Traineeship Report

Setting up a measuring program at Kisayani, to measure the effected area by sand storage dams

June – September 2003

Jan–Kees Bossenbroek CT 9110053
Teun Timmermans CT 1005847

Delft University of Technology
Faculty of Civil Engineering and Geoscience
Department of Watermanegement

Preface

This report is a part of the traineeship from Jan-Kees Bossenbroek and Teun Timmermans, both students of the Faculty of Civil Engineering and Geoscience (CITG) of the Delft University of Technology (DUT). The traineeship, that is a part of the education program, took place from July 2003 to August 2003 at the non-governmental organization (NGO) Sahelien Solutions Foundation (SASOL). This rapport can be seen as a part of the Re-hydrating the Earth in Arid Lands (REAL) project, in which the Delft University of Technology participates.

When we started to look for a traineeship, we were very glad that Maaike Holland from the traineeship office of the DUT helped us with looking for nice traineeships. After a while we found the traineeship at SASOL, a NGO with had contacts with Maurits Ertsen. We want to thank both Maaike Holland and Maurits Ertsen for their help to realise our traineeship. We also want to thank Wim Luxemburg for his technical support, comment on our traineeship proposal and of course for being our technical advisor. Maartje van Westerop did arrange a lot for us, like our journey to Kenya and the places to stay in Kenya, so we also want to thank her.

But of course the most thanks goes to all the people in Kenya. To start with Sam Mutiso, who made it possible for us to do our traineeship in Kenya. We also want to thank Joseph Muinde for being our guide in the Kitui district, translating everything we wanted to say or understand in different languages (Kamba, Swahili and English). Of course we also want to thank all other SASOL-personnel like Ancent , James, Julius and Marie for there information and help. The stay in Kisayani could never have been this nice when the community of Kisayani and Ngunga Kwoko were not so friendly as they were. Already after two weeks we almost felt as we were at home.

It was also very nice to get all kinds of information and advises from colleague students, who already had been in Kenya for a while. So thanks to Fransz Huizing and Erna Ebbinge from the Ex-change program and of course our predecessors Willem Malda, Hessel Winsemius and Sieger Burger from the Delft University of Technology who started with setting up the measuring program. When we were in Kisayani we worked together with two Belgium students; Sam Puttemans and Dirk Neesen, we enjoyed the stay with them and we want to thank them for the nice cooperation.

J.C. Bossenbroek CT9110053
T.P. Timmermans CT1005847

Table of content

Faculty of Civil Engineering and Geoscience
Department of Watermanagement
TU Delft
Delft University of Technology

List of figures

List of tables

1 Introduction

Soil and water conservation has a high priority in the drier sub-Saharan Africa, like Kenya. Storage of water from the rainy season to the dry season, or even from the wet years to the dry years is highly important. Many projects and policies are implemented to improve the conditions of land and water in the areas failed, because they did not recognize the locations specificity of conservation problems and solutions in sub-Saharan Africa and the inapplicability of important methods without adoption. Approaches that try to take into account local conditions (material and immaterial) have come to the front, under the umbrella concept of participatory design, as in Kitui district in Kenya done by Sahelian Solution Foundation (SASOL). Sand storage dams have come to play a central role in the Kitui program of water development. They can store sufficient quantities of water for livestock and minor irrigation as well as for domestic use. If properly sited and build, dams can be a welcome water source. Unfortunately there are also many examples of sand storage dams, which has not been successful. The SASOL Foundation has already a large experience with the building of sand storage dams, they are already building dams for the last ten years. Their experience is, that in the region where the dam is finished it is possible to change the cropping pattern and have more yield of one field. It is also easier to extract the water from the groundwater, because of the rise of the groundwater table.

In the year 2000 the Delft University of Technology (DUT), the Katholieke Universiteit Leuven (KUL), the University of Nairobi and SASOL set up the Re-hydrating the Earth in Arid Lands (REAL) project. The objective of this project was to create some kind of manual that could act as a guide for building sand storage dams. But before such a manual can be made, the total effects (hydrological, economical, social, and agricultural) of the sand storage dams should be scientifically investigated. Our traineeship will be a part of this investigation.

In 2002 a project group from the DUT (CF 628) wrote a report how to do the hydrological measuring. In April 2003 A.S. Burger, W. Malda and H.C. Winsemius started with doing research at a proposed dam site in the Ngunga River in the Kitui district near Kisayani. They also started with setting up a measuring program. We have extended the measuring program and made the measuring points more permanent, so that in the coming years and also after finishing the dam the same measuring points can be used. We also started with measuring the groundwater levels at the measuring points.

This report starts with some general information about Kenya and its climate in chapter 2 and 3. Chapter 4 describes the involved organizations and chapter 5 gives an analysis of the problem, with a problem statement and some objectives of the traineeship. In chapter 6 the theory about the sand storage dams is explained followed by an area exploration in chapter 7. Chapter 8 describes the water balance and in chapter 9 something is said about sedimentation. Chapter 10 and 11 describes the hydrological measurement system and the weather station which are set up during the traineeship. The report ends with some conclusions and recommendations in chapter 12.

2 General information about Kenya

Figure 2.1: Map of Africa

Kenya is situated between 5º Northern latitude and 5º Southern latitude, so half of the country is on the north side of the equator and the other half on the south side of the equator (see Figure 2.1). Lake Victoria, the most western part of Kenya, is located at 35º eastern longitude. Lamu, the most eastern part of Kenya is located at 42º eastern longitude. The fact that Kenya is laying on the equator has a big influence on the climate. There are very different climates in Kenya; this is caused by the big difference in altitude in Kenya. The varies from 0 meter above mean sea level at the coast to 3000 meter above mean sea level at Mount Kenya.

Kenya has borders in the North with Ethiopia and Sudan, in the East with the Indian Ocean and Somalia, in the South with Tanzania and in the West with Uganda and Lake Victoria (see Figure 14.1).

The mean rivers in Kenya are the Athi/ Galana-river which ends in the Indian Ocean near Malindi and the Tana-river that also ends in the Indian Ocean, between Malindi and Lamu.

Kenya covers an area of 583.000 km², this includes 13.600 km² of lake Victoria. In this huge land, almost seventeen times the area of the Netherlands, there are living 31 million people, and the growth rate nowadays is 2,8%. In the seventies and eighties the growth rate was 4% but it decreased by AIDS. The official languages in Kenya are English and Swahili, but there are many other local languages. There are some 20 tribes in Kenya, all with their own language.

Only 42% of the inhabitants of Kenya have access to clean drinking water. But already 87% of the people are now connected to an adequate sanitation.

Kenya is divided in seven districts, namely Central,Coast, Eastern,North Eastern, Nyanza, Rift Valley, Western and Nairobi, these districts are divided in smaller districts as can be seen on the map in appendix 1. You can also divide Kenya in four geographically different zones: The coastal plains; the Rift Valley and the Central Highlands; the lakeshores; and the arid wastelands of Northern Kenya. . Our study area is situated in the Eastern district, and geographically seen in the Central Highlands, at an altitude of circa 800 metres above main sea level.

3 Climate

Kenya's diverse geography means that temperature, rainfall and humidity patterns vary widely, but again there are effectively four zones about which generalizations can be made.

- The undulating plateau of western Kenya is generally hot and fairly humid with rainfall spread throughout the year. The greatest precipitation is usually during April when a maximum of 200 mm may be recorded, while the lowest falls are in January with an average of 40 mm. Temperatures range from a minimum of 14 C to 18 C to a maximum of 30 C to 36 C over the year.

- The Central Highlands and Rift Valley enjoy perhaps the most agreeable climate in the country. Average temperature vary from a minimum of 10 C to 14 C to a maximum of 22 C to 28 C. Rainfall varies from 20 mm in July to 200 mm in April and falls essentially in two seasons – march to the beginning of June ("long rains") and October to the end of November ('short rains'). The mount Kenya and the Abberdare mountains are the country's main water catchment areas, and falls of up to 3000 mm per year are recorded in these two places.

Figure 3.1: Climate data of Nairobi

- In the vast semi-Arid bushlands, deserts and lava flows of northern and eastern Kenya, the temperature can vary from highs of up to 40 C during the day to less than 20 C at night. Rainfall in this area is sparse and, when it does fall, it often comes in the form of violent storms. July is generally the driest month and November the wettest. The average annual rainfall varies between 250 mm and 500 mm. Kisayani and Kitui are a part of Eastern Kenya. Of course this data is far too general to use during the REAL-project. For that reason a weather station is set up in the research area. The data gathered from this weather station can be checked with above mentioned general data.

- The fourth climatic zone is the coastal belt, which is hot and humid year-round, though tempered by sea breezes. Rainfall ranges from a minimum of 20 mm in February to a maximum of 300 mm in May, and is dependent on the monsoon, which blows from the North-east from October to April and from the South-west for the rest of the year. The annual average rainfall is between 1000 mm and 1250 mm (less in drought years). Average temperatures vary little throughout the year ranging from 22 C to around 30 C.

4 Involved organisations & projects

In the next paragraphs the organisations and projects that were involved by our project will be described. The paragraphs 4.1.1 and 4.1.2 are adapted from: Ir. Ertsen; Drs. Twickler; Prof. Ir. Brouwer – Report start-up meeting REAL, TU Delft September 2002. The paragraphs 4.2.1 till 4.2.6 are adapted and somewhat actualized from: Beimers, P.B.; Eijk, A.J. van; Lam, K.S.; Roos, B. – Practical Work Report, building Sand-storage dams, Kitui District, Kenya – Kitui 2001.

4.1 Real

The REAL-project, Re-hydrating the Earth in Arid Lands, is a project done by a consortium that consists of participants which together share experience and knowledge on:

- Design issues, including technical, management and participatory aspects;
- Performance, including hydrological, water use (agricultural and domestic) and health aspects;
- Education, including training of students, staff and farmers;

All are involved in the integration of science and practice, or in other words research and water development.

The participants are shown in Table 4.1

Table 4.1: Participants of the REAL-project

Participant	*Country*	*Knowledge*	*Position*
Delft University of Technology	Netherlands	Design issues Education	University
IRC	Netherlands	Water use performance Health	Research institute
Catholic University of Leuven	Belgium	Agriculture and hydrology Education	University
Sahelien Solutions(SASOL)	Kenya	Design issues Water development	NGO
University of Dar es Salaam	Tanzania	Resource management Education	University
Amsterdam University	Netherlands	Education Sustainability issues	University
Westerveld Conservation Trust	Kenya / Netherlands	Design issues	NGO
Protos	Belgium	Water development projects	NGO
Nairobi University	Kenya	Water use performance Education	University

4.1.1 Objectives

The general objective of the research project is:
To clarify the relation between local practices and the theoretical approaches by focussing on the design, management an performance of small groundwater retaining structures on a communal level in two African countries, Kenya and Tanzania, linking both the individual and the community and theory and practice, resulting in guidelines for participatory design of small water retaining structures in semi-arid regions worldwide.

The main product in which this general objective will be materialized is:
A manual describing how to employ an integrated, participatory design approach applicable in other regions for comparable small water retaining structures.

Other, supporting scientific and technological objects to reach the general objective and main product are specified. At the end of the research project:

1. A systems perspective on design, management and performance of small water retaining structures in semi-arid areas is developed.
2. The performance of existing small water retaining structures, including aspects concerning hydraulics, hydrology, water use and health, is clarified and a participatory small water retaining management approach has been established.
3. Experience with a participatory design, construction and management approach for small water retaining structures in two pilot areas have been documented.
4. Staff, students and local communities involved have participated in experiential learning exchanges in workshops, field visit, formal education and networks.
5. The results of the project have been disseminated through the manual, three yearly reports, three scientific papers and the conference proceedings of a final conference.

4.1.2 Content of the research program

The project is divided into four work packages. Three of them are both geographically and thematically defined, one work package (WP) has the specific aim to integrate the contributions from the other packages (see Table 4.2).

Each package is focusing on a particular aspect of the next triangle (see Figure 4.1):

- Work package 1 integrates the findings and develops the methodology.
- Work package focuses on water use and participation, and its consequences for design. It provides input for WP 3 and 4.
- Work package 3 focuses the environmental effects of dams and ways to consider that in new designs. It provides input for WP 4.
- Work package 4 provides the test-case in which all aspects mentioned are taken into account.

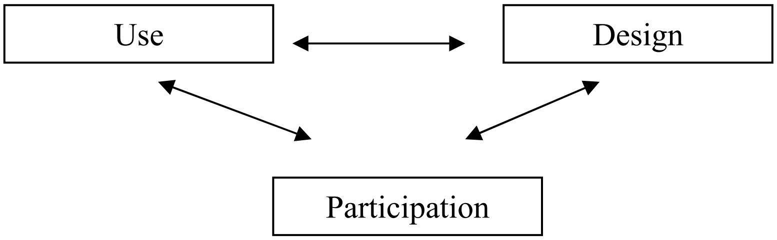


Figure 4.1: Organization research project

Table 4.2: Work packages

Work package	*Central goals*	***Final products***
1. Integration	• To monitor project progress • To administer all project activities and finances • To integrate project findings into a design manual	• Program evaluation report • Small water structures manual • Final conference proceedings
2. Performance	• To evaluate management and use of existing dams • To give recommendations for future design and management of dams	• Management and use of existing structures
3. Integrated design in Kenya	• To determine the influence of user demands on design issues • To give recommendations for future design and construction of dams	• Design report for new structures in Kitui and Amboseli, Kenya
4. Integrated design in Tanzania	• To test the approach and recommendations for user participation in integrated design • To give recommendations for future design and management of dams	• Design report for new structures in Ngorongoroi, Tanzania

Our traineeship and report can be seen as a part of work package 3.

4.2 SASOL

4.2.1 History and founding SASOL

Cyrus Mutiso, Sam Mutiso, Peter van Dongen and Jaap van der Zee founded SASOL foundation in 1990. The name SASOL stands for Sahelien Solutions and is a non-governemental-organisation(NGO). Sahelien is a Arabic word for Arid and Semi-Arid Lands (ASALs). The population in Arid and Semi-Arid Lands all over the world is growing or will be growing in the next decades. However the high potential areas cannot supply the needs of the growing populations, so people have to move to less favorable areas. These less favorable areas are the areas where SASOL is focussing on. The major need in these areas is water. If the lack of water in these areas has been solved, opportunities can rise for the population by increasing the productivity. Not only the livestock and crop production will increase, but also the industrial production, that is now absent in these areas.

SASOL foundation has been founded, because the founders have a different vision of development projects than the most existing development organizations. They have watched the very little impact of development projects on the lives of people in the past century by donor-driven organizations. In there opinion development projects should be a great improvement in the live of people. They think that this can be done by simple low-costs projects where the community places a mayor role in solving their own problems.

Many technologies have been tried to supply water to the communities in the dry periods. Wells are expensive to install; shallow wells also offer a extractive technology, which is not sustainable. Water tanks are expensive and limited by size. Earth dams, with a surface water reservoir, suffer from extensive water losses due to evaporation and they also have a huge potential for contamination and other risks to health. When groundwater is recharged water is stored below the surface in the sand package reducing the evaporative losses. Sand filtration reduces contamination. Isolated sand-storage dams constructed in Kenya during the colonial period from 1940 till 1950 by ALDEV are still functional. For SASOL this was a prove that the technology of sand storage dams is viable.

During the colonial period sand storage dams where often referred to as sub-surface dams because the water is stored below the surface. However the term ‘sub-surface dam’ is used in some countries to refer to a barrier below the surface. It could also be used to refer to a impervious underground barrier in a low-lying area that prevents the lateral flow of groundwater and maintaining or raising the water table. In contrast, a sand-storage dam is made as a concrete or masonry barrier on a ephemeral river (see Figure 4.2). Although the upper side of the wall may be hidden by sand, the lower side is usually exposed, in part due to erosion from the water flowing over the dam.

SASOL was established to address water problems in the Arid and Semi-Arid areas, with a special emphasis on sand-storage dams and shallow wells. In the beginning nobody would fund the dams. So SASOL started a shallow well development with a school-feeding program. This feeding program stopped within a view years after starting due to conflicts with donors. The main reason was however the low structural impact on satisfying the basic needs. The school shallow well program survived till date.

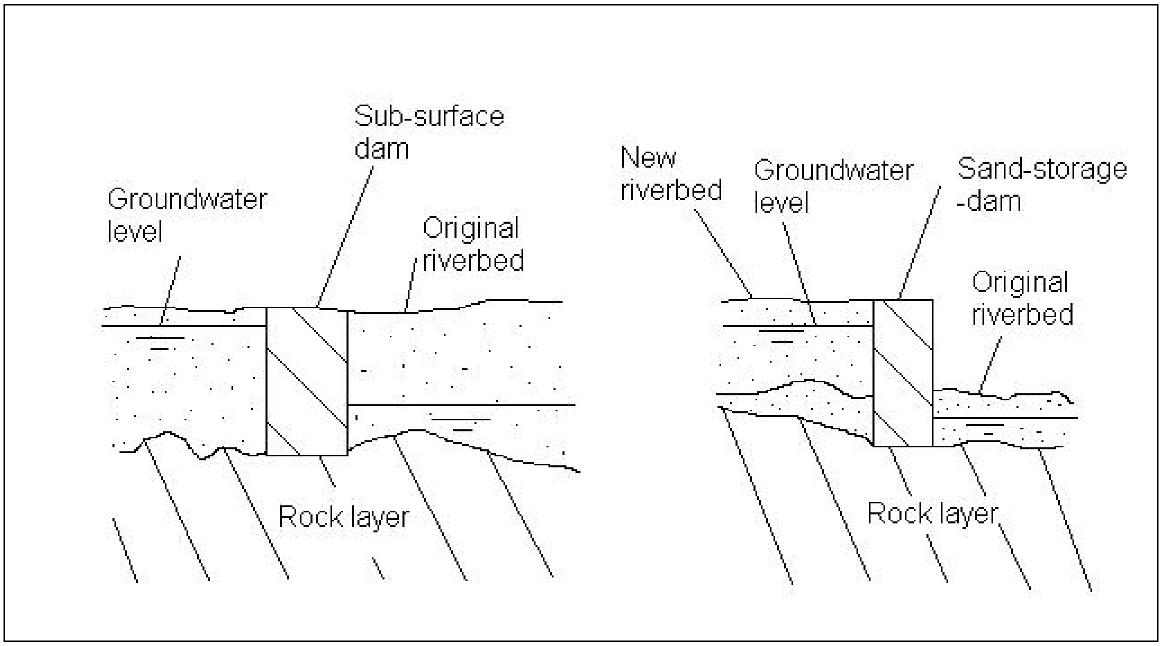


Figure 4.2: Principles of a sub surface dam and a sand storage dam

After that, SASOL focussed on satisfying the important basic need: water. Both primary and secondary schools in a area of 600 km² in the Kitui District, have been supplied by building shallow wells and rainwater storage tanks. This was a good experience for the future projects, because the approach of the school program was a bottom-up approach. The community provided most of the labor and materials for the dams, while SASOL found funding for cement, reinforcement, transport, masons and supervision. The main sponsor for the school program was SIMAVI, a Dutch development agency. This program still continues in Kitui District.

This kind of supplying water for schools has also been used to supply communities nearby the schools. The effects on these local communities are substantial, but the supply of water was insufficient in times of drought. SASOL's focus changed to supply water by building a network of dams, shallow wells and rainwater catchments.

With the funding from WaterAid, a non-governmental organization (NGO) from Great Britain, SASOL started a pilot project on the Kiindu River. This pilot enabled SASOL to test the initial thinking and the practicality of instituting the system. It was also a test of the technology involved and working systems in community organization. From March 1995 until August 1995 five sand storage dams were build Kiindu River. The dams constructed during this period, received water in the October rains that year. SASOL observed an increase of water level at the Kamumbuni dams where the scoopholes used to go down to four meters, but now the water level after the last long drought was only yet 1,25 meter.

So the concept of building sand storage dams for water supply could be approved and the pilot project was followed by twenty-five sand storage dams projects on the same Kiindu

River catchment and was also funded by WaterAid. In 1998, WaterAid was wound up in Kenya and ended the funding on dams. In 1994 the Swedish international development authority (SIDA) and the United Kingdom department of international development (DFID, 1996), started to fund dams in the different rivers in the Kitui District. Every donor finances his own project area, selected by SASOL.

By April 2001, SASOL has already build 260 dams in different rivers in an area of 600 km² in the Kitui District. Although not all dams are working (a few collapsed by El Niño in 1997), most dams have a great impact on the local communities.

SASOL’s turn over in 1999 was approximately Ksh. 9.6 million (about € 145.000).

4.2.2 Objectives of SASOL

The main objective of SASOL is to proof that simple low-cost technology for water infrastructures can improve the lives of people in arid and semi-arid areas so that other development organizations or governments can copy this technology for water infrastructures.

SASOL’s planning is to supply water throughout the year within two kilometers of every house. This is a great improvement compared to the ten kilometers women and children need tol walk to get fresh water in the current project area. Progress can be made in satisfying not only the basic needs of the communities, but progress can also be made in life standard by producing high value crops, like mango’s, beans, maize and peas. The general health of the population will increase by this supply of extra water. Getting water would no longer be a negative impact on the health of women and children who are used to walk ten kilometres for water. The increased farming activities with more variety in crops generate more balanced food and higher income. Energy and time expenditure for fetching water can now be used for other activities, like terracing land.

4.2.3 SASOL’s approach

The projects of SASOL use a catchment development approach for implementation. The approach of SASOL is to develop a catchment in total. Construction of sand-storage dams is the base on which other activities are build on by the community. The catchment approach depends on the cooperation by the community in developing sequential sand-storage dams in the dry rivers coupled with terracing and tree planting on individual plots. The projects are community driven and managed. SASOL uses a bottom-up approach when implementing development projects by letting the community define their own problem, set their own priorities and make their own decisions on how to solve it. SASOL provides the facilities, resources and, if necessary, the required funding. The reason for this approach is first of all the failure of the conventional top-down approach by development organizations in the past and still now. Second, by letting the local community play a major role in solving their own problems, success of the project is more sustained. The community is also encouraged to use and build up their own knowledge, talents, capacities and organization. Finally the local community knows their own situation better then outsiders, like natural and human resources and what may or may not work in a given situation.

4.2.4 Work areas of SASOL

As SASOL is a Kenyan foundation, activities of SASOL are all in arid or semi-arid regions of Kenya. The main activities are in the semi-arid Kitui District. The choice of the Kitui District has the following reasons.

1. Geography and morphology

The Kitui District has a great variety of flat and steep places in high and low areas.

2. Production system

The Kitui District used to have a great production of livestock. By growth of the population and more intensive use of the land by livestock, this production became more and more crop agriculture, because of the higher productivity of the cropped land. The fact that the Kitui District is a net importer of food makes the need to harvest more crops even more important because of the growing population.

3. Soil

The Kitui District has a great variety of soils. The behavior of solutions for the Kitui District on different soils can be reflected on different arid and semi-arid areas in other countries or regions.

4. Social organization

The nature of social organizations for development in Kitui District varies from none social organization to strong organization of the local communities. It is a challenge to organize communities for solving the problems whether they are already organized or not. This makes the Kitui District a perfect experimental area for the solutions of SASOL for arid and semi-arid areas all over the world.

4.2.5 Current organization

In the period of the school feeding program and schools program, the organization was quite extensive. There were more than 20 managers to do the projects. After starting with the sand storage dams, the organization became smaller to be more effective.

Nowadays, the organization of SASOL has a small overhead. A board of governors supervises the activities of the organization. The board has 8 members, who meet each other 4 times a year. The board has to be complete, by law, at least ones a year. In these full board meetings, the board has to call in account for the activities and the expenditures of the foundation. Policy will be adjusted, made or changed and problems in execution of the foundation will come up for discussions, as other relevant items, like Kenya government policy.

Board

- Proffesor Cyrus Mutiso Chaitman

-	Peter van Dongen	Treasurer
-	Francis N.Katua	Vice-Chairman
-	Evaus Ngava	Member
-	Catherine Mumo	Member
-	Maria Mulura	Member
-	Jennifer Mutia	Member
-	Makau Kyambo	Member

Under this board SASOL has an executive board of 5 members. This board is fully authorized to take daily decisions and spent money. The executive board exists of the same members as the board, without the chairman, the treasurer and Makua Kyambo, because they are in Nairobi most of the time. The executive board chairman is Francis N.Katua. He is the co-signatory of all the cheques for payments made by SASOL.

The projects are run by:

<u>Field Manager (Sam Mutiso)</u>
Tasks:
1. Managing SASOL activities
2. Fund raising
3. Supervising personnel
4. Report preparations

<u>Technical Managers (David Ngui Kithuka (British) and Julius Nzomo Munyao)</u>
Tasks:
1. Supervision of the masons
2. Location of the dams
3. Material management
4. Talk with chief, community and site committee
5. Transfer the masons
6. Checking the dams, at least once a year

<u>Community Managers (Mathew Kitema, Ancent Ngungu Mumina, Mutinda Munguti)</u>
Tasks:
1. Making contact with communities
2. Training communities
3. Participator in community based projects
4. Formatting site committee

<u>Administration Assistant (R. Mary Maig)</u>
Tasks:
1. Looking after accounts
2. Data entries
3. Managing office

<u>Group Leaders (Two Headman of the masons)</u>
Tasks:
1. Coordination of work in the field
2. Solve small problems
3. Intermediate between technical manager and masons

<u>Masons (19)</u>
Tasks:
1. In charge of the site
2. Activate the community
3. Liaison between community and SASOL
4. Training at the site (sanitation)

In Figure 4.3 an organogram of the current organization of SASOL is presented.

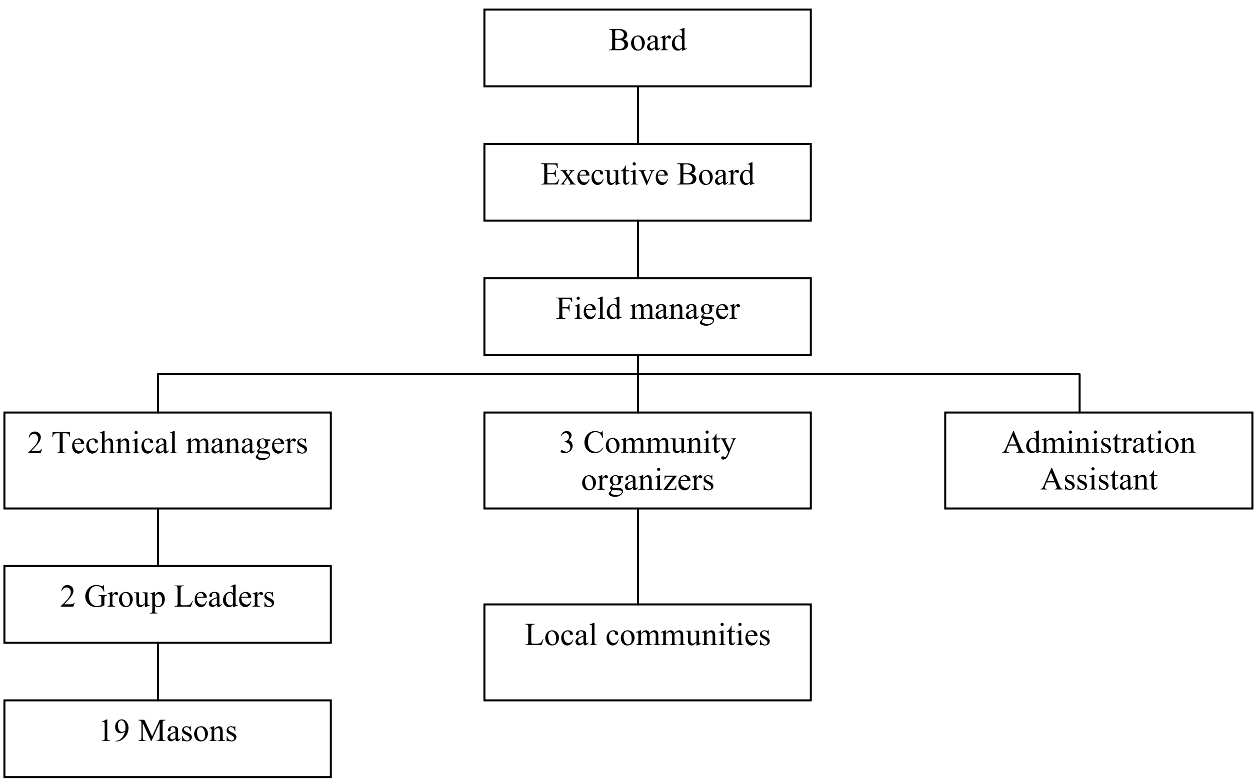


Figure 4.3: Organogram SASOL

4.2.6 Future SASOL

In the future, SASOL plans to keep on building sand storage dams southward from the present area to the Tsavo East National Park. The population density in this region is lower and the soil difference from the situation in the present building area, but it is a challenge for SASOL to prove that this technology for water infrastructure can also work in this area. To finance these dams, SASOL has already found funds from the European

Union for the coming year. Searching for funds for the remaining dams will not be a problem, because of the approved impact of this technology.

Providing water was one part of the objectives. To improve the lives of the population, one has to teach people to use the water efficiently, to maximize their profit. In this view SASOL will promote:

- Environmental land protection by terracing land.
- Agriculture business by cropping high value crops for export and variety in cropping.
- Organizing communities by using the existing organization in the community for building the dams and other purposes.

In 2002 SASOL admitted that scientific proof of the impact of this water infrastructure is needed to be able to go on with this project. Because little is known about the technology of sand-storage dams, documenting the projects is very important. This because other organizations that want to use the technology of sand storage dams does not have to deal with the same problems as SASOL. Research is needed to access the impact of this water infrastructure. Not only to ensure funding and support by other organizations or governments, but mainly to optimize this technology by scientific knowledge. How can SASOL optimize the recharge areas with the dams, how can the production be optimized by optimal use of the water in the catchment, what is the social-economic impact of the dams on the lives of the population? Those are some of the many questions SASOL wants to know for the future to optimize the effects of the dams. Students from the Netherlands of the Delft University of Technology are doing their traineeship with doing investigation of these questions.

SASOL has planned to hire three extra staff members:

- A health manager, to give health education to the dam users. His work will help to reduce the diseases in the project area.
- An agriculture business manager can help the population with the crops. What is the best strategy for cropping, what are high value crops, what crops are sustainable are questions an agriculture business manager has to answer.
- A research manager is intended to coordinate the research programs SASOL wants to undertake.

Until now SASOL did not have the money to employee this people. When a proposal to the European Union is funded, SASOL will implement the planned staff extensions.

5 Problem analysis

5.1 Problem statement

Although there is a large experience with sand storage dams in the Kitui district in Kenya, there is no scientific prove that sand storage dams work properly.

5.2 Objectives

As we were the second group of the Delft University of Technology that went to Kisayani the objective of our traineeship was to continue and improve the measuring system that the former group had set up.

The former group made three crossings of piezometers near the proposed dam site. This was done to see what kind of effect the dam has on the bank infiltration of the river. During our traineeship we want to make more piezometers in the longitudinal direction of the stream to see how big the area is that is affected by the sand-storage-dams and to see if the effects are positive or negative. This measuring system, which is set up, is mend to be able to measure the effects of the sand storage dams on the groundwater table. The effect of the dam can be seen in the difference in the groundwater level in the region between the time before the dam was build en the time after the dam was build. The objectives of the traineeship of the students that went to Kisayani this year were to set up the program and start measurements of the groundwater table in the time before the dam was build.

To be able to call the difference in groundwater level the effect of the sand storage dam, it is also necessary to know the effect of other, external factors, which can affect the groundwater level, like precipitation, temperature and evaporation. For this reason there has to be a weather station in Kisayani, where the mentioned meteorological factors can be measured. If these data is available the part of the difference of the groundwater level due to the external factors can be calculated and thus the effect of the sand storage dam. A rain gauge was already installed at Kisayani Primary School by the previous group, so this can be extended to a more equipped weather station.

Resuming the above mentioned objectives the following objectives can be formulated:

- The continuing and improving of the hydrological measurement system in the Ngunga stream near Kisayani, Kitui district.
- To start measurements of the groundwater levels in the Ngunga stream.
- To extend the weather station at Kisayani Primary School in Kisayani.

6 Theory about the sand storage dams

In this chapter the theory of the sand storage dams will be described. First the building of a sand storage dam will be discussed, followed by a paragraph about the theory of the working of the dams. Finally a several existing dams that we had visited are described. First three dams that are not yet been filled up with sediment will be described and next four dams that are already filled up with sediment.

6.1 The building of a sand storage dam

The sand storage dams are build by the community members of the communities that are going to use the water that comes available after the building of the dam. So if you didn't helped building the dam you are not allowed to use the water. SASOL provides the knowledge that is necessary for building a dam by assigning an artisan to every location were a dam is being build. SASOL also provide the materials, like cement, barbwire and digging equipment, for free.

The first thing SASOL does when they start with building dams in a new area is to look for places where a dam can be constructed. The technical managers go to streams and look for good locations, these are places where there is rock layer near the surface and which are close to a community. If the technical manager has found a good location the community managers go to the nearby communities to interest them for building the dam. If the communities are interested, the building of the dam can start in the first dry period and of course an artisan and equipment has to be available.

The building of the dam is done in four phases. The first thing that has to be done is to make a trench from the surface to the rock layer, sometimes more than 5 metres deep (see Figure 6.1) . The soil and rocks that are dug out of the trench are stored, because they are used for making the dam. The trench has to have at least the wide of the river. In most cases the trench has to be wider, because the necessity of side wings. These side wings have to be wide enough to prevent the river from bypassing the dam and to prevent seepage. After the trench has been made deep and wide enough, the artisan can start with making small walls on the sides of the trench. These walls will be the outsides of the dam. The artisan uses cement and stones, which came out of the trench or are collected in the surrounding of the dam, to create these walls (see Figure 6.2). After making these walls reinforcement is placed in the dams, the reinforcement exists of barbwire and is not placed in a really functional way, as is argued by Beimers, P.B.; Eijk, A.J. van; Lam, K.S.; Roos, B.. When the reinforcement is placed, the space between the walls can be filled with rocks and concrete. The height of the dam is determined by the technical manager and depends on the necessary amount of water that has to be stored in the reservoir and local conditions. Plastering the outside of the dam, to prevent water to get trough, finishes the dam. For more information of building a dam see the Project Report, improved design sand-storage dams, Kitui district, Kenya.

Figure 6.1: Digging a trench **Figure 6.2: Building the wall**

When the dam is finished you can divide the lifetime of the dam in 2 phases.
The first phase is the time that the reservoir of the dam is not yet filled up with sediment, and sedimentation in the reservoir is still taking place. So there is a large surface water reservoir, where the farmers and other water users can easily collect their water. The second phase starts when the process of sedimentation has ended.

6.2 The working of a sand storage dam

By building a sand storage dam in the riverbed a reservoir is created. In this reservoir water can be stored so that it can be used for irrigation, drinking water and for household purposes. When a dam is build a process of filling the reservoir with sediments will be started in the following rain seasons. In this report the time in which the reservoir fills up with sediment, is named phase one. The process of sedimentation goes on until the level of the riverbed has reached the same level as the top of the dam. This process will last four to five years. This number is an experience number, mentioned by SASOL and depends mainly on the amount and the intensity of rainfall during the rain season. If there is no or too less rain there will be no discharge in the river so the process of sedimentation doesn't even start. In the Ngunga stream this was the case for the last two years. If the river is flowing sand particles will sedimentate and, after years, a sand package will be formed in front of the dam. In the first years after completing the dam an open water storage is created (see Figure 6.3). However the water easily can be polluted, the community can already use it. During the process of sedimentation a sand package is formed which can store water. If this process is completed, the size of the sand package has reached its maximum. Now phase two starts and will last for the rest of the lifetime of the dam.

Figure 6.3: Sand storage dam, phase 1

In the sand package that will be formed, water can be stored (see). In the dry season water, which has precipitated during the rain season, can be used. There are several advantages of groundwater storage above open water storage. One of the most important advantages is the biological reliability of the water. If several precautions are taken, ground water will be bacteriological reliable. The main precautions are: to avoid sources of pollution in the surrounding of the dam and to prevent that cattle uses the same scoop holes as the scoop holes that are used by people. A second big advantage is the amount of evaporation. The evaporation of groundwater is far less than the amount of evaporation of open water. Thus in case of ground water storage, there can be made longer use of rain than in case of open water storage. Other advantages are the big amount of water that will be available and the decrease of diseases that are spread by organisms, which uses open water to multiply, like malaria and bilharzia.

Figure 6.4: Sand storage dam, phase 2

Another positive side-effect of sand storage dams is that the infiltration of water in the riverbanks shall increase, due to the higher groundwater table in the river bed in front of the dam. This effect increases the possibilities for agricultural activities on the riverbanks. In the area around Kisayani cultivation of crops is hardly possible because of a lack of water. At several places the groundwater table was as low as 4 metres below surface level, even just beside the river.

The total amount of water that can be stored depends on the size of the sand package, which depends on the height of the sand storage dam, the slope of the river, the width of the river and the depth of the rock layer (see Figure 6.5). The impact of a sand storage dam can be lowered by the presence of a natural barrier, existing of a rock layer that reaches and crops out of the riverbed. This is the case at the proposed dam site in the Ngunga stream (see figure 6.4). 200 meters upstream of the proposed dam site is an impervious rock layer reaching to the surface of the riverbed.

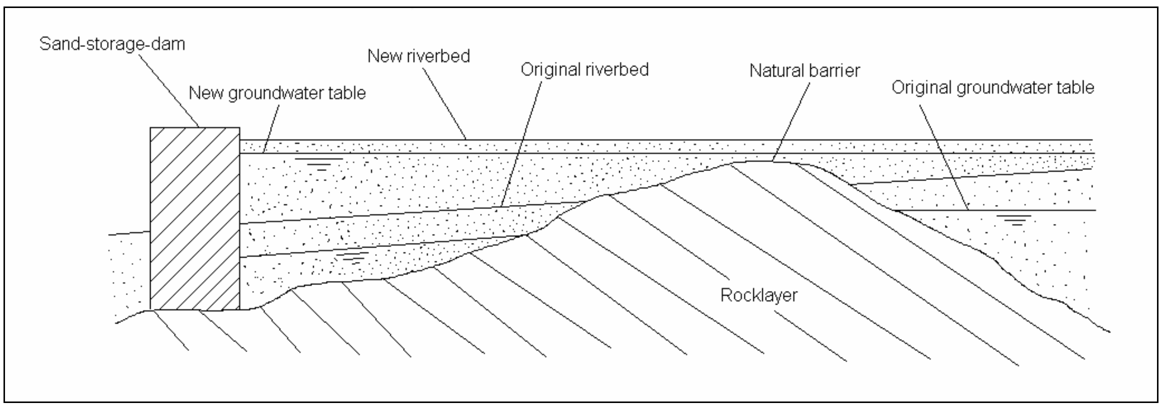


Figure 6.5: The working of a sand storage dam

6.3 *Investigation of existing sand dams*

To see how the sand dams are working in practice we visited several existing dams, which were situated near Kitui.

6.3.1 Sand storage dams phase 1

The first day we visited three dams that were build in 2001 and 2002 and were not yet filled with sediment. So these dams were still in phase 1.
At the upstream side of the dams there were reservoirs that were filled with water. After the building of the reservoirs, agricultural land was created on the banks of the reservoirs.

The farmers that where using the water of the three reservoirs told us that the reservoir didn't fall dry during the dry seasons and that the yield of there land has increased last year because there was more water available. All three reservoirs were still almost full after a month in the dry season. This means that the farmers can make more use of the water, because in the next rain season the reservoir will be filled again. At the end of the dry season the water level of the reservoir should be almost zero, at that time all the water that was available had been used. If the water level of the reservoir is still high at the end of the season there will be spilled a lot of water.

On the next pages the different dams we saw will be described and a few specific properties will be mentioned.

Dam 1: Syokahuryu C:
This dam was built on 18 February 2002 at a narrow point in the river with high banks. The banks existed of sand. The reservoir that was created was almost 150 meter and had, just in front of the dam, a depth of 1,20 meter. The width of the reservoir decreased very rapid with the distance of the reservoir to the dam. Behind the dam the ground was wet and there were some pools. We think that the water came from bank exfiltration or seepage from under the dam.

Dam 2: Syokahuryu B:
This dam location was very handy, because of the rock formations in the riverbed. On both sides of the river the banks existed of rock. Between these rock formations the dam was build. We could see that the level difference of the water in the reservoir was approximately 1 meter. This could been seen from the flood marks in the trees which stand in the water. The reservoir was smaller than reservoir 1, about 40 meters long. The farmers that are using the water from the reservoir told us that the water level in the well had become higher since the dam was build. So the groundwater level near the well has also become higher. Behind the dam there were many pools.

Dam 3: Kamumbuni:
This was a small reservoir, but the water level was still very high, almost at the level of the bar. Behind the dam there were some signs of erosion of the back of the dam. There was a distance between de floor level of the dam and the floor level of the river. It is important to inspect the dams after every rain season to see of there are signs of erosion and to take measures against it. Of course there should also be paid attention of preventing the possibilities of erosion when the dam is build.

6.3.2 Sand storage dams phase 2

At the second day of our investigation of already build sand dams we visited four sand-dams that were already in phase 2. Those dams were build four years ago and were already filled with sediment. At al the dams we saw a groundwater level difference at the dam. In the bed of the river the groundwater level was approximately 25 centimeter under the bed surface. The river where the dams were built in had a width of 10 to 12 meters. The bed existed of course sand with rock formations; the banks existed of rock or sand with elephant grass on it to protect the sandbanks to erosion. There were indications of erosion on some parts of the riverbanks.

Dam 4: Syonganga
This dam was build between two rock formations and creates a groundwater level difference of 1,20 meter.

Dam 5: Kwa Kangesa
This dam was made between a bank existing of sand and a bank existing of rock, there was some seepage trough the sanddam.

Dam 6: Kwa Ndunda
This dam was made between two banks existing of sand. The way of the river was changed by planting elephant grass at the banks, this was done to let the river flow over the dam. There was not much danger of erosion at the other bank because of the high bank.

Dam 7: Kwa Lwanga
This dam was build between two rocky banks, a perfect place, but the groundwater level difference at the dam was a bit disappointing. There was only a difference of 0,40 meter, this can be explained by the fact that the dam was very low.

6.3.3 Benefits of the dams

As seen at the different dam sites, there can be concluded that after building of the dam there became ground and water available for cropping. There were a lot of farmers that grow their crop at the banks of the river. The water they needed for irrigation was gathered in two different ways, depending on the phase of the dam. When the dam was in phase 1, with an open water reservoir, the farmers took their water out of the open water of the reservoir. When the dam has reached phase 2, the reservoir has been sedimentated, the farmers take their water from scoop holes in the riverbed. This is possible by the raise of the ground water level by the dams. It was only strange to see that farmers were also collecting water from scoop holes just downstream of the dam. At this sites there was also a high groundwater level. The inhabitants because of the salinity of the water did not use one well.

The farmers found it easier to collect the water from the open water reservoir (phase1), but the water collected from the scoopholes (phase 2) is cleaner. And a lot of water is evaporated from the open water reservoir, the evaporation in phase 2 is almost negligible.

6.3.4 Conclusions

- There is a water difference at the dam site.
- The farmers say there is more water available and the groundwater level has rise.
- The farmers can use more water then they are currently doing.

6.3.5 What can go wrong?

When we were just walking around in Kitui we found two dams were there had been some problems, as you can see in the pictures below.
In the first picture (Figure 6.6) you can see a dam, which has too short sidewalls, so the river just changed his way and passed the dam on one side. So you should always make the sidewalls long enough. The only measure you can take if the dam is finished and the river still managed to go around the dam is to make other bigger sidewalls, as can be seen in the second picture (Figure 6.7).
In the third picture (Figure 6.8) you can see another possible problem with a dam, this dam has a hole in it. This is not really dangerous or bad, but the groundwater level rise upstream of the dam will be less than when there was no hole, because water is streaming through the hole.

Figure 6.6: Dam with too short sidewalls

Figure 6.7: Dam with extended sidewalls

Figure 6.8: Dam with a hole in it

7 Area exploration

7.1 River profile

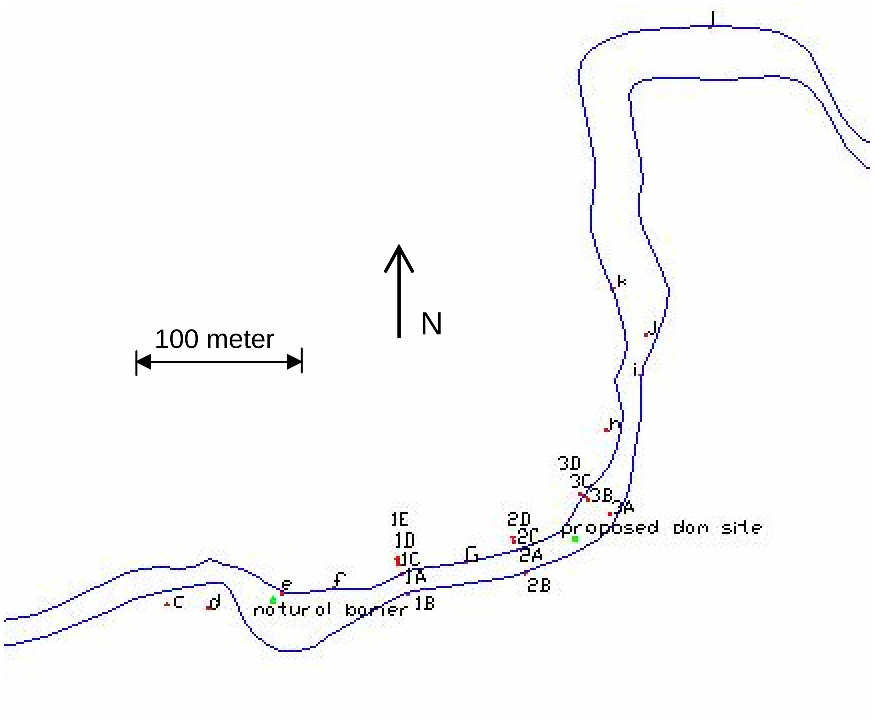


Figure 7.1: River profile near proposed dam site

7.2 Groundwater tables

During the traineeship many piezometers were installed. At several places the groundwater level could be measured, see appendix 2. These data is presented in the graph below, Figure 7.2. Many times the rock layer was earlier reached than the groundwater table so in those cases the groundwater levels could not be measured during the traineeship. Although a good impression of the groundwater tables could be obtained by looking to the depth of the scoop holes in the river. In the wetter seasons it is possible to measure the water depths in the piezometers, also in those, which did not reach the groundwater table in the dry season.
In the part of the river between the way to Kisayani (circa 1300 metres upstream of the reference point) and the Kamunyuni dam, (circa 1000 metres upstream of the reference point) were four scoop holes. At least three of these scoop holes reached the groundwater table. The depth of the water table in these scoop holes was approximately 2 metres below surface level. Just in front of the dam the groundwater table was just below the surface, but due to pollution there was no scoop hole. The next scoop hole that was in use during the traineeship was more than 800 metres downstream of the Kamunyuni dam.

This scoop hole and thus the water table was circa 4 metres deep. Between this scoop hole and the Kamunyuni dam were two other scoop holes that were in use recently, but already at the beginning of the traineeship (in the first week of July) they were already dry.

Between the proposed dam site and point O, 1500 metres downstream, was no scoop hole. Between point O and point P were several scoop holes, all with a water table between 2 and 3 metres below surface level. In this part of the river the water table was rather shallow which, may be points to a natural barrier more downstream. At point P water was found circa 2,5 metres below surface level.

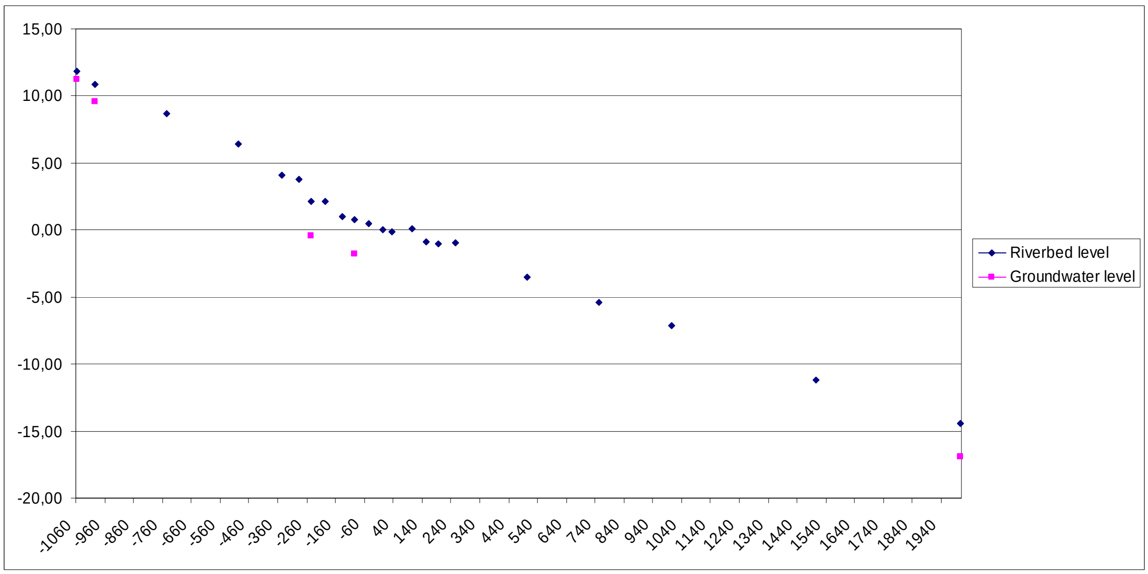


Figure 7.2: Groundwater levels

7.3 Slope area method

In the dry part of the year there is no discharge of the Ngunga-stream, but in the rain seasons of wet years the streams can have a huge discharge. To make a rough estimation of the discharge of the Ngunga-stream during the rain season of wet years, the slope area method was used.

7.3.1 Principles

The slope area method is a method to estimate the discharge of a river. The method is not as accurate as many other methods, but it is sometimes the only method that can be used, like in our situation where there is only a stream in certain times of the year. For the slope area method the cross-sectional area, the hydraulic radius and water slope are required.

The hydraulic calculations are based on Chezy's formula:

$$Q_j = \overline{u}_j \cdot A_j = C_j A_j \cdot R_j^{1/2} \cdot i^{1/2} = K_j \cdot i^{1/2}$$ Equation 7.15

with $K_j = C_j \cdot A_j \cdot R_j^{1/2}$ Equation 7.26

C_j = Chezy coefficient
R_j = Hydraulic radius

The factor K_j, the so-called conveyance, contains the geometrical quantities. When using the Manning sandroughness (n), C_j reads,

$$C_j = \frac{R_j^{1/6}}{n_j}$$ Equation 7.37

By estimating the values of K_j the discharge can be calculated with:

$$Q = i^{1/2} \cdot \sum^{j} K_j$$ Equation 7.48

In the above method the greatest difficulty lies in the determination of channel roughness. It is very difficult for even an experienced surveyor to arrive at an objective value. Indicative values for channel roughness are provided in appendix 9.

7.3.2 Data

The discharge is calculated by using the level difference of the riverbed between the reference point and the point A from crossing 1. Those points are selected because they are both in the riverbed upstream of the big tributary and the river section is straight and uniform. It is supposed that the gradient of the riverbed is the same of the gradient of the water level when the Ngunga-stream is streaming. This is a rough assumption, but it is the only available data. The height of the water level is taken as the height of the riverbanks, from experience it is said to be the height of a once a year discharge.

7.3.3 Calculation

- Height reference point = 0 m
- Height point A from crossing 1 = 1,025 m
- Distance between the reference point and point A from crossing = 144 m
- Gradient of the riverbed / water level I = $\frac{1,025m}{144m} = 0,007 = 0,7\%$
- Width of the river b = 20 m
- Height of the water level at once in a two year discharge h = 1,0 m
- Cross-sectional area A = 20 m²
- Wetted Perimeter P = 22 m
- Hydraulic radius R = $\frac{A}{P} = \frac{20m^2}{22m} = 0,9m$
- The Chezy-coefficient is determent with Table 14.10, for minor streams with a Hydraulic radius from almost 1 the Chezy-coefficient is between 30 and 40

The formula for the discharge from the Ngunga-stream in the rainy season is:

$$Q = C \cdot A \cdot R^{1/2} \cdot i^{1/2}$$

$$C = 30\, m^{1/2} / s \rightarrow Q = 30 \cdot 20m^2 \cdot 0,9^{1/2}\, m \cdot 0,007^{1/2} = 47,6\, m^3 / s$$

$$C = 40\, m^{1/2} / s \rightarrow Q = 40 \cdot 20m^2 \cdot 0,9^{1/2}\, m \cdot 0,007^{1/2} = 63,5\, m^3 / s$$

7.3.4 Accuracy

The accuracy of the data used to calculate the discharge is not very accurate, so the discharge won't be very accurate to. But the biggest error is made with the Chezy-coefficient. This coefficient can not be calculated exactly but influences the discharge linear. In this case the coefficient, and by this also the discharge, already differs 33%. So there is no need to measure the other data very precise, because the Chezy-coefficient is not exact and gives the biggest error.

8 Waterbalance

The water balance is a formula in which you measure all the water that is entering, leaving and staying in a certain research area. This research area must been chosen before the water balance is made. In our case the research areas that we chose was the area between the Kamunyuni dam and the proposed dam site, this is upstream of the proposed dam site and the positive effects of the dam are expected here. And the area from the proposed dam site to 2000 meters downstream of that point. See appendix 2 for a drawing of the research areas, this is downstream of the proposed dam site and the negative effects of the dam are expected here.

The most simple and uniform shape of the water balance is:

$$Q_{in} - Q_{out} = \frac{\Delta B}{\Delta t}$$

Q_{in} = The total discharge of water entering the involved research area in m^3/s
Q_{out} = The total discharge of water leaving the involved research area in m^3/s
$\frac{\Delta B}{\Delta t}$ = The change in the storage of the research area, this is also in m^3/s

You can make a water balance for surface water, groundwater in the research area. In paragraph 8.1 we will show the water balance for the surface water in the research area, this kind of water balance is most important during the first phase of a sand storage dam. In paragraph 8.2 we will show the water balance for the groundwater in the research area, this kind of water balance is most important during the second phase of a sand storage dam.

8.1 The surface water balance

In the first phase of the sand storage dam the reservoir in front of the dam will exist of surface water. The water balance for the surface water reservoir can be used to see how much water comes available for use and to see is how long the reservoir will be full with water when the water from the reservoir is used. The surface water balance has the form of:

$$\partial Q + A \times P - A \times E = A \times \frac{\partial h}{\partial t}$$

- $\partial Q = Q_{in} - Q_{out}$
- Q_{in} = the discharge from the Ngunga stream that is entering the reservoir in front of the dam + the seepage from the banks to the reservoir (water that flows through the banks to the reservoir),the seepage is a function of the water level difference betweeen the reservoir and the groundwater level and the permeability of the banks + the surface runoff from the catchment in the reservoir.[m^3/s]
- Q_{out} = the discharge from the Ngunga stream that is leaving the reservoir by flowing over the dam + the water that is extracted from the reservoir for domestic or

agricultural use + the seepage from the reservoir into the banks (water that flows from the reservoir into the banks).[m³/s]

- A = the surface area of the reservoir, this can depend on the waterlevel in the reservoir.[m²]
- P = the precipitation depth, this is the amount of rainfall.[m/s] This can be measured with a raingauge, which is a part of the equipment of the weather station.
- E = the evaporation, this is the amount of water that goes from the liquid phase to the gas phase.[m/s] This can be measured with a Class B evaporation pan, which is a part of the equipment of the weather station.
- $\frac{\partial h}{\partial t}$ = the change of the waterlevel of the reservoir seen in the time.[m/s]

8.2 The groundwater balance

In the second phase of the use of the sand storage dams, the water reservoir is filled with sediment. So the water in the reservoir is now groundwater. In this paragraph we will make a water balance for the total amount of groundwater in the research area. The formula that needs to be used is:

$$\partial Q_{gws} - A_{plants} \times T + O_{river} \times S + A \times I = A \times n \times \frac{\partial h}{\partial t}$$

- ∂Q_{gws} = the groundwater discharge that is entering the research area minus the groundwater discharge that is leaving the research area and the amount of water that is distracted from the groundwater for domestic or agricultural use.[m³/s]
- A_{plants}= The area of the research area where plants are growing. This is important because the plants distract water from the groundwater for growing.[m²]
- T= the amount of water distracted from the groundwater by plants per m² plant coverage.m³/s/m²
- O_{river} = The area of contact between the river and the groundwater.[m²]
- S= The amount of seepage between the river and the groundwater per m² of contact surface.[m³/s/m²]
- A= the total surface area of the research area.[m²]
- I= the amount of water that infiltrates from the surface water to the groundwater.[m³/s/m²]
- n = the porosity, the empty volume divided by the total volume of the ground[-]
- $\frac{\partial h}{\partial t}$ = the change of the groundwater level in time.[m/s]

9 Sedimentation

The reservoir in front of the sand storage dam will be filled with sediments in the years after the building of the dam. From the experience of the sand storage dams that have been build 7 years ago, it is said that the filling of a reservoir takes about 4 years. The sediment that sedimentates in front of the sand storage dam will be erosion material from the catchment between the build dam and the first upstream dam. In the catchment of the Ngunga stream are a lot of marks of erosion. There are a lot of gullies near the Ngunga stream, especially near the footpaths because there the vegetation is removed . To see how long it takes to fill a reservoir you can make a global calculation of the sediment yield of the catchment. The Fournier calculation is used to make an estimation for the sediment yield.

$$Log_{10} Q_{sediment} = 2.65 \times Log_{10}\left(\frac{p^2}{P}\right) + 0.46 \times \left(Log_{10} H\right)\left(\tan S\right) - 1.56$$

$Q_{sediment}$ = Mean annual sediment yield [gr/m²]
p = highest mean monthly precipitation depth[mm]
P = mean annual precipitation depth [mm]
H = mean altitude above sea level [m]
S = mean slope of the river basin [degrees]

For this calculation you need:

1. Catchment area: this is the area between the Kamunyuni dam and the proposed dam site. The students Malda, Winsemius and Burger calculated this area around 1,5 km².
2. Mean altitude above sea level: Nairobi is at an altitude of 1600m and Mombasa is at an altitude of 0 m. Kitui district and Kisayani is between those two places and the catchment area is not on a hill or in a valley so a rough estimation is an altitude of 800 meter above sealevel.
3. Mean slope of the river basin: This slope is not measured but a roughly estimation.
4. Monthly rainfall: Because there were no data available of a weather station at Kisayani, we used data of the Subchief camp of Kiyatume (from 1975 to 1979. More resent data or from closer places where not available. The numbers in gray background are estimates.

Table 9.1: Calculation of sedimentation

River basin characteristics:	
Catchment area:	2 km^2
Mean altitude above sea level :	800 m
Mean valley floor gradient:	$9 \cdot 10^{-3}$ m/m
Mean slope of the river basin:	7 degrees

Month	Average monthly rainfall in mm

	1975	1976	1977	1978	1979	Mean
Jan	0	0	10	37	218	53.0
Feb	3	0	71	94	4	34.4
Mar	0	6	20	113	105	48.8
Apr	150	66	186	105	209	143.2
May	23	4	4	3	72	21.2
Jun	0	0	0	0	14	2.8
Jul	0	0	0	0	3	0.6
Aug	0	0	0	0	0	0.0
Sep	11	17	0	0	0	5.6
Oct	30	0	0	79	37	29.2
Nov	185	25	60	187	233	138.0
Dec	12	66	196	207	162	128.6
Yearly total	414	184	547	825	1,057	605.4
Max. Monthly rainfall	185	66	196	207	233	143.2
Mean annual sediment yield [tons]	9,682	352	6,285	2,825	2,743	910
Mean annual sediment yield [m3]	4,841	176	3,142	1,413	1,371	455
Equivalent soil loss over entire catchment [mm]	2.42	0.09	1.57	0.71	0.69	0.23

So a very rough estimation of the amount of sediment that comes available is $455 m^3/y$. A part of this sediment will pass the dam but a large part will sedimentate in front of the dam.

10 Hydrological measurement system

To measure different hydrological characteristics of the area, several measuring methods have been applied. These methods and their results are described in this paragraph. The methods, which are described, are:

- Measuring of the groundwater table by using piezometers
- Measuring the hydrological conductivity of the by doing augur hole tests and inverse augur hole tests

10.1 Groundwater

The most important hydraulic parameter to determine the effects of the sand storage dams is the phreatic plane. All points of the groundwater table form this plane. The objectives of the sand storage dams is to form a groundwater storage (see chapter 6.2). If the dams are really effective there should be a higher groundwater level in front of the dams than behind the dams. To prove this assumption a network of piezometers has been installed. This was done by drilling a hole with a hand augur drill. The depth of the holes depends on the depth of the rock layer; in practice the depth of the holes varied from 2 to 4 metres. When the bore hole was finished a PVC tube was placed. The lay out of the network will be described in the next paragraphs. Paragraph 10.1.1 describes the working of the piezometers, paragraph 10.1.2 describes the piezometers that are placed in several cross-sections of the river and paragraph 10.1.3 describes the piezometers that are placed in the longitudinal direction of the river.

10.1.1 Piezometers

The piezometers which are installed exist all of a tube of PVC with a diameter of 4 centimetres. To enable the inflow of water the tube was perforated over the whole length. The space between the tube and the bore hole was filled up with course sand, so that the inflow of water not is hindered. The tube was closed with a lit of the same material as the tube. For a schematically sketch of the tubes see Figure 10.1.

The water level in the varies with the surrounding water table and can be measured with help of a plopping device. Such a device exists of a small plastic bottle that can float on the water, tied at a rope of a few metres. If the plopping device will be dropped into the tube you a sound like ‘plop’ will be heard when the plopping device reaches the water table. To determine the height of the water table in the tube only the length of the rope has to be measured with a ruler.

Figure 10.1: Sketch of a piezometer

During the traineeship came true that local people were so interested in the tubes that some people opened the tube to take a look in the tube. This was not done very carefully so that many tubes collapsed. This caused of course many extra work. To prevent that the tubes could collapse if they should be opened again, a protection of a casing of concrete was made (see Figure 10.2). This casing was also used to write the name of the piezometer, the date (month and year) and the organisation for which the traineeship was done (SASOL and TU-Delft).

Figure 10.2: Concrete casing of the top of a piezometer

10.1.2 Piezometers in cross-sections of the river

The previous group of student which did a traineeship in Kisayani had made three cross-sections with piezometers in the river near the proposed dam site. The purpose of these cross-sections is to investigate the infiltration of groundwater in the riverbanks. This part of the research was done by the previous group so that in this report only will be addressed to the report of their traineeship (report Burger, Malda & Winsemius, 2003)

Two other cross-sections were made near the Kamunyuni dam: one upstream and one downstream of this dam.

10.1.3 Piezometers in longitudinal direction of the river

During the traineeship a series of piezometers was placed in the longitudinal direction of the river. Most of them were placed near the proposed dam site. In the upstream direction piezometers were placed until the Kamunyuni dam which is approximately 1000 meters upstream of the proposed dam site. In the downstream direction piezometers were placed until approximately 2000 meters downstream of the proposed dam site. The surrounding of the proposed dam site shall encounter the heaviest effects of the new dam, so the piezometers near the proposed dam site are placed nearer to each other than the more remote piezometers. For the exact locations of the piezometers see Appendix 2: Map Ngunga stream with piezometers
See document ngunga.wmf

Appendix 3: Data piezometers

10.2 Hydraulic conductivity

Hydraulic conductivity is a measure for the ability of the soil to let water flow through it. The hydraulic conductivity depends on the viscosity of the water and the geometry of the pores in the soil.

Darcy found the following relation between the amount of liquid flowing through the soil, the hydraulic conductivity and the decrease of liquid energy per unit length:

$$q = -K \frac{\partial h}{\partial s}$$ Equation 10.9

Where:	q	is the discharge per area $[LT^{-1}]$;
	K	is the hydraulic conductivity $[LT^{-1}]$
	h	is the hydraulic head [L]
	s	is the distance in flow direction [L]

Hydraulic conductivity measurements can be divided into measurements above the groundwater table and measurements below the groundwater table. In this paragraph first the augur hole test will be described. With this method the hydrological conductivity of the soil below the groundwater (saturated zone) table is measured. Next the inverse augur hole test will be described. This method measures the hydrological conductivity of the soil above the groundwater table (unsaturated zone).

10.2.1 Augur hole test

Priciples

The auger hole method is used to determine the hydraulic conductivity in saturated soils. The large in-situ sample size ensures representatively. The test is relatively simple and when properly performed gives reliable results.

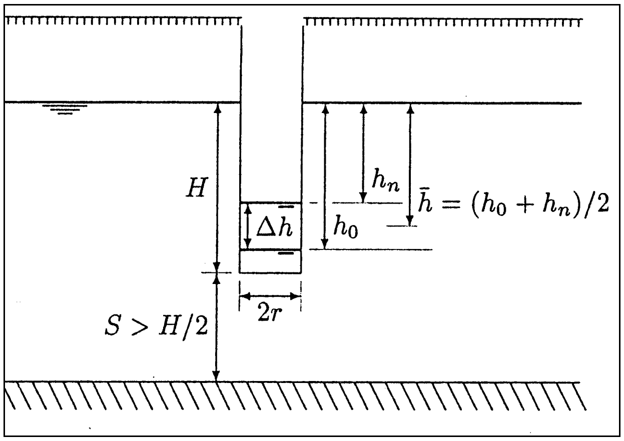


Figure 10.3: Auger hole and parameters

A hole is drilled to a certain depth below the groundwater table (see Figure 10.3). The necessary depth depends on the soil characteristics, for homogeneous soil a practical depth is 60 to 70 cm under the groundwater table. Once the water inside the borehole equals the phreatic head, water is instantaneously extracted from the borehole. The time needed to restore the head and the head difference is the measure to derive at the hydraulic conductivity. The water level inside the borehole is measured with a measuring tape attached to a float at different times from the start, commonly at equal time intervals. The necessary lowering of the water level inside the borehole is about 20 to 40 cm, depending on the hydraulic conductivity of the soil. For a high conductivity the lowering can be 20 cm. The elapsing time, between lowering of the water level in the borehole and the water being at "groundwater table" level again can vary.

Assuming that there is no change in groundwater level during the measurement and that the soil is homogeneous and isotropic, the following relationship holds:

$$K_{sat} = C\frac{\Delta h}{\Delta t}$$ Equation 10.12

Where	K_{sat}	is the saturated hydraulic conductivity [LT^{-1}]
	C	is a geometry factor [-]
	Δh	is the difference in head during measuring time [L]
	Δt	is the measuring time [T]

The factor C depends on the geometrical configuration of the experiment. When the bottom of the borehole is sufficiently above the impermeable boundary, i.e. S>H/2, it can be computed using

$$C = \frac{4000}{(\frac{H}{r}+20)(2-\frac{\bar{h}}{H})}\cdot\frac{r}{\bar{h}} \quad \left[\frac{m}{d}*\frac{\sec}{cm}\right]$$ *Equation 10.13*

Where H is the borehole depth below the water table [L]
$\bar{h}$ is the average draw down during measurement time [L]
r is the radius of the borehole [L]

Results

To determine the hydraulic conductivity of the riverbed several augur hole test were done. When doing the tests several problems occurred. When the borehole was drilled, the walls collapses continue due to the coarse sand. The diameter of the borehole was at several places more than half a meter, but could not be measured in a reliable way. Also extracting of water from the borehole, so that the necessary lowering of the water level should be reached, could hardly be done. Because of mentioned problems there are no data of this test.

10.2.2 Inverse augur hole test

Principles

The inverse auger hole method is used for on-site determination of the hydraulic conductivity in saturated soils. It provides for rapid and simple calculations. The large in-situ sample size ensures representatively.

A hole is drilled to a certain depth, which ends in the unsaturated zone (see Figure 10.4). During measurement, water is pumped into the borehole and the decline of the head inside the borehole is measured. The depth of the hole should be about 50 cm, so a draw down of the water level of about 20 cm can be achieved. The most common diameter for the (inverse) auger hole is 8 cm.

The water head inside bore hole, plus half the radius of the borehole is plotted versus time on semi-logarithmic graph paper. K_{sat} is then computed as

Figure 10.4: Line up of inverse augur hole experiment

$$K_{sat} = 1.15r \frac{\log[z(t1) + \frac{1}{2}r] - \log[z(t2) + \frac{1}{2}r]}{t2 - t1} \qquad \text{Equation 10.11}$$

Where r is the radius of the borehole [L]
Z(t1) is the head at time t1 [L]
Z(t2) is the head at time t2 [L]

As with the standard auger hole test (described in paragraph 10.2.1), this technique is rapid and simple. Disadvantages are that the flow conditions are hard to determine and the requirement for large amounts of water to saturate the surrounding soils.

Results

Three inverse augur hole tests were done near cross-section y: two in the riverbed and one just in the left bank of the riverbed. When a hole was drilled and filled with water, for every time interval of 10, 20, 30 or 60 seconds the water level was measured (see Appendix 4: Data inverse augur hole tests). With equation 10.11 the hydraulic conductivity, K_{sat} can be calculated. To obtain more accurate results, log[z(t)+1/2r]was set out in a graph against the time. Through the graph a trend line was drawn (see Figure 10.5,
Figure 10.6 and XX). Now K_{sat} equals 1.15r multiplied by the slope of the trend line.

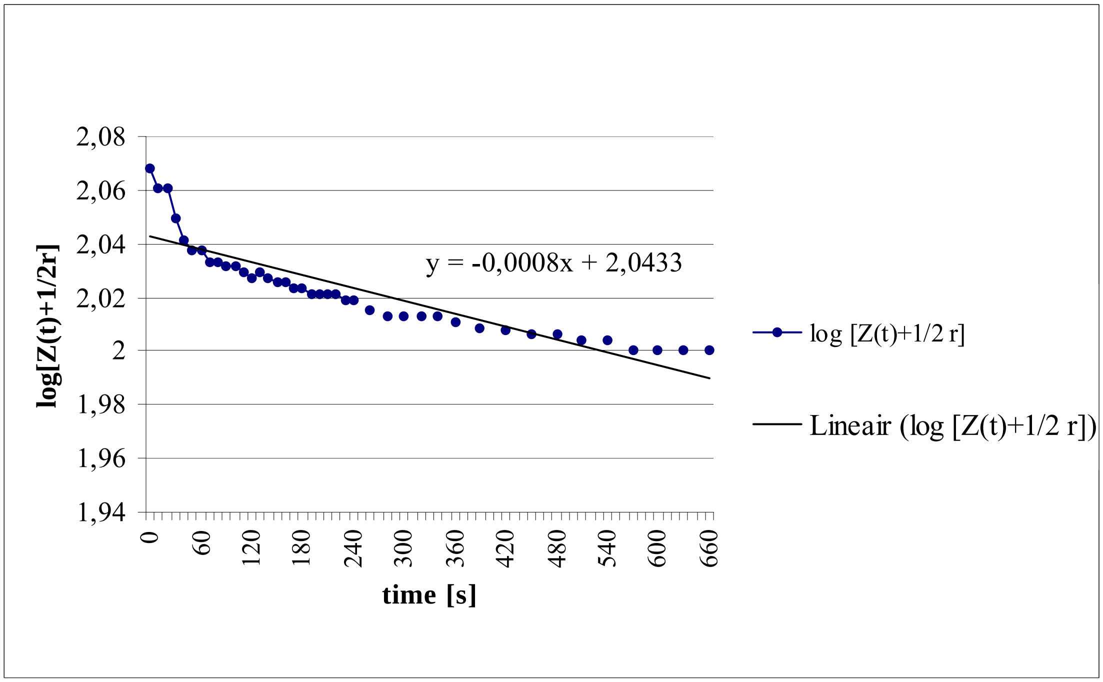


Figure 10.5: Results inverse augur hole test no. 1

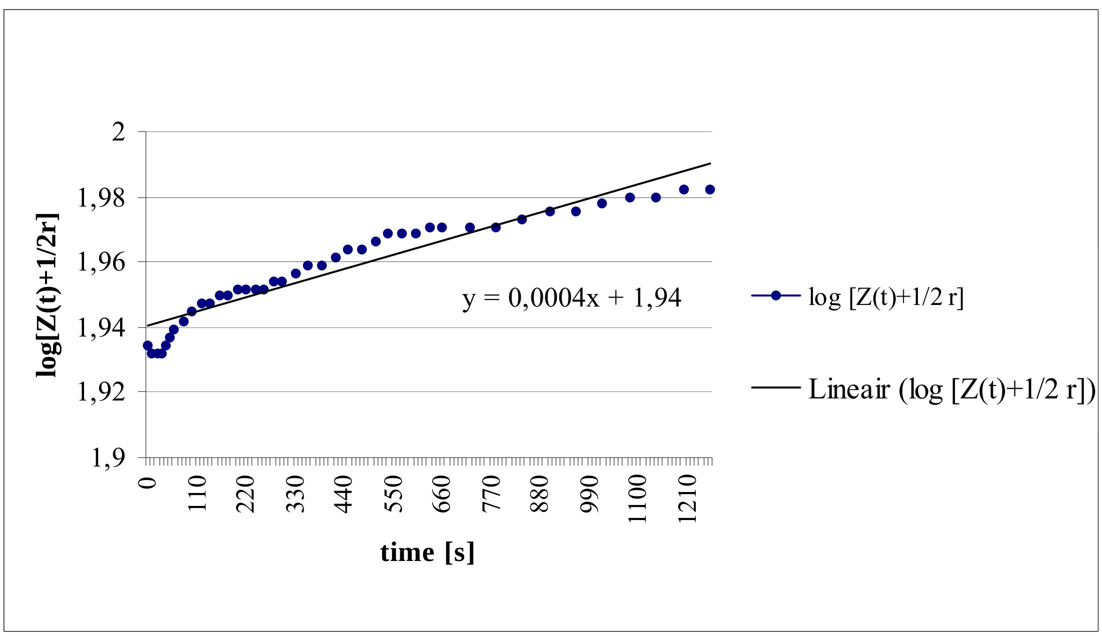


Figure 10.6: Results inverse augur hole test no. 2

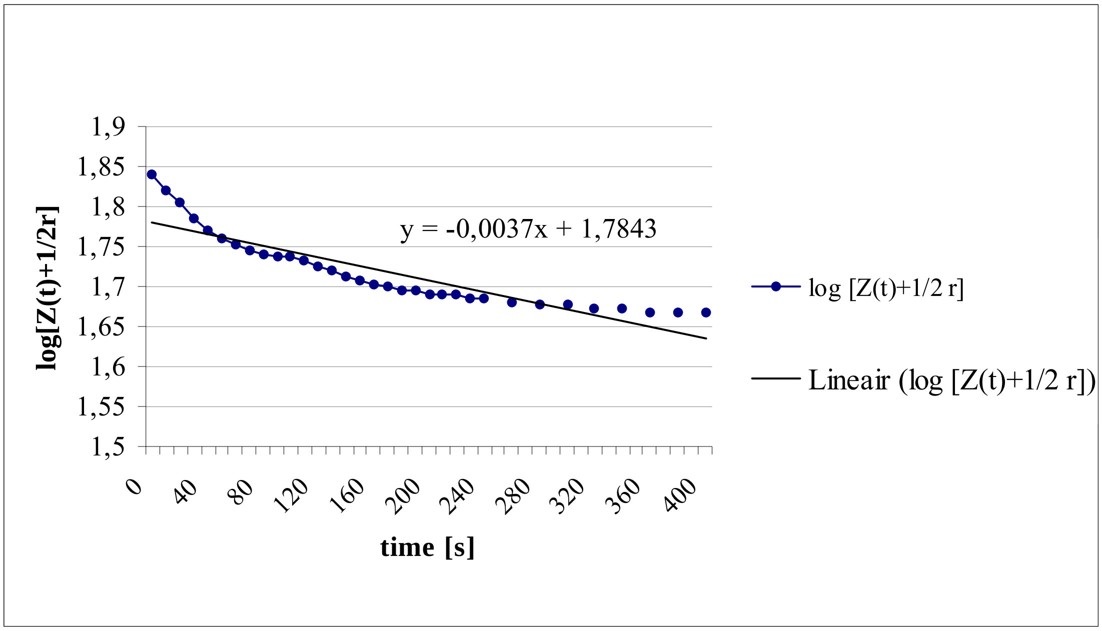


Figure 10.7: Results inverse augur hole test no. 3

The results of the three tests are shown in Table 10.1.

Table 10.1 : Results augur hole tests

	K_{sat} [m/day]
Test 1	4,77
Test 2	2,38
Test 3	22,06

The results of the three tests differs a lot, especially the result of test three seems improbable. The most likely reason for this deviation is the shallowness of the borehole, this was only 0,50 meters. Smearing of the borehole walls is another effect that can influence the measuring. Also inaccurate measuring can be the reason of the deviation. Probably the real hydraulic conductivity of the riverbed is between 2,0 and 5,0 m/day.

11 Setting up a weather station

For the coming research projects of the REAL-project there will be a need of all kinds of data to proof the effect on the groundwater level of the sand storage dams. There is not only a need of hydrological data, like groundwater levels and permeability, but also meteorological data is needed, like temperature, evaporation, humidity and rain data.

To see an effect of the dam on the groundwater level it is necessary to have data from the time before the dam was build and the time after the dam was build. Then you can see if there is a difference in groundwater level between the years before the building of the dam and after the dam was build. It is also necessary to have meteorological data of those years, other wise the difference of the groundwater level can be a result of a wet or dry year. So to prove that the difference of the groundwater level is an effect of the sand storage dam there has to be set up a weather station. The students Winsemius, Malda and Burger already started to set up a weather station at the Kisayani Primary School. They placed a rain gauge there.

One of the most important benefits of the sand storage dams is that the extra water is stored as groundwater. This means that the evaporation of the stored water will be almost zero. To see how much the benefit is we want to measure the evaporation. This can be done with an evaporation pan or with the Penman-formula. For the Penman formula you need a lot of data, like humidity and temperature. So we tried to improve and enlarge the weather station in co-operation of the KU Leuven students Nesen and Puttemans. The following equipment is now available at the weather station at the Kisayani Primary School:

2x Rain gauge:	Iron rain gauge Plastic rain gauge
Thermometer	Mercury thermometer, whit daily minimum and maximum temperature
Thermometer / Hygrometer:	Spring thermometer contains also a hygrometer, which measures the humidity
Evaporation pan:	This pan is an aluminium cooking pan, which is duck in the ground whit a ruler attached on the inside.

To see what kind of problems could be encountered when the equipment was in use, we used the equipment during our eight weeks of traineeship. We encountered a few problems whit the evaporation pan, like:

- Goats drinking out of the pan: We made a fence of bushes but first it was too low and thin. The goats just walked trough the fence or jumped over it. So we cut more bushes and made the fence higher and thicker. Of course the fence would influence the wind and so the evaporation, but this will be less than the effects (50mm) of the goats. At the Kisayani Primary School they made a real fence of barbwire to protect the equipment.

- Birds drinking out of the pan: When the problem of the goats was solved we still found extraordinary measurements. After a few days we found the cause in the birds who where drinking of the water. The solution for this problem was found in making a special construction of wire net to cover the pan. This construction can be removed when the pan is filled. The wire net has meshes that are small enough to prevent birds from drinking but the wind can easily pas the construction. So the influence of this construction on measurements will be minimal.

  The data that are collected at the weather station can be found in annex x. Here you can also find other meteorological data that we found from places nearby. To be sure that the measurements will be done in the right way in the years coming, there was a manual made for the weather station, which is included as annex x.

  The temperature will be measured four times a day and the minimum and maximum temperature will be written down. The evaporation pan is measured ones a day, in the morning. The rain gauges will also be measured every morning.

12 Conclusions and recommendations

12.1 Conclusions

The system that can measure the groundwater level is installed. The area that it covers by the system is big enough to be able to draw some conclusions after the dam is finished. The data that is already collected is like we had expected from visual inspection. The only problem is that we are not sure that the measurement continues after our Belgium colleges have left.

12.2 Recommendations

To be sure that the measurements of the groundwater level are done the same every time, SASOL should assign someone with the task to do the measurements every week and to be responsible for the maintenance of the system.

To be sure that the data from the groundwater level and the weather station are collected well, they should be collected by SASOL every month. At that time the new datasheets can be hand over to the person who is doing the measurement.

A half year after the finishing of the dam a group of students of the Delft University of Technology should go to Kenya to collect all the data and continue the measurement for a while. They also should write a rapport with conclusions about the effect of the san-storage-dams on the groundwater level.

The piezometer at location L is not working well, we think that the piezometer is not deep enough and that the water can't enter the piezometer very well. This piezometer should be re-installed

13 List of reference

- Beimers, P.B.; Eijk, A.J. van; Lam, K.S.; Roos, B. – *Practical Work Report, building Sand-storage dams, Kitui District, Kenya* – Kitui, 2001.

- Ir. Ertsen ; Drs. Twickler ; Prof. Ir. Brouwer – *Report start-up meeting REAL* – TU Delft, September 2002

- Frima, G.A.J; Huijsmans, M.A.; Sluijs, N. van der; Wiersma, T.E. – *A manual on monitoring the groundwater levels around a sand-storage dam* – Nairobi, June 2002

- Burger, A.S.; Malda, W.; Winsemius, H.C. – Research to sand-storage dams in Kitui district – Nairobi, August 2003

- *Re-hydrating the Earth in Arid Lands (REAL)*; Systems research on small groundwater retaining structures under local management in arid and semi-arid areas of East Africa – EC-Fifth Framework Programme ICA4-2001-10191; Technical Annex – April 2002

Abbreviations

DUT	=	Delft University of Technology
CITG	=	Civil Engineering and Geoscience
SASOL	=	Sahelien Solution Foundation
NGO	=	Non-governmental organization
REAL	=	Re-hydrating the Earth in Arid Lands

14 Appendices

Appendix 1: Map of Kenya

Figure 14.1: Map of Kenya

Appendix 2: Map Ngunga stream with piezometers

See document ngunga.wmf

Appendix 3: Data piezometers

Table 14.1: Data piezometers

Name	*Location*	*depth*	*10-7*	*17-7*	*24-7*	*31-7*	*7-8*	*14-8*	*21-8*
Cross. Y	1059 m Upstr.	0,99 m		0,93 [2]	x	D 0,95	D [5]	x	
Cross. Y2	1059 m Upstr.	0,65 m							0,62
Cross. Y3	1059 m Upstr.	0,70 m							0,60
Kamunyuni dam	1030 m Upstr.								
Cross. Z	1000 m Upstr.	2,20 m		1,20 [3]	x	1,26 [4]	1,28 [5]	1,29	1,29
Cross. Z2	1000 m Upstr.	1,26 m							D
Cross. Z3	1000 m Upstr.	1,38 m							D
Point A	750 m Upstr.	0,97 m				D 0,80	D [5]	x	x
Point B	500 m Upstr.	0,76 m				D 0,76	D [5]	x	x
Point C	350 m Upstr.	1,64 m				D 1,15 [4]	D [5]	x	x
Point D	290 m Upstr.	2,67 m				D 2,55 [4]	D [5]	x	x
Natural barrier	270 m Upstr.								
Point E	250 m Upstr.	3,44 m				D 1,98 [4]	2,39 [5]	2,49	2,57
Point F	200 m Upstr.	3,47 m		3,07	x	3,13	3,28 [5]	3,32 [6]	Error [7]
Cross. 1A	144 m Upstr.	2,27 m	2,23	x	x	x	D [5]	x	x
Cross. 1BR	144 m Upstr.	1,27 m	D	x	x	x	D [5]	x	x
Cross. 1CL	144 m Upstr.	3,17 m	3,35	3.42	3,44	3,58	D [5]	x	x
Cross. 1DL	144 m Upstr.	3,48 m	3,30	3.33	3,32	3,36	3,43 [5]	3,45	3,43
Cross. 1EL	144 m Upstr.	2,86 m	D	x	x	D 2,84	D [5]	x	x
Point G	100 m Upstr.	3,04 m				2,53	2,40 [5]	2,43	2,50 [8]
Cross. 2A	48 m Upstr.	1,79 m	D	x	x	D 1,82	D [5]	x	x
Cross. 2BR	48 m Upstr.	0,96 m	X [1]	x	x	D 1,02	D [5]	x	x
Cross. 2CL	48 m Upstr.	3,91 m	3,84	3.86	3,85	D 3,90	D [5]	x	x
Cross. 2DL	48 m Upstr.	3,89 m	3,88	3.89	3,88	D 3,49	D [5]	x	x
Proposed dam site	reference point								
Cross. 3A	34 m Downstr.	1,40 m	D	x	x	x	D [5]	x	x
Cross. 3BL	34 m Downstr.	2,46 m	D	x	x	x	D [5]	x	x
Cross. 3CL	34 m Downstr.	2,48 m	2.41	x	x	x	D [5]	x	x
Cross. 3DL	34 m Downstr.	2,23 m	D	x	x	x	D [5]	x	x
Point H	100 m Downstr.	3,23 m				D 3,18	D [5]	x	x
Point I	150 m Downstr.	2,06 m				D 2,03	D [5]	x	x
Point J	190 m Downstr.	2,70 m				D 2,30 [4]	D [5]	x	x
Tributary	200 m Downstr.								
Point K	250 m Downstr.	1,23 m					D [5]	x	x
Point L	500 m Downstr.	not functioning							

Name	*Location*	*depth*	*10-7*	*17-7*	*24-7*	*31-7*	*7-8*	*14-8*	*21-8*
Point M	750 m Downstr.	collapsed							D [4]
Point N	1000 m Downstr.	0,74 m							D
Point O	1500 m Downstr.	2,09 m							D
Point P	2000 m Downstr.	2,77 m							2,50

Notes:

a) Removed
b) depth 0,95 m
c) depth 1,34 m
d) Borehole was collapsed
e) Definitive piezometer layout
f) measured from top grey tube
g) brushes in tube
h) constriction in tube

Table 14.2: Grounwater levels

Name	Location	7-8-03	Ground-water level	14-8-03	Ground-water level	21-8-03	Ground-water level
Cross. Y	1059 m upstream	D	-	x	-		12,34
Cross. Y2	1059 m upstream		11,83		11,83	0,62	11,21
Cross. Y3	1059 m upstream		11,82		11,82	0,60	11,22
Kamunyuni dam	1030 m upstream						
Cross. Z	1000 m upstream	1,28	9,56	1,29	9,55	1,29	9,55
Cross. Z2	1000 m upstream		10,84		10,84	D	-
Cross. Z3	1000 m upstream		10,84		10,84	D	-
Point A	750 m upstream	D	-	x	-	x	-
Point B	500 m upstream	D	-	x	-	x	-
Point C	350 m upstream	D	-	x	-	x	-
Point D	290 m upstream	D	-	x	-	x	-
Natural barrier	270 m upstream						
Point E	250 m upstream	2,39	-0,28	2,49	-0,38	2,57	-0,46
Point F	200 m upstream	3,28	-1,18	3,32	-1,22	error	-
Cross. 1A	144 m upstream	D	-	x	-	x	-
Cross. 1BR	144 m upstream	D	-	x	-	x	-
Cross. 1CL	144 m upstream	D	-	x	-	x	-
Cross. 1DL	144 m upstream	3,43	-1,25	3,45	-1,27	3,43	-1,25
Cross. 1EL	144 m upstream	D	-	x	-	x	-
Point G	100 m upstream	2,40	-1,66	2,43	-1,69	2,50	-1,76
Cross. 2A	48 m upstream	D	-	x	-	x	-
Cross. 2BR	48 m upstream	D	-	x	-	x	-
Cross. 2CL	48 m upstream	D	-	x	-	x	-
Cross. 2DL	48 m upstream	D	-	x	-	x	-

Name	Location	7-8-03	Ground-water level	14-8-03	Ground-water level	21-8-03	Ground-water level
Proposed damsite	reference point						
Cross. 3A	34 m downstream	D	-	x	-	x	-
Cross. 3BL	34 m downstream	D	-	x	-	x	-
Cross. 3CL	34 m downstream	D	-	x	-	x	-
Cross. 3DL	34 m downstream	D	-	x	-	x	-
Point H	100 m downstream	D	-	x	-	x	-
Point I	150 m downstream	D	-	x	-	x	-
Point J	190 m downstream	D	-	x	-	x	-
Tributarie	200 m downstream						
Point K	250 m downstream	D	-	x	-	x	-
Point L	500 m downstream	-	-	-	-		-
Point M	750 m downstream	-	-	-	-	D	-
Point N	1000 m downstream	-	-	-	-	D	-
Point O	1500 m downstream	-	-	-	-	D	-
Point P	2000 m downstream	-	-	-	-	2,50	-16,90

Appendix 4: Data inverse augur hole tests

Table 14.3: Data inverse augur hole test no. 1

Test number:	1
Radius bore hole (r):	60 mm
Depth hole (D):	0,79 m

Time [s]	Z(t) [mm]	Z(t)+1/2 r [mm]	log [Z(t)+1/2 r] [-]
0	87	117	2.068185862
10	85	115	2.06069784
20	85	115	2.06069784
30	82	112	2.049218023
40	80	110	2.041392685
50	79	109	2.037426498
60	79	109	2.037426498
70	78	108	2.033423755
80	78	108	2.033423755
90	77.5	107.5	2.031408464
100	77.5	107.5	2.031408464
110	77	107	2.029383778
120	76.5	106.5	2.027349608
130	77	107	2.029383778
140	76.5	106.5	2.027349608
150	76	106	2.025305865
160	76	106	2.025305865
170	75.5	105.5	2.02325246
180	75.5	105.5	2.02325246
190	75	105	2.021189299
200	75	105	2.021189299
210	75	105	2.021189299
220	75	105	2.021189299
230	74.5	104.5	2.01911629
240	74.5	104.5	2.01911629
260	73.5	103.5	2.01494035
280	73	103	2.012837225
300	73	103	2.012837225
320	73	103	2.012837225
340	73	103	2.012837225
360	72.5	102.5	2.010723865
390	72	102	2.008600172
420	71.8	101.8	2.007747778
450	71.5	101.5	2.006466042

Time [s]	Z(t) [mm]	Z(t)+1/2 r [mm]	log [Z(t)+1/2 r] [-]
480	71.5	101.5	2.006466042
510	71	101	2.004321374
540	71	101	2.004321374
570	70	100	2
600	70	100	2
630	70	100	2
660	70	100	2

Table 14.4: Data inverse augur hole test no. 2

Test number:	2
Radius bore hole (r):	60 mm
Depth hole (D):	0,70 m

Time [s]	Z(t) [mm]	Z(t)+1/2 r [mm]	log [Z(t)+1/2 r] [-]
0	56	86	1.934498451
10	55.5	85.5	1.931966115
20	55.5	85.5	1.931966115
30	55.5	85.5	1.931966115
40	56	86	1.934498451
50	56.5	86.5	1.937016107
60	57	87	1.939519253
80	57.5	87.5	1.942008053
100	58	88	1.944482672
120	58.5	88.5	1.946943271
140	58.5	88.5	1.946943271
160	59	89	1.949390007
180	59	89	1.949390007
200	59.5	89.5	1.951823035
220	59.5	89.5	1.951823035
240	59.5	89.5	1.951823035
260	59.5	89.5	1.951823035
280	60	90	1.954242509
300	60	90	1.954242509
330	60.5	90.5	1.956648579
360	61	91	1.959041392
390	61	91	1.959041392
420	61.5	91.5	1.961421094
450	62	92	1.963787827
480	62	92	1.963787827
510	62.5	92.5	1.966141733
540	63	93	1.968482949

Time [s]	Z(t) [mm]	Z(t)+1/2 r [mm]	log [Z(t)+1/2 r] [-]
570	63	93	1.968482949
600	63	93	1.968482949
630	63.5	93.5	1.970811611
660	63.5	93.5	1.970811611
720	63.5	93.5	1.970811611
780	63.5	93.5	1.970811611
840	64	94	1.973127854
900	64.5	94.5	1.975431809
960	64.5	94.5	1.975431809
1020	65	95	1.977723605
1080	65.5	95.5	1.980003372
1140	65.5	95.5	1.980003372
1200	66	96	1.982271233
1260	66	96	1.982271233

Table 14.5: Data inverse augur hole test no. 3

Test number:	3
Radius bore hole (r):	60 mm
Depth hole (D):	0,50 m

Time [s]	Z(t) [mm]	Z(t)+1/2 r [mm]	log [Z(t)+1/2 r] [-]
0	39	69	1.838849091
10	36	66	1.819543936
20	34	64	1.806179974
30	31	61	1.785329835
40	29	59	1.770852012
50	27.5	57.5	1.759667845
60	26.5	56.5	1.752048448
70	25.5	55.5	1.744292983
80	25	55	1.740362689
90	24.5	54.5	1.736396502
100	24	54.5	1.736396502
110	23	54	1.73239376
120	22.5	53	1.72427587
130	21.5	52.5	1.720159303
140	21	51.5	1.711807229
150	20.5	51	1.707570176
160	20	50.5	1.703291378
170	19.5	50	1.698970004
180	19.5	49.5	1.694605199
190	19	49.5	1.694605199

Time [s]	**Z(t) [mm]**	**Z(t)+1/2 r [mm]**	**log [Z(t)+1/2 r] [-]**
200	19	49	1.69019608
210	19	49	1.69019608
220	18.5	49	1.69019608
230	18.5	48.5	1.685741739
240	18	48.5	1.685741739
260	17.5	48	1.681241237
280	17.5	47.5	1.67669361
300	17	47.5	1.67669361
320	17	47	1.672097858
340	17	47	1.672097858
360	16.5	46.5	1.667452953
380	16.5	46.5	1.667452953
400	16.5	46.5	1.667452953

Appendix 5: Data temperature measurements

Table 14.6: Data temperature measurements

time	8:30		12:00		16:00		20:00		WAM		Belg	
date	WAM (°C)	Belg(°C)	WAM (°C)	Belg(°C)	WAM (°C)	Belg (°C)	WAM (°C)	Belg (°C)	Mi n	Max	Min	Max
9-07-03	x	x	32	x	35	x	27	x	27	35	x	x
10-07-03	25	x	33	x	27	x	24	x	24	33	x	x
11-07-03	25	x	36	x	32	x	25	x	25	36	x	x
12-07-03	24	x	30	x	31	x	28	x	24	31	x	x
13-07-03	25	x	35	x	30	x	27	x	25	35	x	x
14-07-03	25	x	35	x	34	x	25	x	25	35	x	x
15-07-03	25	x	31	x		x	27	x	25	31	x	x
16-07-03	25	x	32	x	30	x		x	25	32	x	x
17-07-03	24	x	33	x	39	x	27	x	24	39	x	x
18-07-03	x	x	x	x	x	x	x	x	0	0	x	x
19-07-03	x	x	x	x	x	x	x	x	0	0	x	x
20-07-03	x	x	x	x	x	x	x	x	0	0	x	x
21-07-03	x	x	x	x	x	x	x	x	0	0	x	x
22-07-03	x	x	x	x	x	x	x	x	0	0	x	x
23-07-03	x	x	x	x	x	x	x	x	0	0	x	x
24-07-03	25	22	32	x	34	30	25	24	25	34	21	32
25-07-03	23	22	35	x	31	27	25	24	23	35	20	31
26-07-03	23	20	32	x	33	29	25	24	23	33	19	31
27-07-03	28	24	36	x	38	x	25	22	25	38	19	28
28-07-03	24	20	35	x	35	x	26	25	24	35	19	28
29-07-03	23	20	36	x	35	30	26	24	23	36	18	31
30-07-03	24	x	34	x	36	x	26	x	24	36	x	x
31-07-03	25	x	37	x	37	x	26	x	25	37	x	x
1-08-03	27	x	32	x	34	x	26	x	26	34	x	x
2-08-03	23	x	34	x	31	x	25	x	23	34	x	x
3-08-03	26	x	34	x	29	x	25	x	25	34	x	x
4-08-03	24	x	30	x	30	x	25	x	24	30	x	x
5-08-03	22	x	32	x	29	x	24	x	22	32	x	x
6-08-03	26	x	35	x	31	x	23	x	23	35	x	x
7-08-03	22	x	x	x	32	x	x	x	22	32	22	33
8-08-03	x	x	x	x	x	x	x	x	0	0	16	33
9-08-03	x	x	x	x	x	x	x	x	0	0	19	32
10-08-03	x	x	x	x	x	x	x	x	0	0	18	28
11-08-03	x	x	x	x	x	x	x	x	0	0	20	30
12-08-03	x	x	x	x	x	x	x	x	0	0	20	35

time	8:30		12:00		16:00		20:00					
date	WAM (°C)	Belg(°C)	WAM (°C)	Belg(°C)	WAM (°C)	Belg (°C)	WAM (°C)	Belg (°C)	WAM Min	WAM Max	Belg Min	Belg Max
13-08-03	x	x	x	x	x	x	26	26	26	26	17	40
14-08-03	24	22	32	x	32	x	25	25	24	32	18	34
15-08-03	24	23	36	x	34	x	27	26	24	36	20	35
16-08-03	24	22	35	x	34	32	26	26	24	35	18	35
17-08-03	25	22	30	30	33	34	28	27	25	33	18	36
18-08-03	x	x	x	x	x	x	x	x	0	0	20	35
19-08-03	24	21	35	x	28	x	27	27	24	35	19	34
20-08-03	26	23	33	31	30	29	27	27	26	33	19	33
21-08-03	25	23	x	x	34	30	26	26	25	34	20	32
22-08-03												
23-08-03												
24-08-03												
25-08-03												
26-08-03												
27-08-03												
28-08-03												
29-08-03												
30-08-03												
31-08-03												

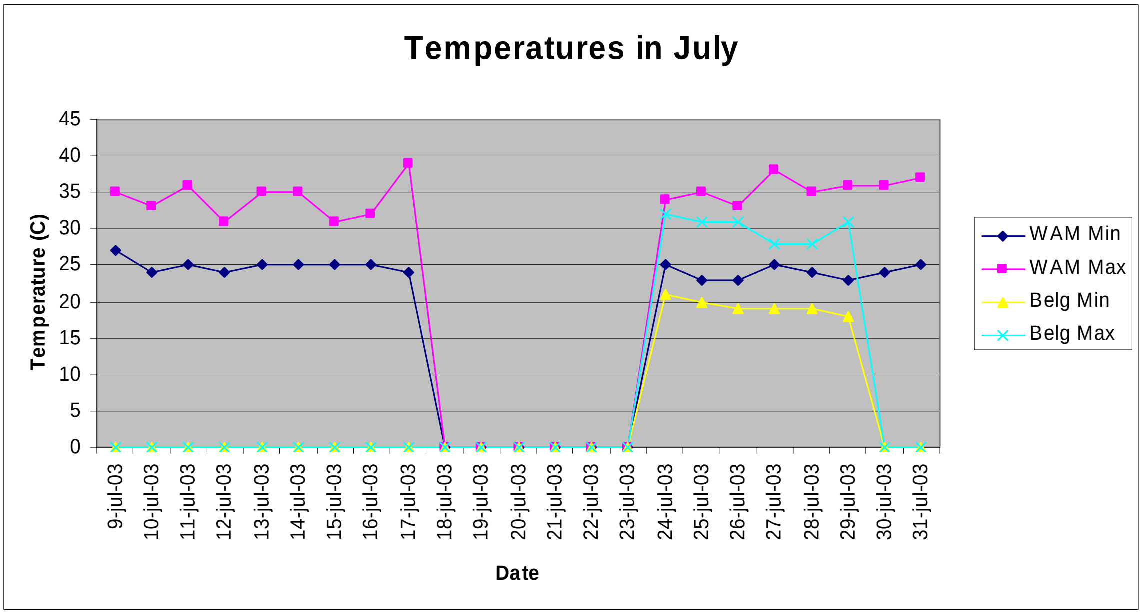


Figure 14.2: Temperatures in July

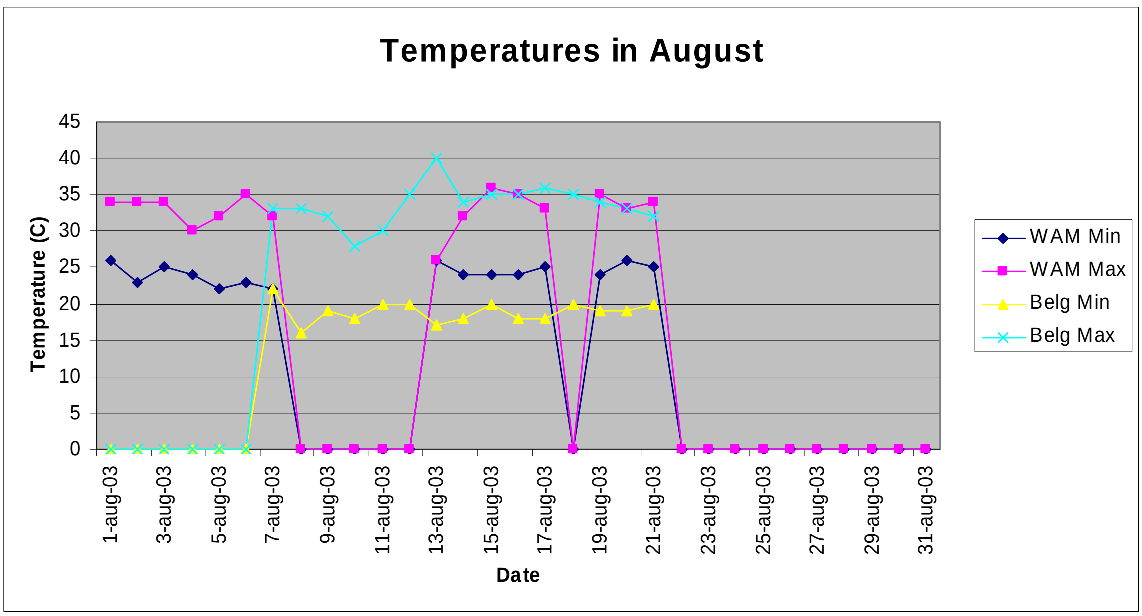


Figure 14.3: Temperature in August

Appendix 6: Data humidity measurements

Table 14.7: Data humidity measurements

time date	8:30 Humidity(%)	12:00 Humidity(%)	16:00 Humidity(%)	20:00 Humidity(%)	Humidity Min	Humidity Max
9-07-03	x	38	34	58	34	58
10-07-03	62	44	64	78	44	78
11-07-03	62	36	44	63	36	63
12-07-03	66	44	38	52	38	66
13-07-03	60	44	46	48	44	60
14-07-03	66	35	40	69	35	69
15-07-03	56	45		52	45	56
16-07-03	67	44	48		44	67
17-07-03	66	47	34	54	34	66
18-07-03	x	x	x	x	0	0
19-07-03	x	x	x	x	0	0
20-07-03	x	x	x	x	0	0
21-07-03	x	x	x	x	0	0
22-07-03	x	x	x	x	0	0
23-07-03	x	x	x	x	0	0
24-07-03	60	48	39	64	39	64
25-07-03	68	34	45	62	34	68
26-07-03	68	40	35	63	35	68
27-07-03	52	40	34	66	34	66
28-07-03	70	42	39	60	39	70
29-07-03	68	30	44	64	30	68
30-07-03	62	32	33	60	32	62
31-07-03	68	30	40	56	30	68
1-08-03	66	40	37	53	37	66
2-08-03	70	40	42	68	40	70
3-08-03	62	38	57	70	38	70
4-08-03	68	55	46	61	46	68
5-08-03	70	44	52	62	44	70
6-08-03	66	38	42	62	38	66
7-08-03	68	x	42	x	42	68
8-08-03	x	x	x	x	0	0
9-08-03	x	x	x	x	0	0
10-08-03	x	x	x	x	0	0
11-08-03	x	x	x	x	0	0
12-08-03	x	x	x	x	0	0
13-08-03	x	x	x	61	61	61
14-08-03	69	41	47	66	41	69
15-08-03	62	38	47	60	38	62

time date	8:30 Humidity(%)	12:00 Humidity(%)	16:00 Humidity(%)	20:00 Humidity(%)	Humidity Min	Humidity Max
16-08-03	68	34	40	58	34	68
17-08-03	60	40	44	56	40	60
18-08-03	x	x	x	x	0	0
19-08-03	72	38	56	58	38	72
20-08-03	68	48	54	58	48	68
21-08-03	74	x	43	64	43	74
22-08-03					0	0
23-08-03					0	0
24-08-03					0	0
25-08-03					0	0
26-08-03					0	0
27-08-03					0	0
28-08-03					0	0
29-08-03					0	0
30-08-03					0	0
31-08-03					0	0

Appendix 7: Data evaporation measurements

Table 14.8: Data evaporation measurements

Date	Remarks	Height before filling(cm)	Height after filling(cm)	Rainfall (mm)	Mean waterdepth(cm)	Pan-evaporation (mm)	Real Date
10-07-03	at kot	x	4,50	0,00	13,10		09-07-03
11-07-03	at kot, mouse in pan	4,30	4,30	0,80	13,00	2,80	10-07-03
12-07-03	at kot	3,90	3,90	0,00	12,70	4,00	11-07-03
13-07-03	at kot	3,30	3,30	0,00	12,20	6,00	12-07-03
14-07-03	at kot	2,80	2,80	0,00	11,65	5,00	13-07-03
15-07-03	at kot	2,20	2,20	0,00	11,10	6,00	14-07-03
16-07-03	at kot	1,70	4,50	0,00	10,55	5,00	15-07-03
17-07-03	at kot	4,00	4,00	0,00	12,85	5,00	16-07-03
18-07-03	at kot, at 6.30	3,40	3,40	0,00	12,30	6,00	17-07-03
19-07-03	Away	x	x	0,00			18-07-03
20-07-03	Away	x	x	0,00			19-07-03
21-07-03	Away	x	x	0,00			20-07-03
22-07-03	Away	x	x	0,00			21-07-03
23-07-03	Away	x	x	0,00			22-07-03
24-07-03	at kot	x	4,50	0,00			23-07-03
25-07-03	at kot	3,80	3,80	0,00	12,75	7,00	24-07-03
26-07-03	at kot, unreal value	-1,60	4,50	0,00	9,70	54,00	25-07-03
27-07-03	at kot	4,00	4,00	0,00	12,85	5,00	26-07-03
28-07-03	at kot, unreal value	0,20	0,20	0,00	10,70	38,00	27-07-03
29-07-03	at kot	-0,60	4,00	0,00	8,40	8,00	28-07-03
30-07-03	at kot, unreal value	2,30	2,30	0,00	11,75	17,00	29-07-03
31-07-03	at kot, unreal value	0,00	0,00	0,00	9,75	23,00	30-07-03
1-08-03	measuring stopt at kot	x	x	0,00			31-07-03
2-08-03	no measurement	x	x	0,00			1-08-03
3-08-03	no measurement	x	x	0,00			2-08-03
4-08-03	no measurement	x	x	0,00			3-08-03
5-08-03	no measurement	x	x	0,00			4-08-03
6-08-03	no measurement	x	x	0,00			5-08-03
7-08-03	no	x	x	0,00			6-08-03

	measurement				
8-08-03	no measurement	x	x	0,00	7-08-03
9-08-03	no measurement	x	x	0,00	8-08-03
10-08-03	no measurement	x	x	3,21	9-08-03
11-08-03	no measurement	x	x	0,00	10-08-03
12-08-03	no measurement	x	x	0,00	11-08-03
13-08-03	no measurement	x	x	0,00	12-08-03
14-08-03	no measurement	x	x	0,00	13-08-03
15-08-03	no measurement	x	x	0,00	14-08-03
16-08-03	no measurement	x	x	0,00	15-08-03
17-08-03	no measurement	x	x	0,00	16-08-03
18-08-03	no measurement	x	x	0,00	17-08-03
19-08-03	no measurement	x	x	0,00	18-08-03
20-08-03	no measurement	x	x	0,00	19-08-03
21-08-03	measurement started at Kisayani primary school				20-08-03
22-08-03					

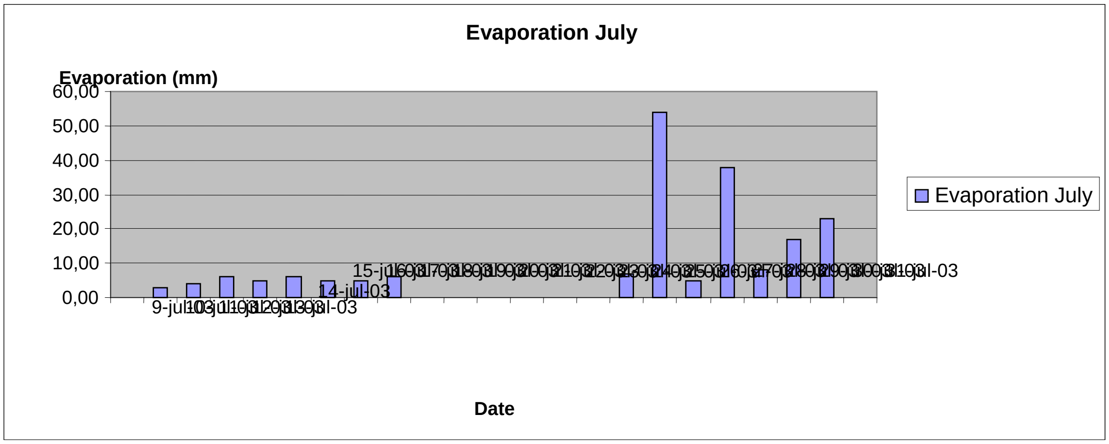


Figure 14.4: Evaporation in July

Appendix 8: Location Sokkia points

Table 14.9: Location Sokkia points

name	X-coordinate[m]	Y-coordinate[m]	straight line distance[m]	river distance[m]	height[dm]	height[m]
H17	-929,55	-511,81	1061,14		171,95	17,20
H16	-893,83	-484,76	1016,82		169,90	16,99
H15	-1005,79	-415,30	1088,15		158,60	15,86
H14	-1012,99	-268,99	1048,10		148,50	14,85
H13	-933,00	-278,38	973,64		130,65	13,07
H12	-942,89	-311,42	992,98		134,65	13,47
Y1	-867,18	-284,38	912,62	1059	123,40	12,34
Y2	-867,64	-281,17	912,06	1059	118,25	11,83
Y3	-868,83	-274,07	911,04	1059	118,15	11,82
Kimunyuni dam	-830,45	-268,97	872,92	1030	111,90	11,19
Z1	-796,87	-255,78	836,92	1000	108,40	10,84
Z2	-795,22	-263,56	837,76	1000	108,40	10,84
Z3	-795,04	-267,68	838,89	1000	108,40	10,84
H11	-667,97	-188,14	693,96		98,10	9,81
A	-608,64	-253,60	659,36	750	86,55	8,66
H10	-593,72	-128,42	607,45		70,65	7,07
B	-481,82	-66,47	486,38	500	64,30	6,43
H9	-428,35	-58,43	432,32		57,95	5,80
H8	-283,65	-21,11	284,44		45,80	4,58
C	-330,46	-52,88	334,66	350	41,00	4,10
D	-296,86	-55,99	302,09	290	37,55	3,76
Mark natural barrier	-244,84	-49,79	249,85	270	27,05	2,71
E	-237,19	-44,05	241,24	250	21,15	2,12
F	-195,53	-40,07	199,60	200	21,00	2,10
1A	-140,82	-28,25	143,63	144	10,25	1,03
1B	-134,90	-45,04	142,22	144	20,20	2,02
1C	-142,78	-20,42	144,23	144	21,10	2,11
1D	-143,87	-18,05	145,00	144	21,80	2,18
1E	-143,97	-16,04	144,86	144	24,20	2,42
G	-88,12	-18,55	90,05	100	7,40	0,74
2A	-47,00	-8,68	47,79	48	4,60	0,46
2B	-40,78	-27,58	49,23	48	14,25	1,43
2C	-49,37	-2,39	49,43	48	16,20	1,62
2D	-50,43	0,74	50,43	48	16,65	1,67
Reference point	0,00	0,00	0,00	0	0,00	0,00
3A	28,39	20,54	35,05	34	-1,30	-0,13
3B	10,12	31,97	33,53	34	-2,85	-0,29
3C	7,82	33,96	34,85	34	3,90	0,39
3D	4,58	36,43	36,72	34	6,85	0,69

H7	45,00	43,97	62,91		-4,45	-0,45
H	25,82	87,34	91,08	100	0,85	0,09
I	53,51	131,29	141,78	150	-8,70	-0,87
J	57,59	163,23	173,09	190	-10,00	-1,00
K	30,36	201,08	203,36	250	-9,70	-0,97
H6	16,45	289,94	290,41		-23,20	-2,32
L	108,72	412,33	426,43	500	-34,90	-3,49
H5	217,88	319,25	386,51		-48,80	-4,88
M	318,22	312,49	446,00	750	-54,10	-5,41
H4	369,86	417,47	557,75		-65,35	-6,54
N	275,32	521,32	589,56	1000	-71,60	-7,16
H3	183,41	616,78	643,48		-85,80	-8,58
H2	284,95	698,37	754,27		-98,10	-9,81
O	455,36	590,62	745,78	1500	-111,60	-11,16
H1	677,84	679,27	959,62		-128,15	-12,82
P	891,25	748,29	1163,73	2000	-143,95	-14,40

Appendix 9: Manning and Chezy's coefficienten

Table 14.10: Manning and Chezy's coefficienten

Type of channel and description	Manning coefficient (n)	Chezy's coefficient			
		R_h= 1m	R_h= 2.5m	R_h= 5m	R_h= 10 m
Excavated or dredged					
Earth, straight and uniform					
Clean, recently completed	0.016 to 0.020	63 to 50	72 to 58	81 to 65	91 to 73
Clean, after wealthering	0.018 to 0.025	55 to 40	64 to 46	72 to 52	81 to 59
Short grass, few weeds	0.022 to 0.033	45 to 30	53 to 35	59 to 40	67 to 44
Rock cuts					
Smooth and uniform	0.025 to 0.040	40 to 25	46 to 29	52 to 33	59 to 37
Jagged and irregular	0.035 to 0.050	29 to 20	33 to 23	37 to 26	42 to 29
Natural streams					
Minor streams (top width at flood stage less than 30 m) on plains; clean, straight, full stage, no rifts or deep pools	0.025 to 0.033	40 to 30	46 to 35	52 to 40	59 to 44
Flood plains					
Pasture, no brush					
Short grass	0.025 to 0.035	40 to 29	46 to 33	52 to 37	59 to 42
High grass	0.030 to 0.050	33 to 20	39 to 23	44 to 26	49 to 29
Rock cuts					
No crop	0.020 to 0.040	50 to 25	58 to 29	65 to 33	73 to 37
Mature row crops	0.025 to 0.045	40 to 22	46 to 26	52 to 29	59 to 33
Mature field crops	0.030 to 0.050	33 to 20	39 to 23	44 to 26	49 to 29
Brush					
Scattered brush, heavy weeds	0.035 to 0.070	29 to 14	33 to 17	37 to 19	42 to 21
Light brush and trees(without foliage)	0.035 to 0.060	29 to 17	33 to 19	37 to 22	42 to 24
Light brush and trees(with foliage)	0.040 to 0.080	25 to 12	29 to 14	33 to 16	37 to 18
Medium to dense brush (without foliage)	0.045 to 0.110	22 to 9	26 to 10.5	29 to 12	33 to 13
Medium to dense brush (with foliage)	0.070 to 0.160	14 to 6.5	17 to 7.5	19 to 8	21 to 9
Trees					
Cleared land with tree stumps, no sprouts	0.030 to 0.050	33 to 20	39 to 23	44 to 26	49 to 29
Same as above, but with heavy growth of sprouts	0.050 to 0.080	20 to 12	23 to 14	26 to 16	29 to 18

Heavy stand of timber, a few felled trees, tittle undergrowth, flood stage below branches	0.080 to 0.120	12 to 8.5	14 to 9.5	16 to 11	18 to 12
Same as above, but with flood stage reaching branches	0.100 to 0.160	10 to 6.5	12 to 7.5	13 to 8	15 to 9
Dense willows in midsummer	0110 to 0.200	9 to 5	10.5 to 6	12 to 6.5	13 to 7.5

Appendix 10: User manual piezometers

Introduction

In the Kitui-district there are already build some 500 sand-storage-dams, but the effect of those dams have never been measured. So the effects of the dams on the amount of water that is available downstream and upstream of the sand-storage-dams is unknown. The purpose of this measuring program in the area of the proposed dam site at Kisayani is to see what the effect of the sand-storage-dam is and to proof that the developed theories are correct. This manual gives information about how to measure the groundwater table whit the piezometers and how to make a new piezometers.

The measuring program

To see what the effects of the sand-storage-dam is it is necessary to have a system of equipment with which it's possible to measure the effect. In this research it is decided that the effect of the sand-storage-dam on the availability of water results in a level difference of the level of the groundwater table. This groundwater level is measured with piezometers that are located in the research area. To be able to see the effect of the sand-storage-dam, you need the groundwater level before the dam was build and after the dam was build. In that way you can see the difference. It is very important to have measurements the whole year round, then you can see the total effect of the sand-storage-dams in all seasons.

Measuring the groundwater level with piezometers

Equipment needed:

- Piezometer
  See next paragraph how they look like and how to make them
- Pincers
- Ruler
- Plopping device
  The plopping device consists of a small cup, with a diameter smaller than the diameter of the tube from the piezometers, and a rope. The cup is connected with the rope and made heavier if needed whit some weight, like sand. It is very important that when the cup is hanging on the rope that the open side of the cup is hanging in the downward direction.
- Paper and pencils

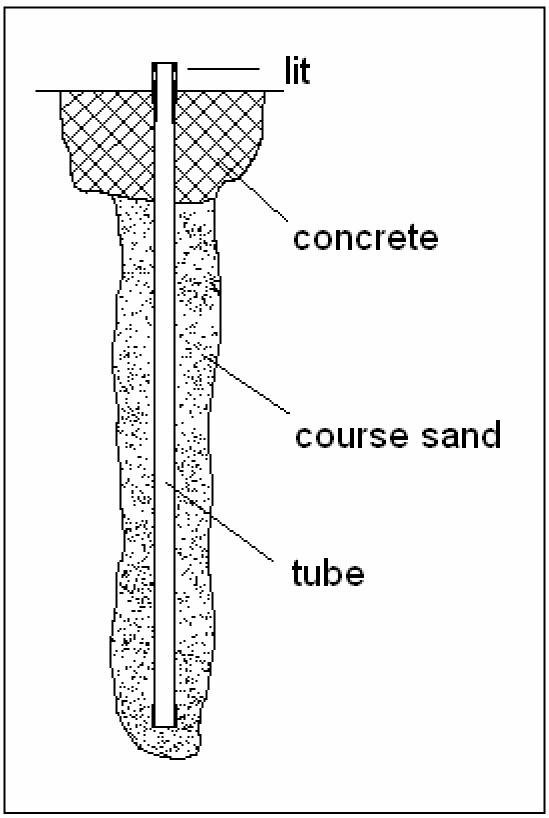
Doing the measurement:

1. Remove the stone that is lying on top of the piezometers
2. Remove all the sand or other stuff that is lying on the concrete casing of the piezometers.
3. Remove the lit of the piezometer, by hand or when this is not possible with the pincers.

4. Let the plopping device very slowly descent in the piezometer. Be sure that the open side is pointed downwards. Continue with descending the piezometers very slowly until you hear a soft plopping-sound.
5. Grab the rope of the plopping device at the top of the piezometer while the plopping device has just hit the water (when you hear the plopping sound). Don't move your hand in the next steps. This hand marks the depth of the groundwater table.
6. Raise the plopping device out of the piezometer, without moving your hand that marks the depth.
7. Use the ruler to measure the distance between the open side of the cup from the plopping device and your hand, which marks the depth of the groundwater level.
8. Write the measured distance down on the measurement sheets whit the pencils.
9. Replace the lit on top of the piezometer.
10. Replace the stone on the piezometer.

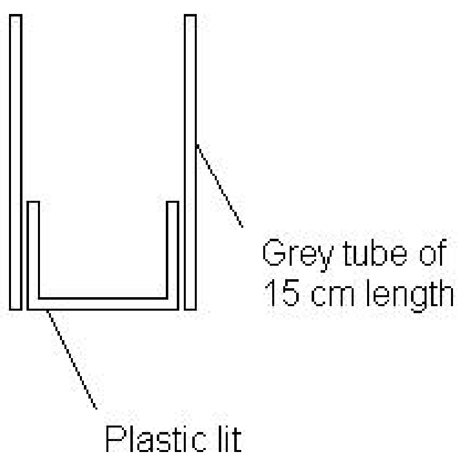
Measurements should be done as often as possible, like once a week. If a piezometer is dry for 2 weeks, it is not necessary to measure the piezometer until it rained again.

Making a piezometer



Equipment needed:
- Auger bore whit extension pieces, length needed depends on depth rock layer
- Black plastic tubes with a diameter of 5,5 cm, length needed depends on depth rock layer.
- Grey plastic tubes with a diameter of 5,0 cm, 50 cm needed per piezometer
- Glue that can be used for plastic
- Plastic lits, 2 needed per piezometer
- Saw or (pocket)knife
- Panga or machete
- Cement
- Bottles for water
- Water, don't need to be clean
- Course sand, you can use the sand of the riverbed
- Stones, small stones can be found in the riverbed and in the surroundings of the stream.

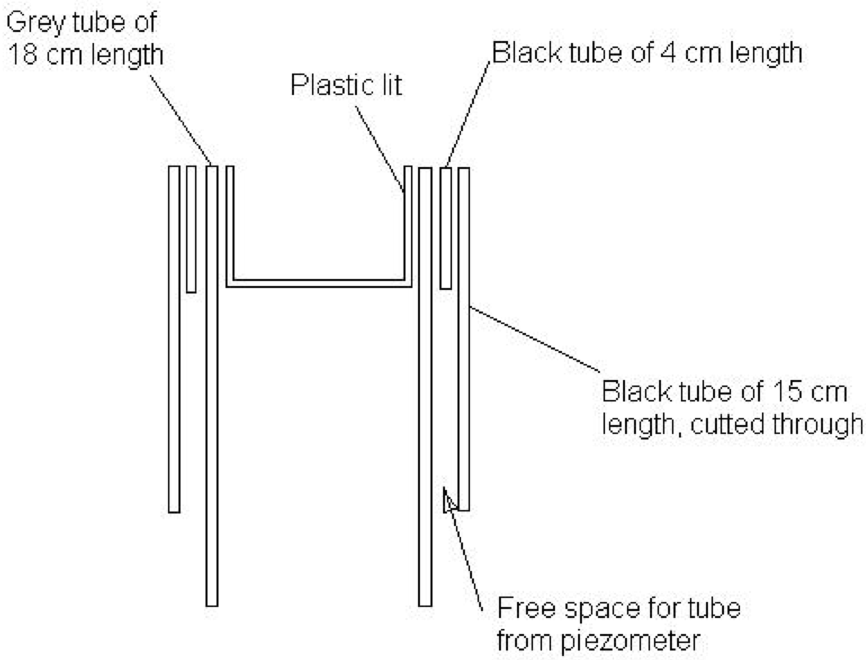
Making the piezometer
1. Go to the location where you want a piezometer
2. Remove the top layer of fine sands with your hand of the panga.
3. Start drilling with the auger bore, if the bore is too low to drill, extend it with a extension piece.
4. Continue drilling until you reach the rock layer or you can't get further because the wet sand doesn't stick in the auger bore. Remove the auger bore.
5. Place the black tube in the bore hole and cut it off 10 cm under the ground surface with the saw or (pocket) knife.
6. Remove the black tube out of the bore hole.
7. Make the lit for the downstream side of the piezometer



- Cut a piece of 15 cm from the grey tube with the saw or knife
- Glue one of the two lits in the 15 cm long piece of the grey tube, with the closed side at the outside
- Let the glue dry

- Glue the piece of the grey tube with the lit in the long black tube, with the lit downside.
- Make some cuttings in the lit, to let the groundwater enter the piezometer without the sand.

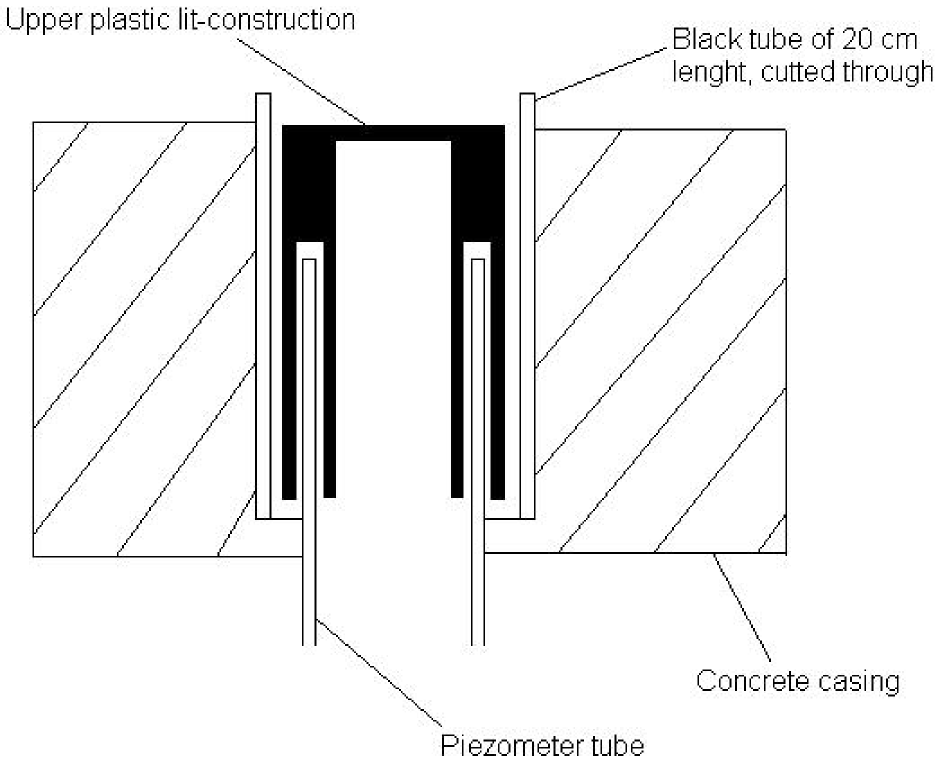
8. Make cuttings in the black tube, to let the groundwater enter the piezometer without the sand.
9. Make the lit for the upstream side of the piezometer



- Cut a piece of 18 cm from the grey tube with the saw or knife
- Glue one of the two lits in the 15 cm long piece of the grey tube, with the closed side at the inside
- Let the glue dry
- Cut a piece of 4 cm from the black tube with the saw or knife
- Glue the black tube of 4 cm on the grey tube of 15 cm
- Let the glue dry
- Cut a piece of 15 cm from the black tube with the saw or knife
- Cut the piece of 15 cm from the black tube through in the longitudinal direction
- Glue the 15 cm piece of the black tube on the piece of 4 cm from the black tube.
- Let the glue dry

10. Place the lit on top of the black tube
11. Place the black tube, with the lits, in the bore hole
12. Fill the empty space in the borehole with course sand, like sand from the riverbed.

13. Make a hole around the top of the piezometer with sides of 40 cm and a depth of some 20cm. You should see 2 a 3 cm of the black tube of the piezometer under the lit. The digging can be done with the panga in hard soils.



14. Cut a piece of some 20 cm from the black tube and cut it through in the longitudinal direction.
15. Place this piece of tube around the lit in such away that the lit is completely under the covering piece.
16. Collect some small stones, sand and at least 15 litre of water.
17. Through some water in the digged pit to wet the ground, followed by a layer of cement.
18. Mix the rest of the cement with the sand and the small stones. You can mix the stuff with the panga, it is better for your hands to do it in that way.
19. Mix the sand, cement and stones with water to make the concrete.
20. Put the concrete in the created pit
21. Through some water on the concrete casing and a lot of cement
22. Write down the date, the organisation and the location in the concrete
23. Let the concrete casing dry for one day.
24. Return after one day and remove the lit. This is necessary to be sure that it is possible to remove the lit. If you try to open it for the first time after a week it is far more difficult.
25. Place a big stone on top of the lit and concrete casing

Examples of measuring datasheets

Table 14.11:Examples of measuring datasheets

Name	*Location*	*depth*	*28-8*	*4-9*	*11-9*	*18-9*	*25-9*	*2-10*	*9-10*
Cross. Y	1059 m Upstr.	0,99 m							
Cross. Y2	1059 m Upstr.	0,65 m							
Cross. Y3	1059 m Upstr.	0,70 m							
Kamunyuni dam	1030 m Upstr.								
Cross. Z	1000 m Upstr.	2,20 m							
Cross. Z2	1000 m Upstr.	1,26 m							
Cross. Z3	1000 m Upstr.	1,38 m							
Point A	750 m Upstr.	0,97 m							
Point B	500 m Upstr.	0,76 m							
Point C	350 m Upstr.	1,64 m							
Point D	290 m Upstr.	2,67 m							
Natural barrier	270 m Upstr.								
Point E	250 m Upstr.	3,44 m							
Point F	200 m Upstr.	3,47 m							
Cross. 1A	144 m Upstr.	2,27 m							
Cross. 1BR	144 m Upstr.	1,27 m							
Cross. 1CL	144 m Upstr.	3,17 m							
Cross. 1DL	144 m Upstr.	3,48 m							
Cross. 1EL	144 m Upstr.	2,86 m							
Point G	100 m Upstr.	3,04 m							
Cross. 2A	48 m Upstr.	1,79 m							
Cross. 2BR	48 m Upstr.	0,96 m							
Cross. 2CL	48 m Upstr.	3,91 m							
Cross. 2DL	48 m Upstr.	3,89 m							
Proposed dam site	reference point								
Cross. 3A	34 m Downstr.	1,40 m							
Cross. 3BL	34 m Downstr.	2,46 m							
Cross. 3CL	34 m Downstr.	2,48 m							
Cross. 3DL	34 m Downstr.	2,23 m							
Point H	100 m Downstr.	3,23 m							
Point I	150 m Downstr.	2,06 m							
Point J	190 m Downstr.	2,70 m							
Tributary	200 m Downstr.								
Point K	250 m Downstr.	1,23 m							
Point L	500 m Downstr.	not							

Name	*Location*	*depth*	*28-8*	*4-9*	*11-9*	*18-9*	*25-9*	*2-10*	*9-10*
		functioning							
Point M	750 m Downstr.	collapsed							
Point N	1000 m Downstr.	0,74 m							
Point O	1500 m Downstr.	2,09 m							
Point P	2000 m Downstr.	2,77 m							

Appendix 11: User manual weather station

Authors:

Bossenbroek, Jan-Kees, Musyimi (DUT) Puttemans, Sam, Mutembe (KUL)

Neesen, Dirk, Wambua (KUL) Timmermans, Teun, Musembi (DUT)

User manual weather station

August 2003

CATHOLIC UNIVERSITY OF LEUVEN, BELGIUM

FACULTY OF AGRICULTURAL AND APPLIED BIOLOGICAL SCIENCE

Delft University of Technology

FACULTY OF CIVIL ENGINEERING AND GEOSCIENCE

DEPARTMENT OF WATER MANAGEMENT

Minimum-maximum thermometer

- **Purpose**:

Reading the daily minimum and maximum temperature.

- **Use:**

The device should be read every day at a fixed time (8.30. a.m.)

The maximum temperature is read on the right side of the thermometer at the downside of the blue bar. (See Figure 14.5)

The minimum temperature is read on the left side of the thermometer at the downside of the blue bar. (**Beware of the reversed scale!!!!**)
Fill in the minimum and maximum temperature in the correct column on the datasheet.
After the readings, press the reset button to reset the thermometer. Stop pressing when the blue bars are on top of the silver bars of the actual temperature. If the blue bars don't go down, you can try to push the reset button and at the same time knock gently on the plastic side (not on the glass) of the thermometer until the bars are down.

- **Note:**

If the minimum-maximum-function of the thermometer is broken (the blue bars don't move when pressing the reset button), the temperature should be read twice a day (at 8.30a.m. and 2 p.m.)
Make sure the thermometer isn't in the direct sunlight, this way the temperature will be overestimated. The thermometer should be under a shelter.

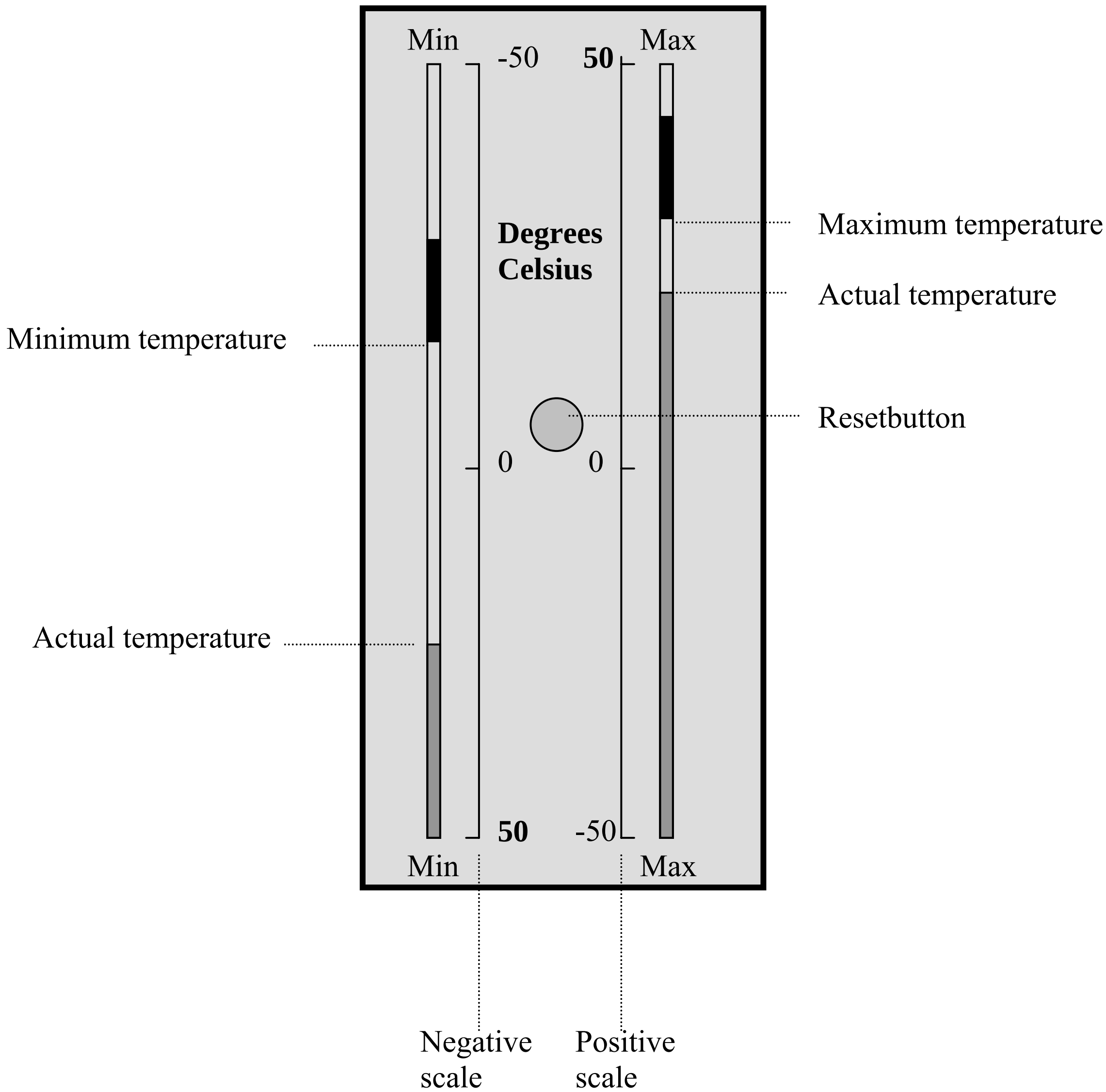


Figure 14.5: Min-Max-thermomether

Green rain gauge

- **Purpose:**

Measuring the daily rainfall.

- **Use:**

The device should be read daily at a fixed time (8.30. a.m.)
When there is water in the device (after rainfall) take the rain gauge out of the holder and read the measuring scale on the beaker corresponding with the water level. (**Remember to keep the rain gauge strait!!!**)
Fill in the correct column on the datasheet (**in millimeters!!**).
Empty the rain gauge and replace it in the holder (make shore it stands straight).

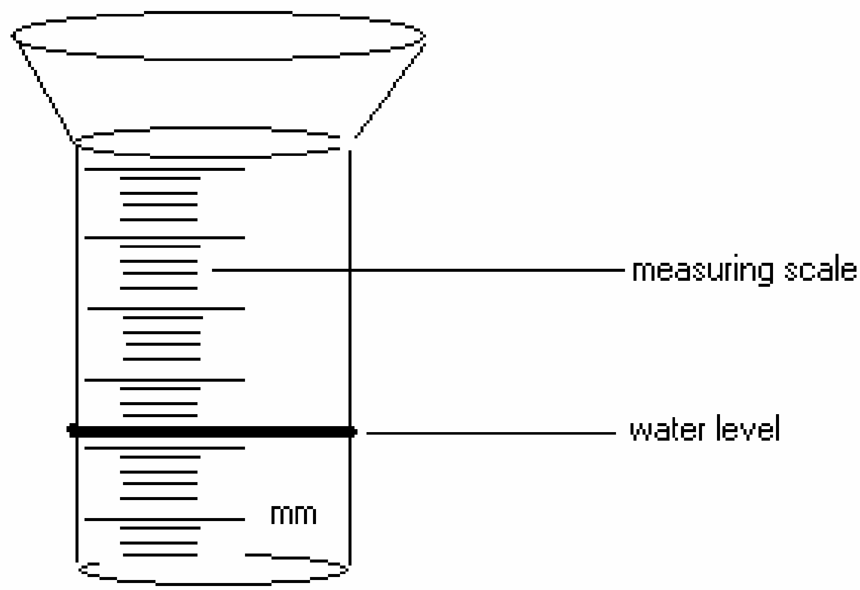


Figure 14.6: The green rain gauge

Metal rain gauge

- **Purpose:**

Measuring the daily rainfall.

- **Use:**

The device should be read daily at a fixed time (8.30. a.m.)
When the device is filled with water (after rainfall) take the rain gauge out of the holder and pour the water in the measuring cup (see Figure 14.7). You can read the amount of water (**in milliliters, ml**) from the milliliter scale of this cup. You can fill in this number in the correct column on the datasheet.
To recalculate the amount of rain **in millimeters (mm),** use the recalculation formula given in box 1. Again, you can fill in this number in the correct column on the datasheet.
Empty the rain gauge after the readings and replace it in the holder (make shore it stands straight).

1. Derivation in symbols

$A(mm^2)$ = watersurface in gauge = $\frac{1}{2} * \pi * (radius)^2 = \frac{1}{2} * \pi * (diameter/2)^2$

$V(ml)$ = measured with measuring cup in milliliters ($ml = cm^3$)

$V(mm^3) = V(ml) * 1000$

$Depth(mm) = V(mm^3) / A(mm)$

2. Derivation of the recalculation formula

Diameter = 12.6cm = 126mm

$A(mm^2) = \frac{1}{2} * \pi * (126mm/2)^2 = 12468mm^2$

$Depth(mm) = V(ml) * 1000 / 12468mm^2$

Recalculation formula: Depth(mm) = V(ml) * 0.0802

Box 1.

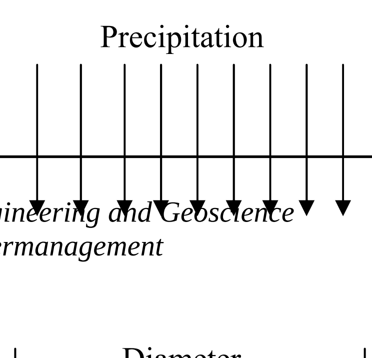


Figure 14.7: The metal rain gauge

Evaporation pan

- **Purpose:**

Measuring the daily evaporation from a free water surface.

- **Use:**

The device should be read daily at a fixed time (8.30 a.m.)
The ruler that is standing in the pan indicates the height of the water level in the pan (see Figure 14.8). If the water level drops below 8 cm, the pan should be refilled with water. So you don't need to refill the pan every day. When the pan is filled with water, the water level should never be higher than 14 cm.

- **How to read the evaporation?**

In the data sheet there are 2 columns for the evaporation. One for the direct readings (read.) and one for the real evaporation (diff.) during that particular day.
Every day you read the height of the water level on the ruler. That height you write in the column of the evaporation readings (read.) of that day. To calculate the real evaporation, you substract the height of the water level of the day before and the height you just read on the ruler. That number you write down in the column for the real evaporation (diff.). If the water level is below 8 cm, you refill the pan (after you did the readings of that day) and you write the new height of the water level in the column of the readings of that day. So, if you have to refill the pan there have to be two numbers in the reading column of that day.

Summarized: Real evaporation (diff) = Height of water level former day – Height of the water level today

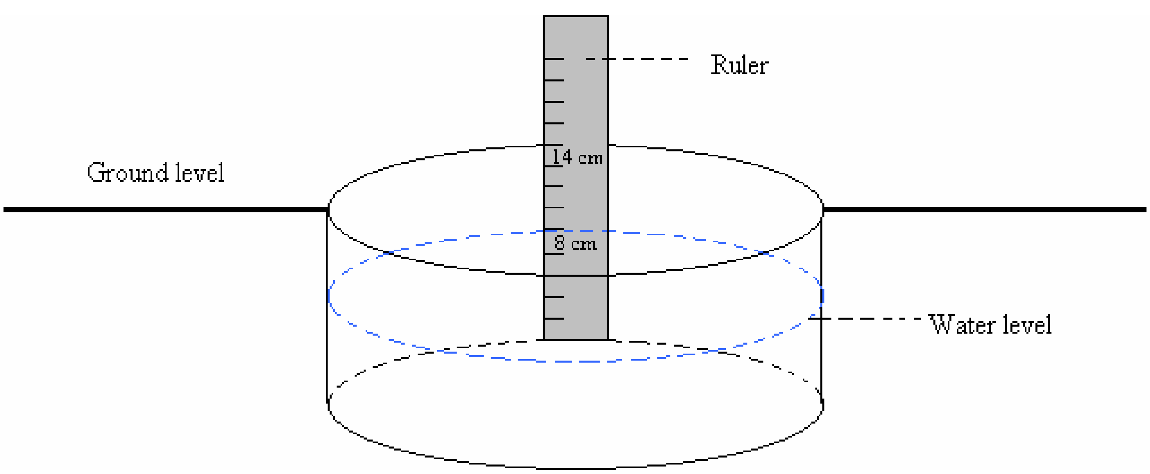


Figure 14.8: The evaporation pan

Humidity meter

- **Purpose:**

Reading the daily relative humidity (expressed in percentage).

- **Use:**

The device should be read 4 times a day at fixed hours (8.30 a.m., 10 a.m., 12 a.m. and 4 p.m.). Fill in the readings at the correct column of the data sheet.
Humidity is expressed in percentages. Read the humidity meter (bottom meter, see Figure 14.9) up to 2 % accurate. The arrow indicates the humidity.
The temperature should not be measured with this thermometer because the readings will not be as accurate as the minimum-maximum-thermometer.

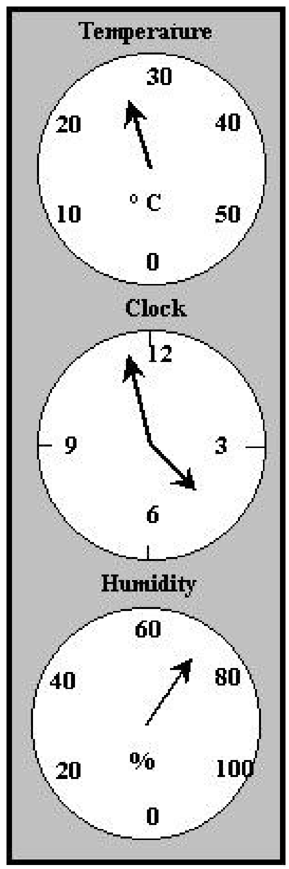


Figure 14.9: The humidity meter:

Example of the data sheets

Table 14.12: Example of data sheet

LOCATION :
MONTH : YEAR :

DAY OF MONTH	MAXIMUM TEMPERATURE	MINIMUM TEMPERATURE	RAINFALL (MM)			EVAPORATION PAN	
			METAL GAUGE		GREEN GAUGE		
			ml	mm		Read	Diff .
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							
21							
22							
23							
24							
25							
26							
27							

28							
29							
30							
31							

DAY OF MONTH	Hunidity at 8.30 a.m.	Humidity at 10 a.m.	Humidity at 12 a.m.	Humidity at 4 p.m.
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				

28				
29				
30				
31				

Practical notes

To make the collection of the data easier and to make it more interesting for the school there are two copies of each data sheet provided for one month. The school should fill in the to sheets at the same time. One of the sheets is for the school archives and the other one should be given to a SASOL member that comes to collect it. We hope this collection will be once a month.