases they have to be built below ground. It is also often cheaper to construct such tanks, even for roof harvesters.

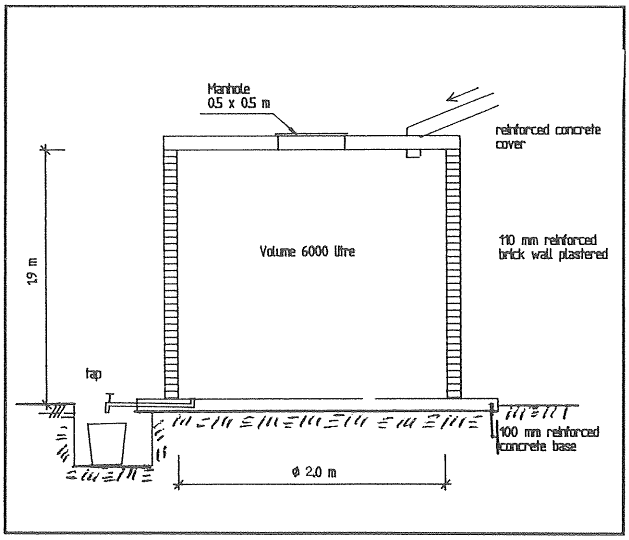


Figure 7.7. Example of a brick tank.

Brick tanks

One method for building a tank above ground level, is with bricks. A strong reinforced concrete base, a bit wider than the internal diameter of the tank, is first laid. A steel pipe fitted with a tap is introduced in the bottom, allowing a 20 litres bucket standing beneath on a concrete base. The pipe can alternatively be connected to a pump-pipe.

The brickwork is now laid in a circle (or rectangle), building up one layer at a time from the base. Reinforcing wires are laid between each layer to give strength. The brickwork is built up to the required height. The internal surfaces are plastered with strong cement mortar and steel floated. The tank cover is now made, either of tin or reinforced concrete. A manhole should not be forgotten, allowing the tank to be cleaned and repaired from the inside (figure 7.7).

Concrete tanks

A tank of reinforced concrete can be made in the same way as the brick tank, with a thickness of 100 millimetres, including the plaster.

When building a tank below ground, deeper and wider tanks can be made. It however requires thicker walls, between 250 and 350 millimetres. Water collected in tanks of this type must either be pumped or siphoned out through piping to lower situated areas. Water can also be pulled up by a rope and a bucket.

Prefabricated tanks

Prefabricated tanks of tin, concrete or glass-fibre plastic are often more expensive than the ones built on the spot. On the other side, they make the building procedure short and give good results.

7.2.5 Standard tank

A standard tank is described in figure 7.8. It can be built above as well as below the ground, but the latter alternative is preferable. The maximum internal height is 3.0 meters and the short width can be up to 3.0 meters. This type can be built with its base formed as a circle, square or rectangle with various lengths.

In order to get a waterproof tank, it is important to make the hardening slow. This can only be done with water spraying and covering tarpaulins. After one or two days the cover is replaced by water filled up in the tank. The design given in figure 7.8 gives a maximum crack width of 0.2 millimetres.

7.3 System at Nkinga Hospital

7.3.1 Harvesters

In the Nkinga Hospital area, there are about 75 buildings with tin roofs. This implies a total horizontal roof area of 18 224 square meters. However, only a part of this area is connected to rainwater tanks. 33 buildings, with a roof area of 7 667 square meters (42 percent), have got the water led to tanks (figure 7.2).

The rainwater is collected at the eaves in a gutter. If there is a tank above the ground, the gutter often leads directly to the top of the tank. When the tank is below ground, the gutter is connected to a vertical drainpipe, which then leads to an under ground pipe connected to the tank.

Thorough information is shown in table 7.1. Detailed drawings and measurements are given in reference [21].

7.3.2 Tanks

The water from these 33 buildings is collected in 69 water tanks, with a total volume of about 1260 cubic meters. An average tank consequently contains about 18 300 litres of water when it is full. The collecting of water is performed with a rope and a bucket (figure 7.9).

More facts about the tanks are given in table 7.2. Detailed information is given in reference [21].

7.4 Water quality

The rainwater is used for infusion, for medicine manufacturing and as drinking-water because it is the water of the best quality. The consumption of this water is about 200 litres per day.

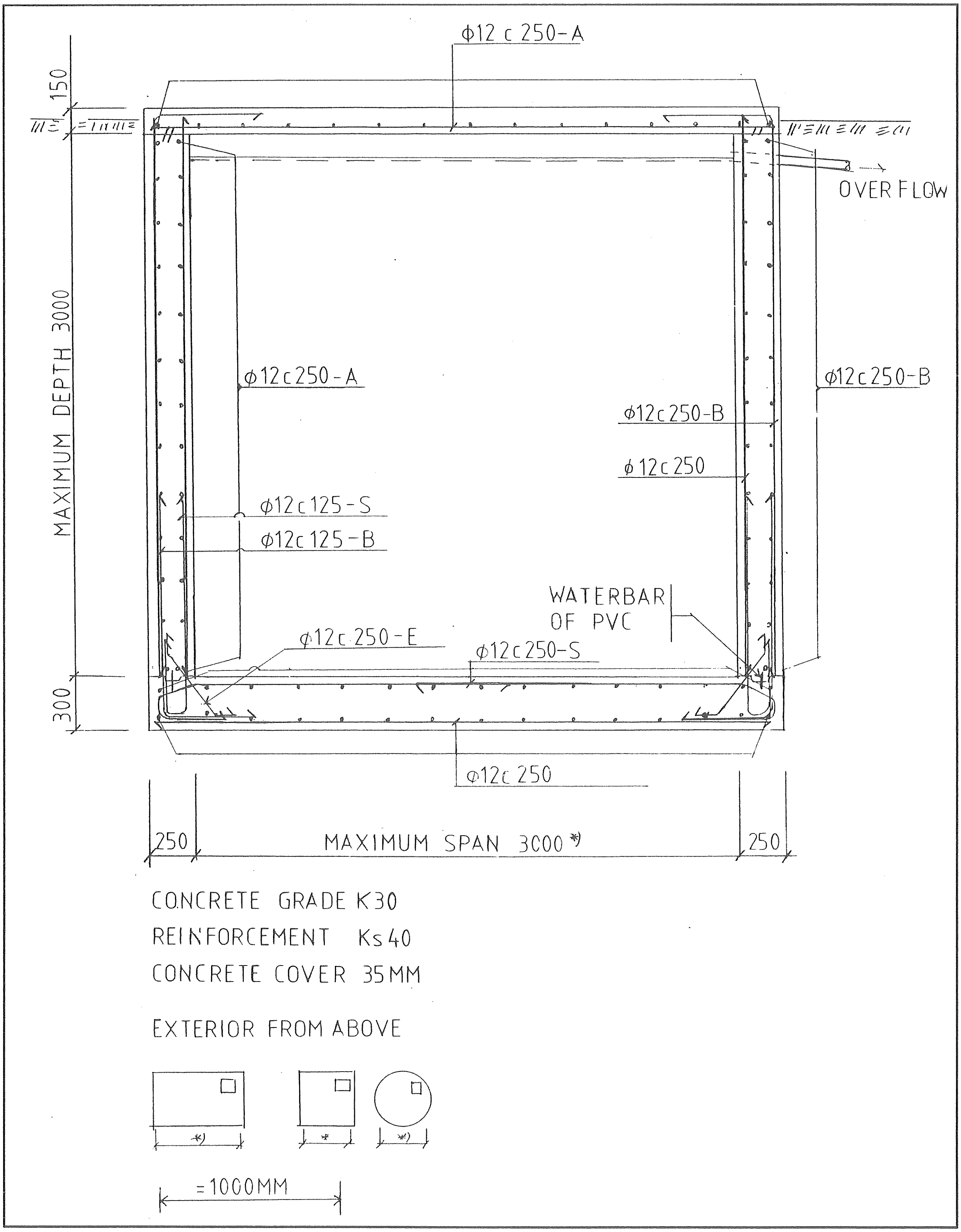


Figure 7.8. Design of standard rainwater tank.

Table 7.1. Rainwater harvesting roofs at Nkinga Hospital, part I (II).

Building	Total roof area (sqm)	Harvesting area (sqm)	Connected to tank	Connected		Non connected		Remark
				gutters	drain pipes	gutters	drain pipes	
A 1,2	167	-	-			G	-	
A 3	142	108	RA 1	G	G	R	R	
A 4	113	88	RA 1	G	G	R	-	Bad slope
A 5,6	167	-	-			G	-	
A 7	142	108	RA 1	G	G	R	R	
A 8	113	88	RA 1	G	G	R	-	
B 1	256	185	RB 1	G	G	G	G	
B 2	151	86	RB 1	G	G	G	G	
B 3	51	-	-			-	-	
B 4	88	-	-			-	-	
B 5	115	-	-			-	-	Store included
C 1	102	-	-			R	R	Store included
C 2	73	-	-			R	-	
C 3	62	-	-			-	-	
C 4	131	-	-			R	R	Store included
C 5	210	117	RC 1	R	R	-	-	
		93	RC 2					
C 6,7	162					R	-	Store included
C 8	137					R	-	Store included
C 9	115	80	RC 3	R	R	-	-	Store included
D 1-3	283	119	RD 1	R	G	-	-	Store included
		58	RD 2					
		61	RD 3					
D 4-7	173	-	-			R	-	Will be pulled down
D 8-11	173	-	-			R	-	Will be pulled down
D 12	76	-	-			-	-	Will be pulled down
D 13	166	-	-			-	-	Will be pulled down
D 14	183	65	RD 4	R	G	R	-	Will be pulled down
E 1	374	374	RE 1	G	G	-	-	
E 2	416	416	RE 2	G	G	-	-	
E 3	361	-	-			G	G	10 m gutter missing
E 4	316	75	RE 3	G	R	R	R	Small pipe dimensions
E 5	125	-	-			R	R	
F 1-5	841	-	-			R	R	Will be rebuild
F 6-10	1002	231	RF 21,22	R	R	R	R	
		58	RF 23					
		247	RF 24					
		73	RF 25					
		107	RF 26					
		169	RF 27					
F 11	346	140	RF 1	G				
		206	RF 2					
F 12	383	238	RF 3	G				
		144	RF 4					
F 13	346	140	RF 5	G				
		206	RF 6					
F 14	346	206	RF 7	G				
		140	RF 8					
F 15	330	133	RF 9	G				
		196	RF 10					
F 16	279	166	RF 11	R				
		113	RF 12					
F 17	376	185	RF 13	G		R	-	Passage to F 22 in-
		76	RF 14					cluded

To be continued...

Table 7.1. Rainwater harvesting roofs at Nkinga Hospital, part II (II).

Building	Total roof	Harvesting	Connected	Connected		Non connected		Remark
	area (sqm)	area (sqm)	to tank	gutters	drain pipes	gutters	drain pipes	
F 18	42	-	-			-	-	
F 19	350	-	-	?	?	R?	R?	
F 20	549	112	RF 15	G	G	R	R	Passage along F 11-
		174	RF 16	R	R	R	R	F 16 included
F 21-23	911	509	RF 17-20	R	R	R	R	
F 24	38	-	-			-	-	
F 25	42	-	-			-	-	
G 1	72	-	-			-	-	
G 2	280	-	RG 1	-	-	R	R	Could be connected
G 3	183	-	-			-	-	
G 4	60	-	-			-	-	
G 5	60	-	-			-	-	
G 6	60	-	-			-	-	
G 7	60	-	-			-	-	
G 8	60	-	-			-	-	
G 9	173	-	-			-	-	Will be pulled down
G 10	92	-	-			-	-	
G 11	92	-	-			R	G	With 200 l barrel
G 12	51	-	-			R	G	With 200 l barrel
H 1	252	47	RH 3	G	G	R	-	Will partly be pulled down
H 2,3	386	108	RH 2	G	G	R	R	
		109	RH 4			-	-	
H 4	33	-	-					
H 5	120	51	RH 5	R	R	R	R	Will be pulled down
H 6	262	-	-			-	-	Will be pulled down
H 7	123	-	-			-	-	Will be pulled down
H 8	161	86	RH 6	R	R	R	R	
H 9,10	300	-	-			G	G	
H 11	160	92	RH 7,8	R	R	R	R	
H 12	-	-	-					Grass roof
H 13	53	-	-					
H 14	446	-	RH 9	-	-	-	-	New roof
J 1-4	369	65	RJ 1	G		G	-	Store included
		65	RJ 2					
		65	RJ 3					
		65	RJ 4					
J 5-8	369	65	RJ 5	G		G	-	Store included
		65	RJ 6					
		65	RJ 7					
		65	RJ 8					
J 9-12	369	65	RJ 9	G		G	-	Store included
		65	RJ 10					
		65	RJ 11					
		65	RJ 12					
J 13-16	239	38	RJ 13	R	G	-	-	Store included
		38	RJ 14					
		38	RJ 15					
		38	RJ 16					
J 17-20	239	38	RJ 17	R	G	-	-	Store included
		38	RJ 18					
		38	RJ 19					
		38	RJ 20					
K 1,2	1607							Under construction
K 3	169							Under construction
			G = Good condition, R = Repair needed					
Totally	18224	7667						

Table 7.2. Rainwater tanks at Nkinga Hospital, part I (II).

Rainwater tank	Volume (cbm)	Connected to building	Connected roof area (sqm)	Condition	Remark
RA 1	71,3	A 3,4,7,8	392	G	
RB 1	83,8	B 1,2	271	G	
RC 1	10,6	C 5	117	R	
RC 2	32,7	C 5	93	G	
RC 3	8,4	C 9	80	G	Plastic
RD 1	21,5	D 1-3	119	G	
RD 2	8,4	D 1-3	58	G	Plastic
RD 3	8,4	D 1-3	61	G	Plastic
RD 4	36,1	D 14	65	R	
RE 1	15,4	E 1	374	G	
RE 2	8,2	E 2	416	G	
RE 3	15,4	E 4	75	G	
RF 1	13,8	F 11	140	R	
RF 2	12,7	F 11	206	R	
RF 3	14,3	F 12	238	R	
RF 4	13,3	F 12	144	R	
RF 5	12,7	F 13	140	R	
RF 6	12,7	F 13	206	R	
RF 7	12,7	F 14	206	R	
RF 8	14,3	F 14	140	R	
RF 9	14,3	F 15	133	R	
RF 10	14,3	F 15	196	R	
RF 11	13,3	F 16	166	R	
RF 12	13,3	F 16	113	R	
RF 13	13,3	F 17	185	R	
RF 14	13,8	F 17	76	R	
RF 15	14,3	F 20	112	R	
RF 16	14,3	F 20	174	R	
RF 17	34,0	F 21-23	25	R	
RF 18	63,7	F 21-23	30	R	
RF 19	22,3	F 21-23	307	G	
RF 20	21,1	F 21-23	147	R	
RF 21	34,1	F 6-10	231	G	
RF 22	41,6	F 6-10	-	G	
RF 23	18,0	F 6-10	58	G	
RF 24	33,5	F 6-10	247	G	
RF 25	32,3	F 6-10	73	G	
RF 26	28,2	F 6-10	107	R?	
RF 27	22,9	F 6-10	169	?	
RG 1	31,5	G 2	-	R	Not connected
RH 1	5,6	H 2,3	-	R	Not connected
RH 2	30,8	H 2,3	108	R	
RH 3	14,6	H 1	47	R	Roots
RH 4	14,6	H 2,3	109	R	
RH 5	18,2	H 5	51	G	
RH 6	33,3	H 8	86	G	
RH 7	12,6	H 11	92	R	Too much dikt in gutter
RH 8	27,7	H 11	-	R	Not connected
RH 9	31,5	H 14	-	R	Not connected
RJ 1	11,2	J 1-4	65	R	

To be continued...

Table 7.2. Rainwater tanks at Nkinga Hospital, part II (II).

Rainwater tank	Volume (cbm)	Connected to building	Connected roof area (sqm)	Condition	Remark
RJ 2	11,2	J 1-4	65	R	
RJ 3	11,2	J 1-4	65	R	
RJ 4	11,2	J 1-4	65	R	
RJ 5	11,2	J 5-8	65	R	
RJ 6	10,4	J 5-8	65	R	
RJ 7	11,2	J 5-8	65	R	
RJ 8	10,4	J 5-8	65	R	
RJ 9	8,4	J 9-12	65	G	Plastic
RJ 10	8,4	J 9-12	65	G	Plastic
RJ 11	8,4	J 9-12	65	G	Plastic
RJ 12	8,4	J 9-12	65	G	Plastic
RJ 13	3,3	J 13-16	38	R	
RJ 14	4,2	J 13-16	38	R	
RJ 15	3,3	J 13-16	38	R	
RJ 16	4,2	J 13-16	38	R	
RJ 17	4,2	J 17-20	38	R	
RJ 18	4,2	J 17-20	38	R	
RJ 19	4,2	J 17-20	38	R	
RJ 20	4,2	J 17-20	38	R	
Totally	1.263,1		7667		

G = Good condition, R = Repair needed

Figure 7.9. Woman collecting drinking-water from a rainwater tank (number RB 1).

All harvester surfaces, being exposed throughout the year, are subject to contamination by dust, insects and birds. Trees are planted around many of the roof harvesters. Leaves, branches and twigs fall down from the trees. The trees also make it possible for the birds to sit just above the roof.

Those harvesters at ground level are also liable to be contaminated by animals and humans. Therefore they have to be properly fenced and kept clean.

Storage tanks can be built either below or above ground. The tanks below ground should be fitted by a hand pump to get fully enclosed tanks. All openings must be covered with mosquito-net.

There are three reasons to build enclosed tanks. First, because of the risk of contamination through the hole for the buckets or with the buckets. Secondly, because of the evaporation and finally, to prevent access of mosquitoes, insects, rodents, lizards, etc.

The tank should have a flood pipe, about 20 centimetres from the top. It prevents the tank from breaking and aerates the water to destruct aerobic organisms and prevent growth of algae.

When this is done, the only source of contamination will be the roof or the collection area. The roofs with its gutters, drain pipes and tanks should be properly cleaned once a year, just before the long rainy season, and the first flush of the new rains should be run to waste. Other collection areas are to be serviced in the similar way.

If these measures are taken, it will result in a consistently low contamination. A study in Zimbabwe shows for instance a concentration of faecal E. coli at lesser than 10 colonies per 100 millilitres of sample, [18]. This means that the water should be potable when it has been boiled.

7.5 Improvements

7.5.1 Harvesters

The rainwater harvesters can be much more developed, and with rather small resources the water quality can be considerably improved.

Near some of the buildings, there are big trees and bushes with their branches overhanging the roofs. The water can be contaminated by parts falling down from the trees, but also by birds and insects sitting on the branches. The branches also reduce precipitation on the roofs by interception. Overhanging branches should therefore be cut.

7.5.2 Gutters and drain pipes

Another problem is related to the transportation system to the tanks, i e roofs, gutters and drain pipes. Many of the roofs and the gutters are insufficiently cleaned. That should be done before the rainy season starts.

Many of the gutters are situated too close to the houses, which makes the rainwater pass the gutters by. Other gutters slope in the wrong direction and a great many of them are lacking their gables. Some houses are fitted with too tiny gutters and drainpipes, to drain the water away when a heavy rain comes. Often grids and nets are missing. They are supposed to prevent leaves and insects coming into the tanks.

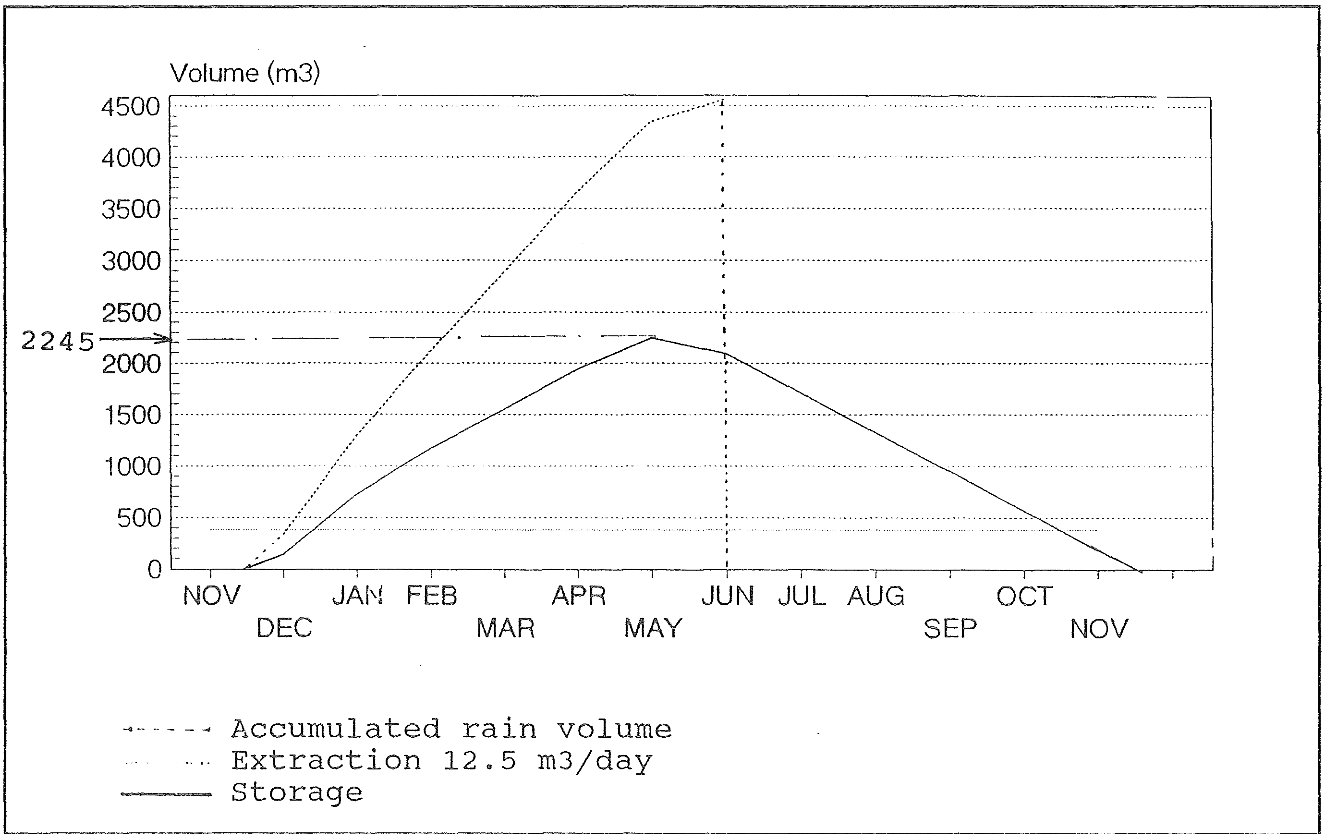


Figure 7.10. Optimum rainwater tank volume.

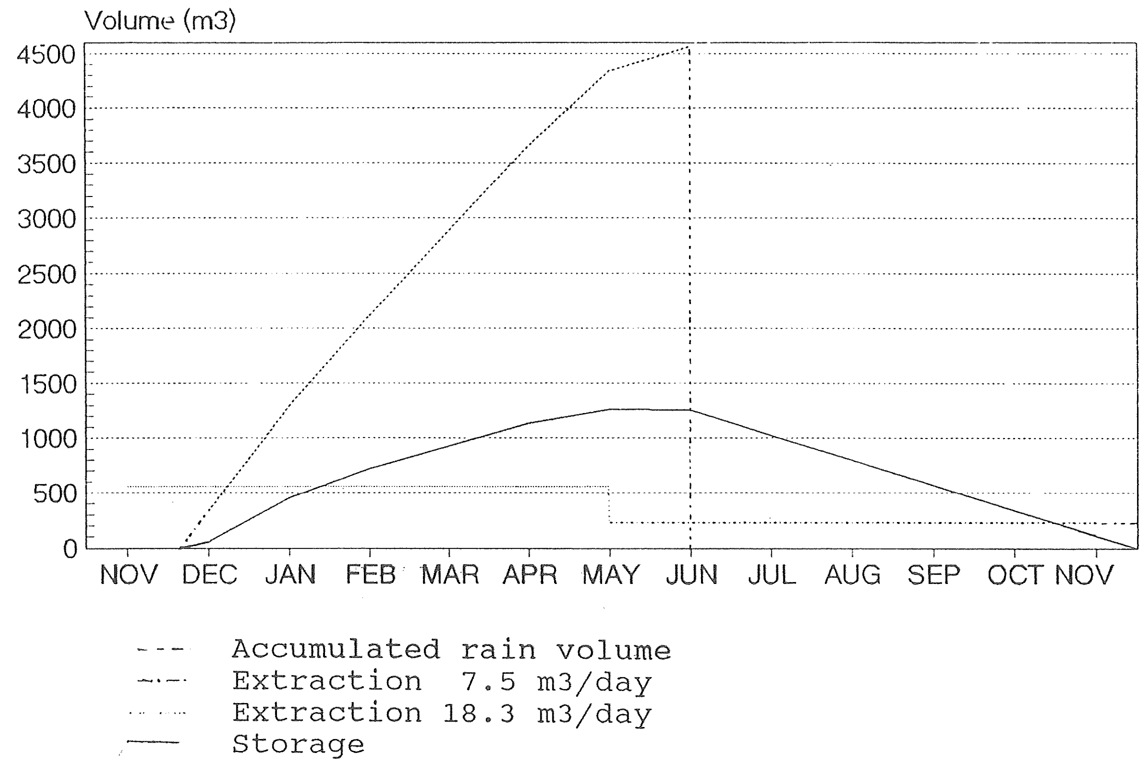


Figure 7.11. Possible extraction from rainwater tanks.

7.5.3 Tanks

The rain falling on the roofs at Nkinga Hospital is a big water source to take care of. The total roof area at the Nkinga Hospital area is 18 224 square meters. 7667 square meters, or 42 percent, of this area is connected by gutters and drainpipes to tanks. The system is running between the middle of November and the end of May. About 744 millimetres of rain falls during this period (figure 3.6).

If every roof area were connected to the system, it would give a total rainwater volume of:

$V = 18\ 224\ m^2 \times 0.80 \times 0.744 = 10\ 850\ m^3$

The efficiency here is 80 percent. It means that nearly 29 cubic meters could be extracted every day. That is about ten times the extraction of today. Today the harvesting area gives:

$V = 7667\ m^2 \times 0.80 \times 0.744 = 4\ 564\ m^3$ (42 percent)

If all of this volume of water were stored, about 12.5 cubic meters per day could be extracted. There is no possibility to store such a volume today. According to the calculations shown in figure 7.10, tank volumes of totally 2245 cubic meters would be needed. That volume could be compared with the total existing volume of 1260 cubic meters.

If every existing tank is filled at the end of May, 7.5 cubic meters of water could be extracted every day during the dry season. However, in the rainy season, 18.3 cubic meters could be extracted per day (figure 7.11).

This volume is however theoretical. Many of the connected roofs with their gutters and drain pipes have a low efficiency. A study shows that only 61 percent of the gutters and drain pipes were classified as good, the rest of them were suffering from problems mentioned in chapter 7.5.2.

Only 22 of the 69 tanks have been classified as being in good condition (table 7.2). The volume of these tanks is 540 cubic meters, i e 43 percent of the total tank volume. If the tanks in good condition were filled at the end of may, 3.2 cubic meters per day could be extracted during the dry season. Considering the bad condition of gutters and drain pipes, 2.5 cubic meter is more realistic. During the rainy season, this means, 7.9 cubic meter per day. An even higher extraction is perhaps possible, when the filling of the tanks in bad condition is faster than the leaking.

7.5.4 Repairing tanks

The harvesting system at Nkinga Hospital has less than half of its tanks in good condition. Most of the tanks built above ground were leaking. Even some of the tanks below ground level leak. Cracks in the underground tanks can depend on movements in the ground, for instance small earthquakes.

Leaking concrete tanks are due to the following reasons:

- ☐ Separation of ballast
- ☐ Insufficient filling of concrete, depending on too much reinforcement or bad vibrations
- ☐ Leaky joints, depending on bad vibrations
- ☐ Porous concrete, depending on low concrete quality, large ballast dimensions, fast hardening or high water/cement-number.
- ☐ Cracks, depending on too fast hardening or low strength

If the tanks are leaking through cracks they can be tightened with epoxy. However, many of the tanks are leaking through the walls and also need a new inside covering. This cover can be made of epoxy or high quality concrete. It is not possible to achieve water caulking with high quality plaster.

Design of new tanks has been described earlier in chapter 7.2.5.

Epoxy plastics

To repair a tank it has to be emptied and totally dried. After the cracks have been detected, high pressure nipples are injected at a distance of maximum 50 centimetres.

To the nipples, a high pressure pump with epoxy composition and hardener, is connected. When the epoxy comes out of the cracks, it is sufficient. Excess epoxy should be removed.

The epoxy quality has to be of a semihard type.

To make a tight inside cover, epoxy can be applied with painting tools. Several layers are needed.

Concrete

A second way to make a waterproof inside is to cast a high quality concrete layer between a wooden mould and the old tank. The quality has to be at least K 50, with a thickness of at least 60 millimetres and a net reinforcement. It is possible to spray the concrete.

7.6 Harvesters at the hospital workshop

7.6.1 Capacity

A new workshop at Nkinga Hospital (number K1 and K2 in figure 7.2) is under construction. The area of the roofs is about 1600 square meters. That will be nearly 10 percent of the total roof area in the hospital area.

The capacity, according to the equation above, is:

$$V = 1600\ m^2 \times 0.80 \times 0.744 = \\ = 950 \text{ cubic meters}$$

That means a daily extraction of about 2.6 cubic meters, about as much rainwater that today is extracted from all the other roofs.

The tanks need to have a volume of:

$$V_R = 5.5 \text{ months} \times 30.5 \text{ days} \times 2.6\ m^3/\text{day} = \\ = 430 \text{ cubic meters}$$

The tanks have to be filled at the end of May and emptied in the middle of November. To increase the accessibility of the water, it could be pumped up in a water tower and then distributed in a separate system.

7.6.2 Design

The gutters and pipes can be designed according to chapter 7.2.3, and the rainwater tanks can be designed according to chapter 7.2.5.

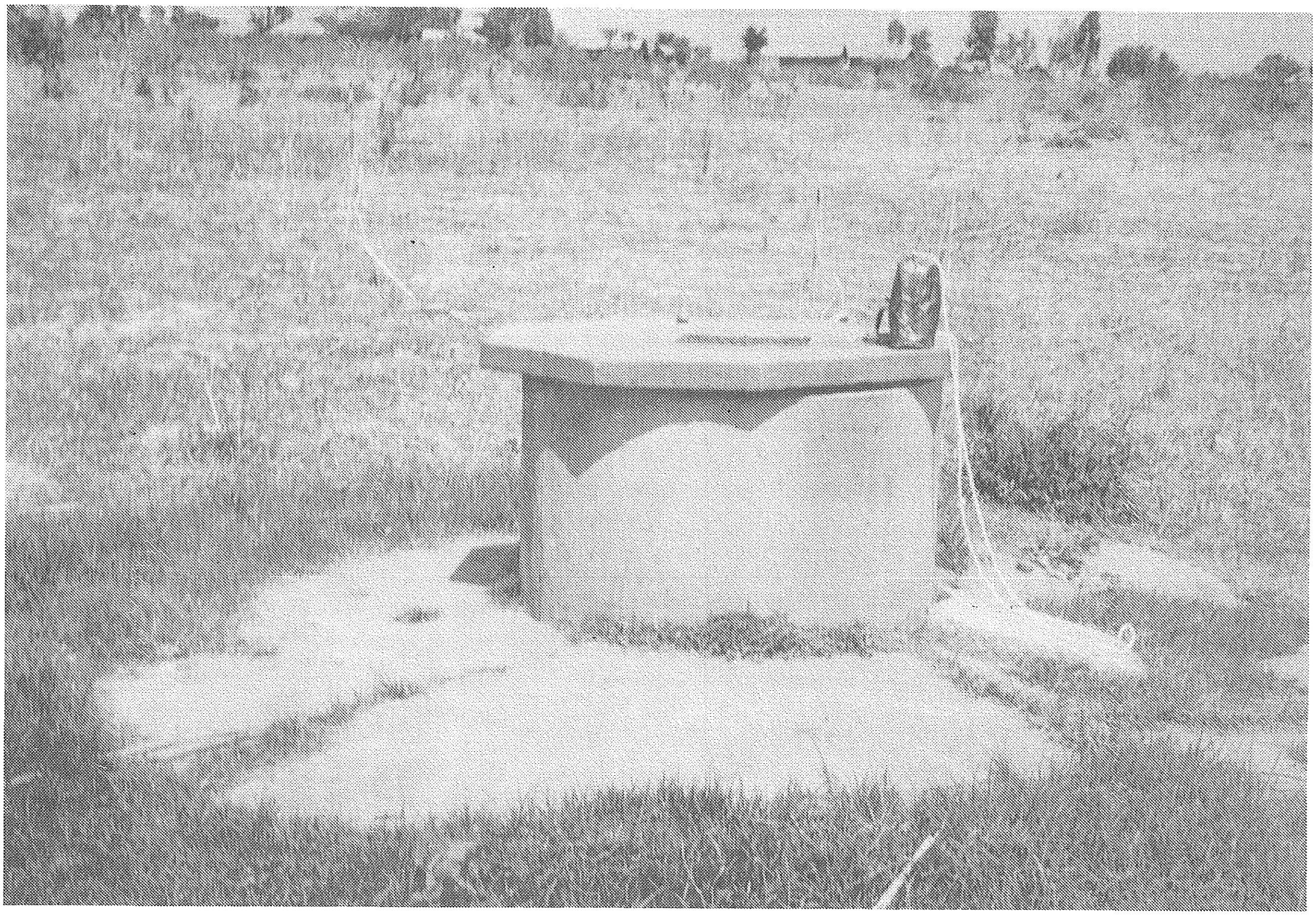


Figure 8.1. Shallow well Ndembezi I.

8 Other water sources

8.1 Survey

There are some water sources in the area that not have been presented in the previous chapters. They are shallow wells, dug holes, small dams, charcos and small streams (figure 8.1). Some of these are only used for cattle, but most of them are used by the people as drinking and cooking water.

8.2 Shallow wells

8.2.1 Survey

In the area of Nkinga, Ulaya and Ndembezi, there are ten shallow wells (table 8.1). Six of them are lined and four are unlined, i e they have no rings.

The location of the wells is shown in figure 4.2. All the wells are surrounded by a clean surface, but they are not equipped with aprons for transport of rainwater away from the wells.

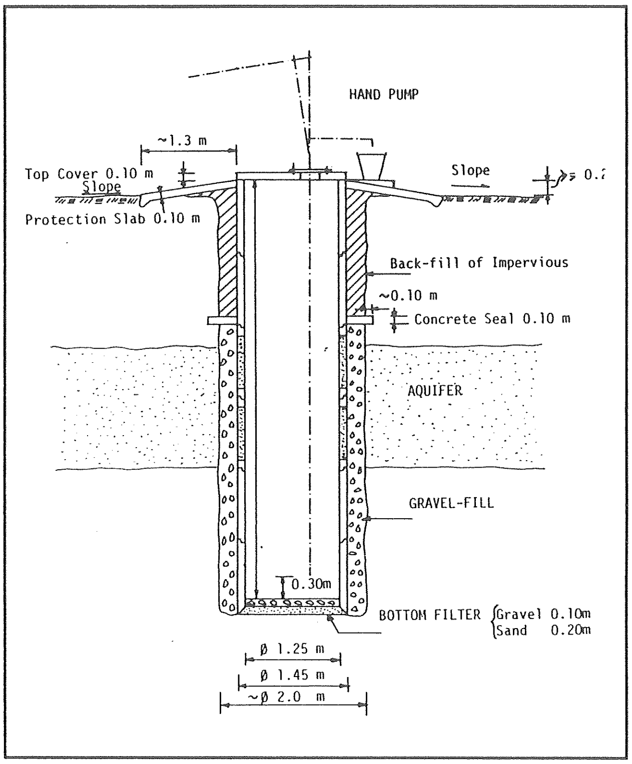


Figure 8.2. Shallow well design.

8.2.2 Design

In this chapter shallow wells are defined as wells with a depth of up to 10 meters, typically rather wide and with a constant diameter. These wells recharge both through the side, and the bottom (depending on the aquifer conditions). Boreholes recharge only through lateral flow into the well tube.

The rural people have always been dependent on shallow wells for their water supplies. Construction of reservoirs and boreholes has been feasible alternatives only in recent years. That requires technical and financial assistance from outside.

A shallow well with good water quality must have a tight cover, protective apron and a hand pump (figure 8.2). Only wells that are deeper than 6 meters have a good reliability.

8.2.3 Nkinga village

At Nkinga, there are three shallow wells. Rope and bucket are used to extract water in all of them . Shallow well Nkinga I has a concrete cover, but the tin lid is missing. The other two do not have covers.

In the early days of Nkinga missionary station, a five meter deep shallow well was dug at the corner of the old dispensary. It was connected to a depression zone, and gave, according to old mama Sherode, thousands of buckets and never ran dry. The well was, however, forgotten and is today below a house foundation.

The ground, that consists of more or less solid granite, is covered with shallow residual soil. The aquifer consists of silty sand and weathered granite, but the water is drained from this layer during the dry season (chapter 3.2).

8.2.4 Ulaya village

The two shallow wells at Ulaya are unlined and they were constructed by the villagers. People take up water with a rope and a bucket. None of the wells have a proper cover, but attempts have been made to cover Ulaya II with wooden logs.

Table 8.1. Survey of shallow wells.

Shallow well	Official number	Depth	Internal diameter	Lining material	Depth to water	Estimated reliability
Nkinga I	-	2.8 m	1.9 m	Bricks	Dry	50%
Nkinga II	-	2.0 m	1.7 m	Stone blocks	Dry	50%
Nkinga III	-	3.5 m	1.0 x 1.4 m	None	Dry	50%
Ulaya I	4:402	4.6 m	1.3 m	None	?	75%
Ulaya II	4:401	4.7 m	1.3 m	None	?	?
Ndembezi I	4:2013	2.9 m	1.0 m	Concrete rings	2.4 m	85%
Ndembezi II	4:2014	14.4 m	2.1 m	Concrete blocks	6.7 m	100%
Ndembezi III	4:2015	3.0 m	1.0 m	Concrete rings	1.8 m	67%
Ndembezi IV	4:403	3.7 m	1.1 m	None	?	100%
Ndembezi V	-	7.6 m	2.0 m	Stone blocks	5.6 m	100%

The geological formation is of granite with a cover of shallow residual soil and the aquifer consists of silty sand, sand and weathered granite.

8.2.5 Ndembezi village

Five shallow wells are located at Ndembezi. They are used as a complement to the water distribution from the Ulaya Dam (chapter 9.4.4). Water is taken from all wells by a rope and a bucket. The lined shallow wells Ndembezi I, II and III, were constructed in 1970 by UNICEF. The first years hand pumps were used, but now all of them are out of order, transformed to antique objects (figure 8.3).

The wells Ndembezi I and II have good covers, but the tin lid is broken on the first one and missing on the second. At the shallow well Ndembezi III, the concrete cover has been removed and there are branches and other strange objects that have been thrown into the well.

The two remaining wells, Ndembezi IV and V have been constructed by the villagers. The first is without cover, the other half-heartedly covered with wooden logs.

The ground is covered with shallow residual soil over granite and in all wells, the aquifer consists of silty sand to sand and weathered granite, except for shallow well V. This well has silty sand to sand and laterit at the bottom.

Figure 8.3. Shallow well Ndembezi II.

8.2.6 Improvements

The traditional shallow well will play an important role in the future, but if with some improvements. However, the water quality should be improved. Today, the sediment content and contamination is rather high, especially in the rainy season, and also in the wells without lining material.

The water quality must be improved. Today, the sediment content and contamination is rather high, especially in the rainy season and for the wells without lining material.

The supply is very good in all ten wells during the rainy season and they can be the most important sources during that period. The three wells at Nkinga are empty during the main part of the dry season, but at Ndembezi the five wells are rather reliable all the year around (table 8.1).

First of all, a tight cover is important. The cover can be made of board or concrete. That will not just result in better water quality, but it will also increase the supply through less evaporation.

To improve the water quality, three more things can be done. First of all, the wells without lining material should be lined. That will cause a lower sediment yield. Secondly, a protective apron will prevent the spill water to transport sediment back to the well. Finally, a handpump would not give contamination through the manhole or from the buckets (see figure 8.2).

The cost for a good handpump in Sweden is today about 2500 SEK (figure 8.4).

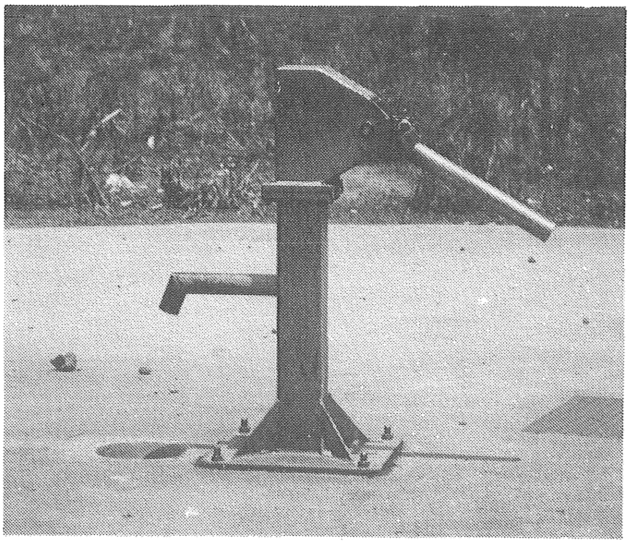


Figure 8.4. Example of handpump.

8.3 Dug holes, small dams, charcos and streams

8.3.1 Survey

Water sources, such as dug holes, small dams, rice field basins and small streams, are very important for the area in the rainy season, not just as potable water, but also for watering the cattle and for the farming.

During the dry season, most of these sources are empty. Water from more reliable sources can then be transported in a tank (figure 8.5).

8.3.2 Dug holes

At the villages of Ulaya and Ndembezi and the in the very surrounding area, the ground water level is close to the ground level. This makes it possible to extract water, just by digging holes. Consequently there are many small holes, and the depths are usually between one and a half and three meters. Most of the dug holes have a circular area, steadily decreasing with the depth.

When this study was made, at the very end of the dry season, some of these holes were still in use (figure 8.6).

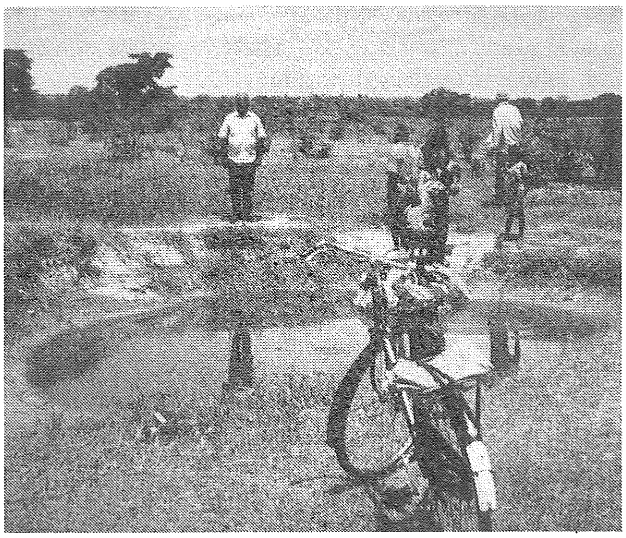


Figure 8.6. People drinking water from a dug hole at Ulaya.

8.3.3 Small dams and charcos

There are five smaller dams in the three villages. A dam here is defined as a water reservoir with an embankment on one side, unlike a charco which is supplied with embankments the whole way around. There are a number of small charcos in the area, all of them are used as rice field basins.

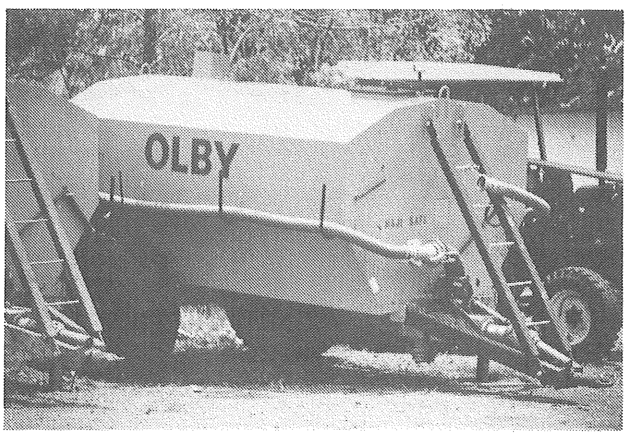


Figure 8.5. Tank waggon with pump.

Next to one of the small dams (number 3:085), there is a trough connected to the dam for watering cattle (figure 8.7). Building such a trough, enclosed contamination is avoided in the dam.

8.3.4 Streams

Most of the streams in the area have no flow during the dry season. In the rainy season, on the other hand, they can reach a considerable flow, and fill up many of the small dams.

8.3.5 Improvements

The contamination can be high in the stagnant water and bilharzia is very common (see chapter 5.7.2). Thanks to relatively small water volumes and such a large surface, each head contributes to the contamination, and the sediment content can also be high per litre.

The fact that the supply is largest just after the rain, makes the sediment content even higher depending on the erosion caused by the rain. The water needs to be treated according to chapter 5.8.2.

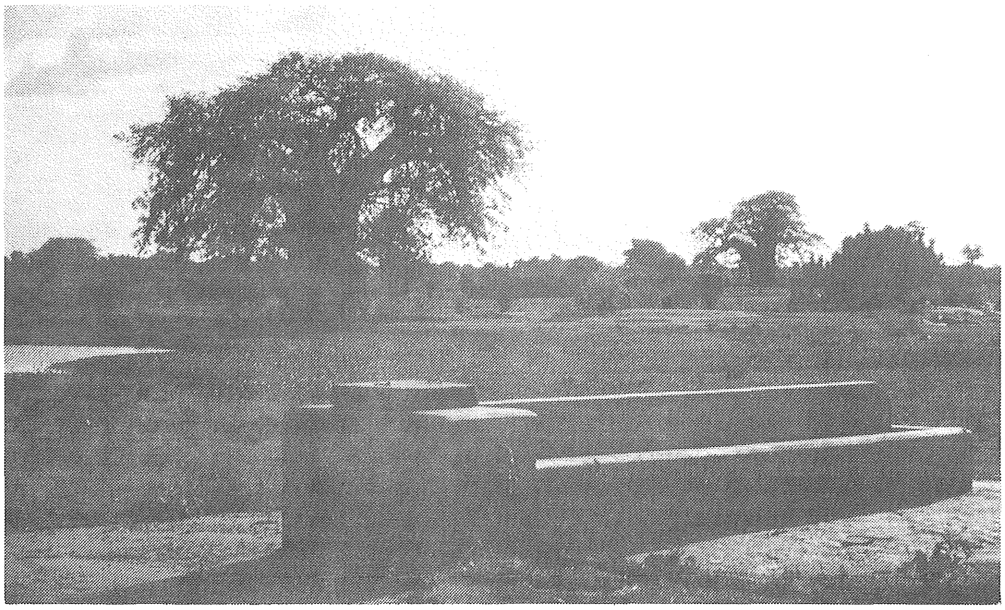


Figure 8.8. Trough connected to dam 3:085.

Because of the bilharzia risk, a health test can be made at Nkinga Hospital. An information program must be started at the schools to teach the children about water quality and bilharzia.

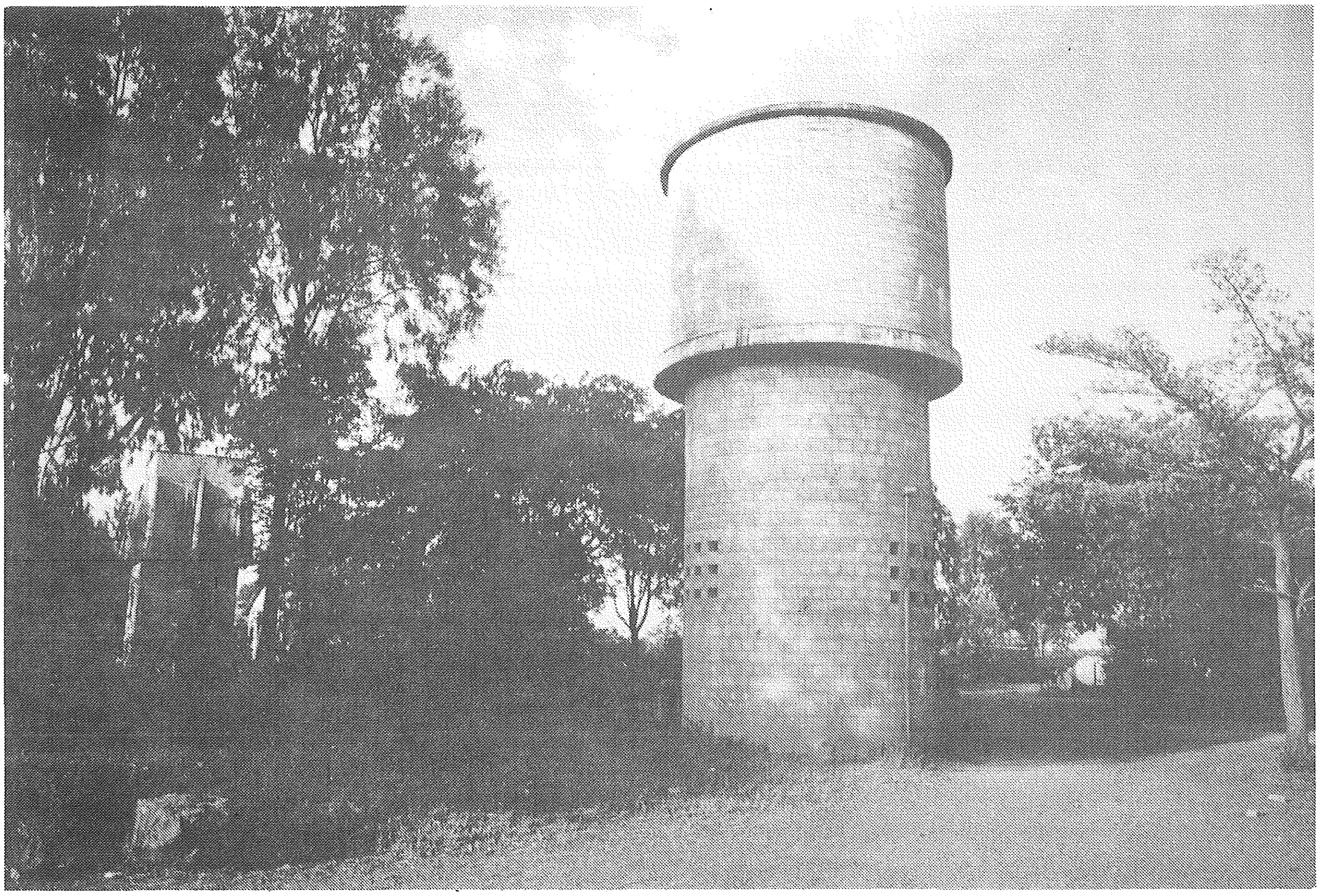


Figure 9.1. The Nkinga Village Water Tower.

9 Distribution systems

9.1 Survey

Water from the Ulaya Dam and from the Borehole 1/79, is being pumped to five water towers at Nkinga Hospital and the three villages Nkinga, Ulaya and Ndembezi.

Three of the towers, the Nkinga Village (figure 9.1), Ulaya and Ndembezi Water Towers are connected to the dam reservoir. Two of these, the Nkinga Missionary and the Nkinga Hospital Water Towers get their water from the borehole. However, the three towers at Nkinga are all connected, which gives the possibility to exchange water.

The water is distributed from the towers to the users.

Two motorized pumps are situated inside Borehole 1/79 and one in the Ulaya Dam pump house.

9.2 Introduction

The distribution system consists of pumps, pipes, water towers, valves and taps. It transports water from the sources to the users.

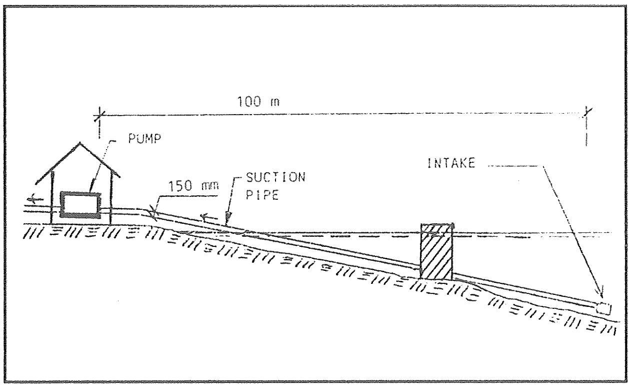


Figure 9.2. Principal function of the Ulaya Dam pump.

When the water flows through a pipe, it loses pressure because of the friction to the walls. With larger pipes, the friction decreases, but the pressure also becomes lower. Smoother pipe materials like plastics and steel gives smaller losses than rougher materials such as cast iron and concrete.

When starting an empty system, it has to be empty of air. This is possible by starting the pump with the air valves in the open positions. The air valves are situated at the highest points of the system. Non return valves hold the water in the system.

Water towers are used to get storage capacity and to increase the pressure. Valves are used in order to direct the water. They can be operated by man or automatically depending on time, flow and volumes.

The methods of lifting water are numerous and varied. The simplest pumps are often the cheapest and can more easily be made from and repaired with local materials. However, they are sometimes less durable and usually, they require more maintenance by the local community.

For a water level less than 8 meters, a shallow well hand pump may be the best choice. For levels, deeper than 8 meters, special deep-well hand pumps would be interesting.

Wind and solar powered pumps may also be used for raising water. However, they are usually rather expensive and they need large storage tanks for the periods when they are not able to pump.

The pumps can also be powered by diesel motors or electric motors. The electric motors need less maintenance and they are usually more reliable than the diesel engines. Therefore, they are preferred where electricity is available. For large raising heights or large flows a motor pump is preferable.

Principally, the pumps can be divided into three different groups, depending on how the water leaves the pump. The centrifugal pump is used for large raising heights, the axial pump for large flows with less raising heights and the diagonal pump for circumstances in between.

9.3 The pump at the Ulaya Dam

9.3.1 Description

A pump installed at the Ulaya Dam pump the water to the water towers at Nkinga, Ulaya and Ndembezi (figure 9.2 and 9.3). The pump is a horizontal multi-stage high pressure centrifugal pump, MOVI 40/6B. It was delivered by C A Mörck, Askim, Sweden and manufactured by Klein, Schanzlin & Becker AG in Frankenthal, Germany (figure 9.4).

The pump is powered by a diesel motor, Lister type 124 ST 2A 28-09, with a speed of about 2100 revolutions per minute. The motor was delivered in 1987/88. The concrete bed has six points of attachment.

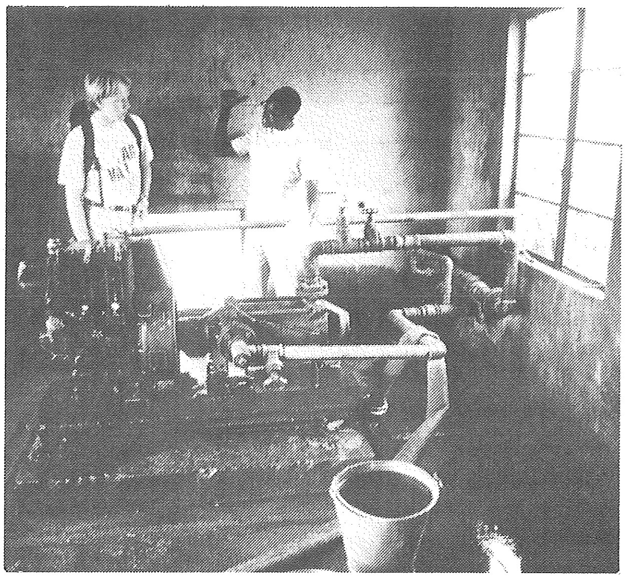


Figure 9.3. Inside the pumphouse at the Ulaya Dam.

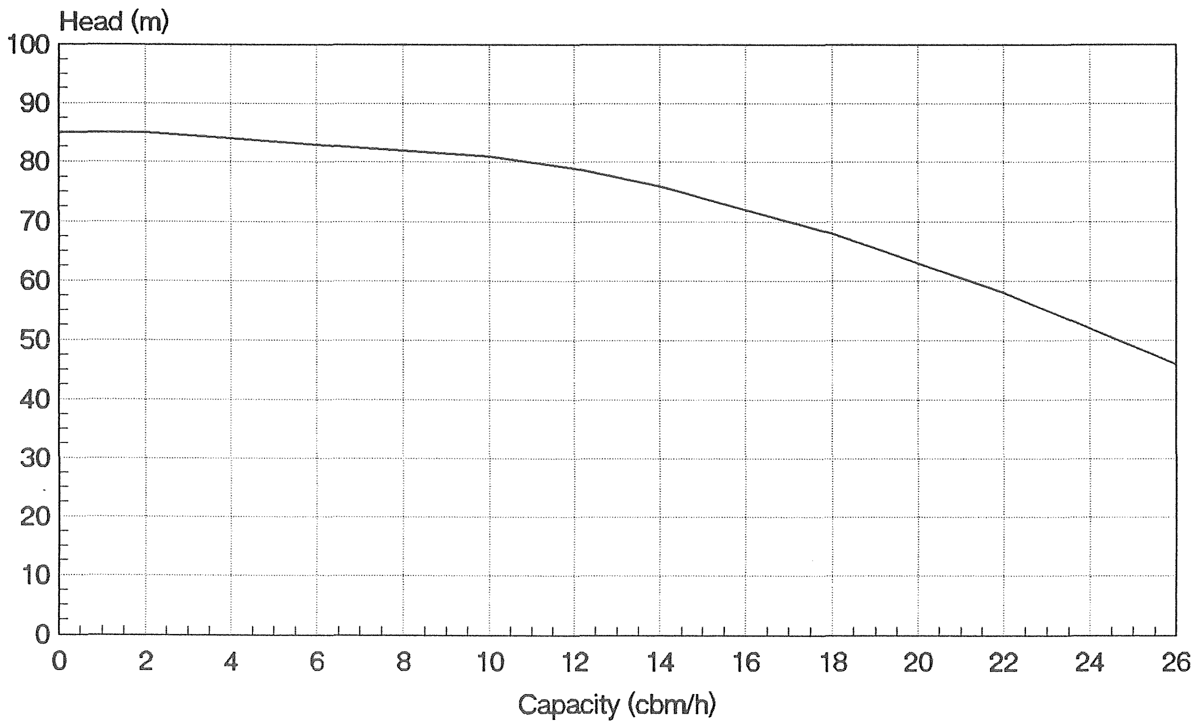


Figure 9.4. Capacity of the pump MOVI 40/6B.

Today, the water is directed partly to Nkinga village, partly to Ulaya and Ndembezi by Idara ya Maji (District Water Engineer in Igunga), according to table 9.1. The water flow from the Ulaya Dam is supposed to be regulated according to this table. However, in reality, the flow varies very much. Sometimes, the pumping to Nkinga starts only about eight o'clock in the evening.

Idara ya Maji has employees for daily maintenance and service. They are also supposed to pay the fuel for the pump motor and the fuel transport. The fuel is delivered by Nkinga Hospital (900 litres per month). Nkinga Hospital makes necessary repair after approval by Idara ya Maji, who pays the cost.

9.3.2 Improvements

The man, who is in charge of the pump is employed by Idara ya Maji. He has to follow the schedule in table 9.1. Otherwise, it is impossible to control that the system works as it is supposed to do. If something happens to the pump or the motor it will be when they are running. It is therefore much more convenient if it occurs in daylight and when the workshop is open, and not in the evening as it will be if when the man starts them too late.

Earlier there was a new extra pump at the workshop for use when the pump at the Ulaya Dam had to be repaired. For some reason this pump was taken away by Idara ya Maji. Of course, this pump or a new one has to be replaced by the authorities.

There are mainly three problems with the Ulaya Dam pump:

- ☐ Lack of financial resources by Idara ya Maji.
- ☐ Wear at the pump caused by sediment.
- ☐ Wear at the pump and the diesel motor caused by misalignment.

Table 9.1. Working scheme for the Ulaya Dam pump.

Direction	Starting	Stopping	Total volume
Nkinga village	1:00 p m	6:00 p m	26 cubic meters
Ulaya and Ndembezi	8:00 p m	12:00 p m	30 cubic meters

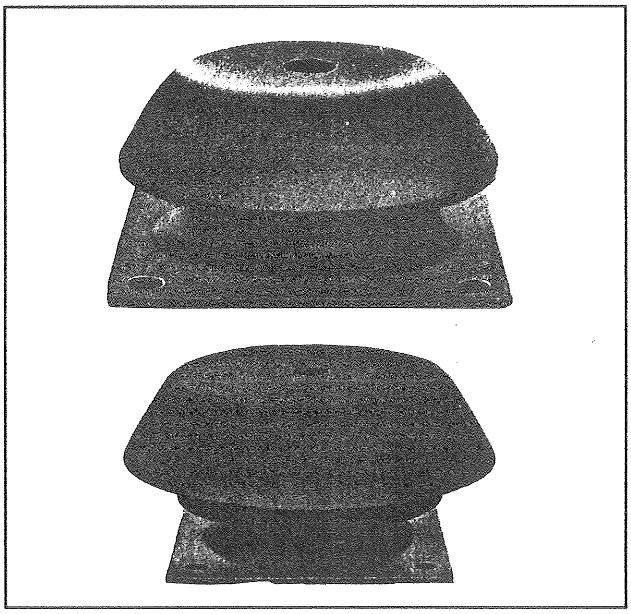


Figure 9.5. Vibration-absorbing feet for pump and motor.

The problems at Idara ya Maji are that they sometimes cannot pay the fuel bills, that the spare pump is used somewhere else or sold, and that the necessary repairs and service cannot be made.

The wear of the pump caused by sediment in the water, causes expensive stuffing packing continuously needing changing. The wear of the packing results in the pump drawing air, which gives very uneven flow, varying from none to normal. The packing is also hard to find in Tanzania. The wear at the pump caused by sediment can be eliminated through the acts described in chapter 5.6.4.

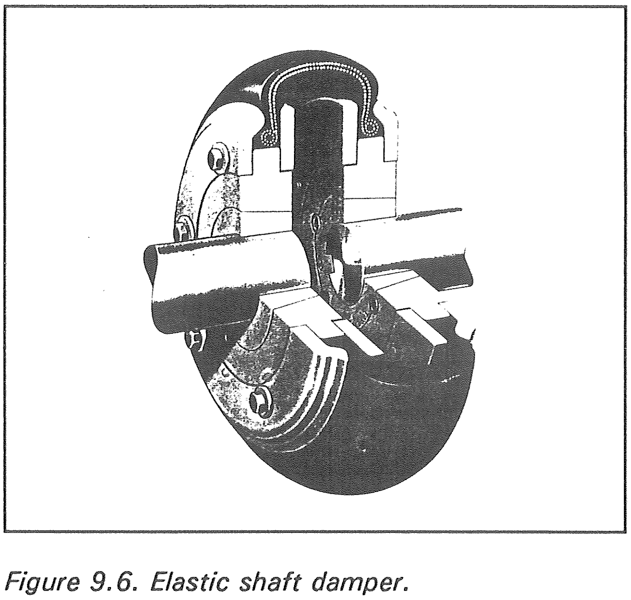


Figure 9.6. Elastic shaft damper.

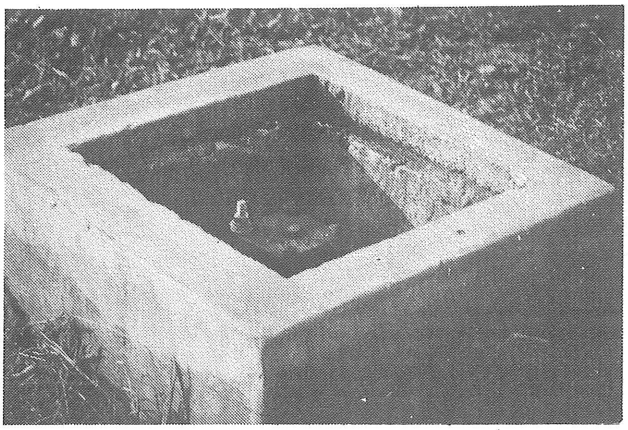


Figure 9.7. Air valve at 1130 meter from pump house.

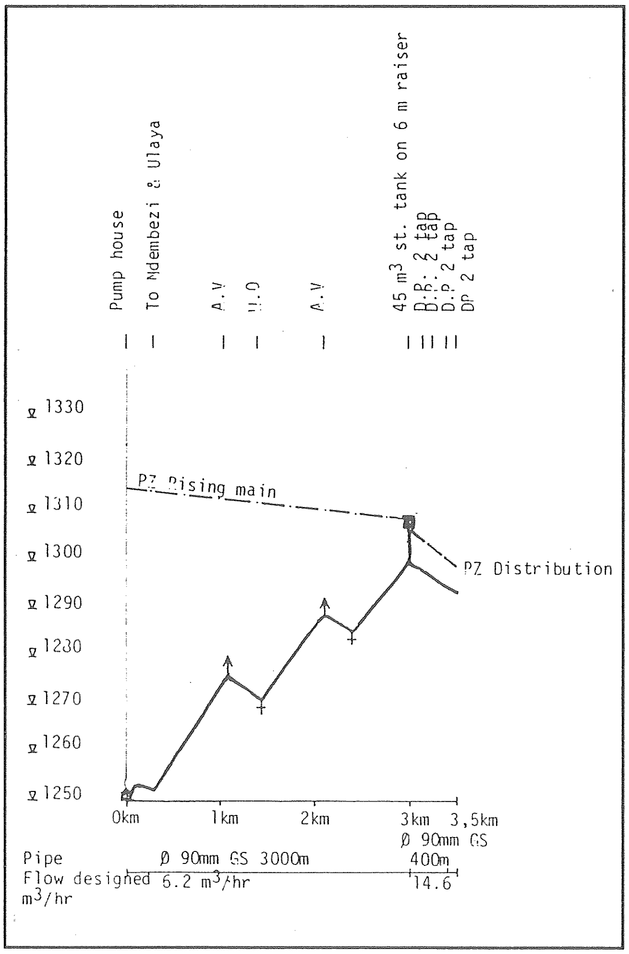


Figure 9.8. Longitudinal section of the pipe to the Nkinga Village Water Tower.

That will decrease the risk for air draw and gives a constantly high flow in the rising main.

The flow into the water towers is often very uneven, depending on the pump problems described above, with peaks of about 9000 litres per hour.

It is difficult to get the motor into a position that is exactly lined with the pump. With a parallel misalignment or a conical misalignment, the bearings in both the pump and the motor can be serious damaged.

The misalignment can be corrected by a steel framework. On this framework, the pump and the motor is installed. With adjustable screws, they can be installed exactly.

The framework is placed on eight to ten vibration-absorbing feet directly on the concrete floor. This will also decrease the noise in the pump area (figure 9.5).

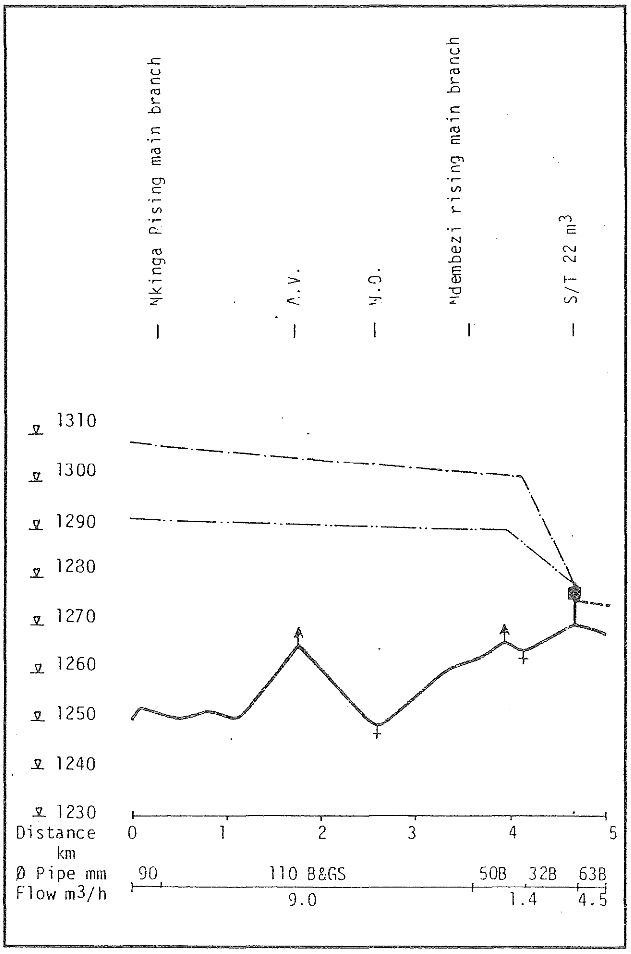


Figure 9.9. Longitudinal section of the pipe to the Ulaya Water Tower.

The shaft coupling between motor and pump should be utilized with an elastic shaft damper (figure 9.6). In the same way, the pipes should be connected to the pump via dampers.

The cost for the feet is about 200 SEK each, and for the dampers it is about 1500 SEK each (in Sweden).

9.4 Distribution from the Ulaya Dam

9.4.1 Rising main

The water is pumped from the pump house at the Ulaya Dam to the Nkinga Village Water Tower, the Ulaya Water Tower and the Ndembezi Water Tower (figure 4.2).

The rising main starts with a 90 millimetres galvanized steel pipe with pressure class M. After 300 meters, there is a valve where the direction, either south to Nkinga or north to Ulaya and Ndembezi is chosen. The pipe that continuous to Nkinga is of the same type. At 1130 meters and 2150 meters from the pump house, air valves have been installed (figure 9.7).

The Nkinga Village Water Tower is situated 3 000 meters down the pipe, and there is also a non return valve (figure 9.8).

As mentioned, the pipe to Ulaya and Ndembezi starts at the valve 300 meters from the pump house. It is a 110 millimetres PVC pipe (pressure class B) with an air valve at 1500 meters from the ramification. After 2240 meters of this pipe and 1078 meter of 110 millimetres galvanized steel pipe (pressure class B), there is a new ramification. The direction west to Ulaya or north to Ndembezi can be chosen with a valve.

The Ulaya pipe is at first a 540-meter polyester pipe with 50 millimetres diameter and then a 540-meter pipe of the same type, but with 32 millimetres diameter, leads the water up to the Ulaya Water Tower. Both pipes are in pressure class B (figure 9.9).

The Ndembezi pipe continues from the ramification outside Ulaya with a 5378 meters long 90 millimetres PVC pipe, connected to a 500 meters polyester pipe, with a diameter of 63 millimetres (both in pressure class B),

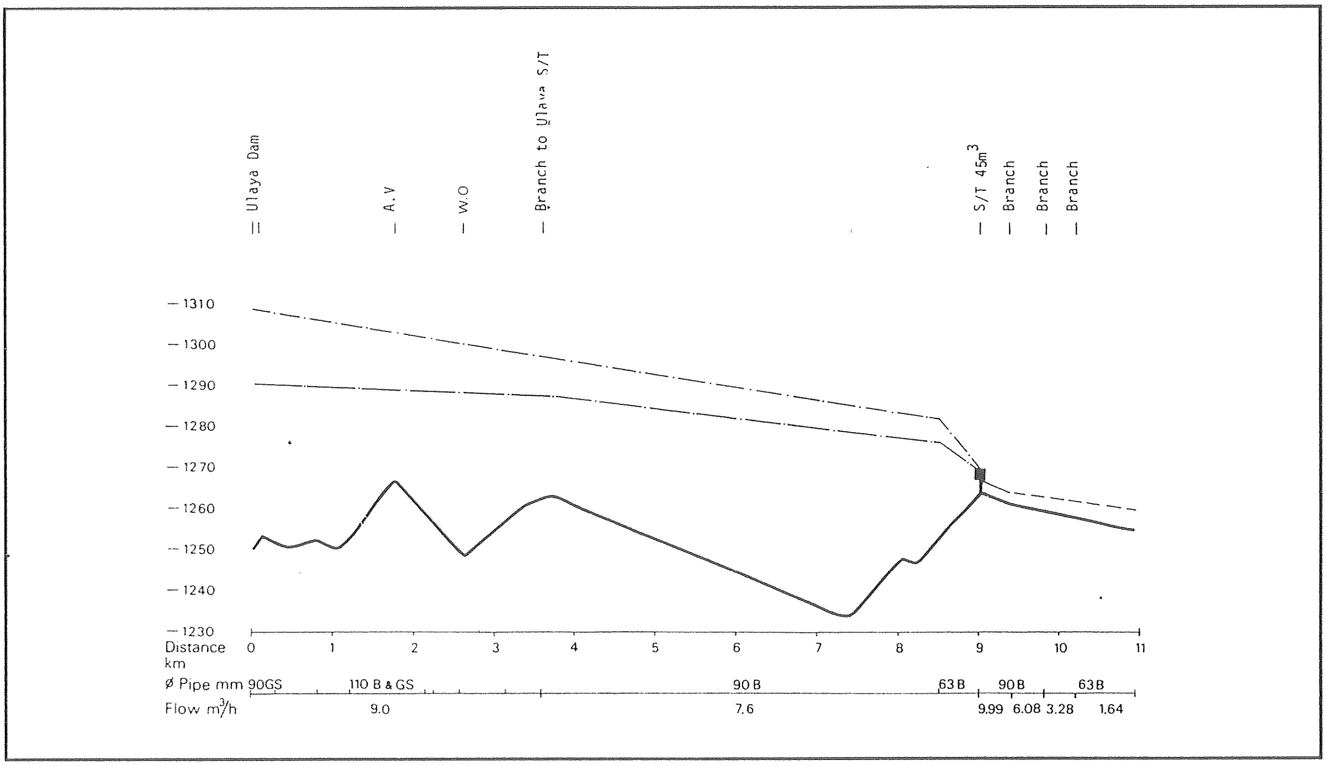


Figure 9.10. Longitudinal section of the pipe to the Ndembezi Water Tower.

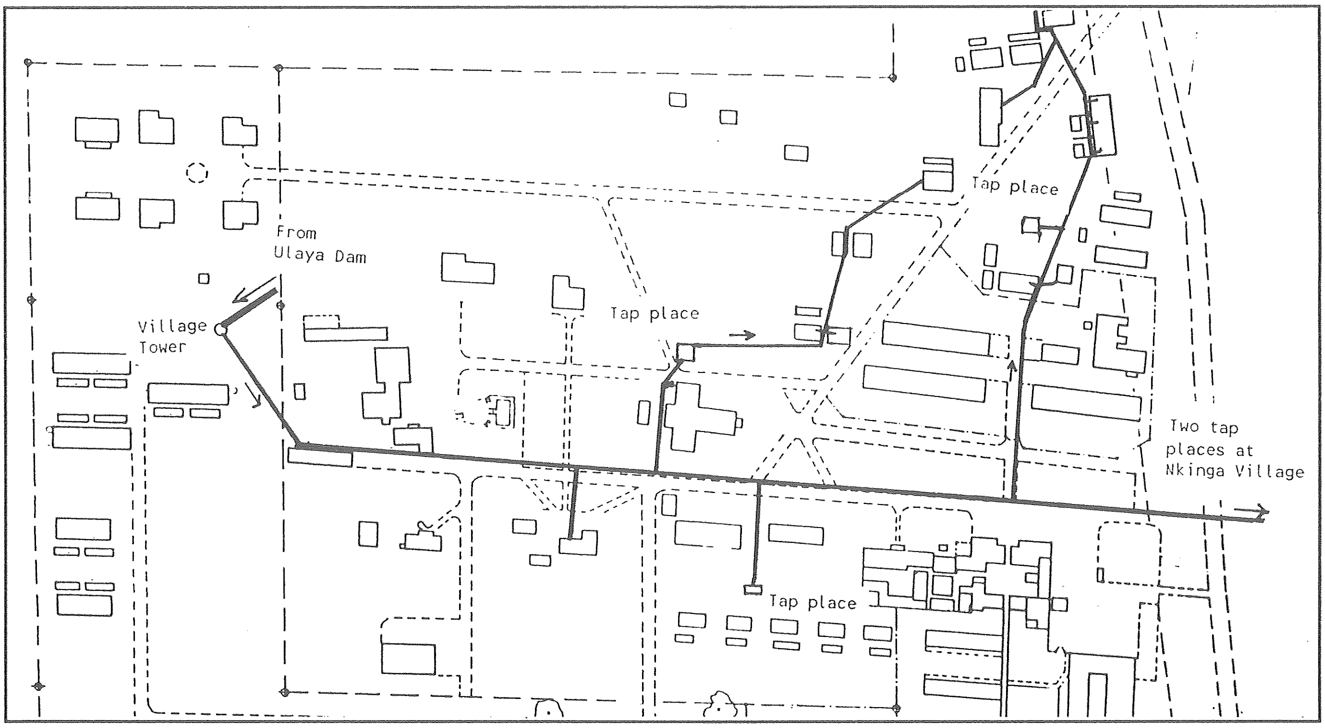


Figure 9.11. Site plan of distribution system at Nkinga village.

Figure 9.12. Tap outside Nkinga Pentecostal Church.

which leads up to the Ndembezi Water Tower (figure 9.10).

The rising main works irreproachably.

9.4.2 Nkinga village

The village of Nkinga gets its water from the Ulaya Dam via the Nkinga Village Water Tower. The water is distributed to eleven staff houses and five tap places (figure 9.11 and 9.12).

The tower was built in 1968 by Idara ya Maji, the District Water Engineer (figure 9.1). Its official volume is 45.0 cubic meters, and the full supply level is at a height of 1320.5 meters. The inner diameter is 4.23 meters and the full supply height 3.20 meters.

However, 0.23 meters up from the bottom water cannot be emptied, and the tower cannot be filled up to more than 1.12 meters from the top. That means that the efficient volume is just 26.0 cubic meters, and the full supply level at a height of 1319.4 meters.

The tank rests on a column basement, 6.0 meters high.

9.4.3 Ulaya village

The Ulaya Water Tower is situated west of the road at the village of Ulaya. It serves the village with water from the Ulaya Dam, and it was built in 1974 by Idara ya Maji. The tank is placed on a 4.5 meters high raiser. The volume is 22.0 cubic meters, and the full supply level at about 1278 meters above sea level (figure 9.13).

Figure 9.13. The Ulaya Water Tower.

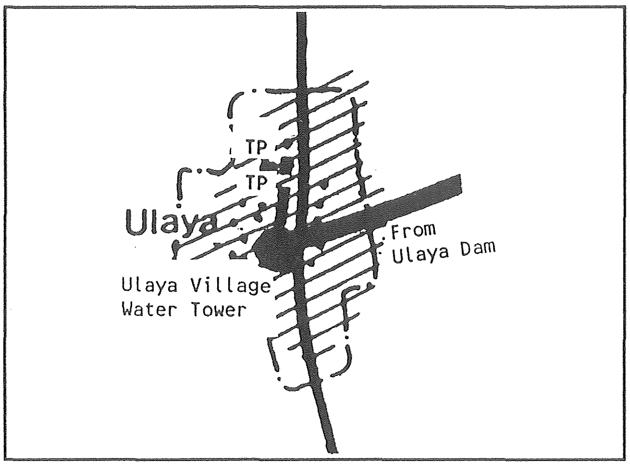


Figure 9.14. Site plan of distribution system at Ulaya.

The water from the Ulaya Water Tower is distributed to two tap places in the village (figure 9.14).

Figure 9.15. The Ndembezi Water Tower.

9.4.4 Ndembezi village

The Ndembezi Water Tower is situated in the southern part of Ndembezi, east of the road between Simbo and Ziba. The water comes from the Ulaya Dam and the tower was built in 1974 by Idara ya Maji. On a 3.0 meters high raiser, a 42.0 cubic meters large tank is situated. Full supply level is at about 1270 meters (figure 9.15).

The water is distributed from the tower to six tap places (figure 9.16).

9.4.5 Improvements

The water runs from the Nkinga Village Water Tower to five tap places. When filling the water tower, the outleading pipe valve (number 21) should be closed, at eight o'clock in the morning, the man in charge, employed by Idara ya Maji, should open this valve.

There are two problems. At first, the man in charge has at some times forgotten to close the valve. This means that in the morning when the women in the village are waiting for the water to be turned on, there is no water left in the tower. Second, the man in charge often does not opens the valve until nine or ten o'clock. The women

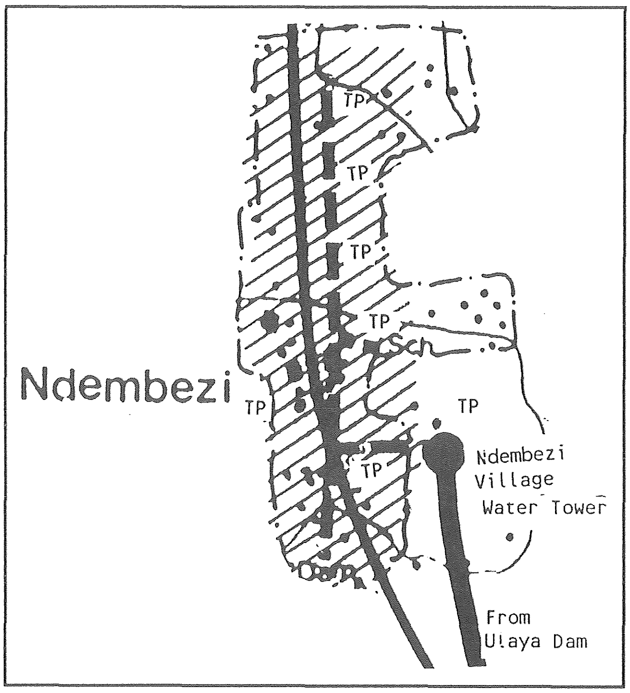


Figure 9.16. Site plan of distribution system at Ndembezi.

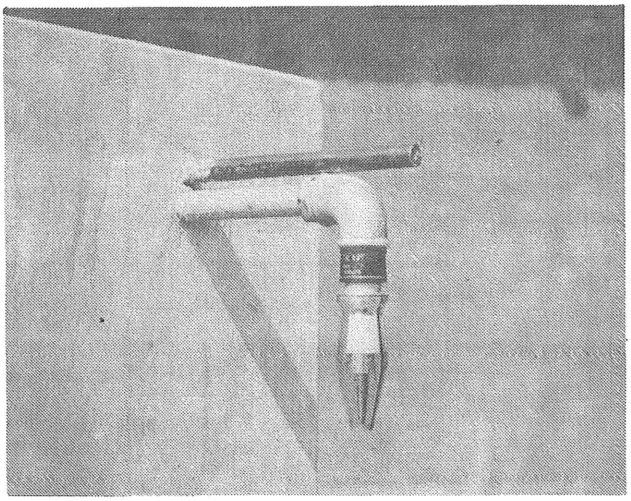


Figure 9.17. Self-closing tap.

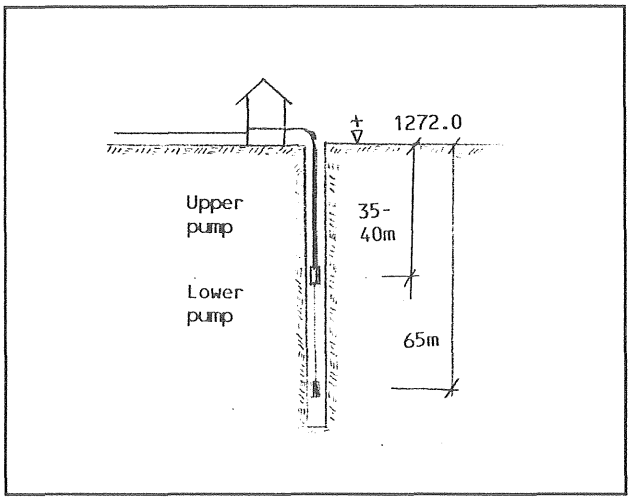


Figure 9.18. Principal function in the Borehole 1/79.

who work at the hospital therefore cannot collect water at the taps.

There has been some unofficial connections to the distribution systems by people in the village. These new taps, drawn into the houses, lie rather low. This results sometimes in a very low pressure upwards at the public taps and a very low volume of water. The new unofficial connections in the village must be closed, otherwise the pressure upwards will be too low to produce water at the public taps.

The taps are often left open after collecting water. Therefore all taps should be replaced by self-closing taps as the one showed in figure 9.17. The handle has to be pulled up with one hand to open the tap, and when the handle is released, the tap closes. With a steel bar just above the tap, it is impossible to remove the tap by turning it around. It is also a good bar for hanging buckets and prevents stress of the tap.

The Nkinga Village Water Tower can be repaired and rebuilt so that the efficient volume of 26.0 cubic meters (according to chapter 4.8.6), can be enlarged to 42.7 cubic meters.

At Ulaya and Ndembezi villages, the taps are often left open, and they empty the water towers. They should be replaced by self-closing taps. With such taps, the water supply is usually sufficient.

9.5 The pumps in Borehole 1/79

9.5.1 Description

Two pumps are installed in the borehole to pump the water from Borehole 1/79 to Nkinga. The upper pump is placed at a depth of 35—40 meters, the lower one at about 65 meters (figure 9.18 and 6.1). They are both of the same type, Grundfos SP 8-25. The pump consists of a submersible electric motor, directly connected to a multistage centrifugal pump (figure 9.19).

The pumps are powered by two 9.4 ampere diesel generators. These generators are placed in a house just near the borehole.

The lower pump was earlier connected by a cable to Nkinga Hospital. This cable was damaged by white ants, and the pump is, until a new cable is installed, supplied by a temporary generator. The fuel is paid by Nkinga Hospital.

The upper pump gets its electricity from a diesel generator, for which Idara ya Maji officially is supposed to pay the fuel.
The flow is today about 3000 litres per hour for the lower pump, and 4500 litres for the upper one. On one day, about 30 cubic meters of water is taken from the borehole. Both pumps were bought and are owned by Nkinga Hospital.

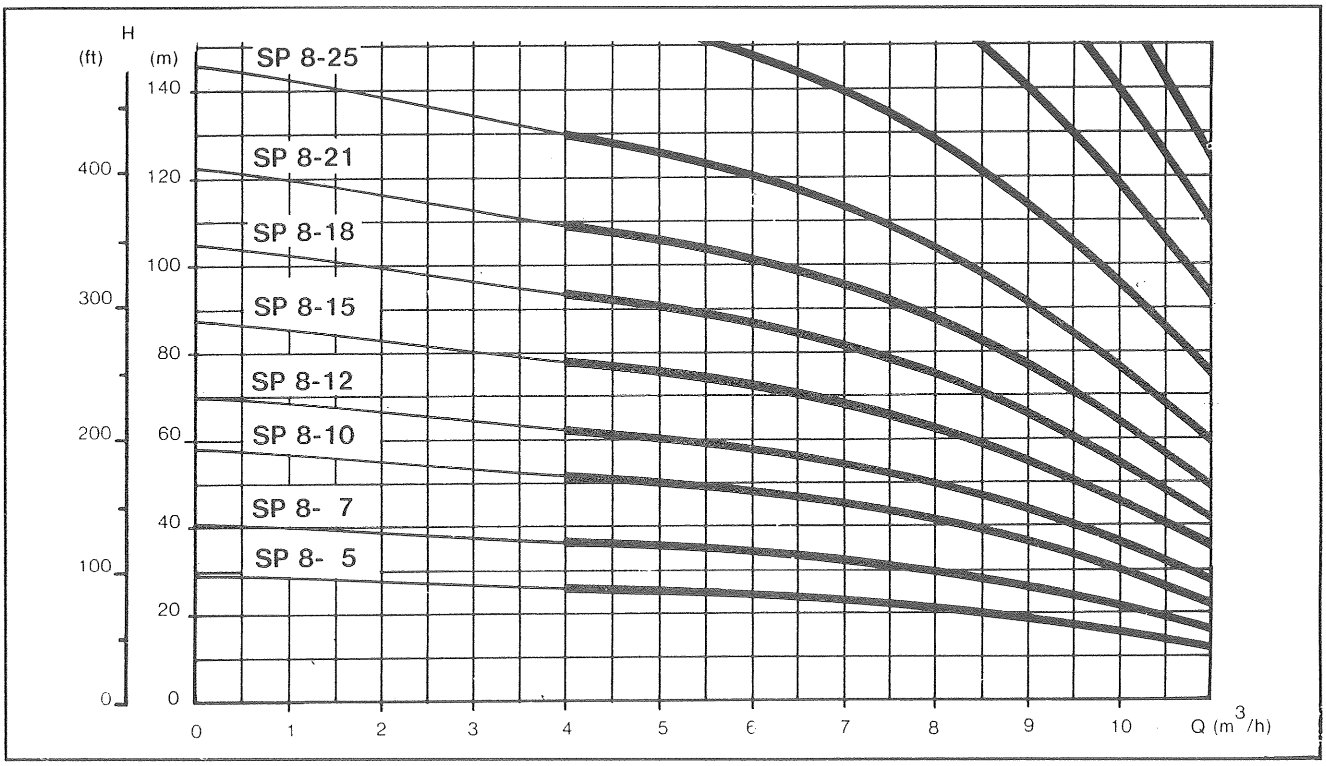


Figure 9.19. Capacity for the pump Grundfos SP 8-25.

9.5.2 Improvements

The official working schedule for the pumps is given in table 9.2. Today, when the two pumps are run by diesel generators in the pump house, both pumps are started and stopped at the same time for practical reasons. This causes disruptions to the official time schedule.

Instead of the two diesel generators, a new electric wire should be installed. It will serve both pumps with enough power to run them simultaneously. If the wire includes a control cable, it is possible to direct the electric power to each one of the pumps or to both.

When making the grave for the wires, it is important to dig deep enough so that white ants cannot reach the cable insulation.

The turning on and off on the electricity can be automatic by level indicators in the water towers, or manual.

Table 9.2. Working scheme for the borehole pumps.

Pump	Day	Starting	Stopping	Total volume
Lower	Monday - Saturday	7:00 a m	10:00 a m	9 000 litres
		4:00 p m	7:00 p m	9 000 litres
	Sunday	7:30 a m	10:00 a m	7 500 litres
Upper	Monday - Saturday	7:30 a m	10:10 a m	5 300 litres
		4:15 a m	7:00 a m	5 500 litres
	Sunday	7:00 a m	10:00 a m	6 000 litres
		4:00 p m	7:00 p m	6 000 litres

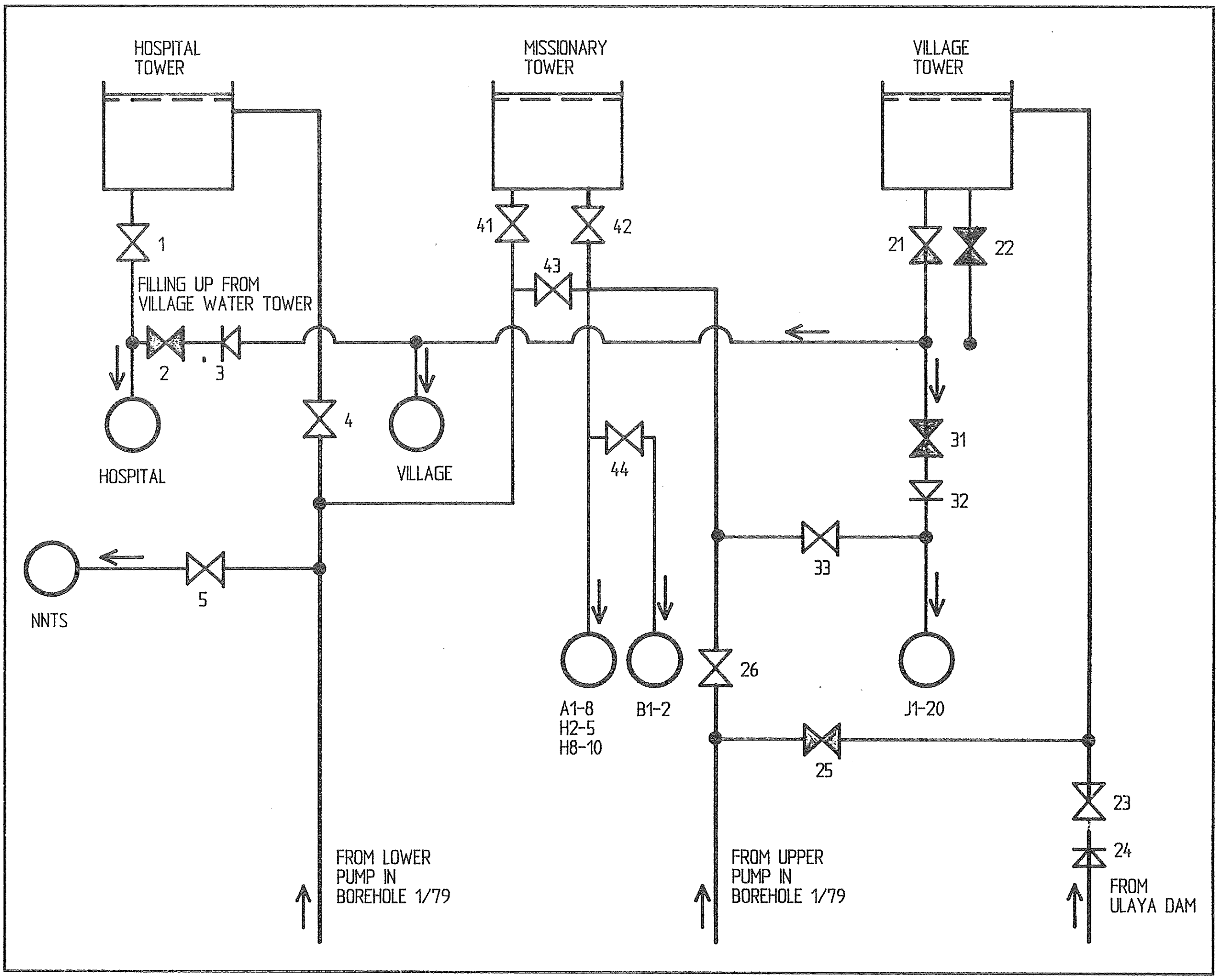


Figure 9.20. The combined system between water towers and users at Nkinga.

9.6 Distribution from the Borehole 1/79

9.6.1 Rising main

There are two separate pipes from Borehole 1/79. One from the lower pump and one from the upper. They are made of PVC plastic and they have a diameter of 50 millimetres and a length of about 2200 meters each. The pressure class is B (figure 4.2).

The pipe from the lower pump is situated on the eastern side of the road between Simbo and Ziba, along the diagonal road west of Nkinga Nurses and Midwives Training School, and leads up to the Nkinga Hospital Water Tower.

The pipe from the upper pump is situated on the other side of the road, the western side, and it is connected to the Nkinga Missionary Water Tower. There are no non-return valves in this pipe.

9.6.2 Distribution at Nkinga Hospital

The distribution system at Nkinga Hospital is complex, the complexity caused by many extensions and changes that have been made during the years. The users can be divided into five groups; the hospital, the nursery school, the missionary houses, the staff houses and Nkinga village.

The distribution system in the village is described in chapter 9.4.2. The remaining four user groups get their water from the two water towers in the hospital area, the Nkinga Hospital Water Tower and the Nkinga Missionary Water Tower. The system, and the connection to the Nkinga Village Water Tower, is described in figures 9.20 to 9.22, and in table 9.3.

The Nkinga Hospital Water Tower

The water comes to the Nkinga Hospital Water Tower from the lower pump in the borehole and supports the hospital. The tower was built by Sten Munther (He is today at the Swedish School in Nzega, Tanzania) in 1982. The tank is placed upon a column basement of reinforced concrete (figure 9.23).

The volume is 10.6 cubic meters, with walls of 20 centimetres thickness including a reinforced plaster of five centimetre. The inner dimensions are 2.20 × 2.20 meters and the height 2.80 meters, but with 2.40 meters up to an overflow pipe. The full supply level is at 1316.3 meters.

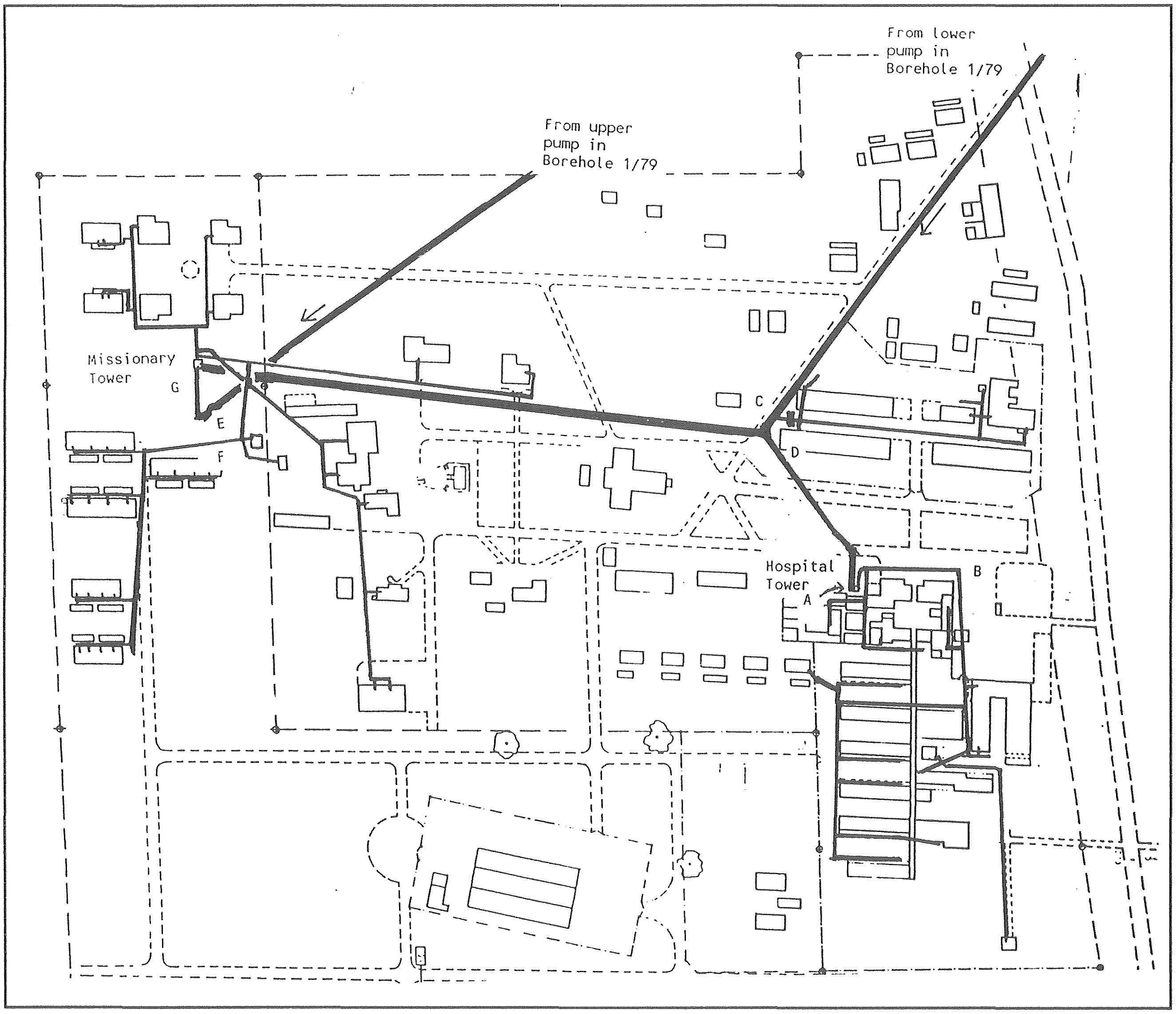
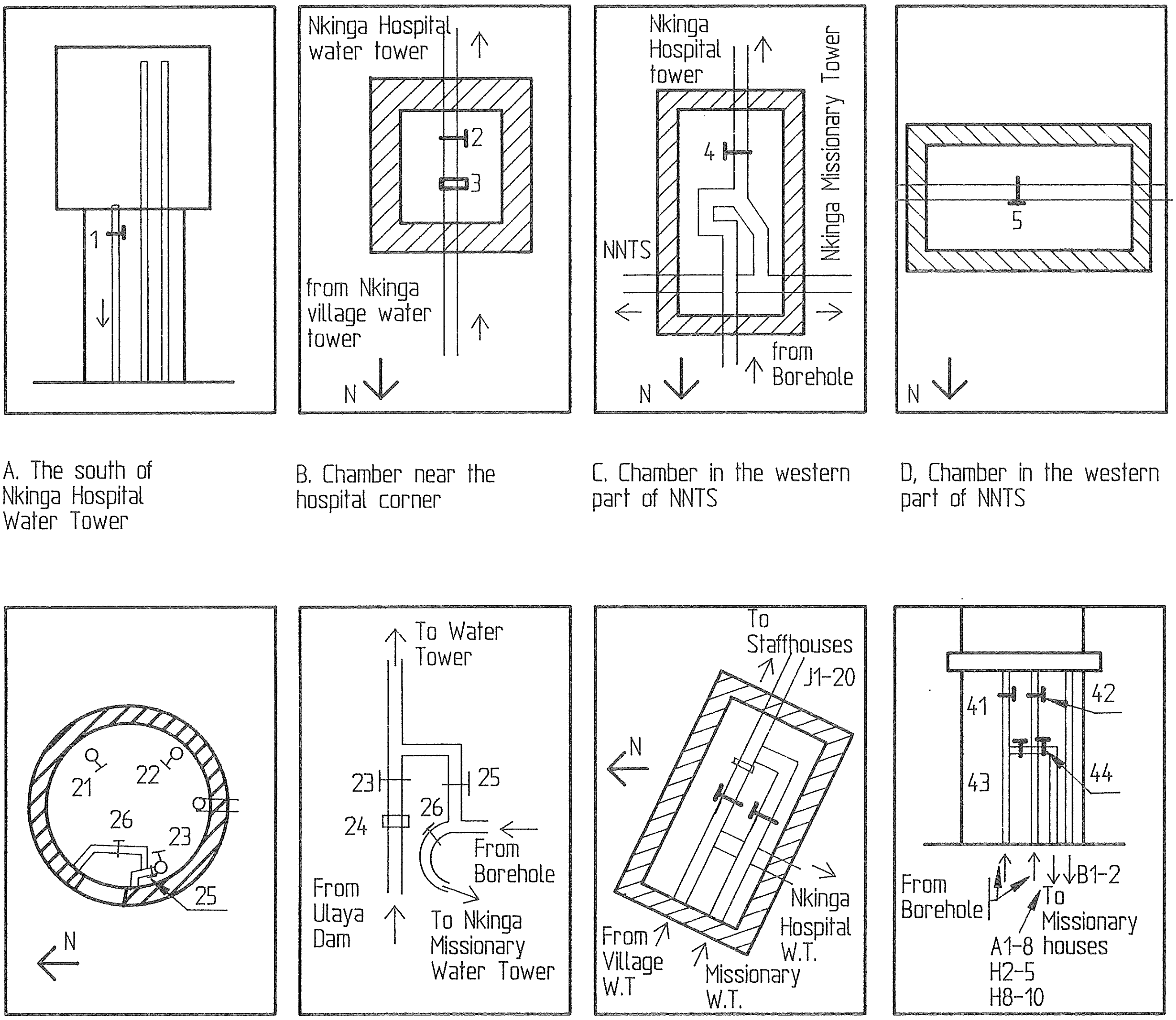


Figure 9.21. Site plan of distribution system at Nkinga Hospital.



A. The south of Nkinga Hospital Water Tower

B. Chamber near the hospital corner

C. Chamber in the western part of NNTS

D, Chamber in the western part of NNTS

E. Inside Nkinga Village Water Tower from above

F. Inside Nkinga Village Water Tower

G. Chamber just north of Nkinga Village Water Tower

H. The north side of Nkinga Missionary Water Tower

Figure 9.22. Location of valves at Nkinga Hospital.

The Nkinga Missionary Water Tower

To serve the missionary and staff houses at Nkinga Hospital, water from the borehole's upper pump is pumped up to the Nkinga Missionary Water Tower (figure 9.24).

The tower is divided into two parts. Each half is also divided, but communicates at the bottom. It was built in 1975/76, and it has a volume of 15.9 cubic meters. The full supply level is at 1317.5 meters, 1.2 meters higher than the hospital tower.

9.6.3 Improvements

The pipe from the lower pump is connected with Nkinga Nurses and Midwives Training School (NNTS) and a

Table 9.3. Valves in distribution system at Nkinga.

No	Location	Normal position	Position when pumps out of order
1	A	Open	Closed
2	B	Closed	Open
3	B	Non return valve	
4	C	Open	Closed
5	D	Open	Open
21	E	Changed according to 5.8.4	
22	E	Closed	Closed
23	E	Open	Open
24	E	Non return valve	
25	E	Closed	Closed
26	E	Open	Closed
31	F	Closed	Open
32	F	Non return valve	
33	F	Open	Open
41	G	Open	Closed
42	G	Open	Closed
43	G	Open	Open
44	G	Open	Open

transverse pipe to the Nkinga Village Water Tower. There is no non-return valve before the hospital.

If something went broken in the distribution system in for instance the NNTS buildings, the system including one of the water towers, would empty its water into the NNTS buildings. Furthermore, until the pump is turned off it would continue to pump water into the buildings.

The pipe from the upper pump goes to the Nkinga Missionary Water Tower. On the way to the tower there is a connection to the staff houses, number J1—J20 (figure 7.2). The pipe is connected at the bottom of the reservoir and there is no non-return valve. Therefore, a break at the staff houses or downstream would empty the whole system.

The pipe from the lower pump has to be directly connected to the Nkinga Hospital Water Tower. It means that from this tower, a new pipe has to be connected for the supply to Nkinga Nurses and Midwives Training School (NNTS). Another pipe has to be connected from the missionary tower to the valve location C (figure 9.22), for the staff houses. Just before entering the water tower a non-return valve should be installed in both cases.

A new pipe between the missionary and the Nkinga Hospital Water Tower has to be connected from the valve location at NNTS to the hospital tower. The pipes can be a of PVC-type with a diameter of at least 50 millimetres.

Even if it is hard to survey, the distribution system at the hospital area works well, yet the Nkinga Missionary Water Tower should be repaired. It leaks about 50 to 100 litres per hour, at full supply level. The inside of the reservoir is covered with green algae, the water, however, is clear.

The Nkinga Missionary Water Tower can be repaired from the inside according to the methods described in chapter 7.5.4. A wooden cover is today covering the top, but is partly rotten and broken. The covering is therefore not tight for insects, birds and falling parts from the trees (figure 9.25). After the reparation a tight cover should be manufactured and mounted. It can be made of a steel frame and boards. For inspections, it should have a manhole, 50 × 50 centimetres, and a water level indicator.

Figure 9.23. The Nkinga Hospital Water Tower.

Water is transported from the higher situated missionary tower to the hospital tower, as long as the missionary tower has a water level of 1.40 meters, or more. When the hospital tower is full, the surplus water goes to the rainwater reservoirs at the hospital yard (RF 21—25).

The basement of the Nkinga Hospital Water Tower can, according to the builder, bear a load of at least twice the load today.

9.7 Future developments

9.7.1 New laundry at Nkinga Hospital

A new laundry is needed at Nkinga Hospital. The area between the hospital and the new workshop is reserved for this purpose. A new distribution is then needed with new water towers. They should be placed at heights and they should have a volume of at least twice the daily consumption at the laundry.

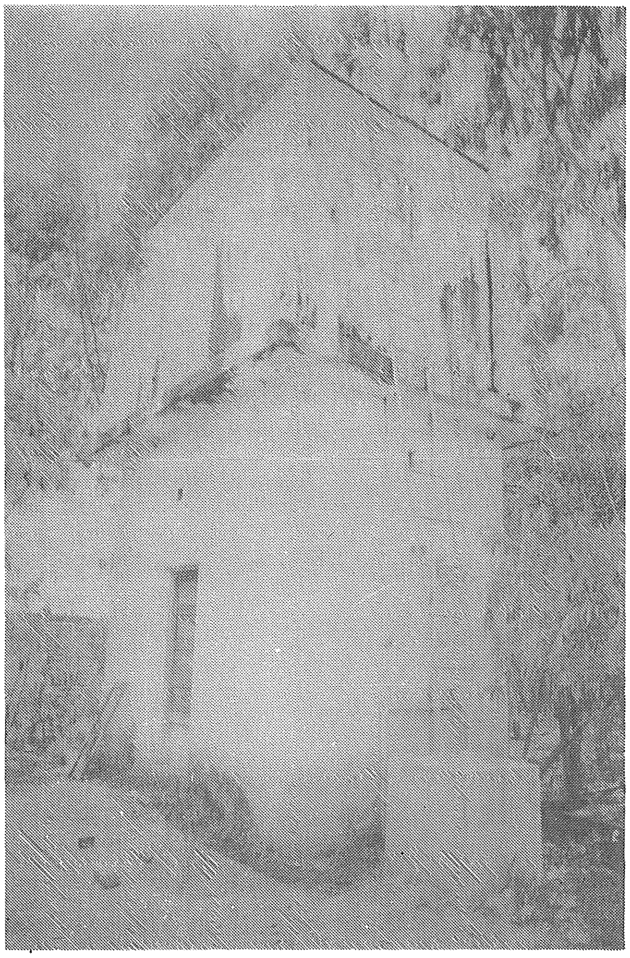


Figure 9.24. The Nkinga Missionary Water Tower.

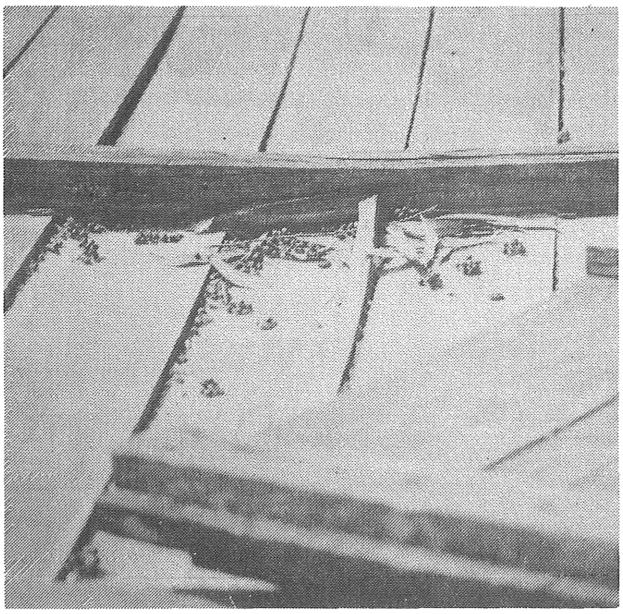


Figure 9.25. Cover to the Nkinga Missionary Water Tower.

9.7.2 Distribution from the Ulaya Dam

A new pump, motor and a larger rising main has to be installed to increase the extraction from the Ulaya Dam to 500 cubic meters.

9.7.3 Distribution from the Borehole 1/79

The flow from the two pumps in the borehole can be increased. With a pump-time of 16 hours, instead of 6 hours today, the daily flow will increase from 30 to 70 cubic meters. No changes need to be made in the distribution system.

Appendix A

Borehole descriptions

1992

Johan Anderson
Ronny Wahlström

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A.1 Survey

In the area of Nkinga Hospital and the three villages, four boreholes have been drilled. They are called number 181/78, 1/79, 48/79 and 4/76. Only Borehole 1/79 is used today.

A.2 The Borehole 181/78

An investigation of the depth of overburden was made. To locate the drilling of this borehole, a seismic profile was carried out. This is described in appendix B.

The profile shows that the bedrock lies very deep. In the deepest parts, it lies about 70 meters under ground. The borehole is situated in the upper part of the slope, where the overburden is 41—50 meter deep covering a possible weakness zone.

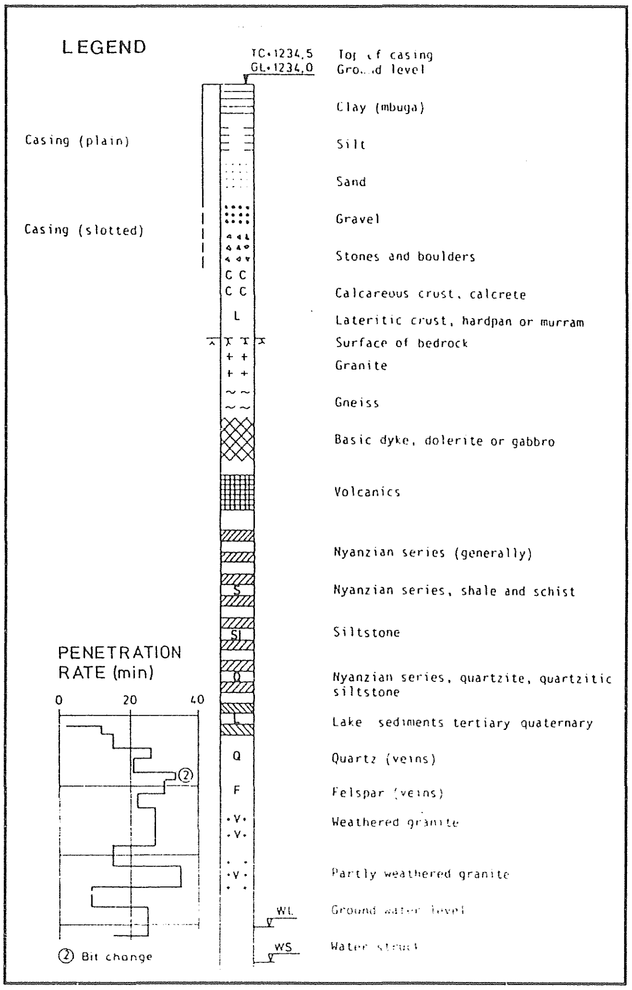

Figure A.1. Legend for borehole profiles.

A.2.1 The borehole profile

The borehole profile is illustrated in figure A.1 and A.2.

A.2.2 Description of the profile

Lower level: (m)	(m)	Thick-ness: (m)	Descripion:
1244.0			Ground level
1242.7	(-1.3)	1.3	Dark grey silty clay.
1231.1	(-12.9)	11.6	Greyish—brownish gravelly sand of weathered granite.
1219.0	(-25.0)	13.4	Brownish reddish silty sand with pieces of red granite, partly weathered, probably boulders or stones, secondary ferruginous, coatings on fissure surfaces.
1211.4	(-32.6)	19.2	Transition zone between the granitic material above and brownish sandy gravel of weathered red granite and more basic, partly, doleritic material. The latter material is rounded.
1202.2	(-41.8)	9.2	Greyish sandy gravel of granite, possibly a big boulder.
1191.6	(-52.4)	10.6	Sandy rather coarse gravel of bedrock, doleritic rounded material and granite chips.
1171.7	(-72.3)	19.9	As above but the doleritic rounded material is dominating. The dolerite is partly metamorphic.
1162.0	(-82.0)	9.7	As above but the doleritic rounded material is dominating. Some pieces of quartz.

A.2.3 Comments

The borehole caved in 27.7 meters below ground level (+1216.3) when it was drilled during the rainy season. The fact that the roads were too wet to bear the drilling rig, made it impossible for the drillers to return and finish the drilling. No well logging could therefore be performed. But the penetration rate gives some important information, which has been used for the determination of the bedrock surface.

The seismic investigation (chapter B.4.1) indicated a considerable depth to bedrock at the borehole site. According to the sample analysis, the loose sediments below the clayey surface layer consist of sand and gravel until the level +1230 meters (15 meters below ground level).

From +1192 meters the doleritic material is dominating, which is the reason for locating the bedrock surface at that level. The composition and the appearance of material indicates that the drilling was penetrating a fault zone.

Water was struck three times between 38 and 46 meters below ground level, but this water disappeared. Obviously, it drained off when a passage was open downwards.

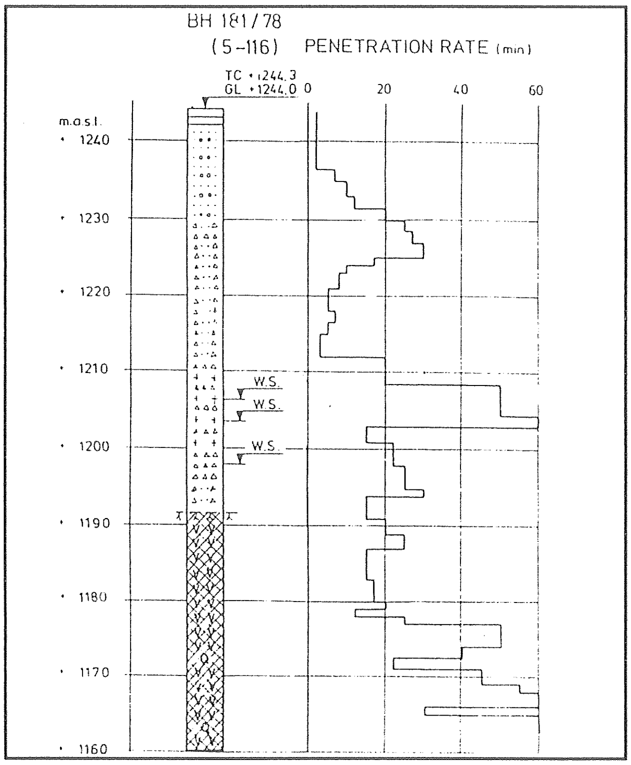

Figure A.2. Profile of the Borehole 181/78.

No static ground water could be measured because of the caving.

A.3 The Borehole 1/79

In order to determine possible weakness zones in the fault line, a magnetic and a seismic investigation was made (chapter B.3.2 and B.4.2). The profiles showed weaknesses, and some of them were connected with the lower parts in the valley.

The location of the borehole was based partly upon the results of the seismic profile (6-209), partly upon the results of the magnetic one (6-320). The last profile exposes an anomaly connected to a low velocity.

A.3.1 The borehole profile

The borehole profile is illustrated in figure A.3.

A.3.2 Description of the profile

Lower level: (m)	(m)	Thickness: (m)	Descripion:
1272.0			Ground level
1269.3	(-2.7)	2.7	Grey clay with some sand layers.
1264.7	(-7.3)	4.0	Gravelly sand or very weathered granite.
1263.2	(-8.8)	1.5	Very weathered granite.
1259.2	(-12.8)	4.0	Partly weathered greyish granite.
1256.1	(-15.9)	3.1	Partly weathered reddish granite.
1254.6	(-17.4)	1.5	Fresh greyish reddish granite.
1251.6	(-20.4)	3.0	Fresh greyish granite high in mica.
1246.5	(-25.5)	5.1	Fresh reddish granite with rusty coatings.
1222.6	(-49.4)	23.9	Fresh greyish reddish granite.

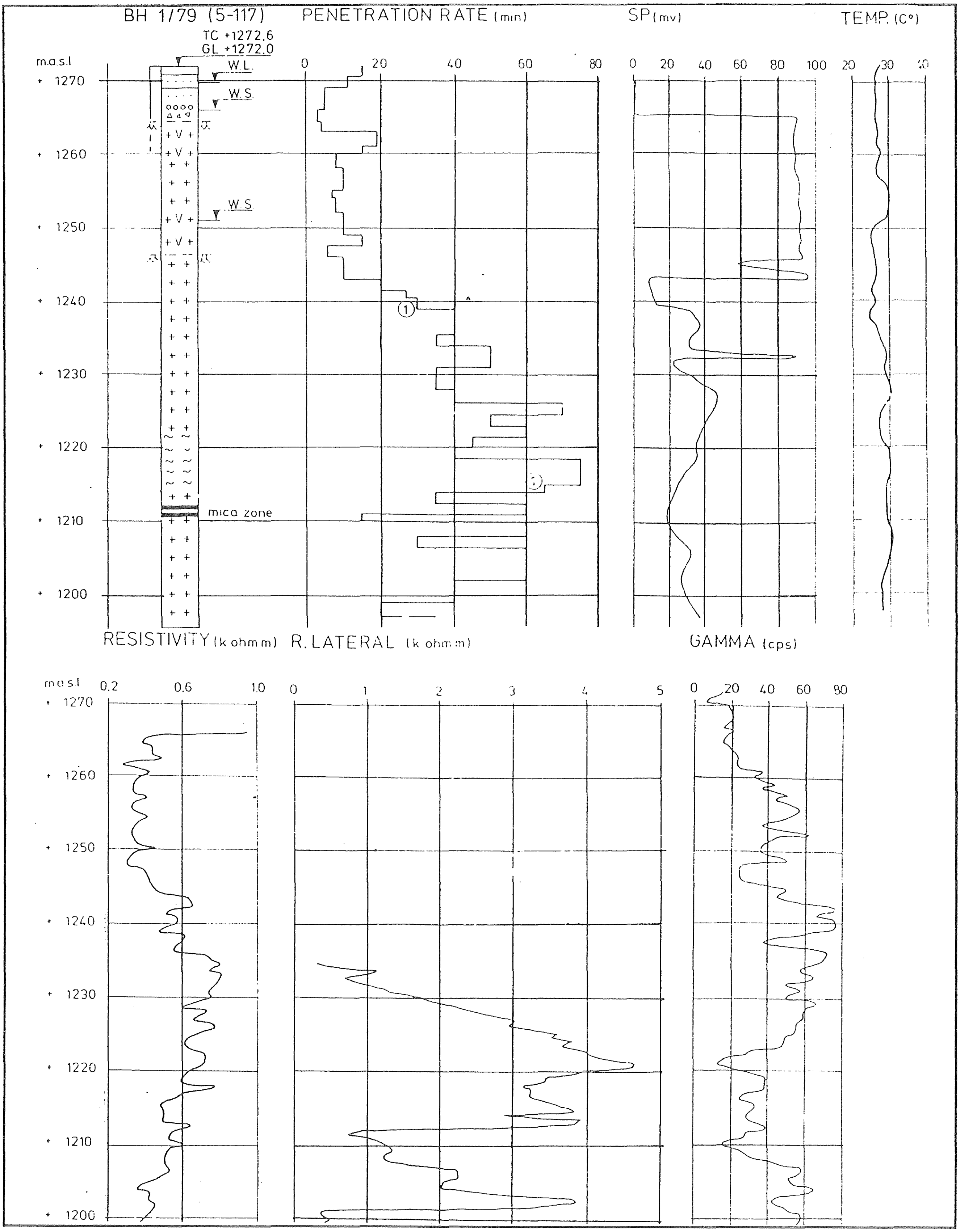

Figure A.3. Profile of the Borehole 1/79.

1215.0	(-57.0)	7.6	Grey gneiss high in mica.
1211.9	(-60.1)	3.1	Fresh greyish granite with rusty coatings.
1210.4	(-61.6)	1.5	Micaceous zone possibly dislocation.
1204.8	(-67.2)	5.6	Fresh greyish granite.
1198.2	(-73.8)	6.6	Fresh reddish granite with some rusty coatings.

A.3.3 Comments

The overburden consists of a great extent of sandy gravelly material. The first possible bedrock surface is about 9 meters below ground level and the other possible location is about 26 meters below ground level. The layer between the two possible bedrock surfaces is granitic, but partly weathered. It coincides rather well with the velocity layer of 1300—1600 meters per second in the seismic profile 6-209 (chapter B.4.2). The thickness of this layer was inexplicable until the drilling and penetration were obtained.

The results of the seismic profile and the resistivity measurements indicate porous water bearing material with high potential and low resistivity down to the lower alternative of the two surfaces.

Below this zone the penetration rate increases considerably with some variations up and down. Even the gamma log varies considerably, where the low cps-value in the gamma log indicates porous material and higher cps-value indicates more dense material.

The water struck was at 5.8 meters and 21.0 meters below the ground level. The water temperature is +26°C down to 16 meters, and then increasing to +30°C at the depth of 21 meters below the ground level. Further down the temperature is about +26—27°C. From the level of 42 meters and downwards, the temperature is around +30°C.

The cooler zones indicate flow of water into the hole.

The depth of the borehole is 73.8 meters and is cased plain to 11.6 meters below ground. The rest is without casing. The static water level was 1.8 meters down from ground when the borehole was drilled.

The yield from the borehole was tested in 13 hours immediately after the drilling by using a so called airlift, and the result was 13 cubic meters per hour.

A.3.4 The well test

The well test was made as an aquifer test (even called constant discharge test) to decide the capacity of the borehole and to estimate the hydraulic parameters storage coefficient (S) and the transmissivity (T). The test was carried out in 24 hours and recovery data were also taken to verify the accuracy of the pumping data (figure 6.2).

Because of the problems with the equipment, the borehole was not tested with higher discharge than 6.8 cubic meter per hour. The transmissivity was calculated to 3.6×10^{-4} square meters per second and the storage coefficient to 5.0×10^{-2}.

A.4 The Borehole 48/79

The borehole is situated just near the Borehole 1/79, described in the previous chapter.

A.4.1 The borehole profile

The borehole profile is illustrated in figure A.4.

A.4.2 Description of profile

Lower level: (m)	(m)	Thickness: (m)	Descripion:
1271.8			Ground level
1270.3	(-1.5)	1.5	Greyish sandy clay.
1268.8	(-3.0)	1.5	Weathered granite probably boulder.
1267.2	(-4.6)	1.6	Greyish sandy silt.
1265.7	(-6.1)	1.5	Gravelly silt or weathered granite boulder.
1260.5	(-11.3)	5.2	Greyish sandy silt.

A.4.3 Comments

This borehole was drilled in order to get information about the well test carried out in the Borehole 1/79.

The depth of the borehole is 11.3 meters and the water struck at 6.1 meter below ground level in the silty sand layer.

The static water level was 3.6 meters down from ground when the borehole was drilled. The Borehole 48/79 was cased plain down to 10.3 meters and cased slotted further down to 11.3 meters.

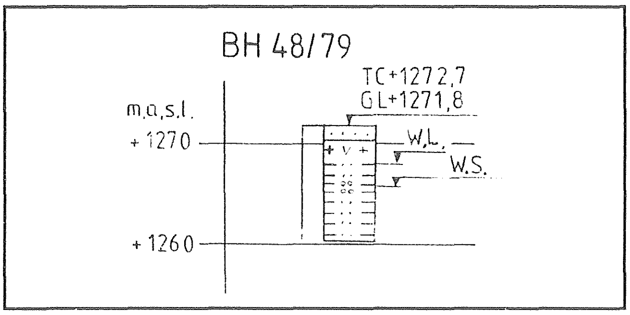

Figure A.4. Profile of the Borehole 48/79.

A.5 The Borehole 4/76

The borehole is situated just outside, north of the Nkinga Hospital area (figure 4.2).

A.5.1 The borehole profile

The borehole profile is illustrated in figure A.5.

A.5.2 Description of the profile

Lower level: (m)	Thick- ness: (m) (m)	Descripion:
1304.7		Ground level
1091.3	(-213.4)	No geological investigations were made.

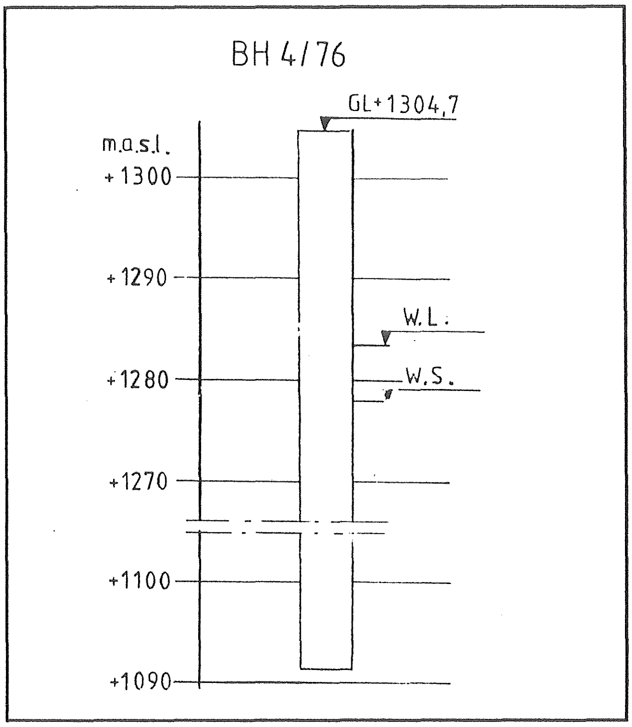

Figure A.5. Profile of the Borehole 4/76.

A.5.3 Comments

The depth of the borehole is 213.4 meters and the water struck at 26.8 meters below ground level. The average yield is 0.2 cubic meters per hour, [6].

The quality of the water was poor with high extent of calcium, and was therefore, because of low yield and high head, only used until 1982.

The top cap is still present, but unfortunately occupied by bees.

Appendix B

Geophysical investigations

1992

Johan Anderson
Ronny Wahlström

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B.1 Survey

The geophysical investigations near Nkinga Hospital and the three villages comprised three surveys:

- ☐ Resistivity survey
- ☐ Magnetic survey
- ☐ Seismic survey

B.2 Resistivity survey

Resistivity survey is one of three different types of geophysical investigations, carried out by the company Brokonsult in 1978, [6]. The other two methods are Magnetic survey and Seismic survey, here described in the following two chapters, B.2.1 and B.2.2 (figure B.1).

In a Resistivity survey, a direct current or a low-frequency alternating current is sent through the ground between two electrodes, the current electrodes. Because of the resistance in earth materials, some voltage loss is measured by potential electrodes, placed on the ground.

The ability of a rock unit to conduct an electrical current depends on three factors:

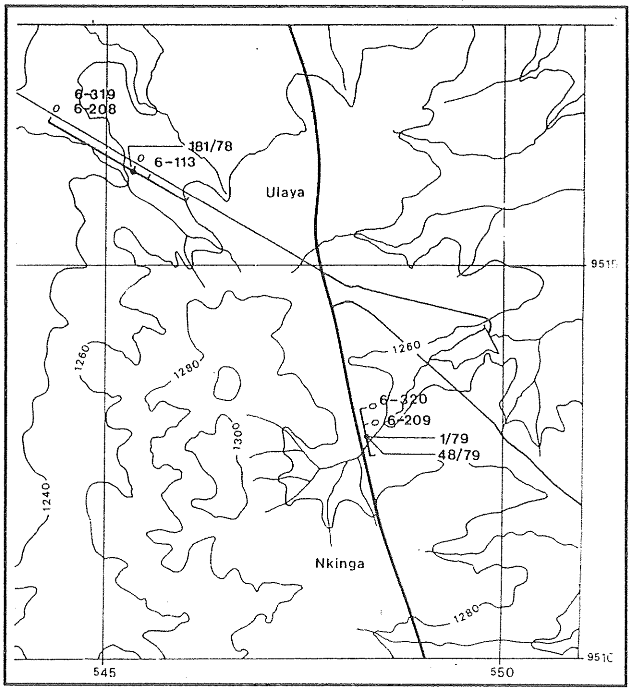

Figure B.1. Location of the geophysical investigations.

- ☐ The amount of open space between particles, the porosity.
- ☐ The degree of interconnection between those open spaces.
- ☐ The volume and conductivity of the water in the pores.

B.2.1 The profile 6-113

The resistivity profile (number 6-113) was carried out west of Ulaya along the dirt track from Ulaya to Nzega. It descends down the slope and ends at the Idudumo Dam, the dam in the Kogongho Basin (see figure 4.2).

The slope is the topographical mark of the fault line running south to north, called the Nzega Fault (see chapter 3.1).

The line has its starting point about three kilometres west of Ulaya village. It has a length of 840 meters and it finishes about two kilometres west of the village.

The distance between the resistivity readings was 100 meters.

On the same line there are also a magnetic (6-319) and seismic profiles (6-208). However, they start further west and the resistivity profile has its starting point at the distance of 1160 meters further east. The distance from the starting point of the magnetic and seismic profiles is here used also for the resistivity profile.

Results

The results are shown in figure B.2. The bedrock seems to climb from 50 meters at distance 1160 meters (starting point) to some 10 meters below ground level at 1600 meters. Further east, the resistivity indicates presence of weathered bedrock (about 340 ohms) to large depths. At a distance of 2000 meters the depth increases to about 100 meters.

The overburden consists of weathered material in the eastern part and of gravelly fairly dry sand. The sand presents resistivities between 22 and 200 ohms depending of the water content. The topsoil of the western lower part of the profile consists of silty clay and is averaging 23 ohms. In the east the topsoil layers are sandy and occasionally lateritic with resistivities varying from 110 to 2900 ohms.

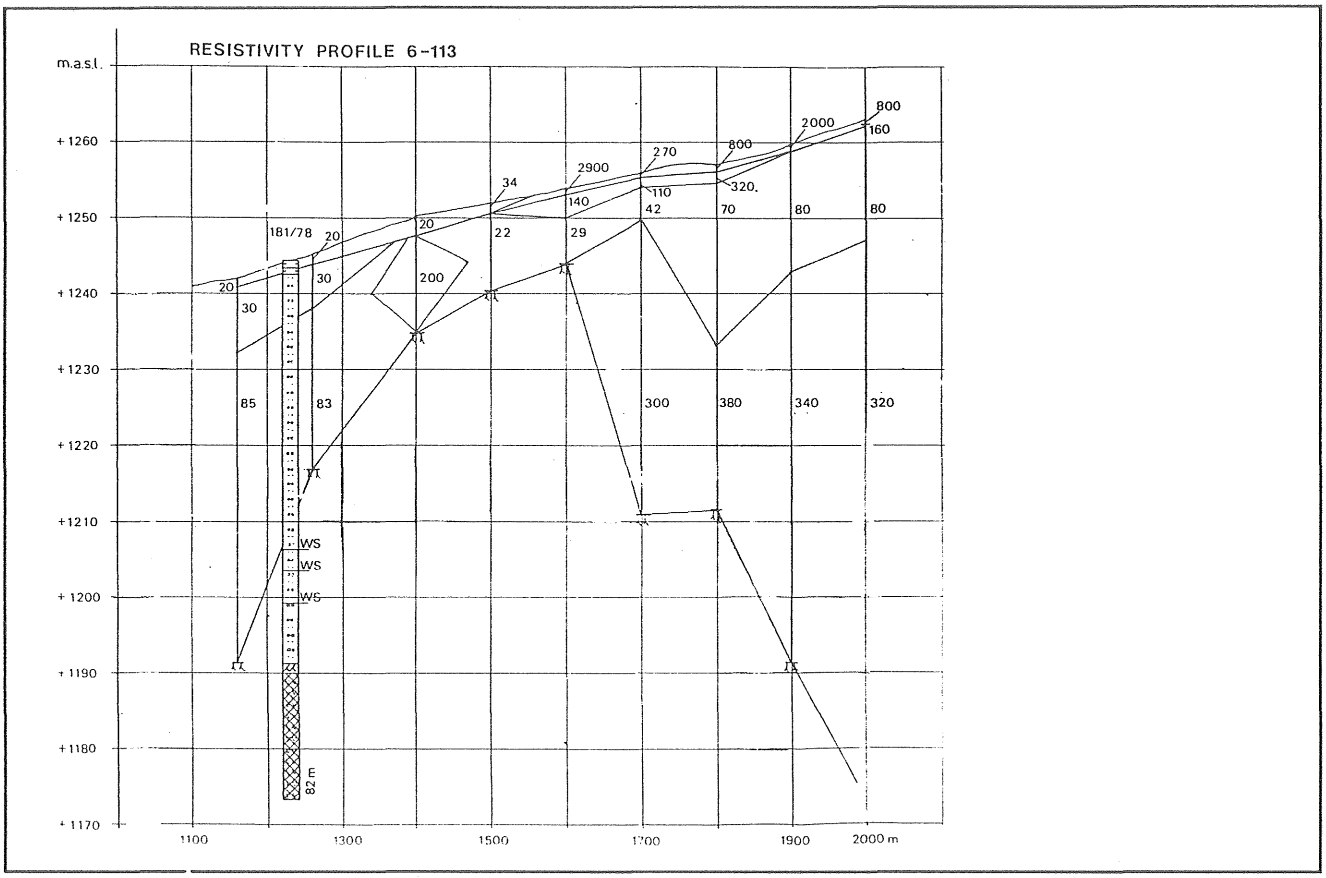

Figure B.2. Results of the profile 6-113.

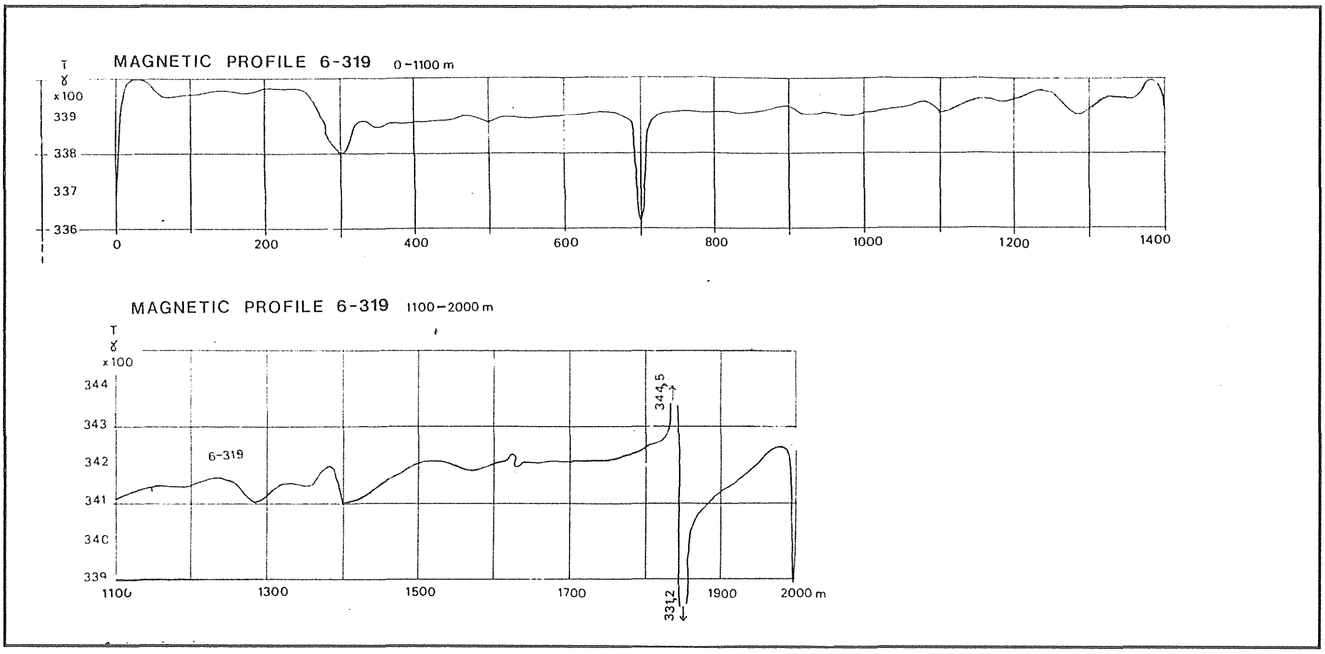

Figure B.3. Results of the profile 6-319.

Conclusions

In general, the resistivities achieved in profile 6-113 are too high to indicate the existence of promising aquifer.

B.3 Magnetic survey

Magnetic anomalies are caused by distortions of the earth's magnetic field created by magnetic materials in the crust. The magnetic anomalies reflect the type of rock in a general way and give an indication of the depth to the basement rocks.

The measurements are made with a portable instrument at regular intervals along traverses. If it is desirable to produce a contour map, the measurements are made in a grid pattern. When only profiles are being measured it is important to orient these perpendicular to the strike of the magnetic structures, if possible.

B.3.1 The profile 6-319

The profile was situated on the same line as the resistivity profile, west of Ulaya along the dirt track between Ulaya and Nzega. The profile starts about four kilometres west of Ulaya village and ends about two kilometres from the village (figure 4.2).

The magnetic readings are made every 20 meters.

Results

The magnetic measurements gave an interesting contribution to the interpretation of the seismic survey, the profile 6-208 (see chapter B.4.1).

At 300 meters, the magnetic measurements decreases rapidly and then increases rapidly again. That can be compared with the seismic profile 6-208. It shows a sudden "hump" of the bedrock surface followed by a low velocity in this zone.

The combined information from the two geophysical methods points towards a transition from one bedrock to another, possibly in connection with a slight fault. From 300 meters and onwards the magnetic valves slowly increase, indicating gradually decreasing depths to bedrock.

At 1840 meters, a very strong and sharp anomaly indicates the presence of a tectonic zone. The direction appears to be parallel to the major fault line. There are also indications of weathered and fissured bedrock in the resistivity measurements (chapter B.2.1), but the fairly high resistivities of this feature is not very promising from the ground water point of view (figure B.3).

B.3.2 The profile 6-320

The profile is situated about one kilometre north of the village Nkinga along the road between Simbo and Ziba. The profile is crossing the valley that possibly corresponds to a secondary fault line striking in west-northwest (chapter 3.1).

The valley is rather flat and dewatered by a creek. Along the creek the soil consists of clay and silty clay, but on both sides of the valley, silt and sandy silt dominates.

Some granitic boulders are found on the ground in the higher parts. In the east, some outcrops of granite are found. The length of the profile is 700 meters.

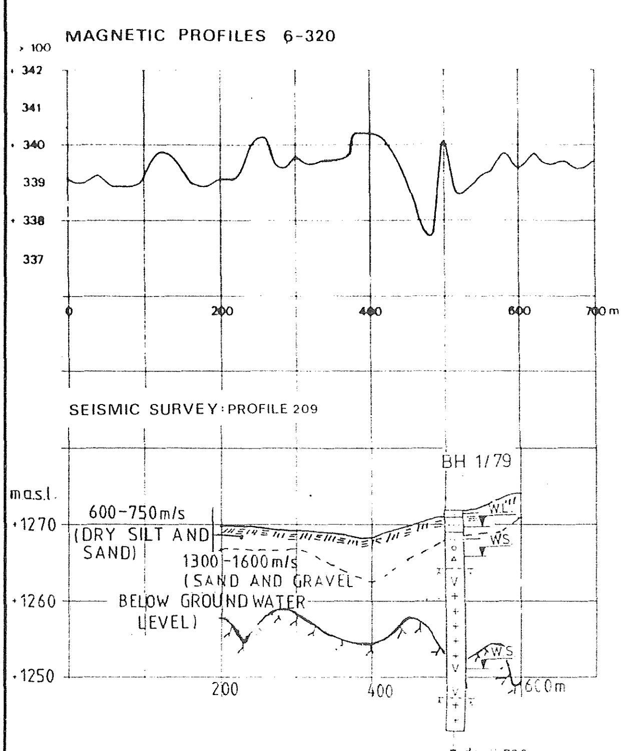

Figure B.4. Results of the profile 6-320 and 6-209.

Results

A weak anomaly was achieved at 400—550 meters. It ranges from 34 040 to about 33 760 gammas. Compared with the seismic profile, a weakness zone of 2200 meters per second was obtained (figure B.4).

B.4 Seismic survey

Seismic surveys can be divided into reflection and refraction seismic surveys. Brokonsult used the refraction method.

Seismic methods use sound waves to determine the thickness and extent of aquifer materials. A seismic wave is generated in the ground and read by geophones on the ground.

The generated waves are dilational (sound waves), shear and surface waves. The dilational waves travel faster and are almost exclusively used in explosive exploration.

These waves are produced by explosive charges propagated through different media with different velocities. The velocities are affected by a number of factors; presence of ground water, bedrock quality, depth to bedrock and variations in the soil. Different factors can be identified by correlating the computed velocities with geological knowledge.

The geophone spacing was 5 meters in the following surveys.

B.4.1 The profile 6-208

The profile has the same starting point as the magnetic profile 6-319 and it has a length of 1400 meters (figure 4.2).

Results

The overburden exposes three different velocity layers. The top layer has a span of 400—600 meters per second, which corresponds to dry silt and sand. The next layer is supposed to consist of wet compact sand and silt and has a span of 600—1300 meters per second. Finally, the

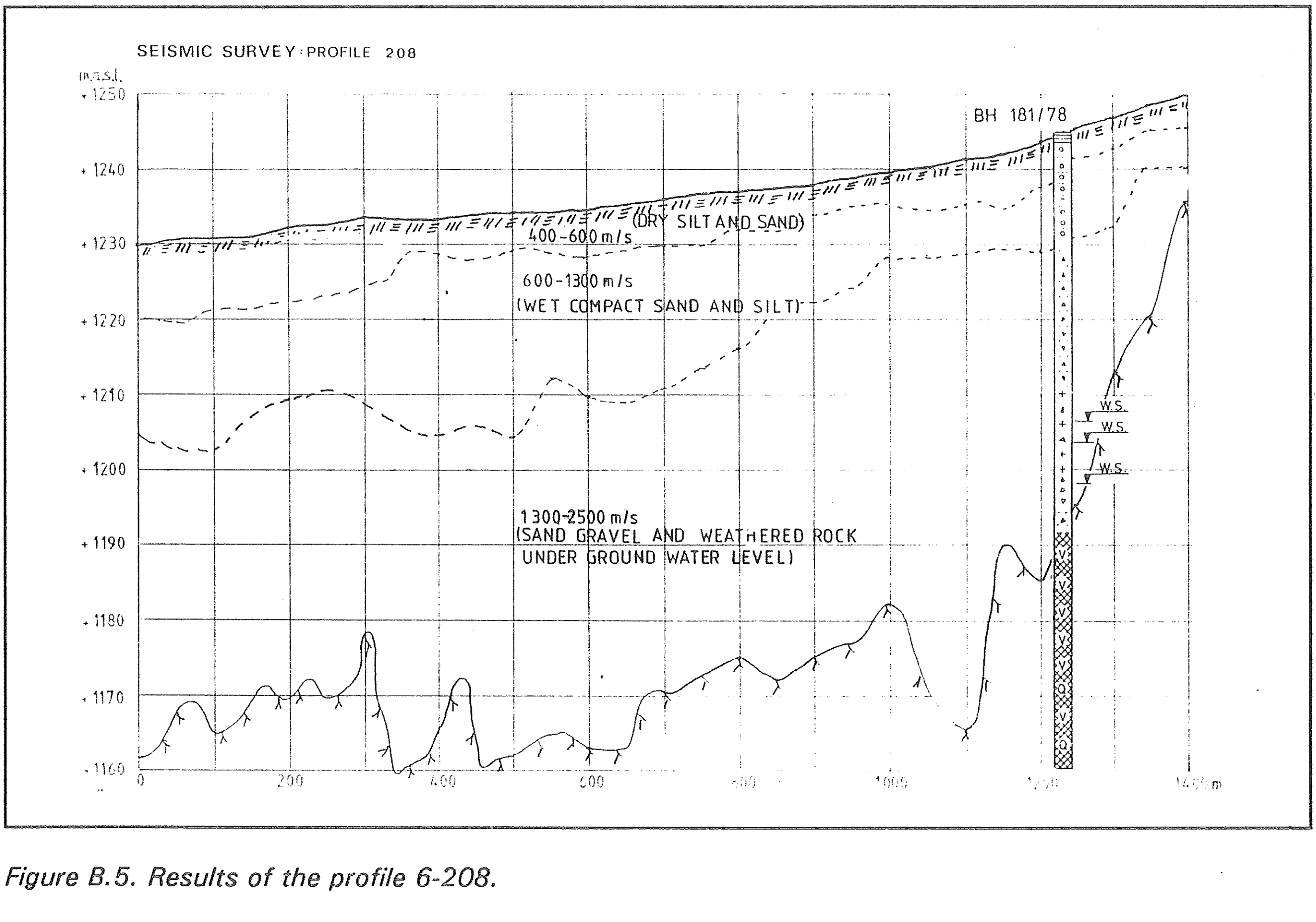

Figure B.5. Results of the profile 6-208.

bottom layer has velocities of 1300—2500 meters per second and indicates sand gravel and weathered bedrock under the ground water level.

The bedrock in the main part of the profile, in distances up to 1000 meters, has wide zones of normal granite velocity of 5000 meters per second. However, here and there are some low velocity zones noticed, which might belong to the fault. The frequency of these zones increases with the depression between distance 1030 and 1150 meters, and the tendency continuous with well marked zones from 1230 to 1330 meters. It is suggested that the fault zone coincides with the increasing trend of low velocities between 1130 and 1370 meters from the starting point (figure B.5).

Information about the Borehole 181/78 at the distance 1230 meters are available in chapter A.2.

B.4.2 The profile 6-209

The profile starts 200 meters south of magnetic profile 6-320 (figure 4.2). The length of the profile is 400 meters.

Results

The overburden exposes two different velocity layers. One top layer, 600—700 meters per second, interpreted as dry silt and sand, and one layer with the velocity span 1300—1600 meters per second, which is supposed to correspond to sand and gravel below ground water level and possibly also very weathered and decomposed granite, for instance in the depressions.

The surface of the bedrock is slightly undulating and the only well marked depression is noted between 310 and 330 meters. In the very bottom of this profile point, there is a low velocity zone recorded with about 2200 meters per second. The ordinary granite velocity 5000 meters per second dominates in the profile and it is only intersected by a few narrow low velocity zones (figure B.4).

The Borehole 1/79 is located 317 meters from the starting point, and in chapter A.3 there is more information.0

Appendix C

A study of water supply at Isanzu Dispensary and Clinic in Nzega District, Tanzania

1992

Johan Anderson
Ronny Wahlström

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C.1 The Isanzu Dispensary and Clinic

The village Isanzu, 13 kilometres southeast of Nzega in Nzega district, Tanzania (figure C.1), has a dispensary and a clinic. It is run by the Pentecostal Churches Association in Tanzania (PCAT) as a subdivision to Nkinga Hospital.

The dispensary has 10 beds for guests, and a staff of up to 20 persons.

C.2 Geology, hydrogeology and hydrology

C.2.1 Geology

The area is consists mainly of lateritic soil. It is created through
chemical weathering of the bedrock, and often several meters deep.

The lateritic soil is soaked on nutritious substance, which makes it poor for farming.

There is no open bedrock in the area.

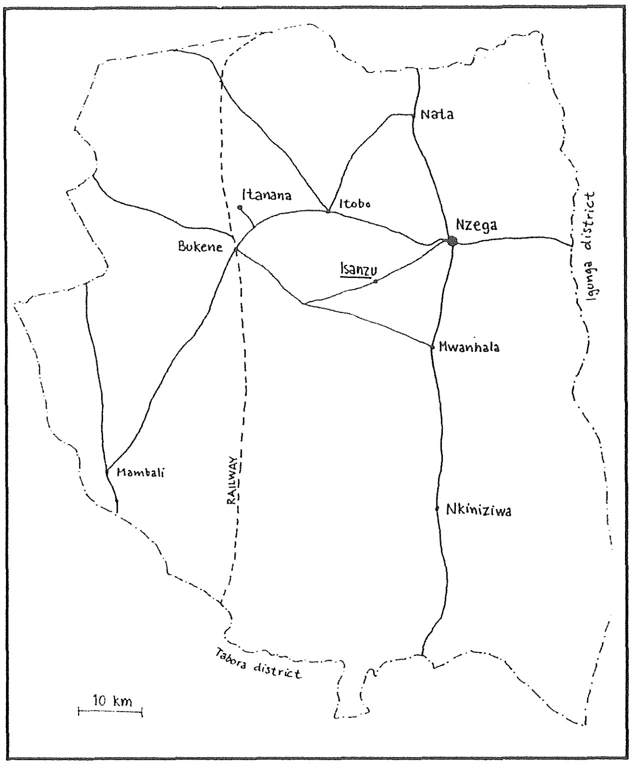

Figure C.1. Nzega district, Tanzania.

C.2.2 Hydrogeology

The main water bearing layers in the area should be sand and gravel layers, non of them visible. The groundwater

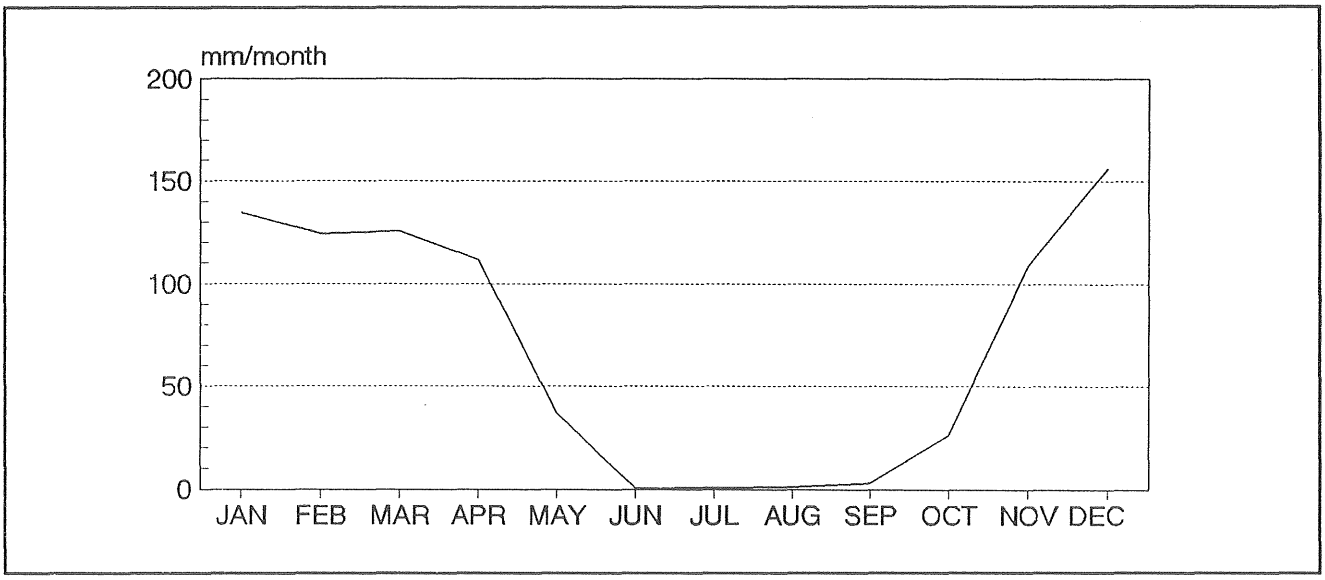

Figure C.2. Average monthly precipitation at the Mwanhala station (1957—1989).

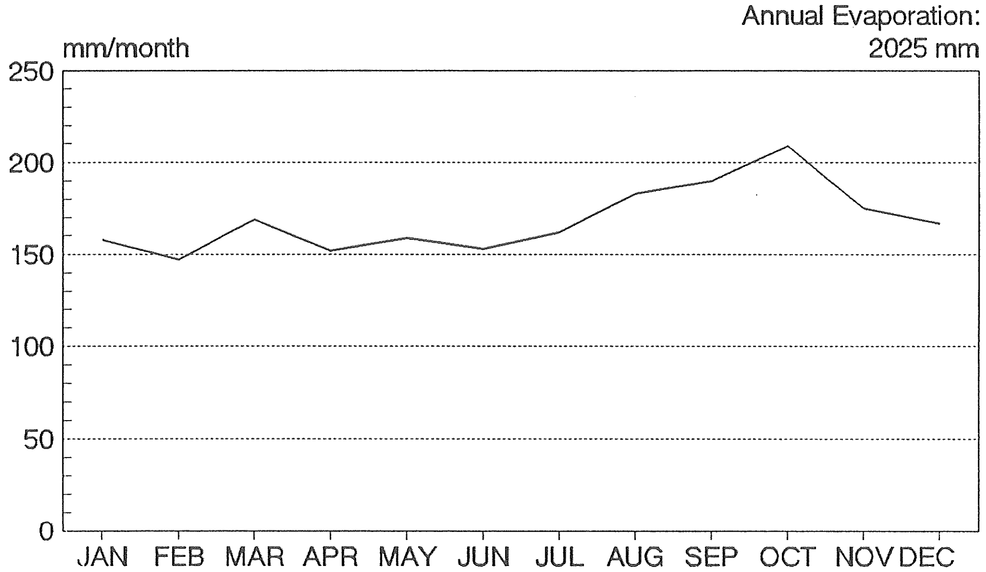

Figure C.3. Average monthly evaporation at the Mwanhala station (1969—1977).

level probably lies rather close to the surface, within some five to ten meters, but there are probably low possibilities for a good flow.

The level of the groundwater varies with the seasons, and is at its deepest just before the rainy season in October, November.

C.2.3 Hydrology

The average monthly precipitation at Mwanhala (13 kilometres southeast of Isanzu) can be used as representative figures for Isanzu (figure C.2 and C.3). The dry season from May to September has normally no precipitation. The average yearly rainfall is at Mwanhala 830 millimetres.

The hot and dry climate causes a very high evaporation, 5.5 millimetres per day on average in Mwanhala. That implies a limited recharge of precipitation.

C.3 Existing water supply systems

C.3.1 Shallow well

On the southern side of the main road to Nzega, just outside Isanzu, there is a lined shallow well, built by UNICEF.

The well is situated close to the road and near a number of big trees. The depth is about six meters, and there is a concrete cover, but without lid for the hole. It is utilized with a handpump.

When the observation was made in October 1991, at the end of the dry season, the well was totally emptied. According to the employees at the clinic, its water is usually sufficient during the first three months of the dry season. That means until July or August.

One of the reasons for the dryness is probably that the trees are taking all of the water that flows around the well during the dry season.

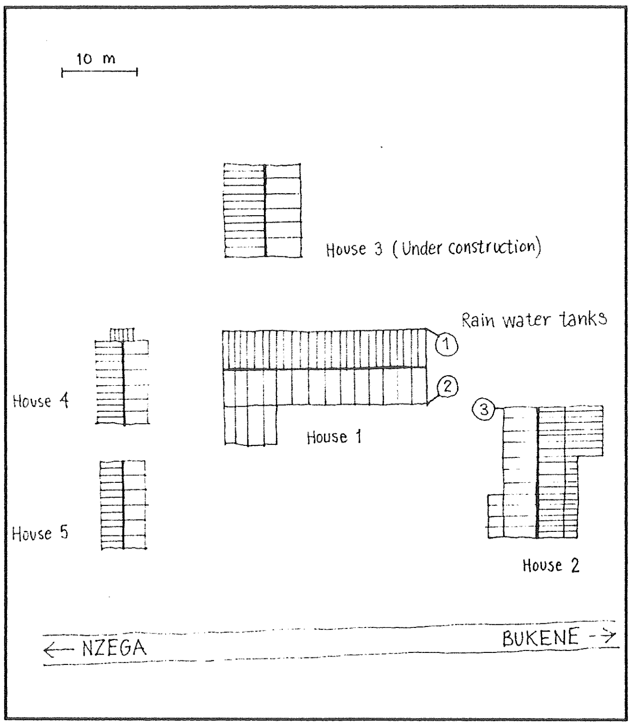

Figure C.4. Site plan of the Isanzu Dispensary and Clinic.

C.3.2 Stream

Some hundred meters south-east of Isanzu, there is a small stream. Even at the end of the dry season, water stands in its lower parts. At the time for the observation (October 1991), it was used as a washing place and to collect water from.

Just near the stream there is a lined shallow well. The lining consists of just two concrete-rings. The upper ring is completely over the ground, the lower almost under. However, the well that previously had a depth of only about 70 centimetres, now has no depth at all.

This shallow well has no cover or apron.

C.3.3 Rainwater harvesters

The clinic's demand for drinking-water should be met by the rainwater harvesters.

The site plan and the houses are shown in figure C.4 - C.7. House number 1 is connected to rainwater tank 1 and 2, house number 2 to tank number 3. The three other buildings are not used as rainwater harvesters (table C.1).

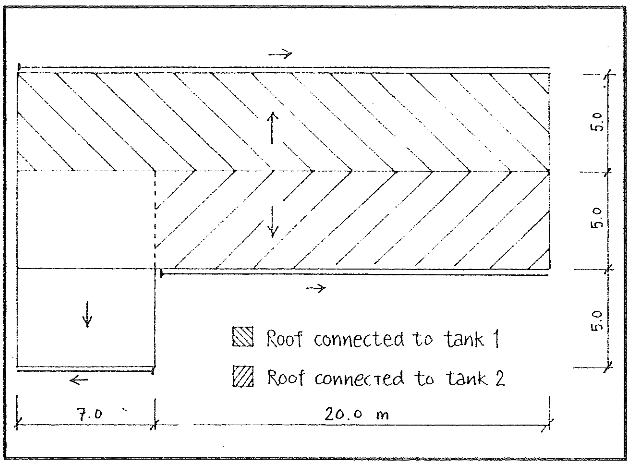

Figure C.5. Horizontal roof area, house 1.

The three tanks are all of one type. They are a prefabricated glass-fibre plastic tanks, with a volume of 8.4 cubic meters each. The tank is assembled from two halves with 72 screws and nuts as shown in figure C.8. In the bottom, there is a tap applied for collecting water in a bucket. The taps are normally locked with padlocks.

C.3.4 Condition of the rainwater harvesters

The roofs are in good condition, and was at the time for the observation well cleaned. The same can be said about the gutters.

Rainwater tank number three was empty. Eight screws with nuts were missing in tank 2, and five in tank number 3. Probably they have been taken away. Tank 1 is assembled without washers and therefore the screws are

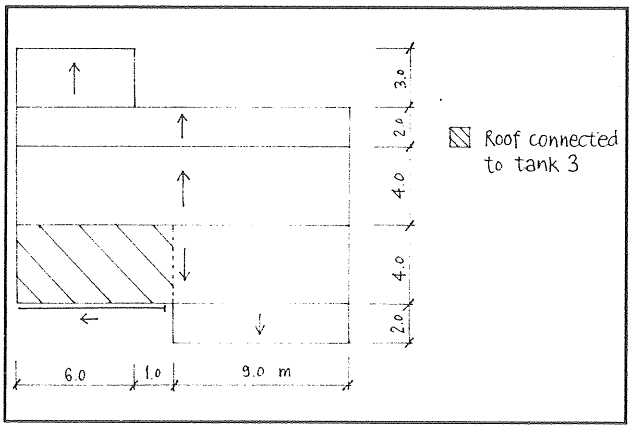

Figure C.6. Horizontal roof area, house 2.

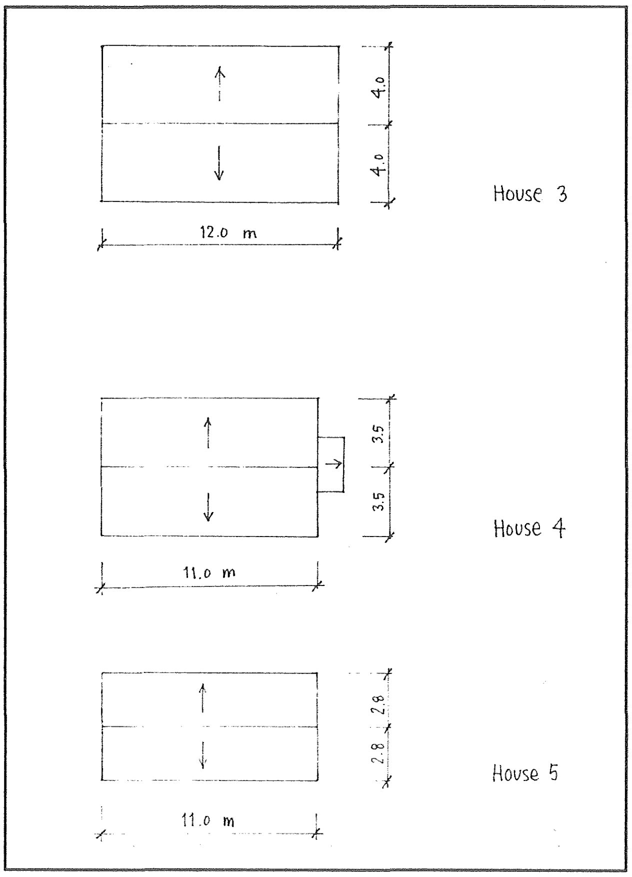

Figure C.7. Horizontal roof area, houses 3, 4 and 5.

difficult to remove. On the other hand, the brims of the two halves are cracked at several places, and marks from leakages could be seen the whole way around the tank.

All these three tanks were leaking at the joints. This reduces the useable volume to the half, to 4.2 cubic meters each.

Table C.1. Rainwater harvesters.

House number	Roof area (horizontal)	Exploited roof area
1 Front	170 sqm	100 sqm (59%)
1 Back	135 sqm	135 sqm (100%)
2 Front	86 sqm	32 sqm (37%)
2 Back	120 sqm	-
3	96 sqm	-
4	77 sqm	-
5	60 sqm	-
Totally	744 sqm	267 sqm (36%)

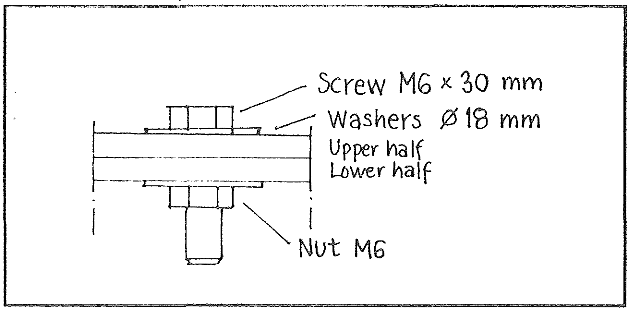

Figure C.8. Assembling the two brims.

C.4 Consumption and demand

C.4.1 The clinic

The users can be divided into five groups:

- ☐ The clinic
- ☐ The staff and their families
- ☐ The families living next to the clinic
- ☐ The school
- ☐ The church

The clinic's consumption is:

☐ Water to drink and for cooking:	30 litres/day
☐ Water for washing up:	10 litres/day
☐ Sterilization and for the dispensary:	10 litres/day
☐ Water for daily cleaning:	80 litres/day
☐ Cloth washing twice a week: (300 l/time)	86 litres/day

Total daily consumption is in average 234 litres.

C.4.2 The staff and their families

The staff of up to 20 people, including their families, brings the number up to 100 persons. If we assume an average consumption of 3 litres per person, this results in a consumption of 300 litres per day (one and a half bucket of water per employee).

C.4.3 The families living next to the clinic

Living in the area next to the clinic are about 150 people. With a consumption of 4 litres per person it means 600 litres per day.

C.4.4 The school

Outside the village of Isanzu, there is a school with 700 pupils. Their consumption during the dry season is about 100 litres per day.

C.4.5 The church

At special celebrations, which occur seldom, up to 350 litres of water can be consumed.

C.4.6 Total consumption

An average day during the dry season, the consumption is:

234 + 300 + 600 + 100 = about 1250 litres,

giving a monthly consumption of 37.5 cubic meters.

C.5 Improvements of water supply systems

C.5.1 Shallow well

The shallow well described in chapter C.3.1 seems rather hopeless to improve regarding the flow to the well under the dry season. A tight lid to the cover could however prevent the evaporation (see chapter C.2.3) and in that way increase the water supply.

C.5.2 Stream

Even if the supply is reliable during the whole season, there is a water quality problem. Therefore the existing well should be extended. It can be done by placing two or three more lining rings on the existing two. The

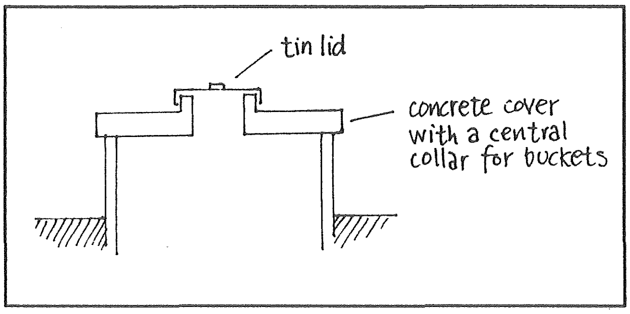

Figure C.9. Cover of the shallow well.

digging will take place inside the rings until about a quarter of the upper ring is dug.

On the bottom, a 20 centimetres thick layer of gravel is placed. Finally the well is completed with a cover illustrated in figure C.9.

This work will create a reliable source with sufficient water quality. The water has to be boiled to be potable.

C.5.3 Rainwater harvesters

The roofs that is connected today to the tanks, give an average year the following rainwater volume:

$V = 267 \text{ m}^2 \times 0.80 \times 0.830 \text{ m/year} = 174 \text{ m}^3$

(With 80 percent efficiency and 830 millimetres annually rainfall)

It can be assumed that the consumption during the rainy season is about 20 percent lower than during the dry season, owing to the higher number of other water sources and their access.

This means a relative consumption of 77 millimetres per month during the dry season and 61 millimetres per month during the rainy season:

$77 \text{ mm} \times 6 \text{ months} + 61 \text{ mm/month} \times 6 \text{ months} =$
$= 828 \text{ mm}$

This should be compared with the annual precipitation of 830 millimetres, see chapter C.2.3.

When optimizing the accumulated storage volume, as in figure C.10, the minimum reservoir volume should

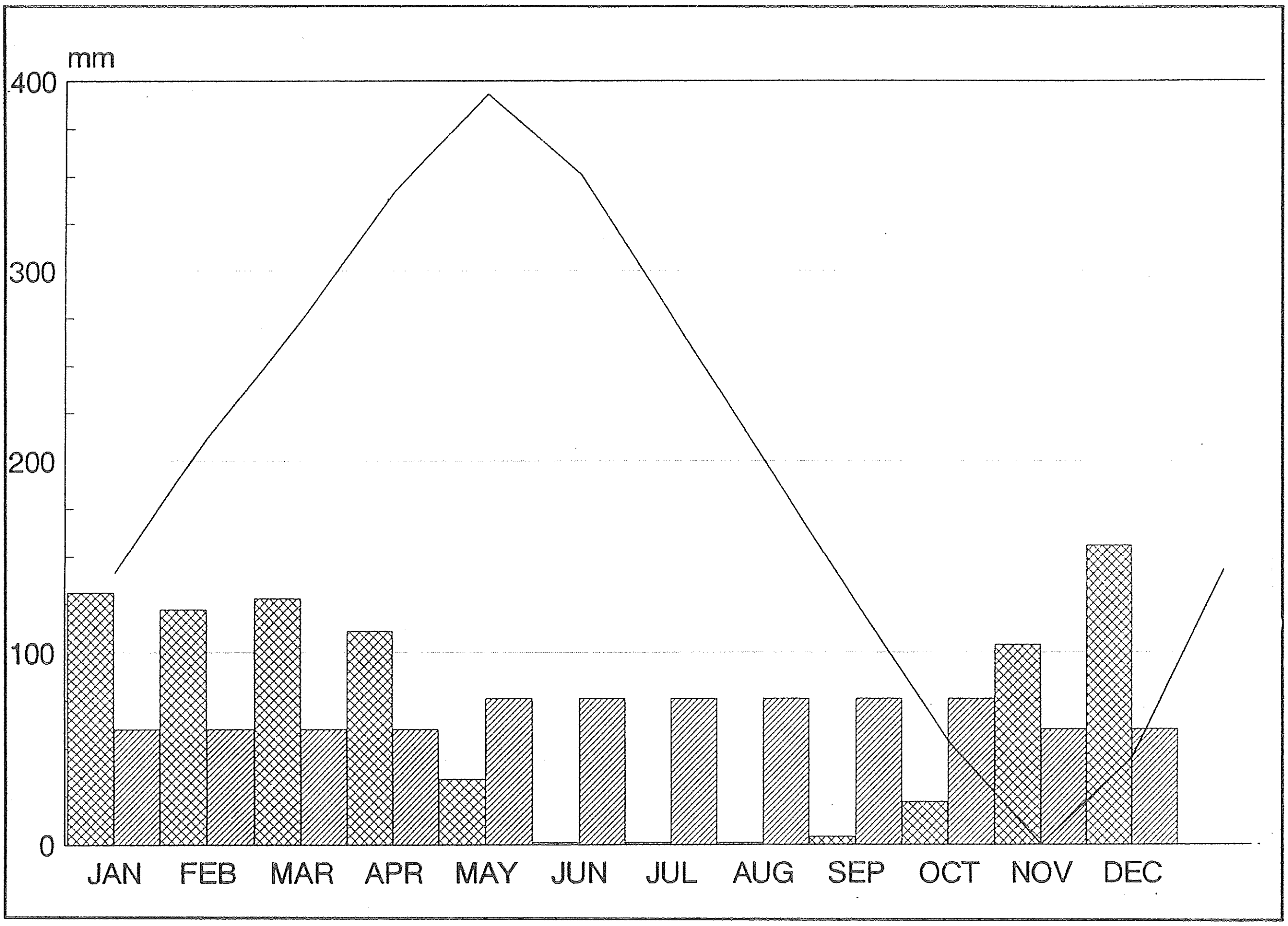

Figure C.10. Precipitation, relative consumption and maximum stored volume (mm/month).

correspond to a precipitation of 393 millimetres. Minimum reservoir volume:

V_R = 267 × 0.80 × 0.393 = 84 cubic meters

This can be compared with the existing reservoir volume of 3 × 4.2 cubic meters, i e 12.6 cubic meters. It corresponds with a precipitation of:

p = 12.6 m^3 / (267 m^2 × 0.80) = 0.059 m = 59 mm

According to accumulated storage volume in figure C.11, the reservoirs are dry in June and for five months.

Reservoirs related to existing demand

The monthly consumption of 37.5 cubic meters according to chapter C.4.1, corresponds to a precipitation of:

p = 37.5 m^3 / (267 m^2 × 0.80) = 0.175 m = 175 mm

During the rainy season, we can assume a 20 percent lower consumption, i e 140 millimetres. However, with existing reservoirs and roofs, only the month December gives a sufficient volume.

Table C.2. Tanks related to existing demand.

House number	Roof area (horizontal)	Required tank volume
1 Front	170 sqm	55 cbm
1 Back	135 sqm	43 cbm
2 Front	86 sqm	28 cbm
2 Back	120 sqm	39 cbm
3 Front	48 sqm	15 cbm
3 Back	48 sqm	15 cbm
Totally	607 sqm	195 cbm

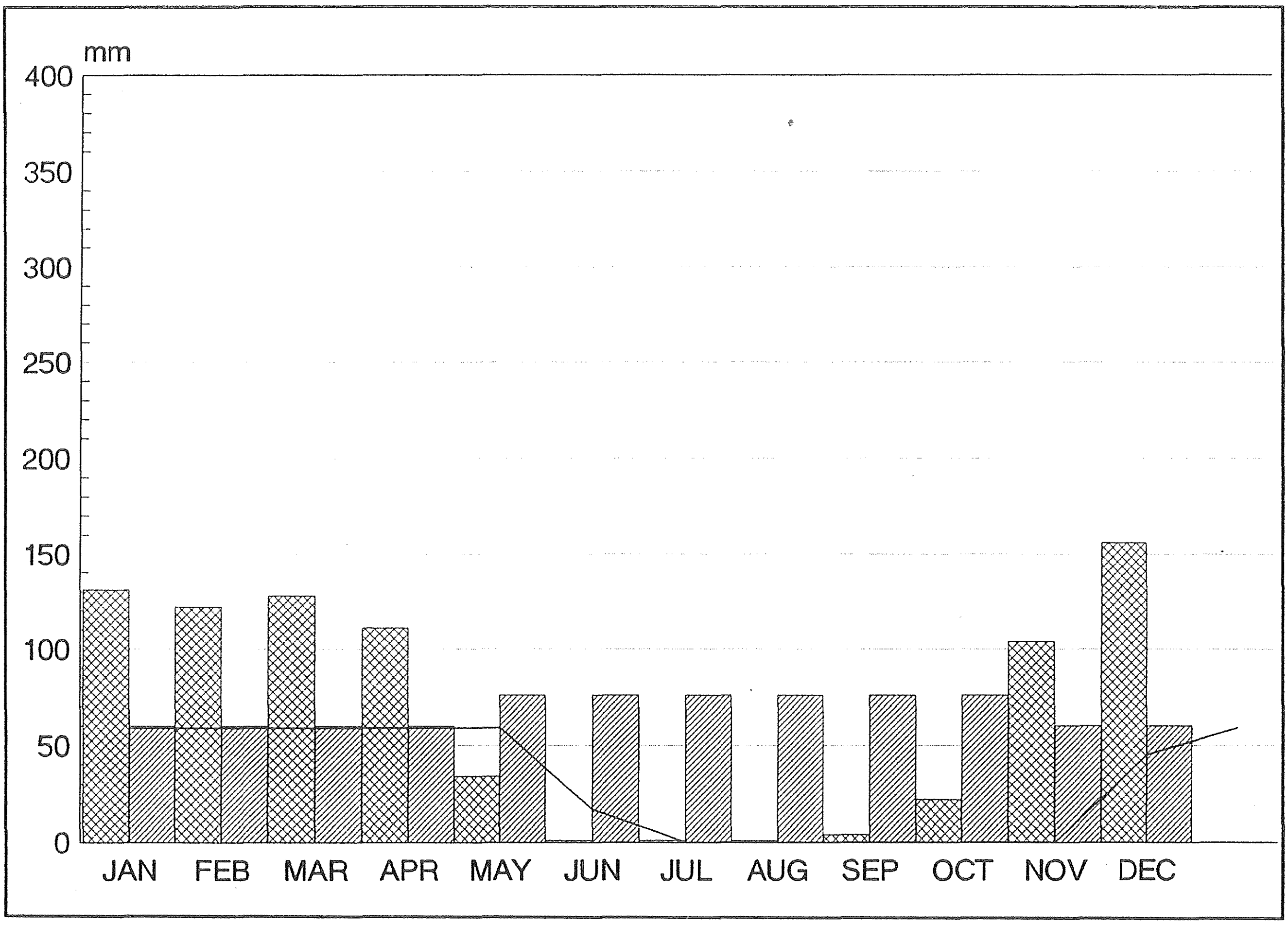

Figure C.11. Precipitation, relative consumption and stored volume with the tanks of today (mm/month).

To manage to cover the demand with rainwater, we have to have a roof harvesting area of:

$A = 175 \text{ mm} \times 267 \text{ m}^2 / 76 \text{ mm} = 615 \text{ m}^2$

For that roof area, the reservoirs should have a volume of:

$V = 175 \text{ mm} \times 84 \text{ m}^3 / 76 \text{ mm} = 195 \text{ m}^3$

The roof area of 615 square meters can almost be achieved through using the back of house number 2, the whole front side of house number 1 and 2, and both sides of house number 3. This gives an area of 607 square meters.

Thanks to larger roof area, all figures still corresponds to figure C.10.

The reservoir volume of 195 cubic meters is harder to achieve. Required volume is tabled in showed C.2.

If repaired, the three glass-fibre tanks can be used, for instance for the back of house number 2, giving a volume of 25 cubic meters.

The other tanks can be built in many ways, see chapters 7.2.4 and 7.2.5 in the main report.

With these improvements, the supply will be 1250 litres per day on average from May to October and 1000 litres per day on average the other half of the year.

With figure C.10, it is possible to make a control schedule, to compare the actual volume in the tank with the calculated one.

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