SAND-STORAGE DAMS ON BLACK COTTON SOIL

A RESEARCH ON THE POSSIBILITIES TO CONSTRUCT SAND-STORAGE DAMS ON BLACK COTTON SOIL

KITUI DISTRICT

PROJECT REPORT

CF 628

G.A.J. Frima	9247183
M.A. Huijsmans	9380358
N. van der Sluijs	9354628
T.E. Wiersma	9102938

In co-operation with:
SASOL foundation

May 2002, Nairobi

Some remarkable quotes during our stay in Kenya:

“Every concept in every situation generally has the same solution”

“If you come in peace, you bring a treasure”

“Please the country, but also please yourself”

Colophon

Sand-storage dams on black cotton soil.
First edition May 2002

Delft University of Technology is not responsible for the consequences of any kind, resulting from applying data, calculations and conclusions to be found in this report.

Authors: G.A.J. Frima
M.A. Huijsmans
N. van der Sluijs
T.E. Wiersma
M. Muyanga
M. Isika

Lay-out, editorship, cover and pictures are all done by CF 628: G.A.J. Frima, M.A. Huijsmans, N. van der Sluijs and T.E. Wiersma.

Published by:
G.A.J. Frima
Email: Frimakenia@hotmail.com

Preface

On behalf of our study, Civil Engineering of the Delft University of Technology, we have been working on this project, concerning the construction of sand-storage dams on black cotton soil (BCS) in southern Kitui in Kenya. The project is a part of more projects concerning sand-storage dams, all accompanied by the Delft University of Technology, the University of Nairobi and SASOL.

For us this project is part of our 4th year program and we decided to go to Kenya, because of the challenge to help a developing country. We spend 9 weeks on the project from March 11th till May 10th 2002. The projectgroup exists of four people, all specialised in hydraulic engineering.

As we were exploring in the dark side (there is no information on BCS) we had to do field research. Since there was not enough time to gain all the information needed, we had to write this report on a base of assumptions. However a design process with different solutions is given. With more information in the near future, this report can be used to determine and to design the right concept.

Our counterpart SASOL and the UNESCO chair of the University of Nairobi have initiated the project. SASOL is trying to build sand-storage dams on BCS and to know more about hydrological impact of the dams. SASOL is continuously developing their knowledge and database on all aspects of the sand-storage dams. The department of project education of the TU Delft arranged that several groups have worked with SASOL till now.

During this time we stayed in Nairobi for report writing, in Kitui to explore existing dams and Ikanga for our field research. The report writing took place in the Apostles of Jesus Youth Technical School in Nairobi.

We would like to thank prof.ir. R. Brouwer, ir. M.W. Ertsen of the Delft University of Technology for accompanying us and for the confidence in sending us to Kenya. We also thank prof. J.M. Bahemuka of the UNESCO chair of the University of Nairobi for informing us on the habits of the local communities. Also thanks to the last years group of Beimers, Lam, Roos and Van Eijk for their practical advise.

Special thanks to prof. C.G.M. Mutiso, chairman of the board of SASOL and Sam Mutiso for their advice, confidence and accompanying. As an employee of SASOL we would like to thank Joseph Muindey for helping us. For the contribution to this report we would thank Milu Muyanga and Mutua wa Isika.

Thanks to Maartje van Westerop for arranging our tickets and our stay and providing useful contacts. For the accommodation, the learning of Swahili and the adventures in the National Park we thank father Joseph. We thank Jo, Joyce, Jolien and Cathy for their social support and bringing us closer to the Kenyan people.
We also would like to thank KLM, Royal Dutch Airlines, for their assistance and support in Nairobi.

Last but not least, we want to thank our sponsors. Without their financial support this project would not have been possible. Because still much has to be done, not only in Kitui, but also in

all developing countries, we hope these generous companies will not hesitate to sponsor next groups.

First sponsor:
Mos Grondmechanica Rhoon

Second sponsor:
Van Oord ACZ dredging

Donator:
Wavin
Fund international stages of the Delft University of Technology
Waterleiding Maatschappij Overijssel
WSO fund
Hydron Zuid-Holland

We wish all companies involved good luck in achieving their goals and we hope that in the future all water problems can be solved.

Nairobi, May 2002

Anton Frima
Markus Huijsmans
Niek van der Sluijs
Tjitske Wiersma

Summary

The Kitui district is located in east Kenya. Like other arid or semi-arid areas the climate is very hot and dry, the rainfall is highly erratic and the evaporation is high. Due to this climate the scarcity of water is a major problem. The northern part of Kitui is mountainous where the ground consists of rock and red soil. The southern part is rather flat and the ground consists of black cotton soil (BCS).

SASOL (Sahelian Solutions Foundation), a non-governmental organisation (NGO), was founded in 1990 to solve the lack of water, which will improve households in the communities. In pursuit of its objectives SASOL, in co-operation with local people, built sand dams, shallow-wells and rainwater storage tanks for community members. Together with local communities SASOL has been constructing over 250 dams in an area of 600 sq. km. SASOL uses a bottom-up approach when implementing the projects by letting the community members define their own problem, setting their own priorities and making their own decisions on how to solve it. The sediment in the reservoir of the sand-storage dam, contains the water and the people can extract water from scoop holes.

<u>Problem definition</u>

- SASOL is especially interested in the construction of storage dams in the BCS area of the district. The problem is the lack of knowledge on constructing storage dams on black cotton soils.
- The knowledge on the ground layers and the different soil characteristics is nearly none. A good soil profile doesn’t exist, at least not until the depth of an impermeable layer. It is uncertain where the water in the various catchments areas flows.
- Another uncertain parameter is the discharge. It is not known how much water runs off, evaporates or disappears in the ground layers.

<u>Objective</u>

To develop a number of designs for sand-storage dams constructed in the black cotton soil area.

<u>Important demands</u>

- The dam may not settle, due to consolidation of the clay
- The construction has to withstand forces caused by swelling and shrinkage of BCS that might damage the construction.
- Unwanted change of the river course should be prevented.

In order to come up with concepts, field research has been done on the Semea River. The river exists of flood plains and narrow river channels. Augurments at different places in the river and in the banks resulted in a general soil profile. However this profile is based on a small number of augurments and the augurments did not reach the desired depth, so the layer underneath the limestone layer is still unknown. In the profile we first see a layer of sediment and than a layer of BCS. A mixed layer that turns into the permeable white limestone layer is under the BCS. (see figure 4.5)

The most important conclusions are:

- The BCS is impermeable
- The white limestone layer is a product of BCS and is permeable and the water in the area flows away through this layer

- The main problem is not the swelling and the shrinkage of BCS, but the flowing away of water.

For different soil profiles, concepts are developed:

1. Impermeable layer at reachable depth under the white layer	A. Stone-masonry dam B. Impermeable sub-surface shield C. BCS dam
2. Thick permeable layers	A. Stone-masonry dam B. Storage tanks or trenches C. Impermeable shields
3. Very thick BCS	A. Stone-masonry dam B. Impermeable shields C. BCS dam

Another possibility to store water in the area is to block the outlet of the catchment area. It is difficult to find the outlet, because this will need seismic study. This technology is not available as yet, so this solution will not be explored further.

Because the principle of stone-masonry dams is familiar to SASOL, a BCS dam, an impermeable shield in the reservoir and a deep impermeable shield are more of interest to SASOL and designs are made for these concepts.

<u>BCS dam</u>
When there isn't any sediment or little sediment in the river, a dam has to be constructed to catch sediment.
In this design the core consists of BCS. The core has to be protected against dehydration with plastic. To protect the plastic, stones must be placed on top; this is called protection/filter layer. The stones must be resistant to the flow forces. Two base layers of different grain diameters are placed underneath this protection layer. The dam is also designed to be internally and externally stable. The protection goes to the reattachment point. Different protections against dehydration and different impermeable shields under the dam are evaluated. The best option is a stone and plastic protected dam with a BCS shield.
This dam is not feasible, because it needs a lot of stones and the construction method is difficult. The main interest in this design is constructing with BCS as a construction material and can be of use for further research.

<u>Impermeable shield on an impermeable layer</u>
In this situation a firm impermeable layer is assumed to be at a feasible depth. Shields will be put through the BCS-layer, the white layer and into an impermeable layer underneath. Different materials are evaluated. In this evaluation a trench filled up with BCS ended up as the best option. Because the knowledge on the soil characteristics is so little, the design and calculations were made for the second best option instead of a shield of BCS: the plastic waved shield. These shields are not that expensive, impermeable and low in weight. Calculations have shown that the shields can withstand the forces of the ground water flowing through the layers. The shields are easy to construct although a lot of excavating has to be done. The most important effect of the shield will be the slowing down of the run-off (both surface and subsurface). The building of the shields is very labour-intensive and it will take time before the results are visible. So constructing this design may prove to be a bit risky, before further research is conducted.

Shield in reservoir

In this situation sediment is already present in the riverbed and an impermeable layer underneath the white layer is not reachable. The shield will end in the rather impermeable BCS layer and hold water in the sediment this way. BCS got the best marks in the evaluation, but again, because of the lack of knowledge, it was decided to choose another material. A design was given for a plastic membrane, constructed in an s-shape. The shield has to be held in place by beams at the top and bottom end. The construction is simple and there is not a lot of excavation needed. Even though the storage capacity of a shield is low, the costs are not that high. Given the fact that the shields will influence the area in a positive way, it is believed to be a feasible solution on the long run for a BCS-area where an impermeable layer is unreachable.

Conclusions and recommendation

In this early development stage of water containment in the area by SASOL, a lack of knowledge stands in the way of constructing either sub-surface dams or sandstorage dams. It will be more reachable to create a construction that slows down the water rather than creating a reservoir that contains the water.
The value of presented concepts will prove itself after experiments and research.

Table of contents:

1. Introduction

1.1 Project context

Two obligatory subjects in the curriculum of Civil Engineering at University of Technology Delft are the reason of the undertaking of project group CF 628 in Kenya. In the last four months of the fourth year of the curriculum everyone has to execute a six weeks project and a practical work experience for a period ranging between six to ten weeks. When the project is done abroad, six weeks is a rather short period to gain good insight into the project. Therefore the group has decided to combine the project and practical work experience.

The project and practical work experience will be done in Kitui District, Kenya. In appendix I an overview map of Kenya, including the location of Kitui District, is added. For several years a non-governmental organisation SASOL has been developing storage dams to contain water for household purposes. Three groups of the University of Technology Delft have already been in Kenya to participate in optimising the design of storage dams.

In our project period we will analyse the potential failure mechanisms in order to come up with designs of several concepts to build storage dams on Black Cotton Soil (BCS). Halfway through our stay in Kenya another group will arrive to build an experimental dam, using our findings and recommendations.
In the second period of our stay, we will study the hydrologic aspects of storage dams on sand. This will be the practical work experience.

1.2 Objective of this report

The objective of the final report is to design several concepts to build storage dams on Black Cotton Soil (BCS).

1.3 Contents project proposal

In the next chapter the history of water management in Kitui District is outlined. A description is given on the location, the organisation, and the history of the project, as well as former groups who worked on the project. In chapter 3 the objective, restrictions and plan of activities are given. The results of our field research in the BCS area are described in chapter 4.

The different concept designs are generated in chapter 5. Two concepts are worked out in the following chapters: a BCS-core dam in chapter 6 and an impermeable shield in chapter 7 and 8. Conclusions and recommendations are outlined in chapter 9. Maps and drawings are shown in the appendices.

2. Water management Kitui

2.1 Kitui District

Kitui Town is located in Eastern Kenya. [4] It is the administrative centre for the Kitui district, which is one of the twelve districts that make up the Eastern Province. The district covers an area of 20.556 square kilometres, including 6.369 square kilometres of the Tsavo National Park, inhabited by wildlife. It is divided in eight administrative divisions. In figure 2.1 a map of Kenya, including the location of Kitui district, is shown.

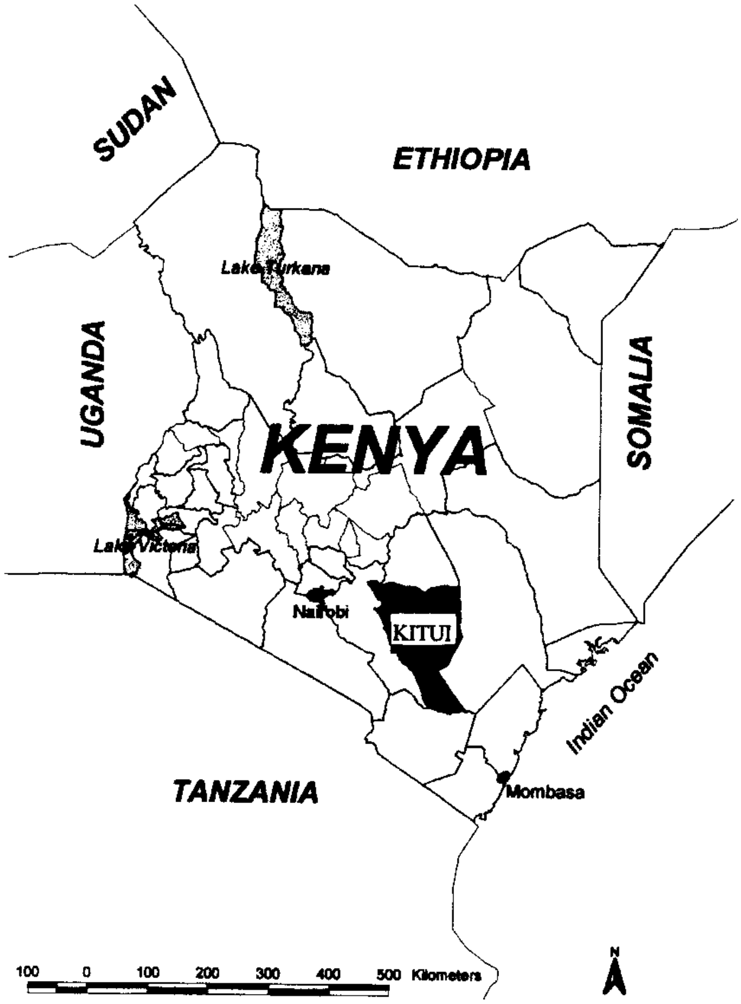


Figure 2.1: Map of Kenya

The Kitui district lies between 400 and 1.800 meters above sea level. The Yatta Plateau lies in the Southeast of the district between the rivers Athi and Tiva. The eastern side is almost flat with shallow widely spaced valleys and with some hills. In the higher part of the district they have more rainfall and therefore more productive areas. The main crops in the district are corn and beans.

The climate is hot and dry as in arid and semi-arid areas. The rainfall is very erratic and the rate of evaporation is high. The potential evaporation is over 2000 mm per year. That makes intensive use of the land hard. In the district there are two rain seasons, from April till June and from November till January. One in the three rain seasons is a total failure. Dry periods are between June to September and January to February. The amount of rainfall depends on the location in the district and the topography. The higher areas receive 500-760 mm per year and the lower part less than 500 mm per year. The minimum temperature is 20 °C degrees and maximum over 30 °C degrees.

The population of Kitui District was estimated to be more than 624.000 on 2001 (213 persons per square kilometre) and is growing at a rate of 3.3 % per year. There are slightly more female than male.

The main problem in the area is inadequate water for a larger part of the population as there are only a few water sources such as rivers and springs. The major sources of water are perennial rivers. To access water, people and animals have to travel for long distances especially during the dry season and drought. In some areas people walk for 25-30 kilometres in search of water. Most rainwater is not harnessed. It finds its way to the Indian Ocean. If this rainwater can be stored, it can be used during the dry season and drought.

2.2 SASOL

SASOL (Sahelian Solutions Foundation), which is a non-governmental organisation (NGO), was founded in 1990 to solve the lack of sufficient household and production water. Together with local communities SASOL has been constructing dams in an area of 600 sq. km. In pursuit of its objectives SASOL, in co-operation with local people, build sand dams, shallow-wells and rainwater storage tanks for community members. The available water is of a good quality since there is no use of pesticides or industrial pollution. SASOL focuses on an area about 600 sq. kilometres in the Central Division (765 km2) because it has the highest population density of all the divisions.

The sand dams are preferred by SASOL because of the low costs per cubic meter of water and the sufficient quantities of water that can be stored. Also the fact that good locations for these sand dams are widely available in the project area makes it valuable to focus on them.

A "sand-storage dam" is constructed above the surface and collects the water in the sediment that, during the coarse of its life span, settles behind the dam. The water is held upstream from the dam. Wells are built either in the river channel or in close proximity to the river.

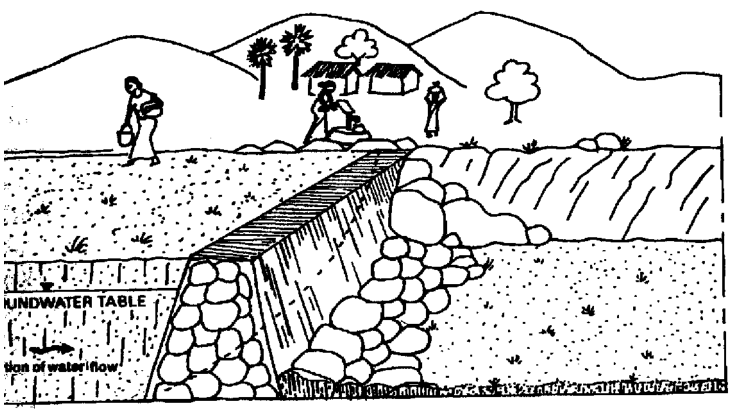


Figure 2.2: principle of a sand-storage dam [2]

SASOL has constructed over two hundred sand-storage dams in co-operation with the local communities in the central part of the Kitui district. The effects of the dams have become noticeable. People, who had to walk many kilometres for household water in dry periods, are now supplied with clean water during the whole year.
In the future, SASOL wants to keep on building dams southwards from the sand/ rock area to the Tsavo East National Park. The population density in this region is lower and the soil differs from the situation in the present building area. To finance these dams, SASOL has found funds from the European Union.

2.3 University of Nairobi

Support from the University of Nairobi consists of information on different aspects of the storage dams.

Prof. J.M. Bahemuka informed us on social aspects. Because we work with communities during our field research, we got a lecture from David Kawai on the politics, economics and the social behaviour of these communities. Also our approach to the people is discussed. A social-economic impact of the sand-storage dams by Mutua wa Isika and Milu Muyanga is given in chapter 4.

Prof. C.G.M. Mutiso gives technical support.

2.4 Previous project teams

Three groups of the University of Technology Delft have already been in Kenya to participate in optimising the design of storage dams.

First Group 1999:
- Assessment of the sand-storage dams built by the Westerveld Conservation Trust in Tsavo Park.
- Research streamlines around the dams.

Second Group 2000:
- Development of the sand-storage dams and new designs for sand-storage dams.
- Feasibility study of a bridge over a river in Tsavo Park.

Third Group April to July 2001:
- Optimised design of sand-storage dams.
- Manual on design, location, construction, and maintenance.
- Proposal hydrological study on the effects of sand-storage dams.

2.4 Present knowledge

During the last years more than two hundred dams have been built in several rivers in the Kitui-area to store water during the dry season and periods of drought. Since the building of these dams the groundwater level has risen. The concept of sand-storage dams has proved itself; three UTD student groups have improved the design. To gain an impression on the

performance of the dams we visited ten dams, which were in different stages of their life span. A report of our experiences is written in chapter 4.
Dams have not yet been constructed in the BCS-area by SASOL. It is expected, due to the swelling characteristics of the BCS, that the dams will crack in periods of drought.
The only present knowledge on the ground layers is a soil profile made by a ground survey service in 1978 [10], but it only describes the layers till a depth of 1.60 meters. It was only a reconnaissance survey.

2.5 Lack of knowledge

SASOL is especially interested in the construction of storage dams in the BCS area of the district. The problem is the lack of knowledge on constructing storage dams on black cotton soils. SASOL has no experience at all in building dams in the BCS-area.
The knowledge on the ground layers and the different soil characteristics are nearly none. A good soil profile doesn't exist, at least not until the depth of an impermeable layer. It is uncertain where the water in the various catchments areas flows.
Another uncertain parameter is the discharge. It is not known how much water runs off, evaporates or disappears in the ground layers.

3. Project description

This chapter starts with a description of the Black Cotton Soil area, the target area for our project. Paragraph 3.3 contains the objective of our project. The problem approach of our project is presented in 3.4 together with our plan of activities. The chapter also gives a list of restrictions for the new design of the sand-storage dam on Black Cotton Soil.

3.1 Location description

The material of interest in the planned area is a clay soil, popularly known as Black Cotton Soil. The project area is in the southern of Kitui district, which is comprised of these soils. The BCS is a clay soil that consists of particles of the remains of swamps. It is known as the swelling clay. This is due to its character of swelling when wetted and shrinking upon drying. The BCS has a clay mineral called montmorillonite and it is this mineral that is responsible for the swelling and shrinking. [8] This mineral forms a layered structure, which absorbs water and swells.

The southern part of the Kitui district is a rather flat area, situated around 850 meters above sea level. This part of the district is dry, and the temperature is generally higher than in the northern parts of the Kitui District, where dams on rock have already been constructed. The intensity of the rainfall is very low and spread over a small number of quite heavy showers. In chapter 4.7 this will be reviewed.
In the area several riverbeds are situated. Usually there is no water in the riverbed. Our field research has taken place at the Semea River at the height of Ikanga town. This river and our findings on the soil are described in chapter 4.

3.2 Problem description

The problems concerning the design of a water storage facility are mentioned in the next paragraphs.

3.2.1 Problem analysis

Now the concept of sand-storage dams has proved itself useful, SASOL is interested in other dam types and alternative construction methods. They are especially interested in the construction of storage dams in the black cotton soil area of the district. In this district the lack of water is a big problem. In the wet season the water can only be found in the deeper soil layers. In the dry season people move to other places to get water or walk for hours to obtain water.
SASOL has no experience in building dams in this area. Only one dam has been built by another organisation. This dam is described in chapter 4. In short, the dam has caused a sand reservoir to develop, but it doesn’t seem to hold any water.
There is little knowledge on the soil layers and the different soil characteristics. It is uncertain where water flows in the various catchment areas.

3.2.2 Problem definition

There is a lack of knowledge on constructing storage dams on clay soils. It is expected that because of swelling characteristics of the clay, the soil will crack in periods of drought. Another expected problem is the cracking of the dam by settlements of the soil. From chapter 4 a new problem arose, this is the water disappearance through the limestone layer.

3.2.3 Objective

The objective is to develop a number of designs for sand-storage dams constructed in the black cotton soil area.

3.3 Plan of activities

To come up with a number of solutions the following approach was used.

3.3.1 Problem approach

To pursue the objective a thorough literature search was done in the Netherlands. The objective of this literature study was to gain knowledge on soil characteristics and methods on soil research. We visited MOS Soil Mechanics and talked to several experts on the subjects. In Nairobi we met Peter Westerveld, with whom we discussed black cotton soil characteristics. Prof. Judith Bahemuka and David Kawai lectured us on the customs of the Kitui District and their inhabitants.
In Kitui we visited several sand-storage dams in the northern part of Kitui District to gain insight in the current design of the SASOL sand-storage dams and the effects of the dams. We visited dams under construction to see the construction techniques and used materials. We also saw dams of which the construction was completed a couple of months before. The reservoir was filled with water. During the field trips we also visited some dams built in 1997. The reservoirs of these dams were filled with sediment.
After this we visited the black cotton soil area. We stayed in Ikanga near the Semea River where we conducted our research. To find out more about the different soil layers and soil characteristics, we augured up to a depth of 3,60 meters. The results of these measurements are given in chapter 4 of this report. The measurements have been evaluated and the different layers have been mapped. From this the possible failure mechanisms are derived. In this report an overview is given of the possible designs for the storage dams constructed in BCS.

3.3.2 Activities

Wk.	Kw.	Activity	Location
1	11	Research/ literature study	Neth.
2	12	Research/ literature study	Neth.
3	13	Departure / acclimatisation	Nairobi
4	14	Field research	Kitui
5	15	Field research	Ikanga

6	16	Technical evaluation	Nairobi
7	17	Development designs	Nairobi
8	18	Writing final report	Nairobi
9	19	Reserve, report writing, next group Presentation findings SASOL	Nairobi/ Kitui

Literature study
Search the Internet and the library on the following subjects:
- Fluid mechanics: river discharge, erosion, hydrostatics and open channel hydraulics.
- Soil mechanics: Clay characteristics (morillonite behaviour), aquifer behaviour, test set-ups
- Foundation techniques: clay foundation.
- Researching concept design possibilities in literature

Field research
- Visit sand-storage dams and construction sites
- Visit the BCS area
- Auguring in riverbed, riverbanks and surroundings
- Measurements on soil characteristics (permeability of BCS and river sediment)
- Material research both in Kitui and Nairobi

3.4 Restrictions

The following restrictions apply if the project is to succeed.

3.4.1 Boundary conditions

Technical

- The designed construction should be built only using available equipment.
- No skilled workers are needed to build the construction. SASOL can provide in masons and a welder.
- The construction should be designed in such a way that it can withstand the force of flowing water, both surface and sub-surface water.
- The construction has to store water and sediment.
- The construction has to withstand forces caused by swelling and shrinkage of BCS that might damage the construction.
- Water should not pass the sides of the dam (in the sand storage dams on sand wings are chosen to protect against this phenomenon).
- Unwanted change of the river course should be prevented.
- Erosion around the construction has to be prevented.

Functional

- The construction method must be appropriate for the whole BCS-area.
- Negative influence on the agriculture in the area has to be prevented.
- To fill a potential storage reservoir in the riverbed, sediment has to be transported by the river.

3.4.2 Starting points

Technical

- Unwanted seepage at any side of the construction should be prevented.
- No or little maintenance should be needed.
- The materials used should be as durable as possible.
- Vulnerable materials should be avoided as much as possible.
- Potential reservoirs have to be filled annually.

Functional

- The building process has to be suitable for a community-based approach.

Financial

- The construction must be constructed at the lowest possible price per cubic meter storage.

3.4.3 Assumptions

Functional

- There will be enough people to build the designed construction.
- Community workers are not paid.
- The community provides the needed materials for the constructions if possible like stones, sand and water.
- After completion, the community is responsible for the maintenance of the dam.
- Assumptions made on the soil characteristics and the ground layers are made in chapter 4, the field research.

Economical

- The ideas of SASOL follow the principal that water is a primary need to the community. This results in the fact that expensive water is better than no water.

4. Field Research

4.1 Introduction

The field research exists of two parts. One side is the research on working sand-storage dams constructed in the red soil area of Kitui. Second is the research on the BCS-area and the soil profile in this area.

A good insight in the existing dams together with all data of the area will lead to good designs for dams or other solutions on BCS. However, there is no data available on the rain or the soil in this area. To come up with designs a lot of assumptions must be made. So after this chapter there will remain some unanswered questions. The conclusion and recommendations will give a range of investigations, which must be conducted in the near future.

In this chapter first the social-economic effects of the dams in the northern part of Kitui are given. Then a summary of the report of last year group will give an insight in all technical aspects on sand-storage dams. A description of the Semea River, which is the primary river to need control and a research to the only existing dam, are following. After that an indication of the soil profile is given. All the results of our experiments are in appendix II. An explanation of the hydrological situation is given at the end of the chapter. Finally the conclusions and recommendations are stated.

4.2 Social economical impact (by Mutua Isika, G-C.M Mutiso and Milu Muyanga)

Kitui dams and food security

SASOL, founded in 1990, assists Kitui communities to address household and production water scarcity through the sand dam technology.

The planning objective was to shorten the distances to water sources to below two kilometres whilst making water available for alternative production systems. Typically, women walk 10-15 km to water sources in the district. To date, 320 dams have been constructed in central Kitui. Globally, this project has the highest number of sand dams. The distant second project, globally, is found in Machakos- the neighbouring district, at Utooni, with 120 dams. These two projects have the highest concentration of sand dams anywhere in the world.

Construction of sand dams is economically and socially effective since the technology is simple and lends itself to participatory development. Communities contribute labour, sand and stones, artisan housing and food for the people working on dams as well as the artisan.

Sand dams are not new in Kitui. An ex-World War 1 soldier, Mr. Nzamba, constructed the oldest dam, in 1928, at Mathima Location, Mutomo division. He had seen the technology in his travels. It is still functioning. The colonial government built a few more in the fifties. Since then a few more have been built by an assortment of development organizations. The technology has gone through the most severe test of all - time. The lifetime of the newly constructed dams is expected to be more than 100 years with minimal maintenance. The dense construction adapted in Kitui regenerates ephemeral rivers run all year long.

Data from an ongoing Social and Economic Impact Study indicates that the sand dams have immediate impacts on cost of water. For example, at Mbitini market the price of water was reduced by 75%, from Ksh. 20 to Ksh. 5, as a result of the construction of the sand dams. But perhaps most significant is the transformation of production. With increased quantity of water, the local people grow kales (*Sukuma wiki*), tomatoes, onions, improved varieties of mangoes, bananas, sugarcane, bee keeping and horticultural and tree seedling nurseries. Fishing, which was uncommon in the area, is a new economic activity. Brick making is on the rise.

In year 2001, Ithumula/Maluma Sub-location, Chuluni Division, was able to meet tomato demand for Kitui town, thereby blocking suppliers from outside the district. At this rate, this technology and maximum utilization of the availed water for production will definitely reverse the vegetable and fruit supply chains in the District for the district has been a net importer. Kitui District, an ASAL district has begun to export some vegetables and fruits, mainly improved mangoes, among other products.

District wide interview data from the study shows that households owning land adjacent to the regenerated rivers are now earning over Ksh 100,000 in the dry three months of August, September and October from bucket irrigated vegetables. Income from horticultural trees is on the rise, though yet to be aggregated and documented. There are 1,969 households in Maluma/Ithumula sub-location. 38.5% of the interviewed households reported that they were engaged in vegetable planting the first year after completion of the dams. Conservatively assuming that only 2% of the households did serious planting, the first year, and further averaging down the household earned income to Ksh 90,000, with an average household having 8 people, the dry months per capita income is Ksh. 3,750. This compares to the mean income from food sales of Ksh. 125 as reported in the 1999 Welfare Study by CBS. The vegetable household incomes translate to Ksh 3.1m. during the first year of adoption for the entire Maluma/Ithumula region. This figure is collaborated by the local councillor who estimated that Ksh.4 m. was earned in the sub location. For the whole district, keeping the same assumptions, the dams could generate Ksh. 118 m. during the dry three months whilst using the land for other production during the rest of the year. We should note that there was no extension effort on this new production. With these incomes, the whole district can move into a higher economic plane dramatically. Further, from a health point of view, consumption of vegetables and horticultural produce has impacted positively on health, especially of women and children. This is the way to fight poverty.

The impact of the dams is not just in terms of incomes and health. Sociologically organising for the dam construction has led communities to improve leadership, more systematic community organisation and prioritisation of development, including identification of interrelationships between sectors. They are more conscious of the fact that they can bring positive development with their own skills and resources. More systematic organising has led to dealing with community issues like shortage of wood for cooking and construction etc. Households are able to plan their consumption of farm products. Sanitation has also improved. Key in this is the construction of toilets. These issues are part of the training for dam construction.

SASOL sought technical cooperation with the ministry responsible for water and the local universities and failed for the first ten years. It sought and got technical backup from Department of Civil Engineering, Technical University- Delft, The Netherlands. Technical evaluation of the sand dams technology was done in the 2001. This year technical evaluation of water quality, especially for human consumption, will be done. A trans-disciplinary group from Amsterdam, Technical University-Delft, Leiden and the University of Nairobi, will study the sustainability of the dam system this year. Video documentation of construction techniques is done and is available from Ukweli studio. An impact assessment video will soon be available form the same source.

Four staff members of SASOL have trained with TU-Delft and IRC. It is expected that each year a number of SASOL staff will be send for training. At the same time a project of training University of Nairobi students in the project area will start this year.

Water AID (UK), DFID, SIDA and SIMAVI are the main development collaborators in this project.

4.3 Sand storage dam principal

During a week stay in Kitui, about ten sand-storage dams were visited. These dams were visited to get an impression of their performance. This impression is needed for the project group to transfer the working concept in north Kitui District to the BCS area to the south. Information gathered on materials, dam-dimensions, foundation and area-parameters have to be translated to an area with different characteristics.

An extensive description on the dams in the north is written down in the report "Building Sand-storage dams", [4,5] written by the UTD student group (may 2001) that studied the dams built by SASOL in the northern parts of Kitui District. In this report detailed descriptions on the building- and design process are given, as the result of their practical fieldwork. During the design process for southern Kitui the reports applicability for this area will become clear.

Below, the following characteristics of a sand-storage dam (shown in figure 4.3) in the north are described:

- Working of a sand-storage dam
- Foundation of the dam
- Construction process and used materials
- Location choice
- Dam dimensions
- The reservoir
- Erosion

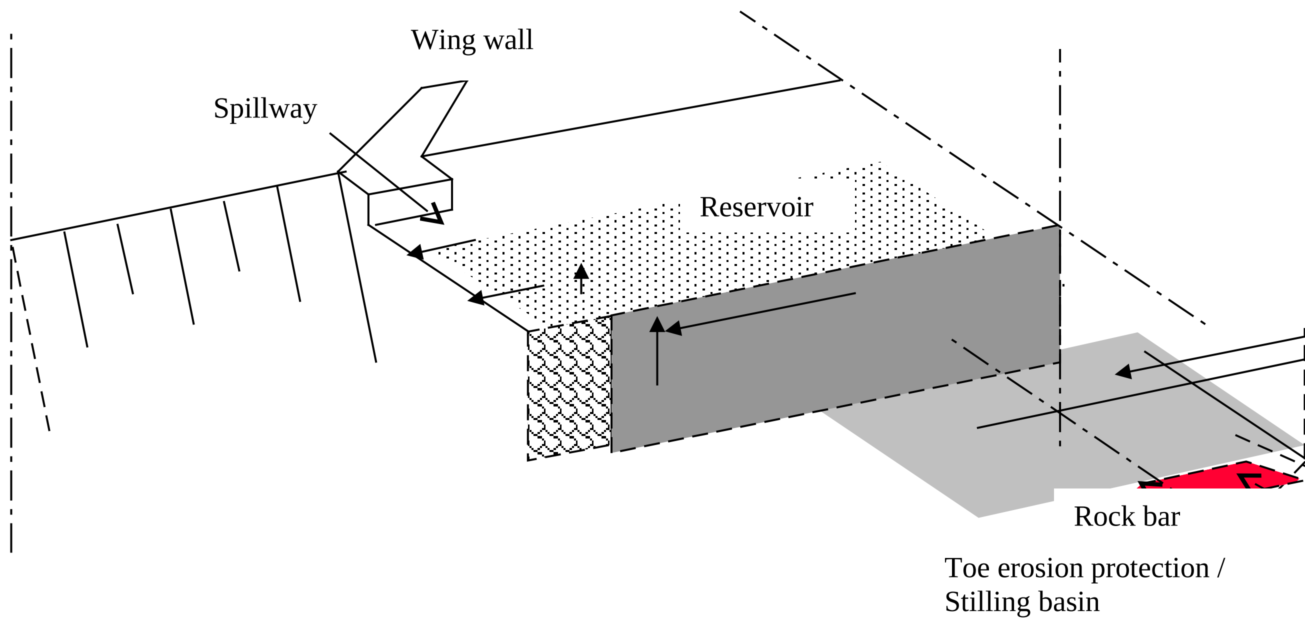


Figure 4.3: Principle of a sand-storage dam

4.3.1 Working of a sand-storage dam

The working and principal of a sand-storage dam is rather simple: a dam is built in the riverbed in a lateral direction. In time, sediment is deposited upstream of the dam, which creates a reservoir that contains water in periods of drought. By the use of wells and scoop holes this water can be obtained from the reservoir and used for various purposes. Often an off-take well is constructed near the dam. This shallow well is said to give the best water quality, but people still tend to use scoop holes to get water. Sometimes wells are polluted, due to dead animals or vegetation inside the wells. Under the direction and guidance of SASOL the dams are built by local communities, which profit from the dam by receiving water. This concept has proven itself useful in the northern parts of Kitui were a large number of dams has been built. Various dams are still under construction and plans for new dams in this area are on the table.

4.3.2 Foundation

The base of the dam is founded on a firm impermeable layer that is found below the riverbed. The foundation depth depends on the fact whether and on which level base rock, clay or murram (soil with small stones) is found. Base rock is the best foundation for a dam. Clay is the second best foundation. The clay in the northern Kitui District is very compact and does not settle.

4.3.3 Construction process and materials

The most important material at the building site of a dam is water. It is used for many activities like mixing cement, cleaning and wetting the fresh masonry. The process of fetching water can be a time consuming activity due to distances that have to be covered from nearby rivers to the building site. First of all, the wings of the dam are constructed, using stone-masonry. This prevents water to leak in the foundation trench of the wing walls during the rainy season. Finally the spillway is constructed. The parts of the wing walls under the surface of the banks are built by filling the foundation trench with masonry comprising hardcore (broken stone) and mortar. At certain distances, reinforcement steel is laid. For this purpose, barbed wire is used. A mason from SASOL takes care of the masonry of the dam. The community takes care of supplying mortar and handing stones to the mason. After filling the dam with hardcore and mortar, grooves are made in the top layer. These grooves form a rough surface on which can be plastered. Plastering the dam is the last part of the execution.

4.3.4 Location choice

The SASOL representative looks from a technical point of view whether there is a location to build the dam. If so, SASOL's technical manager will try to convince the community this is the best location. Criteria of the technical manager for a good dam location are:
1. Storage capacity of the possible reservoir
2. Soil characteristics of the location
3. Is it a good place to work?

4. Is the river at this location naturally confined between banks, even during flooding?
5. Is the river straight? Locations near a bend are unfavourable.
6. Is there a rock bar across the riverbed? Possibly without a fracture (as far as can be ascertained by probing with an iron rod). Such rock bars are the best foundation and occur quite frequently in the northern project areas.
7. Are there enough materials in the surroundings (clean sand, stone and water)? It is time-consuming and expensive when stones, water or sand have to be imported from other places.
8. Distance between a previous dam and a new dam (recommendation is 1/2 km for steep rivers and 1 kilometre for gentle rivers). Another important issue is the height of the previous dams (series).

These criteria have to be compared to the situation of the southern Kitui area. Sometimes water may be needed at a location where the favourable conditions are absent. In such cases, risk of failure and bad performance is high.

4.3.5 Dam dimensions

The UTD student group (May 2001) performed a study [4] on the dam dimensions, especially on the wings, the spillway and the stilling basin at the downstream side of the dam. Their new findings and advises on the dimensions were given to SASOL, to be used during the design process for dams in this area.

4.3.6 The reservoir

The potential yield (volume of extractable water) of the reservoir depends on the following factors:

1. Volume of sand in the reservoir

Depending on the slope of the riverbed and the transported sediment a sediment reservoir will develop upstream from the dam. The expected volume of this reservoir has to be calculated in order to predict the potential yield.

2. Porosity and water-containment capacity of the sediment

This porosity can be estimated by testing the sediment that is already found in the riverbed. It is assumed that the sand from the present bottom gives a good indication of the sand that is going to settle in the reservoir after the dam has been constructed.

3. Extractability of water from the reservoir-sediment

The extractability is the quantity of water that can be extracted from a saturated volume, expressed as a percentage of the total volume. This can be found by measuring how much water can be drawn gravitationally from sediment saturated with water.

4.3.7 Erosion

Erosion around a construction, built in the riverbed, can endanger the performance and the life expectancy. Erosion around the dams constructed in northern Kitui can roughly be divided into three places of erosion, each with their own protection.

1. Downstream of the dam, overflowing (falling) water can damage the riverbed and riverbanks.
A stilling basin was designed to prevent this phenomenon. All dams that have been built and designed the past few years are equipped with a stilling basin either made by concrete or rocks.

2. Erosion next to the dam damaged some of the first dams that were built by SASOL.
This erosion caused the river to flow next to the dam and water from the reservoir was given the opportunity to run off.
The wings built into the riverbanks were also designed, next to seepage, to prevent this.

3. Erosion of the dam construction.
Water flowing over the spillway has a potential to damage the dam construction. To prevent this, the dams are being plastered.

4.4 Semea River description

The Semea River flows through the Ikanga region in the south of the Kitui District. The Semea River is one of the main rivers in the region. The Ikanga region is named after its mayor town Ikanga. The Semea River flows past Ikanga town at 2 km to the east. The Ikanga region is the heart of the agricultural and cattle trade in the area.
The Semea River is formed in the Mbitini hills and flows for approximately 25 km as the Matavika River before it becomes the Semea River. It continues for another 10 km as the Semea River before it joins up with the Nzeeu River, which has passed Kitui upstream of Ikanga town and is therefore polluted with sewage and chemicals.

The soil in the riverbed mainly consists of Black Cotton Soil on which a layer of sediment is deposited. This sediment is a composition of red sand and grain sized particles and is 1 m thick in places. This Black Cotton Soil presents us with a number of complications, which will be discussed later in the report.
The cross section of the river changes dramatically throughout it's coarse. It ranges from quite narrow, approximately 5 m in width with banks of approximately 2 m in height, to floodplains that stretch for a couple of kilometres without the definition of banks. The gradient of the slope of the river is very minor (1º-2º), which causes the river to adjust to small variations in the landscape.
In places the river is confined between banks, the width of the river varies here between 5 m to 20 m with banks up to 4 m. The vegetation on the banks is quite dense with a range of plants, bushes and the occasional tree. When there is heavy rainfall, these passages are flowing rapidly with water getting up to 4m high. There is no water flowing the river when there hasn't been any rainfall. Then the water can be found in places at a depth of 3,5 m in the soil. This also varies greatly even at short distances from each other.
In other parts the river spreads out without a specific river coarse. The area here is very flat. There are small gullies formed by erosion all throughout the flood plain. Vegetation covers the whole plain: thorny bushes, thick grass and trees on embankments that are located on strips through the plain. Here it is very hard to determine were the water flows in the layers of the soil. Sediment is spread out over the plain with slightly higher concentrations in some spots. A layer of black cotton soil is present where there is no sediment.

The field research conducted on the river consisted of determining the soil layers by auguring. Observations were made concerning geographical changes along its coarse. The map of the river is added in appendix I. The locations of the drill-holes are pointed out on this map. Profiles of the soil taken from these locations are analysed in following paragraphs.

There are a number of communities that are reliant on the water from this river. The upstream parts of the river have less water to draw from then the downstream parts. The water shortage is a bigger problem here. To the west of this river there is a large area, which has very little water in the dry season. This area is quite remote and the people have to walk for many miles in the dry season to get water.
The people in this district would benefit greatly if some of the water that flows through the river can be contained, which has been unsuccessful so far.
During a meeting with Professor Mutiso the importance, origin and possibilities of the Semea River were discussed. The following comments arose from the meeting and are useful to the design process. An extensive further research will prove itself worthful.
BCS is a fertile soil. If enough water is present, the area will have a very high agricultural potential. The BCS-soil is, due to its plasticity when wetted, easy to handle and does not contain any rocks.
At this moment 12 % of the Kenyan populations lives in high potential areas. Now that these areas have become overpopulated, people are forced to migrate to arid and semi-arid areas. Current figures show that 45% of the Kenyan population live in low-potential areas, like the area around the Semea River. Water-containment is the key to changing these areas into potentially attractive areas.
During the periods of drought, communities are forced to obtain water at distances that vary up to 30 kilometres covered in one day. These distances are walked by people and donkeys, which carry up to two barrels of 20 litres each.

It has become clear that the Semea River can be an agricultural flourishing area if a good water containment system is established.

4.5 Present sand-storage dam Semea River, Ikanga

During several conversations with the supervisors from SASOL and the local community of Ikanga, it became clear that several years ago an unknown party or organisation had constructed a dam in the river. It is believed that the dam was constructed with the same principal as a sand-storage dam. Because it is unknown who built the dam, the information gathered on the construction (process) is questionable. The location of the dam is marked in the map of the Semea River in appendix I. A picture of the visible part of the dam is added. Due to a thick layer of sediment, only a small piece of the dam is visible.

Figure 4.4: picture present sand-storage dam.

4.5.1 Details of the dam

It is believed that the dam was constructed on a "white" layer (probable limestone) and that the height of the dam is three meters in the middle. The dam has very small wings in the riverbanks, anchored in Black Cotton Soil. The width of the dam is 60 centimetres. The width of the river is 26 meters. The construction of the dam is made of impermeable concrete. It is believed that the dam has not cracked or moved due to expansions or settlement of its foundation. The gaps besides the built dam are filled with sediment.

4.5.2 The reservoir

Up- and downstream of the dam the Semea River shows a thick layer of sediment. The sediment consists in red sand and grain-sized particles that are highly permeable. Two augur tests were both carried out up- and downstream of the dam at a distance of about 5 meters at each side. Both augurments came to a depth of 1.20 meters. This is where the water table was reached, what caused the borehole to collapse due to instability of the sediment.
At both sides of the dam there were found reservoirs of sediment. The upstream reservoir was stretched up to about 3 kilometres. A local man explained that the reservoir of sediment started developing after the dam was constructed.

4.5.3 Failure of the dam

After talks with the local community it became clear that the reservoir does not hold water in the dry season. The community finds water 200 meters downstream in the riverbed in a scoop hole (dug with shovels) that holds water at a depth of almost 6 meters below the riverbed in the driest period and almost in the white layer.
The presence of the white permeable layer and the sediment, which was used to fill the construction hole, are the main causes. The water in the sediment flows along the dam to the white layer. In the white layer the water flows in every direction. Figure 4.5 shows a cross section over the length of the river near the dam.

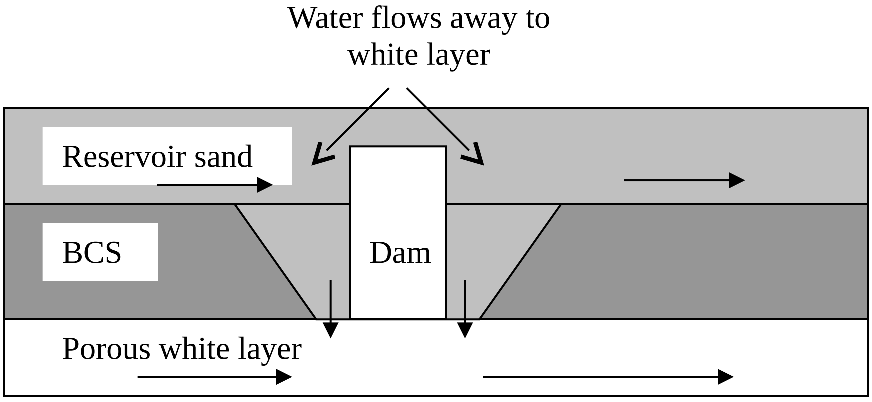


Figure 4.5: Construction of the failed dam

4.5.4 Conclusions

Various conclusions can be derived from the findings in the field, and the conversation with the local community.
It has to be kept in mind that a big part of the findings are based on the opinion of local people.

1. The dam has caused a layer of 1.5 meter of sediment to settle in front of the dam, and for a small part behind it.
2. The reservoir of sand and grain does not contain water during the year. The reason that water was found in the scoop holes near the dam is expected to be a result of the rain that fell during the wet period.
3. The white layer under the dam is a firm but permeable layer that does not cause any movement or cracking of the dam. It can be a useful layer for foundations.
4. The sediment has decreased the depth of the riverbed. This causes the river, in case of high discharge after heavy rainfall, to flow besides the river embankment.
5. Somehow it must be prevented that the water leaks away through the white layer.

4.6 Black cotton soil research

To gain insight in the soil profile, without modern techniques, we used a manual augur and asked the local people. Local people can give an estimate, by their experience of making scoop holes, how deep the layers are. Our augur was 3,6 meters long, so below that depth only estimations and assumptions can be made. We did 5 measurements on various places in the neighbourhood of the river. The places are: in the bank just near the bed, at 100 meters distance of the bank, in the river 1 kilometre upstream of the existing dam, in de floodplain downstream and in the bank in a deep and narrow canal. In appendix II all the profiles are given. From these profiles we extracted one average profile given in the next section.

4.6.1 Soil profile

The local people were saying that the white layer is found approximately between 15 and 20ft. So this is between 5 and 7 meters. Wells in the neighbourhood were all dug to 6 meters deep. We are especially interested in this layer, because it is very permeable as we learned from the existing dam in the previous section.

Depending on the place of the borehole, whether it is in the riverbed or not, there is a sand layer above the BCS. In [7] we found a soil profile of BCS with a thickness of 160 centimetres. As we found in our measurements the layer is 1,5 till 2,0 meters thick. After this layer comes a mixed layer with an increase of moisture till the white layer is reached.
This white layer is supposed to be a property of the BCS. BCS contains $CaCO_3$, the calcium forms the rocky permeable layer. The thickness of the white layer is unknown. At borehole 3 we discovered a kind of yellow lime underneath a whitish layer, but we keep this layer for unknown.
As a result of our field research we are able to draw the following profile:

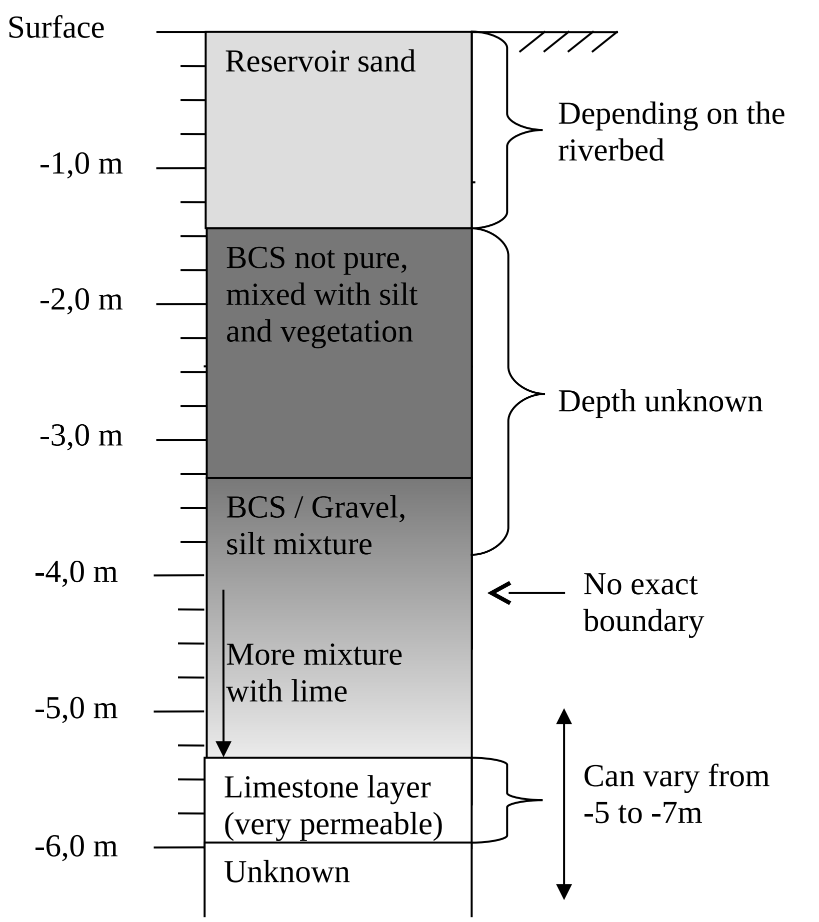


Figure 4.6: Soil profile

4.6.2 Soil characteristics

The reservoir sand:
- Fine to medium sand
- Permeable

The BCS:
- Fine clay particles
- Mixed with silt particles
- Very low permeability
- Little roots/ old vegetation

Mixed layer is like BCS layer but:
- More and more mixed with lime particles
- More permeable
- Higher concentrations of lime particles and even little lime stones

White layer:
- Permeable
- Hard
- Easy to break compared to rock especially when it is wet.

4.7 Hydrological description of the area

The Semea River is the main river of the BCS- area, so basic knowledge of this water system is required in order to be able to design a dam. The water that reaches this area will either run off, seep into the ground or evaporate, from the soil, from the water surface or through plants. The exact ratio between these different processes still needs to be determined, but estimation will help us come up with a solution for the BCS problem.

4.7.1 Precipitation in the area

There are two rain seasons in this area: from April till June and from November till January. One in three rainy seasons is a total failure. The total amount of rainfall in a decent rainy season is approximately 500 mm – 760 mm a year in the higher regions of the Kitui district and less then 500 mm in the southern regions like Ikanga, spread out over showers that last for 1 hour up to 2 hours with an intensity of approximately 40 mm – 60 mm / hour. Unfortunately a good database on rain characteristics in the Kitui District does not exist at the moment. The rain intensity differs greatly even at short distances. Due to changes in the landscape (hills, rivers etc.) the amount of rainfall can vary from 325 mm a year in one place to 800 mm a year only 10 kilometres away.

To determine a more precise discharge of the catchments area, data on rainfall on different locations for at least a whole year round, preferably longer, needs to be acquired.
This can be obtained by for instance supplying the local primary schools with rain gages and test-result forms. Schools are suggested, because they are widely spread over the area and it is useful to teach the children that it is important to acquire data.

4.7.2 Surface run-off after rainfall

The run-off of water of an area is affected by the type of soil, the gradient of the slope, the lateral gradient of the banks, the type of vegetation on the banks and the evaporation of water from the surface of the open water table.
In this particular area with BCS the water doesn't drain into the soil at a fast rate due to the impermeability of the ground, so a large amount of the water is allowed to flow away without being absorbed.
The land in the area is very flat in lateral direction as well longitudinally, so the water does not necessarily flow to a river branch after rainfall, as it would be the case in regions with hills where the water automatically will flow through the valley.
Usually the permeability is higher which causes the water, which is stored in the ground, to seep from the banks into the riverbed. But in this case the water table in the banks is insufficient and the permeability is of such nature that the water will not seep into the riverbed.
The run off is believed to be 40 % of the amount of rain.

4.7.3 Seepage into the soil after rainfall

Although the BCS-layer does not seem to be very permeable, some of the rainwater will seep through it very slowly. This is concluded from the fact that the upper layer of BCS, just under the sediment was wetter than the lower layers. The amount of rainwater that seeps through depends on the humidity of the BCS-layer. Just after a very dry period the layer will be dry and it will absorb more than after a period of rainfall.
The water that is absorbed by the BCS-layer will seep, although very slowly, through to the white layer. Once the water has reached the white layer it then is directed longitudinally or sideways depending on the soil gradient.
Seepage is estimated to be 20 %.

4.7.4 Evaporation of water in the area

The potential evaporation in this area is over 2000 mm a year. So it can be said that lots of water evaporates before it runs of or is absorbed by the ground. Water stored in the upper 30 centimetres of the sediment is subject to evaporation.
The vegetation in the riverbanks also absorbs water. A lot of water will be lost through a process called evapotranspiration. Plants lose water to the atmosphere.
The amount of water lost through evaporation would be approximately 40 % of the water in the system.

4.8 Conclusions

All conclusions are drawn from the research described in this chapter. This is the first data processed on the area. In section 4.9 recommendations are made on further research.

- The white limestone layer, which is a part of the BCS, is found in the whole area under the BCS layer. The BCS layer varies in thickness from 0,5 up to 4 meters. This layer is very porous and thus permeable. The layer is hard, but easy to break compared to rock, especially when it is wet. The detailed soil profile is given in section 4.6.2 in figure 4.3.

- There is enough sediment found in the riverbed, mostly sand. This can be used to fill up a reservoir or to use for construction purposes.

- There are flood plains of more than a kilometer wide with gullies. Deep, narrow canals connect these flood plains to each other. In case of heavy rainfall, the water in the canals is concentrated and flows rapidly. In the flood plains there is a wide, slow flow.

- Due to the impermeable character of BCS, there is a fast run off from the steeper slopes to the river. This impermeability also causes the water in the flood plains to hardly seep into the BCS.

- Up on banks the country is very flat, the slope is less than 1%, and heavily vegetated. This vegetation dries out during the dry season.

- It has become clear that the problem of the area has a different character than expected at the start of the project. The main problem of the area is not found in the swelling character of BCS, and possible cracking of the dam by this phenomenon. These problems are subordinate to the main problem. Water is not being held by the area and flows away through the white layer and on the surface.

4.9 Recommendations

Various recommendations can be made with regard to the Semea Sand storage dam, near the village Ikanga, built 8 years ago.

- To gain more insight in the foundation, the development of the reservoir and the location choice of the dam, it might be useful to find out which organisation has built the dam. If they can be traced, their insights might come in handy.
- A detailed study of the sediment and its origin might have useful outcome for the choice of location of possible future dams.

To create a database on the geology of the area, it is recommended to perform an extensive field research. This research should at least include the following:

- Augurments throughout the area, especially to determine the thickness of white layer and a possible impermeable layer below the limestone.
- Determining the edge of the BCS area, downstream of the river.
- Performing soil tests on samples that can be conducted with simple field equipment.
- Determining a possible outlet of the river; the place where groundwater leaves the target area.
- Determining if a location of white limestone at a small depth exists, this could be a suitable location for a construction.
- Performing research on soil development by interviewing the local communities.

To create a database on the hydrologic system of the area, it is recommended to perform an extensive field research including the following:

- Interviewing communities at different places, asking for experiences with the river and visible characteristics.
- Mapping possible floodplains, next to the river.
- Mapping the outlet area of the river, if possible. This might be a difficult task due to difficult access to the area because of dense vegetation.
- Mapping various forms of vegetation in the dry period (June), this can give an indication of the groundwater concentrations.

At this moment, the use of accurate equipment for field research is too expensive to be used in the field. For instance, seismic equipment could be useful to determine the groundwater level at large depth during the dry period. Investments in this kind of research equipment can prove to be of value in the future.

5. Concept development

5.1 Introduction

In this chapter concepts are made for a number of hypothetical profiles of the soil in the Semea River. This is the only way to proceed with this project, since there is no further information present on the composition of the soil in the area than the information already presented in this report. If the composition of the soil of the Semea River would be known a specific design could be made, however the shortage of time restricts us from doing further research on soil profiles in the Semea River, so we are forced to make assumptions on profiles. These hypothetical profiles are chosen because they are likely to occur or would be a good basis for the construction of sand storage dams.
This wider approach is also more useful to SASOL, because it can be applied in the whole BCS-area. It's not likely that one soil profile covers the whole area.
For every profile several concepts are designed. After a simple evaluation the best concept is chosen. For three different concepts, favourable in a specific situation, dimensions will be calculated. A few other ideas on a different approach to the problem are explained later on in chapter 5. These ideas are not of high priority to SASOL, so they will not be looked into as deeply as the other concepts.

All concepts are designed for the river channels. As this river is characterised by flood plains and wider shallower parts, extensions on the designs of sand-storage dams can be made. Changes in the width of the riverbed do not affect the basic principal of a design concept. The following section is dedicated to secondary problems, due to the flatness of the area. At the designing of the concepts an evaluation is given on the applicability of the dams in the wider parts of the river.

A supplement on the restrictions is given in section 3.4. There are also some other requirements stated. In chapter 6,7 and 8 the designs will be checked on their response on these demands.

The last paragraph gives conclusions and the reasons for our further designing.

5.2 Flatness of the area

Description:
The south of Kitui is known as a rather flat area. The approximate slope angle is 1% both lateral towards the river as in the downstream direction. The river exists as three different characterised areas: deep river channels, shallow wide riverbeds and extensive flood plains. In times of floods the river width can be over 1000 meters. The surroundings of the riverbanks change into a swampy area.

The concepts, given later on in this chapter, are designed for the river channels only. A short evaluation on their applicability to a wider riverbed is covered briefly as well. A short description of the possible problems and their basic solutions is first given in this section.

Possible change of river course

Because of the changing width of the river, there is a possibility that the river will find his way around the dam, when constructed in a wider part of the river.

Solutions:

- Increase the width and the height of the wings. The river will be forced to flow over the spillway of the dam.

  Disadvantages:
    - Hard labour
    - A lot of material is needed compared to the volume of the reservoir, because the wings don't increase the reservoir volume
    - Bigger forces on the ground

  Advantage:
    - Better seepage prevention around the dam
    - Slowing down the run-off water, so the water stays in the whole river system a lot longer
    - Different designs for the wings can be made

- Apply vegetation on banks, so a new course will be hard to find, because the soil is kept in its position due to the vegetation. The flow around the dam will be slowed down.

  Disadvantage:
    - Time needed for growth, very fragile in the beginning
    - Maintenance after very dry periods, vegetation can be dead

  Advantages:
    - Environmental benefit
    - Low costs

- Constructing wooden, iron or plastic shields upstream from the dam in the riverbanks or low BCS dams.

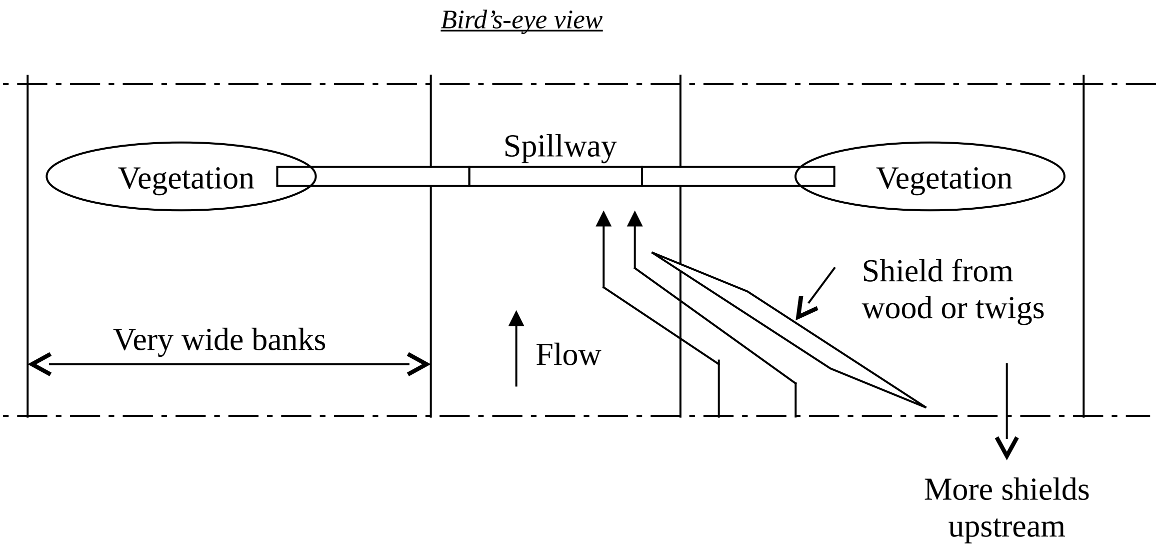


Figure 5.1: Two solutions 1. Vegetation at the wings
2. Wooden, iron or plastic shields

Disadvantage:
- Durability of the shields
- Availability of the material in the area
- Increased current velocities

Advantages:
- Easy constructing

Change of the river course:
It must be kept in mind that a good solution is to construct the wings from the same material as the main body of the dam designed in section 5.5 to 5.7, when the design is applied in wider riverbeds. However when a material is not available in the neighbourhood, the solution can be very expensive.
The advantage of the use of vegetation is not yet clear. The area is already heavily vegetated in the wet season. The water is still able to run off over a wide area. The vegetation, present at this time, does not force the water to create a river coarse. It has to be found out whether other or denser vegetation will make this happen.

A dam can have more than one purpose in the case of BCS. A dam's main objective is to store water in a reservoir without letting the water leak away. In the case of a flat wide BCS-area, where the water can flow away in many different directions, just slowing the water down and keeping it in the system is already considered an achievement.

5.3 Restrictions

This section is an addition to the restrictions from chapter 3. The earlier restrictions are still in effect.

Assumptions

- The k-value of the sand in the reservoir is 10^{-3} – 10^{-6} m/s.
- BCS is very low permeable, k-value of about 10^{-8} – 10^{-10} m/s.
- When wetted, BCS becomes impermeable.
- For construction purposes, enough BCS can be expected present in the area.

Boundary conditions

- BCS is subject to settlement if forces, for instance a dam construction, are placed on top. This settlement can take weeks to several years depending on the humidity.
- The foundation can be built on the white layer only if there is no water flowing through this layer.
- Excavating BCS for any purpose is recommended to be done when the BCS is wet, because of its increased plasticity.
- BCS settlement can be prevented partially when it is compacted up front. Compaction is difficult to carry out and might require special equipment.
- There is enough sediment transported by the river, which can be used for construction purposes and to store water.

Demands

- The dam must be resistant against tipping over.
- Seepage length must be long enough.
- The dam has to be resistant against the forces of the river flow and the deposited sediment.
- There is no erosion allowed to occur on the banks and at the toe of the dam.
- Swelling and shrinking may not damage the construction of functional performance of the dam.
- Rising of the riverbed due to the sediment reservoir may not change the river course.

5.4 Evaluation subjects

Some points of interest for any concepts developed are taken into consideration beforehand.

<u>Construction method</u>
Dams can be constructed using the established construction method used by SASOL. This method is executable with the local community and a mason from SASOL. The expertise of SASOL will prove itself useful in this concept.
The construction method using impermeable shields or plastic or a dam with BCS-core is yet unknown to SASOL, and therefore might require skilled workers.

Materials available
Rocks are not found near the Semea River up to now. If rocks are not found nearby, the process of getting rocks and using them to construct can become expensive and time consuming.
To construct a dam from BCS is favourable, because it can be excavated in the neighbourhood.
Sand is available, due to transport by the river.
The availability of impermeable shields is yet unknown, as are the costs.

Erosion protection
BCS is rather resistant to erosion and therefore doesn't need heavy protection. A bed of rocks on the downstream side can be considered sufficient. Besides the BCS surrounding the construction, the dam and the sediment reservoir have to be protected against erosion as well.

5.5 Situation 1: impermeable layer at reachable depth

5.5.1 Soil profile

In this situation the upper layers are as described in the soil profile in 4.6.1. So this means there is sediment from 0 to – 1,5 meters, then BCS to –3 meters and after that the layer of BCS mixed with gravel and lime stone. The white layer starts at – 5 meters and its assumed thickness in this situation is 5 meters. Under the white layer (so at a depth of 10 meters) an impermeable layer is assumed to be present (for example rock).
In this profile the groundwater level is expected to be somewhere in the white layer.
The thickness of the white layer in this profile is chosen to be 5 meter, because this seems to be a thickness where it is still possible to dig through it to reach the impermeable layer. If the layer becomes thicker, it will become impossible to get through it and so the profile will change into situation 2. If it turns out that digging this deep is too hard, you have to proceed to situation 2.

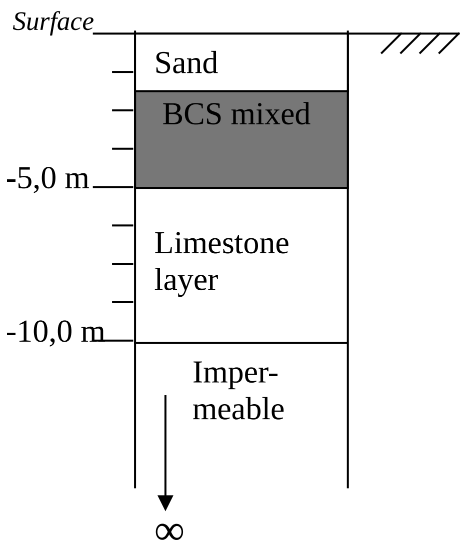


Figure 5.2: soil profile situation 1

5.5.2 Impermeable shields

Impermeable shields are used in almost every concept. In this section at forehand a sum up of the advantages and disadvantages is given. The placing of the shields, which depends on the slopes of the area, is also explained.

Advantages and disadvantages:

To prevent water seeping underneath the construction, an impermeable shield must be placed. This shield has to start in the impermeable layer and there must be a watertight seal between the construction and the shield.

There are different options to choose from when it comes to the choice of materials used for the impermeable shields.

1. Iron shields
   Advantages: cheap, available, watertight when connected by welding
   Disadvantage: short life expectancy because of damage by rust
2. Plastic shields
   Advantages: Light material
   Disadvantages: connection to construction, availability
3. Excavate a trench and fill it with concrete/ cement
   Advantage: strong
   Disadvantages: expensive, lots of labour, because of deep excavating
4. Excavate a trench and fill it with pure BCS
   Advantage: cheep, when available nearby
   Disadvantages: lots of labour, because of excavating

Water flows through the white layer and will find a new path when it hits the shields. Because of the little permeability of the BCS, the water will find it easier to flow around the sides of the shield than through the BCS layer on top. The following paragraph reflects on the desire to create a water storage facility and not just to slow the water down. To avoid water flowing to the sides impermeable shields must be places here as well. The BCS layer is rather impermeable; overpressure will exist beneath the BCS layer, because the water is being pushed up against the shields and cannot get up into the BCS layer. If the BCS just upstream from the dam is excavated and this void is filled with sediment, this creates a column or trench in which the water can rise easily. In this sediment the water is able to rise to its actual piezometric level. Pressure differences will force the water to flow up in this sediment. If the piezometric level does not reach the same height as the level of water in the reservoir, it is not a good solution to excavate the BCS layer. The water from the reservoir will flow to the lower level in the excavated part and seep into the white layer.
In the dry season the groundwater level is much lower than it is in the rainy season. This can be derived from the fact that the wells upstream from Ikanga do not contain water in the dry season in contrast to the rainy season, in which they do contain water. Downstream from Ikanga the people dig scoop holes to get water. In the dry season they have to dig several extra meters to reach the water. Research has to be done to find out if the piezometric level will reach the height of the water level in the reservoir in dry season as well.
The impermeable shields on the sides have to be placed up to the level where the piezometric level is at the same chart datum height as the highest expected piezometric level just next to the dam. This makes sure that no water will seep out of the reservoir where these shields end. If one decides to excavate the BCS and create a tunnel with sand one has to be absolutely sure that the white layer is sealed of at the sides and at the bottom next to the dam. If there are any leaks in any of the shields or at the connection with the dam, the water from the reservoir will just seep away.

Instead of excavating the whole BCS-layer it is also possible to dig trenches and fill them with sand (sand poles or drains).

Placing the shields:

It depends on the gradient of slope of the white layer where to place the shields. When the gradient in the lateral direction is less steep than in the longitudinal direction the shields can be placed like the wings in Kitui north (small angle with construction).

In figure 5.3 three views are given. The bird's-eye view shows the directions of the currents near the dam and the area in which water is stored (the striped line). Both cross-sections give the slope angle of the surrounded area.

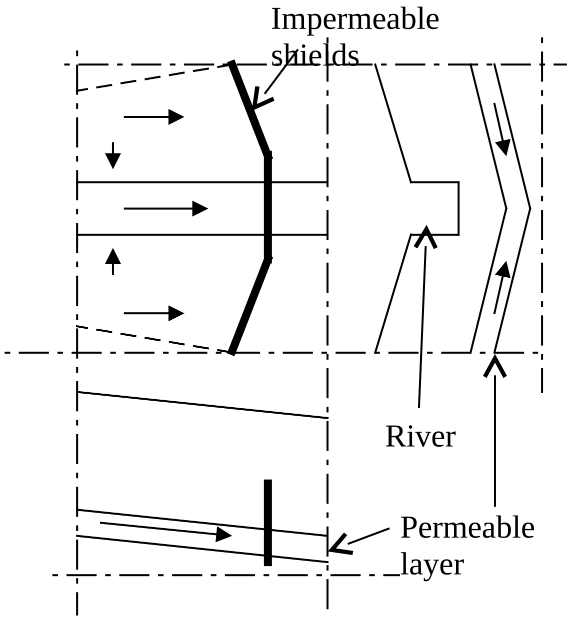


Figure 5.3: Three views for placed shields under a small angle

There are some places where the lateral direction is steeper and the water is flowing from the sides away of the river. The shields should be placed in a more longitudinal direction to hold the water (angle up to 90 degrees). See figure 5.4.

For every single situation the optimal ratio between labour/ material costs and an extra cubic meter of a catchments area has to be determined. In a flood plain area, which has a width of several kilometres, it will not be as worthwhile to build an extra meter of impermeable shield, as it will be in a rather steep area.
If the main objective is only to slow the water down the side shields are of less importance. These only apply when the water needs to be kept in the reservoir. Long lateral shields are more effective for slowing the water down.

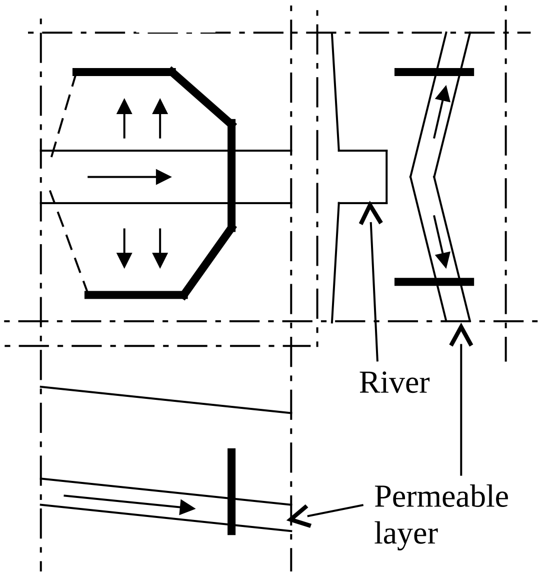


Figure 5.4: Three views for placed shields under a large angle

5.5.3 Concepts

<u>Concept A: stone-masonry dam</u>
For the design of the dam in this construction the regular design built in the north of Kitui will be used. The dam is founded on the white layer. It needs to be considered that if there is a pressure build-up in front of the dam and the water is allowed to flow through the white layer

at a faster velocity, it will damage the skeleton of the white layer and seepage tunnels will form. Eventually this will undermine the foundation under the dam.
An impermeable shield under the dam through the white layer into the impermeable layer protects the construction from seepage underneath.
The dam itself can be built from rocks, when they are available in the neighbourhood. Although transport is expensive, using only cement will be even more expensive.
The stilling basin, the way it's built in the northern part of Kitui, is probably not necessary, since erosion is not expected. It might be useful to put some stones just downstream of the dam to protect the dam against the forces of the swelling BCS when it gets wet. At the upstream side the dam is already protected against swelling by the sand-drains.

Advantages:
- Construction method of the dam familiar

Disadvantages:
- Rocks are not available nearby
- Lot of excavation to be done

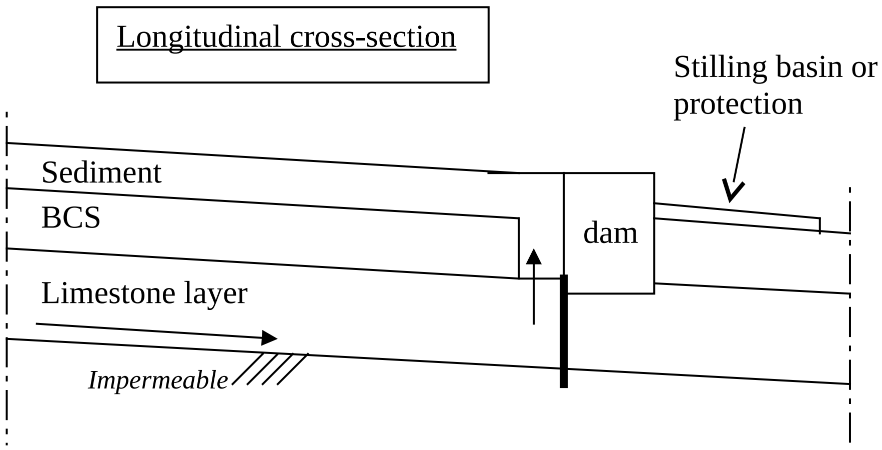


Figure 5.5: situation 1 concept A

Points of attention:
While making a design for this dam, attention should be paid to the connection of the impermeable shield to the dam. One has to be absolutely certain that no water is seeping through this connection.
Further research has to be done on the amount of stones that is needed downstream of the dam to protect it from the forces of the swelling BCS layer.
The use of the white layer as a firm base to construct the dam on is subject to further study. There is still little known about the firmness of the white layer when wet. If there is no water flowing through this layer underneath the dam, it might withstand the forces caused by the weight of the dam.

<u>Concept B: impermeable subsurface-shield</u>
When the riverbed is already filled with a layer of sediment (as it is near the existing dam), it is not necessary to build a dam. Impermeable shields, which block the water, will be a sufficient solution. To protect these shields from forces of the flowing water in the riverbed (after heavy rainfall), the shields should be placed underneath the surface. Research has to be done on possible erosion of the sediment after heavy rainfall. If (part of) the sediment moves when the water is flowing through the riverbed, the shield might appear at the surface. This will give different forces on the shields. When calculations are being made on the dimensions of the shield, this has to be taken into account.
Another option is to construct the shield up to a height of one meter above the surface. Downstream of the shield a three-dimensional construction has to be built to reinforce the shield. Sediment will settle upstream from the shield, so this option is especially good when the reservoir is likely to increase.

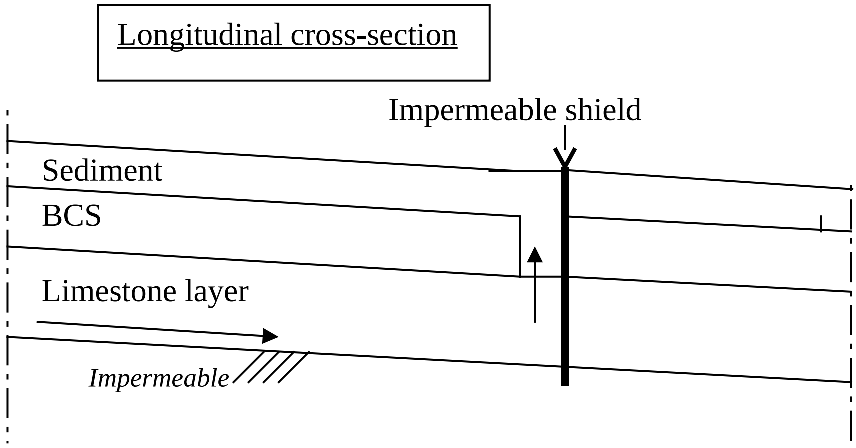


Figure 5.6: situation 1 concept B impermeable shield.

Advantages:
- Little material needed

Disadvantages:
- Unknown construction method

Points of attention:
As mentioned above, further research has to be done on possible erosion of the sediment after heavy rainfall.
The shields have to be built from a tough material; the water forces under the surface can be very strong. Maybe placing the shields under a small angle towards the upstream side of the

river may prove to be beneficial to the balance of forces. This will decrease the chance of deformation.

<u>Concept C: BCS dam</u>

In this concept the dam is built on the BCS layer and constructed from BCS. The BCS core can be surrounded by tarpaulins (a polypropylene membrane), which keeps the humidity at a certain level. Rocks are placed on the plastic membrane to protect the dam from erosion or damage by the power of water. A spillway can be constructed from concrete or cement. At the upstream side of the dam an impermeable shield has to be constructed from the top of the dam, through the BCS and the white layer into the impermeable layer.
The BCS that has been excavated to dig the sand pipes upstream of the dam can be used to build the dam.

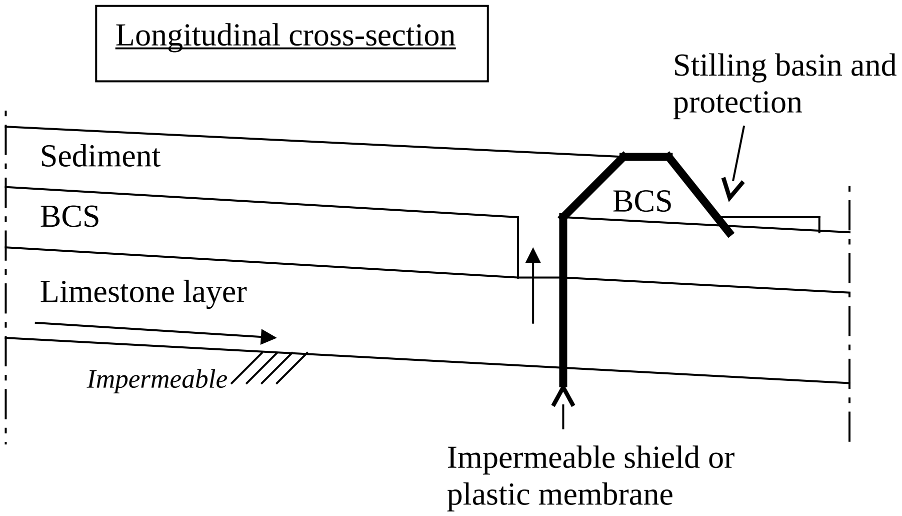


Figure 5.7: Situation 1 concept C

Advantages:

- Material cheap and available

Disadvantages:

- Behaviour of BCS-core unknown and difficult to predict
- Construction method unknown

Points of attention:

Further research has to be done on the characteristics of the BCS. A construction method has to be developed in which the BCS core is compacted in a strong way on the BCS layer. It has to be sure that the construction will not move.
Another point of attention is the dehydration of the BCS-core enclosed in the plastic membrane. During very big draughts the core might still dry out which might cause movement in the structure.

5.6 Situation 2: thick permeable layers

5.6.1 Soil profile

It is stated in chapter 4 that the layer beneath the white layer is unknown, now concepts are made for the assumption of a permeable layer underneath. Of what material this layer consists does not matter. The limestone layer in figure 5.8 is very thick. The main issue here is the permeability of the ground below -5 m, an impermeable layer is not reachable. The groundwater level is supposed to be found in the white layer at an unknown depth. Because sand was found in the riverbed, the indication of a layer of sediment is made in the concepts.
All concepts will still be a good solution, if it turns out that there only is a thick layer of BCS.

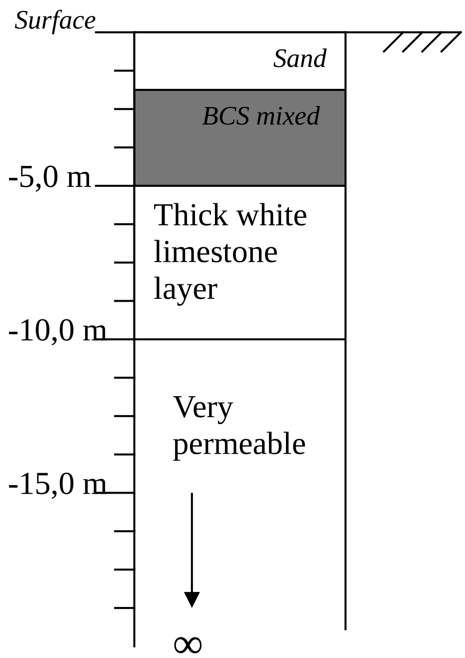


Figure 5.8: Soil profile situation 2

5.6.2 Concepts

Because of the thickness of the permeable layer, assumed to be till infinite depth, there is no way to build through it, to create an overpressure. Water will always flow underneath and around the construction.

<u>Concept A: stone-masonry dam</u>

A normal stone-masonry dam based if possible on the limestone layer. The BCS layer prevents the water to flow to the permeable white layer. An adjournment (seal) prevents leakage through the connection between the BCS and the dam. In the extra sediment water can be stored. In case of a flatter area, the wings can be extended to create a bigger reservoir.

Advantages:
- Building techniques of the dam familiar to SASOL

Disadvantages:
- Stones are not available, so long transport required
- Long wings are expensive due to scarcity of stones
- There is always water flowing through the white layer, which may cause the layer to loose its firmness, hence the dam will sink. Other foundation techniques will probably be necessary.

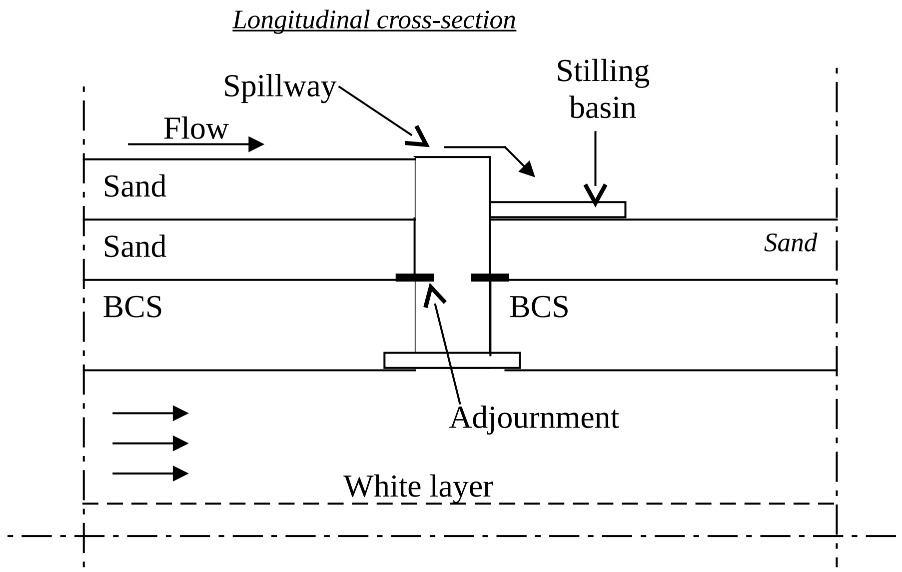


Figure 5.9: situation 2, concept A stone-masonry dam

<u>Concept B: tanks or trenches</u>

Creation of extra storage by building tanks or trenches in the riverbed is an option. The sides of a tank can either be constructed of concrete, BCS or plastic. The concrete must be resistant against the swelling of the BCS. If a tank is made from BCS, the walls made of BCS must be sealed properly without cracks.
Plastic shields between the sand and the BCS can prevent leakage from the sand to the white layer along the walls of the tank.
Water can be extracted by the use of wells and scoop-holes, depending on the depth of the tank or trench.

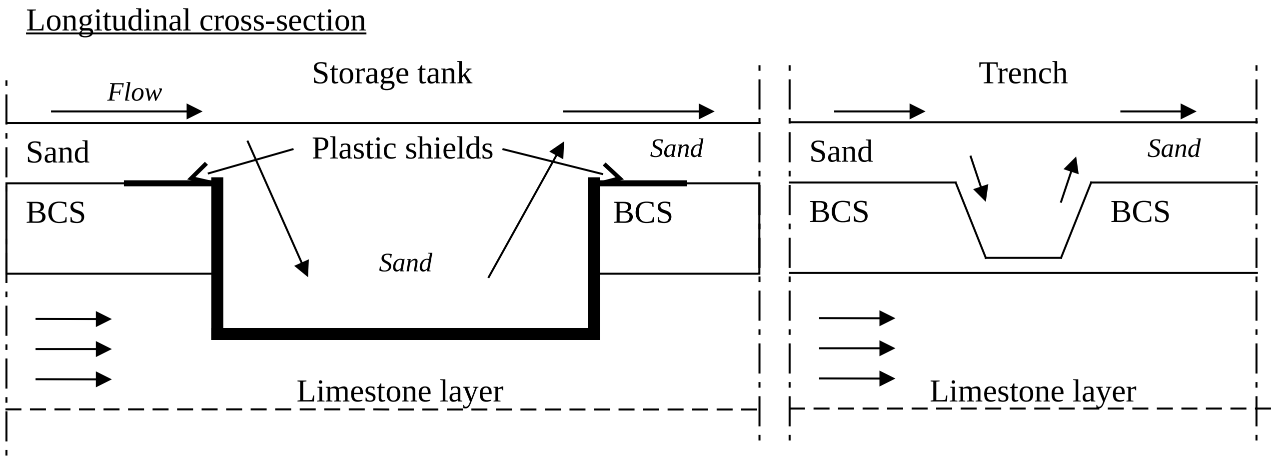


Figure 5.10: situation 2, concept B tanks or trenches

Advantages:
- No harmful side effects to the environment like erosion, because there is no change in morphology.

Disadvantages:
- Difficult construction method for the sides of the tank
- A lot of excavating

Concept C: impermeable shields

The objective is to build up pressure in the groundwater by putting impermeable shields into the white layer and by directing the flow to the middle of the riverbed.
Then replacing the BCS with sand will force some of the water to flow up into sand layer. A part of the water will flow away underneath the shield and a part will be pushed up through the sand. There are uncertainties about the amount of pressure build up and the amount of pressure in the dry season. Nevertheless this concept is taken into account. In section 5.5.2 the characteristics and the (dis)advantages of shields constructed with different materials are given.

Advantages:
- Wings easy to extend

Disadvantages:
- Lots of excavation
- Many shields needed
- Pressure may not be sufficient

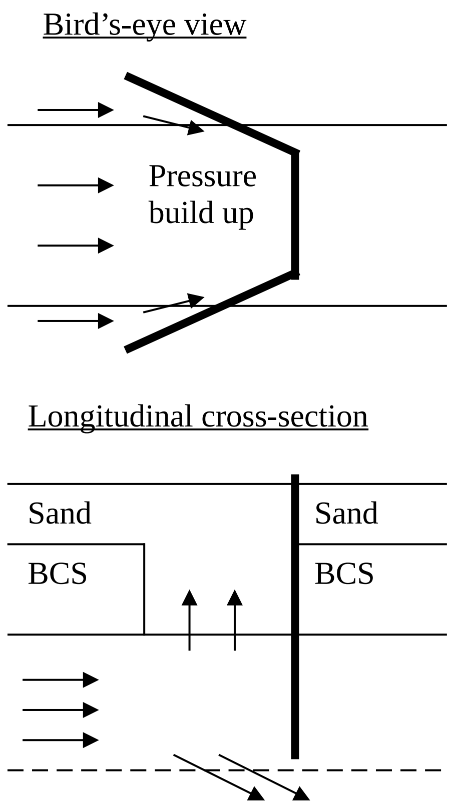


Figure 5.11: Situation 2, concept C impermeable shields

5.6.3 Evaluation

Stone masonry dams
This type dam is the easiest known way to build a dam, only the material is rather scarce, so costs can be very high. The bigger problem, which comes with constructing a stone masonry dam on BCS, is the lack of knowledge about the white layer. Sometimes this layer can function as a solid base, but some cases of dams build on limestone have been known, where the limestone crumbled when wet.
This concept is not very attractive for SASOL because it is expected to be expensive and one can foresee problems with the foundation of the dam.

Tanks and trenches
These solutions need a lot of excavation and tanks are difficult to construct. As said above, they can be built to increase the storage capacity.
Tanks and trenches are believed to be labour intensive and there is not enough insight in the hydrostatic pressure on the shields. Trenches and tanks can always be constructed as an addition to the storage capacity.

Impermeable shields
Because the limestone layer is very porous, the possibility of a lack of water pressure is quite possible. Nevertheless this option will be looked into because of the possible revenue versus low risks.

5.7 Situation 3

Described in this section are the possible designs of dams or constructions that can be constructed in a layer of BCS up to a great depth.

5.7.1 Soil profile

The research described in chapter 4 showed that BCS is present in an impure and a pure composition. The thickness of the layer has not always been determined. Below, various concepts are made for the following situation:
- BCS layer present up to an unreachable infinite depth
- BCS (pure or impure) is impermeable, especially when wetted. The top layer needs very little water to become saturated.

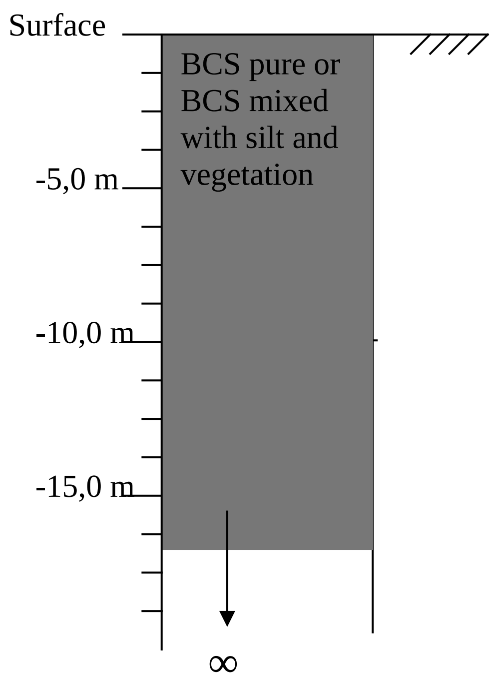


Figure 5.12: Soil profile situation 3

The presence of the layer described above is yet undetermined. The concepts described in this situation can also be applied to the other situations described in this chapter 5 for the BCS layer on top of a permeable layer.

5.7.2 Concepts

<u>Concept A: stone-masonry dam</u>

This concept consists of building an original dam lateral to the riverbed. Using rocks and masonry, the dam is built in the same way as the dams that have already been successful in other places. Although the dam is built in a familiar way, the characteristics of the soil ask for new solutions on the design. The main characteristic that has to be taken into account is the swelling and shrinking character of BCS. Because no other layers are present, the dam has to be founded on BCS (directly or indirectly). A drawing of the following concept is given below in figure 5.13. Due to the flatness of the area a low dam construction is required. Because the absence of a suitable layer for a foundation, it's preferable to design a dam with a minimised height. This will decrease the dams weight and prevent large settlement. It also decreases the amount of material needed.

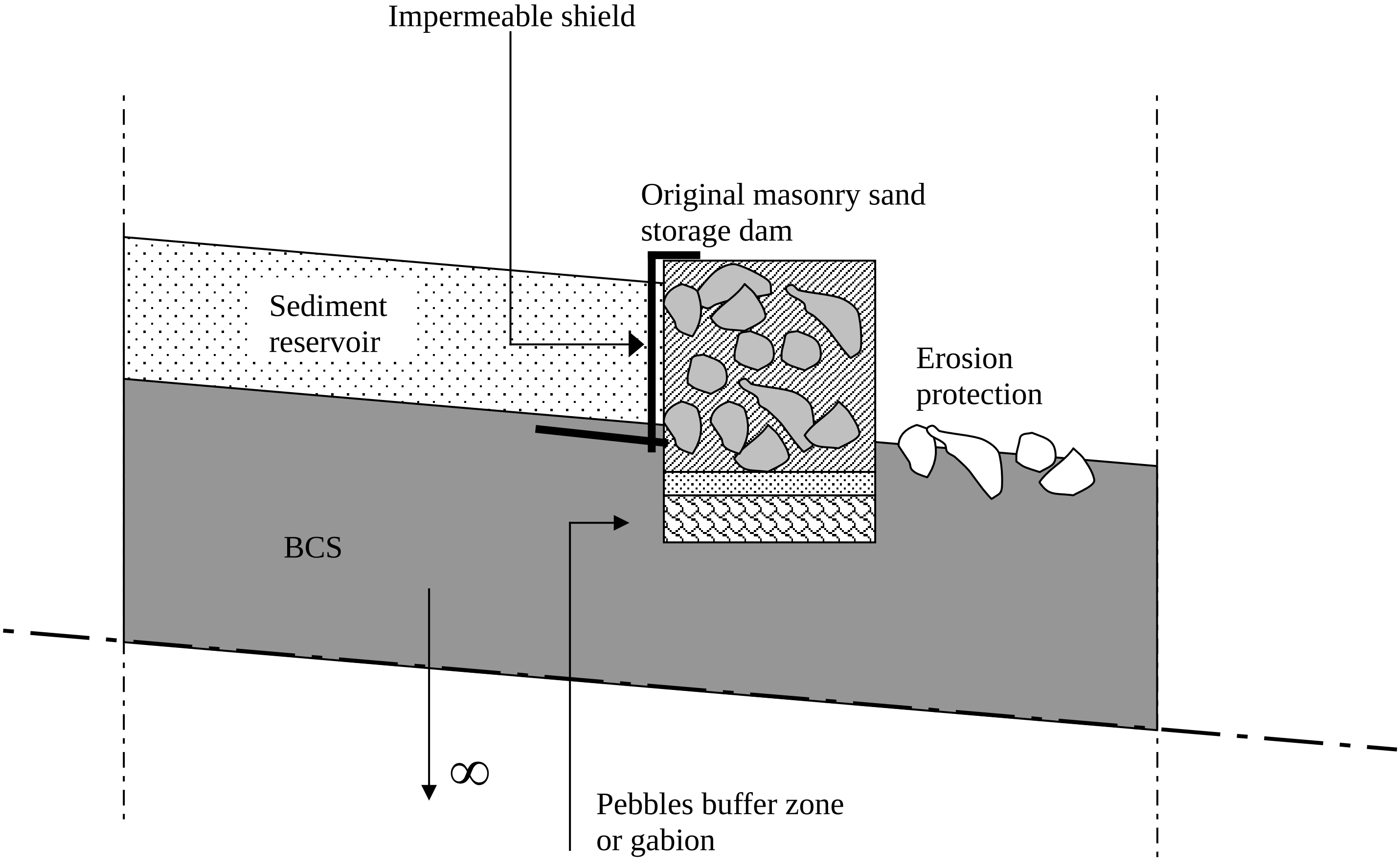


Figure 5.13: situation 3 concept A

Advantages:
- Familiar construction method of the dam
- No heavy protection for erosion needed
- Not a lot material needed

Disadvantages/ problems:
- Construction method sophisticated
- Knowledge about soil behaviour

- Settlement can endanger the construction so drainage might be needed to control this process
- Material not available

Points of attention for concept A:
- Possibilities of compaction of the BCS below the foundation of the dam.
- Costs and availability of impermeable membranes or shields.
- Increased width of the dam can decrease settlement.
- Possible difficult connection of the impermeable membrane to the dam construction.

Concept B: impermeable shields

At several sites in the Semea River significant depths of sediment sand were found. If this sediment is already present, a construction in the sediment should fulfil the function of stopping the water from flowing away through layer of sediment in the riverbed. In this concept, a design will be developed that can be constructed in a riverbed filled with sediment. The fact that there is already sediment on each side of the construction is used to develop a balance between the two sides of the construction. This present balance asks for a lighter construction than a sand-storage dam, built with masonry. The downstream side of the construction should be protected against erosion in order to maintain this balance.
At some point downstream there can be expected an area where no sediment has arrived yet. A sand storage dam can be constructed for the purpose of creating a sediment reservoir. Now, a series of impermeable shields can be build.

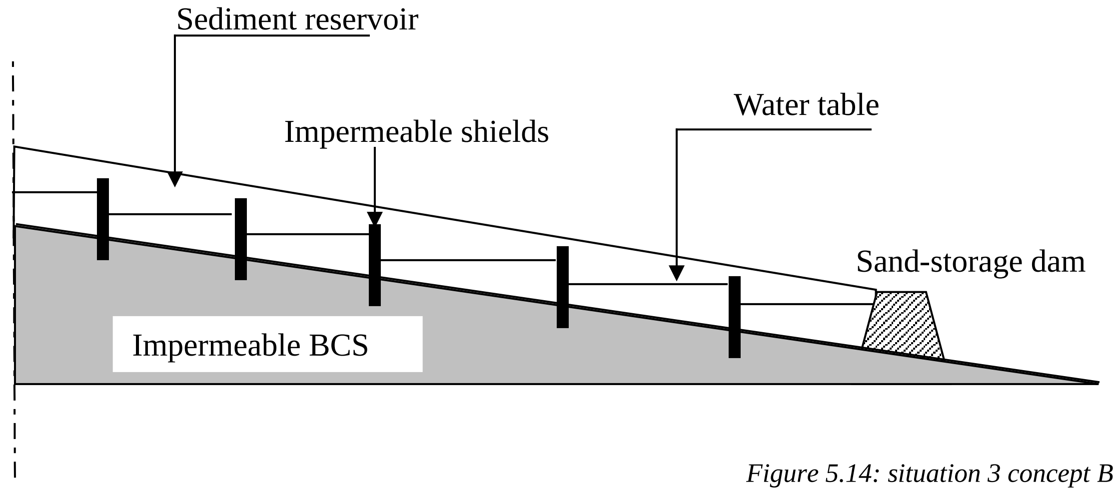


Figure 5.14: situation 3 concept B

Advantages:
- Less material is needed, expected lower costs
- Small excavation needed
- Light constructions experience less trouble due to settlement.
- Very few rocks needed. They are scarcely available.

Disadvantages/ problems:
- Seepage through connections.
- The construction method is unknown

Concept C: BCS dam
In this concept, the impermeable character of BCS is used to contain water in the sediment reservoir. The dam is build with BCS taken from the area. This use of dams is also described in section 5.5.3. The BCS used in the construction has to be protected against erosion. Although BCS is a tough material to erode when it is in the ground and compacted, it can easily erode when wetted and not supported by surrounding ground pressure. To prevent this erosion, rocks are placed on the BCS dam.

5.8 Blocking the outlet

As mentioned in the introduction there are other solutions to the problem than the concepts of the sand-storage dam or subsurface dam. One of them is blocking the outlet of the catchments area.
The catchments area of the Semea River is oval shaped, and becomes narrower to the south. The water is flowing through the white layer to the more narrow part. In the southern part of the Kitui district the BCS-area ends and since the white layer is thought to be a product of the BCS, the white layer is expected to end as well. A solution to contain the water in the whole area is to block the outlet by a long sub-surface dam. The water pressure in the whole area will rise and will stay in the white layer during the dry periods water, so wells will have water during the whole year.

Two possible situations

1. At the end of the BCS-area a new area starts in which the ground layers are permeable at least until the same depth as the white layer. The water just flows into the permeable layers of the new area and disappears.

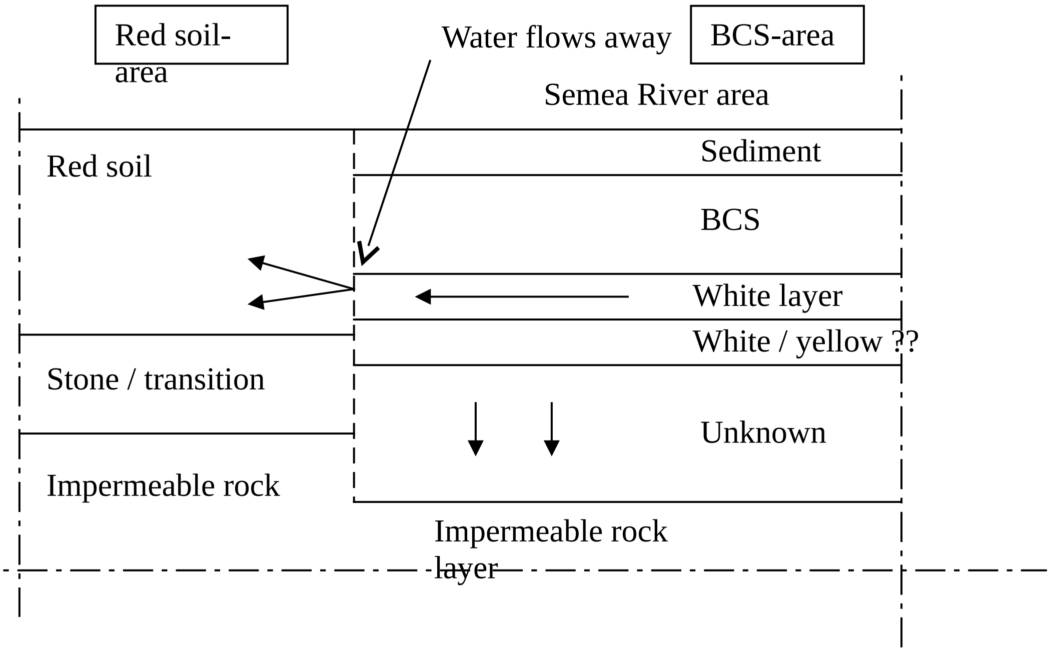


Figure 5.15: water flowing trough outlet

2. At the end of the BCS-area the white layer is blocked by an impermeable layer, which already keeps the water in the white layer. The water only seeps away from the BCS-layer into the layer, which is continues in the red soil area. This situation is rather unlikely. The BCS-layer is not very permeable and the water flows through it very slow, so it is unlikely that the amount of water that disappears from the BCS-area only seeps away through the BCS-layer.

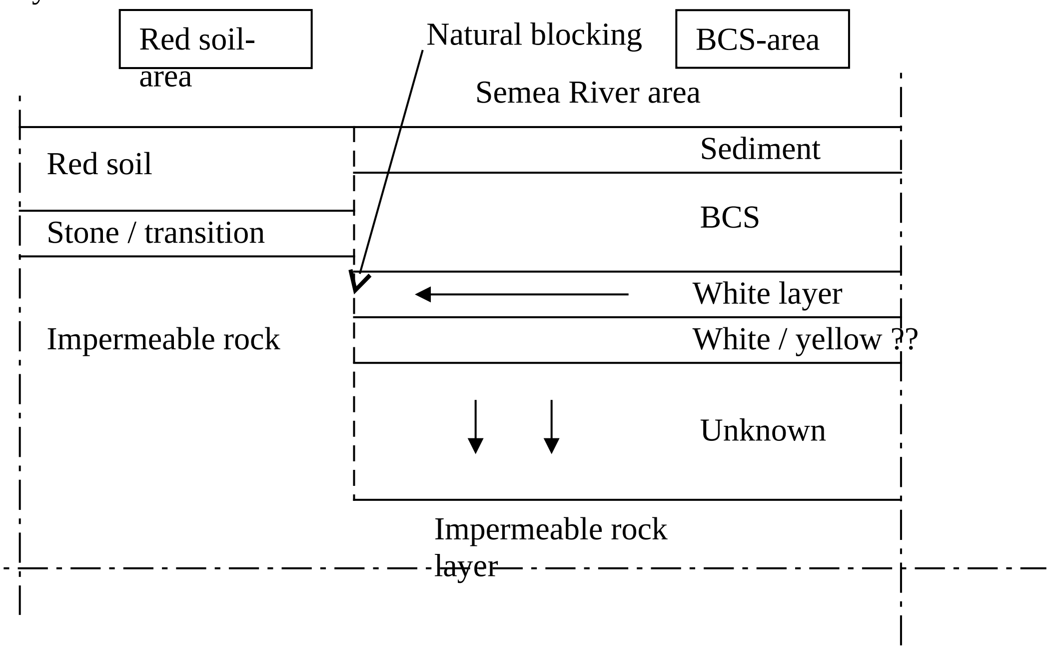


Figure 5.16: blocking of the outlet

Solution
Build a dam at the outlet at the end of the BCS-area. This dam has to be built at the depth of the impermeable layer. The dam will block all the water that flows through the white layer. Slowly the (ground) water level upstream of the dam will increase. Because the dam is located at the end of the BCS-area (most downstream location), the whole BCS-area is the catchments area for this dam.

The advantage of building a dam at the outlet is that you only have to build one dam; it will catch all the water. So you only have to excavate once till the impermeable layer (which is expected to be rather deep). Due to the fact that no research has been done on the exact location of the outlet, the width of this outlet is not known. Possibly the dam must cover a width of one kilometre or even more, which will be quite expensive (excavation and materials). The community, which lives near to the outlet, might have to do all of the work. SASOL's approach is to work in co-operation with all the communities, who benefit from the dam. Another disadvantage is that it is uncertain how long it will take, before the water level has risen in the whole area.
Blocking the outlet might be worthwhile, since only one dam is needed.

5.9 Wells

Downstream of the existing dam two wells were visited that had water all year round. The wells were dug to depth of 20 feet, 6.6 meters. The wells are founded on the white layer, which holds the water. The water is pumped up by a mechanical hand-pump, so no diesel is required to run an engine for the pump as needed with deep bore holes. There is enough water to supply the surrounding people and people who come from far. In dry periods this is the only source of water in the area next to the Nzeeu River. However this river is polluted, yet people still get their water from Nzeeu River.

The wells are thought to hold water, because they are located at the bottom of the catchments area of the Semea River system. The layer underneath the white layer near the wells is probably impermeable and closer to the surface than upstream, otherwise the water would disappear here in the dry season as well. Here it is possible to build a well without a dam. Near the origin of the river system the wells don't hold water in the dry season, because during the dry season the delayed groundwater flow has left the area through the white layer or is beyond the reach of the wells. If a well is to function here it can only work in combination with a water containment system like for instance a dam.

SASOL has no interest in only building wells. SASOL only builds wells in combination with dams. A well draws water from the water table, where as a dam recharges the soil as well as supplies the people with water from the reservoir. A dam does more than just address the main target: create a water supply for the people. A sand-storage dam creates a better water table throughout the whole area, and thus improves the hydrologic situation in the area slowly changing the climate.
Putting wells in the upper area of the Semea River would only be a short-term solution that only works during certain periods of the year.

One of the benefits of constructing wells, if it is suitable to build a well, instead of dams is the fact that they are easy to build and not as costly as constructing a dam. The construction period of a well is a lot shorter than that of a dam.

5.10 Conclusions

From the sections 5.5 to 5.7 we can conclude that there are two different concepts that are of more interest for SASOL because of their innovative character: impermeable shields and an earth dam with a BCS core. Stone masonry dams will be quite expensive and are expected to present problems.
In the next chapter we will design the concepts. Equations, thumb-rules, dimensions together with drawings will give better insight and can be used for constructing as a reference when exact soil profiles and area data are available.

The reasons to design these concepts in chapter 6,7 and 8 are given:

<u>Impermeable shields</u>
Shields are recommended in almost every situation. Because of the special characteristics like flexibility, we will design a dam using impermeable shields only. When used as a sub-surface dam, shields probably will be strong enough to resist the forces. Above the surface a reinforcement of some kind will be needed. Also the way of placing of the shields, direction and length, is determined.

A sub-surface design with a side step to a construction sticking out above the surface is the result.

<u>Earth dams with BCS-core</u>
Because BCS is lighter (prevents settlement) than stone and impermeable as well, it could be a good option to construct the dam with BCS. Special attention must be made to the erosion and the resistance against the flow forces. Together with the BCS-core also some impermeable shields will be used in the designs.

A design for earth dams with a BCS-core, erosion protections and also the connection of impermeable shields is the result.

6. Earth dam with BCS-core

In this chapter, a design is made for constructing a sand storage dam constructed with BCS. In the first sections, the various dam components are discussed and the application of possible materials. After an evaluation of concepts, one of them is designed into detail. After that section, the recommended construction method and planning are given. At the end of the chapter, the finances and feasibility of the design is given.
When reading this chapter, it has to be held in mind that the solution of an earth dam can also be applied to the situation of an impermeable shield to deep layers, as described and designed in chapter 7.

6.1 Dam components

6.1.1 Body of the dam

In this concept, the core of the dam construction is made out of BCS. Although the BCS is at hand in large amounts, its characteristics ask for precaution. Humidity changes cause the BCS to swell and shrink. If BCS is applied, an effort should be made to keep the humidity at a level that makes the BCS easy for construction. Large shrinking can endanger the construction and an effort should be made to the humidity at a rather high level. The upstream reservoir can fulfill this task if water is present in the sediment.

<u>Compaction</u>
To improve the strength and stability of the BCS in the dam, it is recommended to use compacted BCS. In compacted BCS the void ratio is decreased. This lowers the amount of water needed for the BCS to become impermeable, and it increases the power of the BCS to keep the water in its pores. The advective forces of water particles to the soil particles are higher. Also, due to compaction, the soil particles have a larger touching surface, also increasing its strength. In section 6.3.5 the method of compaction will be related to the dams foundation.

<u>Turning over</u>
External forces of the dam can cause a dam to turn over. River flow and soil pressures can endanger the stability of the body of the dam.

<u>Sliding of the dam</u>
The connection between the BCS core and the BCS-layer below has to be able to withstand forces that might cause sliding movement.

<u>Settlement</u>
Increases stresses on the foundation will cause it to settle. This might cause damage to the dam and a loss of performance.

Turning over, sliding of the dam and settlement are checked for a fictive dam in section 6.3.

6.1.2 Protection

There are various forces that can endanger the construction. River discharge transporting sediment can erode the top layer and sides of the dam and the dam can sink. A very important phenomenon is dehydration of the BCS. Concrete or plastic can protect against it. To protect the dam against these influences, various solutions can be designed. The following three options are suitable for the area and the present knowledge, a comparison is made between the three of them:

<u>1. Closed concrete layer</u>

The core of BCS is covered with a concrete layer, protecting it from erosion. To prevent the BCS core from dehydration at the downstream side a shield can be placed at this side. Dehydration of the BCS core causes it to incline and result in possible cracking of the concrete cover. The depth of the shield has to be determined in the design process.

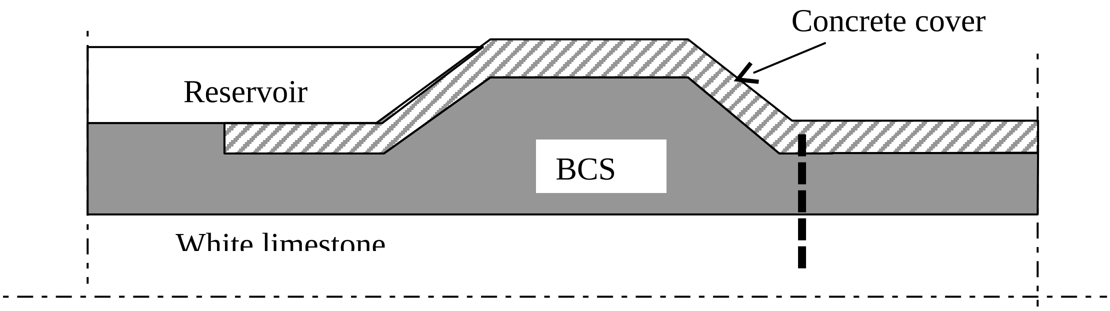


Figure 6.1: concrete-protected dam

Disadvantages:
- Costs high: cement and stones needed
- Stones not available in surrounding of the dam
- Difficult to construct

Advantages:
- Less maintenance
- Durable
- Concrete can stand the forces of the water
- Watertight

2. Gabions with plastic foil/ membrane underneath

This concept uses a gabion to protect the core from erosion and a plastic sheet to protect it against dehydration. A gabion can be described as a mattress of rocks that are bound together by a frame of iron wire. This gabion keeps the rocks together and prevents the core from being eroded. A plastic shield is build below the gabion to maintain the cores humidity at a required level.

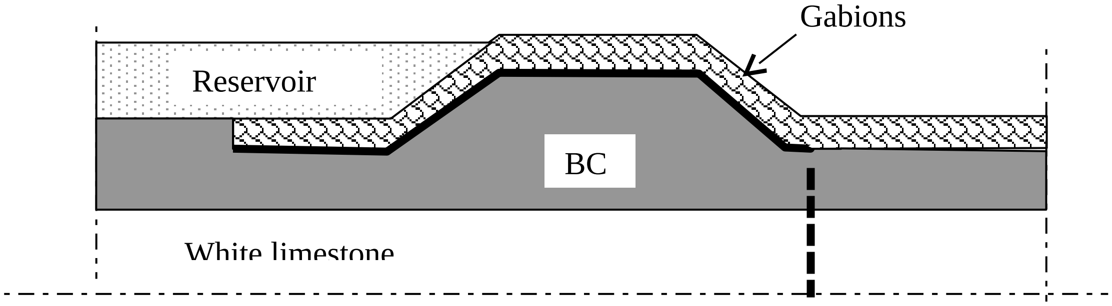


Figure 6.2: gabions-protected dam

Disadvantages:

- Costs of gabions are high
- Difficult to construct
- Plastic and gabions are not durable compared to natural materials

Advantages:

- Less maintenance
- Gabions resistant against flow forces

3. Rock with plastic foil/ membrane underneath

Thick plastic has to be protected against transported sediment; this sediment can scour the plastic. Only fine sand will be taken away by the flow. Big rocks can be put on the plastic, but also can damage it. One or two layers in between as a base layer will be sufficient.

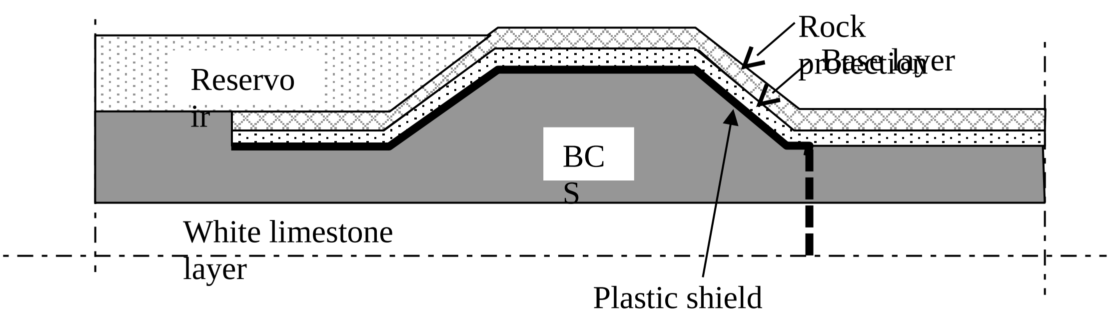


Figure 6.3: Rock-protected dam

Disadvantages:

- Stones not available in surrounding of the dam
- Difficult to construct the different layers
- Lot of maintenance

Advantages:

- Durable

- Watertight

6.1.3 Impermeable shield

To prevent the water from flowing away under the dam through the white limestone layer, an impermeable shield will be placed and the dam core will not dehydrate. In the figures 6.1 to 6.3 the shield is marked with a thick striped line. A little sum up of the different materials is given below. It has to be held in mind that the shield will only be used for water containment if a rather thin layer of BCS and limestone is present, and below an impermeable layer. If these layers are not present and only a thick layer of BCS is found, shields can be used to slow the water down.

<u>a. BCS</u>
BCS is available in the whole area and it is also impermeable if saturated. A trench can be dug in the white layer and this can be filled with the BCS. This material can be used independent of the material used for the protection.

Advantages:
- Less maintenance
- Durable
- Low cost
- BCS available in neighborhood

<u>b. Plastic</u>
Plastic can be used, but the connection with the dam protection is difficult.

Disadvantages:
- Difficult to construct
- Availability of plastic

Advantages:
- Less maintenance
- Durable

<u>c. Concrete</u>
When a concrete protection is built, it is easy to extend the structure and also make the impermeable shield of concrete. When used other material it will not be favorable.

Disadvantages:
- Difficult to construct
- Availability of cement and stones

Advantages:
- Less maintenance
- Durable

6.2 Material evaluation

In this evaluation the different solutions for the components protection (6.1.2) and impermeable shield (6.1.3) are combined. Some combinations are not evaluated, because they are too difficult to construct. Especially the attachment of concrete with gabions or rock is difficult and not logical and will therefore not be evaluated.

Criteria and weights from last year group and SASOL:

The different criteria are clarified below [4]:

1. <u>Costs</u>
   The first criterion is about the relation between construction costs and the volume of stored water. A high score means low costs per volume-stored water; a low score means an expensive solution.
2. <u>Maintenance</u>
   This criterion is about the maintenance that is needed during the lifetime of the construction. A high score means little or no maintenance; a low score means much maintenance to keep the structure in a good condition.
3. <u>Durability</u>
   The durability criterion gives the durability of the materials that are used in the construction. Materials that tend to wear quickly get a low score, wear-resistant materials get a high score.
4. <u>Vulnerability</u>

The vulnerability criterion describes the reliability of the construction and its response to exposed forces. Strong structures like concrete dams get a high score, vulnerable structures get a low one.

5. <u>Availability</u>
   The availability of different materials in the area is rated in this criterion. Materials that are easy to obtain in the wanted amounts receive a high score. If materials are hard to find, or have to come from a long way, they get a low score.
6. <u>Construction</u>
   This criterion describes the suitability of the construction technique for community based building. Most techniques that are simple and require a lot of manpower are good for community building and get a high score. Construction techniques that are complicated and require craftsman will get a low score.
7. <u>Extendibility in lateral direction</u>
   Whether a construction is easy to extend in lateral direction of the river into the (flood)plains next to the river is rated by its extendibility. A structure that is easy to extend in this direction gets a high score. Is the direction difficult to extend, than it will receive a low score.
8. <u>Water tightness</u>
   Good water tightness will get a high score, poor water tightness gets a low score.

<u>Evaluation:</u>

	Protection material →	Concrete			Gabion and Plastic membrane		Rock and Plastic membrane	
	Shield →	BCS	Plastic	Concrete	BCS	Plastic	BCS	Plastic
Criteria:	*Weights:*	1a	1b	1c	2a	2b	3a	3b
Costs	25	4	2	1	3	1	7	5
Maintenance	10	5	5	5	3	3	2	2
Durability	10	5	6	7	3	4	4	5
Vulnerability	10	5	4	2	7	6	5	4
Availability	10	8	6	6	5	4	6	5
Construction	20	5	4	3	7	5	6	5
Extendibility	10	5	5	5	6	6	6	6
Water tightness	5	4	5	6	5	6	5	6
		500	415	365	480	385	550	475

Table 6.1: concept evaluation

<u>The choice:</u>
From this evaluation one can conclude that a BCS core with plastic and rock protection combined with a BCS shield is the best option to use. At forehand when the dimensions are not determined it is difficult to make a decision on an evaluation like this. After calculations had been made it became clear that the amount of stones will be very large and the costs are estimated too low. Although constructing in concrete is familiar to SASOL we chose to work out this principle of stone protection.

6.3 Design (process)

In this section various design features are present and worked out. We design this fictive dam on some dimensions we assumed at forehand. Actually the process is iterative. A higher dam results in larger stone dimensions, but also in a larger reservoir volume. This chapter only gives the calculations of a few principles like settlement and stone dimension. In the future the most feasible design can be determined with this chapter. For recommendations on optimisation see section 6.10.

6.3.1 *Starting points and boundary parameters*

<u>Dam dimensions [7]</u>
To apply the various design steps, a fictive dam is used with the following dimensions and elements:
Various parameters:

w_{BCS}	= Specific weight BCS [kN/m^3]	= 18
w_w	= Specific weight water [kN/m^3]	= 10
w_{dam}	= Specific weight dam (inclusive all protection and plastics [kN/m^3]	= 22
$w_{sat,sediment}$	= Specific weight saturated sediment [kN/m^3]	=20

The dimensions shown in figure 6.4 are used in the equations and formulas used in this section. The BCS layer is in the figure 5 meters. The settlement is calculated on this depth.

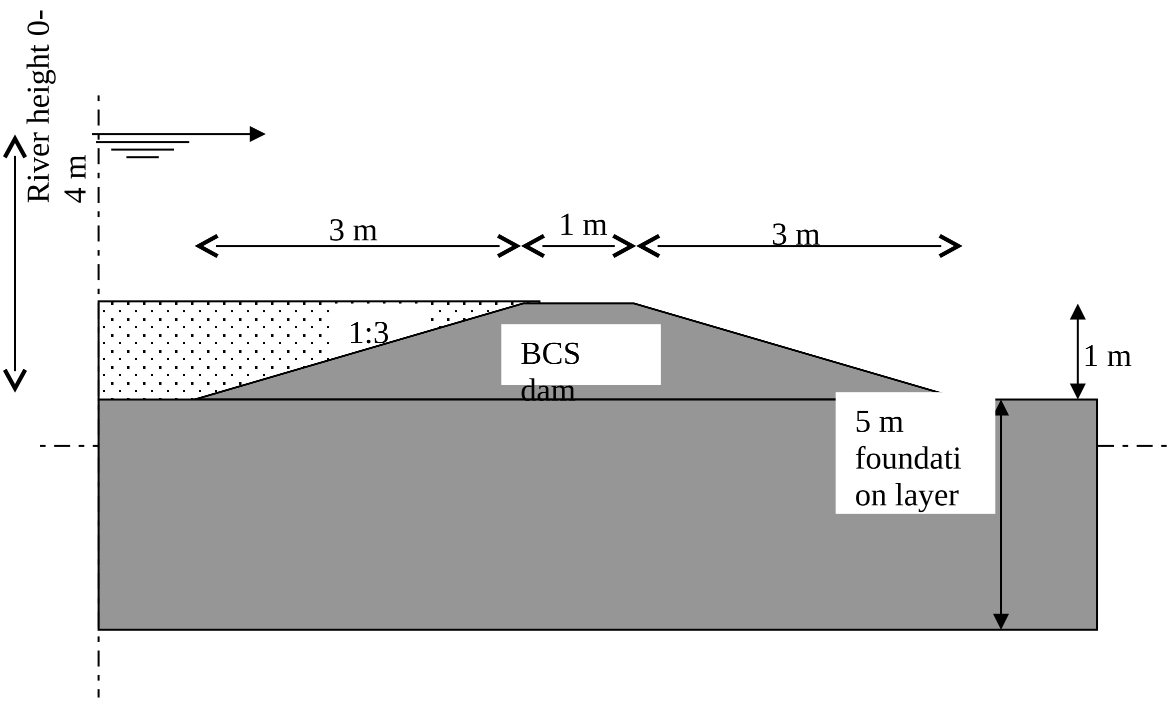


Figure 6.4: dimensions dam

<u>BCS characteristics</u>
The following dam parameters are used for the calculations made below. Since no information is at hand on BCS, parameters are used from [6].
This book contains parameters on various kinds of clay but not specific on BCS. Parameters are used for the characteristic of '*clay with little sand and moderate strength*.' Whether these values are applicable on the area has to be determined in future research.

e	=Void ratio [-]	= 1.06
c'	= Cohesion [kPa]	= 10
E_{gr}	= Elasticity module [kPa]	= 3000
k	= Permeability [m/s]	= $1 * 10^{-8} – 1 * 10^{-10}$
φ'	= Angle of repose [˚]	= 22,5
C_c	= Primary settlement index [-]	= 0,237

C_a = Secondary settlement index [-] = 0,05

River peak discharge

Do determine the forces and required protection of the dam, it is important to determine the river peak discharge. Below, a method is handed that can be used to determine the needed protection.

With the formula of Manning as described in [5] section 5.7 we calculate the peak discharge Q_p with the next formula:

$$Q_p = S_f \frac{1}{n} R^{\frac{2}{3}} A s^{\frac{1}{2}} \qquad (6.1)$$

Where:

Q_p = Peak discharge [m^3/s]

S_f = Safety factor

n = Manning’s roughness coefficient = 0,03 [$m^{1/3}/s$]

R = Hydraulic radius [m] = wetted cross-section (A)/wetted parameter (P)

A = wetted cross-section [m^2]

s = energy gradient ± slope of river bottom

Peak discharge:

As we heard from the communities in Ikanga, the water level in the Semea River could be up to 4 meters in the parts where the river was 10 m wide. We take a Manning’s coefficient of 0,03, which is for minor natural streams as shown in [4] section 5.6. For the safety factor we take 1,3. The banks in the river are vertical, so A = 10 * 4 = 40 m^2 and P = 10 + 2 * 4 = 18 m. R = 40 / 18 = 2,22 m. From the maps (see appendix I) we determined in the lower parts of the river a slope angle of 0,1%. The peak discharge is:

$$Q_p = 1{,}3 * \frac{1}{0{,}03} * 2{,}22^{\frac{2}{3}} * 40 * \sqrt{0{,}001} = 93{,}3\ m^3/s$$

Flow velocities [3]

The further calculations concern a dam of 1,0m high and slopes of 1:3 (18,4°). There are special ways to determine the most favorable height and slope angles. In our recommendations we will mention different methods.

Just after the dam is finished, when there is no sand in the reservoir, the velocities above the dam are the biggest at peak discharge. In times of lower discharges there can be a shallower overflow with critical flow, but the velocities won’t exceed the velocity determined below with the Bernoulli formulae.

With the formula of Bernoulli on the energy head the flow velocity can be determined. The energy head remains constant over the river longitudinal, because there is no energy dissipation in the contraction before the dam. There are two formulae to determine the U_2 and the d_2. These are constant discharge (6.4) and the constant energy head (6.5).

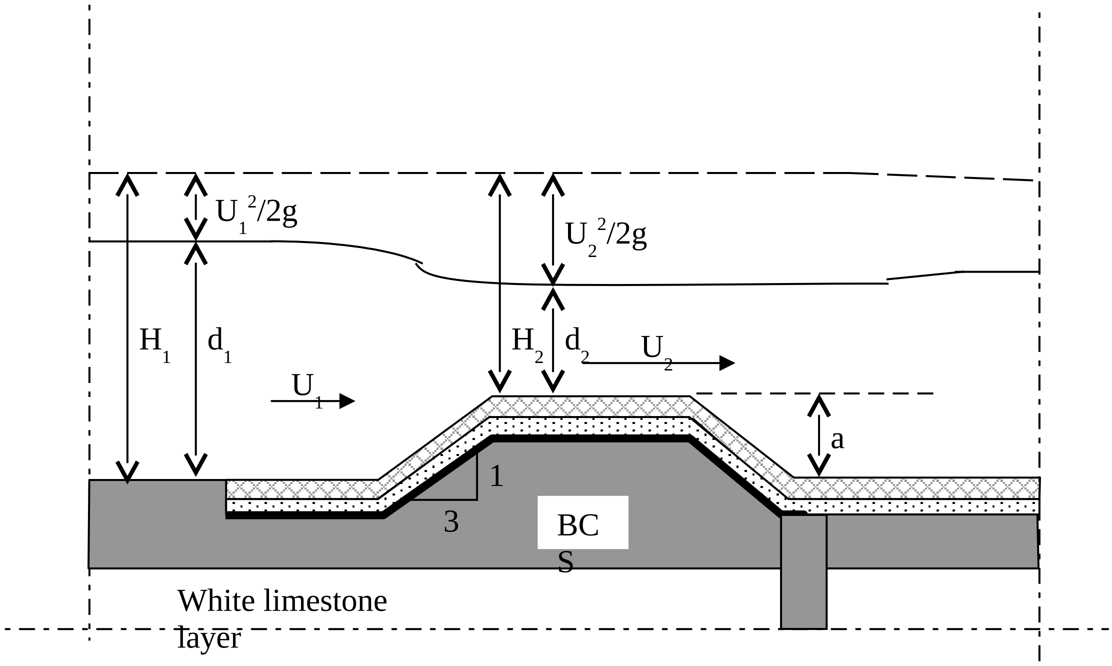


Figure 6.5: Flow over a sill

$$H_1 = d_1 + \frac{U_1^2}{2g} \text{ [m]} \quad (6.2)$$

$$H_2 = a + d_2 + \frac{U_2^2}{2g} \text{ [m]} \quad (6.3)$$

Constant energy head: $H_1 = H_2$ (6.4)

Constant discharge: $U_1 d_1 = U_2 d_2$ (6.5)

Where:
H = Total energy head [m]
z = potential head [m]
d_1 = water depth [m]
U_1 = flow velocity [m/s]
g = gravity [m/s^2]
a = height of the dam [m]

Flow velocities

Q_p was calculated to be 93,3 m^3/s. The velocity upstream of the dam then is U_1 = Q / A = 93,3 / 40 = 2,33 m/s.
The total energy head upstream:

$$H_1 = 4 + \frac{2{,}33^2}{2*10} = 4{,}27\ m$$

The energy head above the dam must equal the head upstream of the dam and the same discharge. With a height of the dam of 1,0 meter, the next equations can be

$$H_2 = a + d_2 + \frac{U_2{}^2}{2g} = 4{,}27 \quad and \quad U_2 d_2 = U_1 d_1 = 9{,}33\ m^2/s$$

We assume d_2 to be 2,5 m. U_2 is then 3,73 m/s and H_2 is 4,19 m.
If we try 2,0 and 3,0 for d_2 we see H_2 respectively to be 4,09 and 4,48 m. Trial and error gives in the end that d_2 = 2,65 m and U_2 = 3,52 m/s.
The new R = 26,5 / 15,3 = 1,73.

6.3.2 External stability

The external stability of the dam has to be checked on various phenomena.

Turning over
The dam construction has to be protected against forces trying to overturn the construction. In the report "Improved Design Sand-storage dams" [4] the method to check the possibilities of turning over is given on page 63-65. The BCS dam, described above, is checked with this method. With the designed dimensions the dam will withstand overturning forces easily. If, in the future, new dimensions are designed for the BCS dam, it is recommended to check the dam by the method described in the report.

6.3.3 Sliding of the dam

To prevent the dam from sliding downwards due to up stream forces, the balance between horizontal forces and the critical shear strength of BCS has to be checked. [15]
The next equation has to be met:

$$\sum F_{hor} \leq V_{Crit.shear.strength} \text{ [kN]} \qquad (6.6)$$

The critical shear strength can be calculated with the following formula:

$$V_{crit.shear.strength} = \tau_c * A \text{ [kN]} \qquad (6.7)$$

A= sliding surface dam-foundation [m^2]

$$\tau_c = \text{critical shear stress} = c' + \sigma'_{gr,foun} * \tan\varphi' \qquad (6.8)$$

Where:
$\sigma'_{gr,foun}$= Vertical grain stress on the surface between dam and foundation.
Applying the formulas written down in the last years report, this stress can be determined.

Check on sliding of the dam

$\sigma'_{gr,foun} = (H_{dam} * Wdam * \gamma_{dam}) - (H_{dam} * W_w * \gamma_{water})$
$= (1 * 22 * 0,9) - (1 * 10 * 1,0) = 10 \text{ kN/m}^2$
$\tau_c = c' + \sigma'_{gr,foun} * \tan\varphi' = 10 + 10 * \tan 22,5^\circ = 15,3 \text{ kN/m}^2$
$V_{crit.shear.strenght} = \tau_c * A = 13,3 * b*d = 13,3 * 4 * 10 = 534 \text{ kN}$
Where b= effective width of foundation base = 4 m
d= length of dam = 10 m

$$\sum F_{hor} = H_{dam} * d * (F_w + F_{gr',hor}) = [kN]$$
$$= H_{dam} * d * (\frac{1}{2} * W_w * H_{dam} * \gamma_w + \frac{1}{2} * K_{a,gr} * ((W_{gr} * \gamma_{gr}) - (W_w * \gamma_w)))$$
$$= 1 * 10 * (1/2 * 10 * 1 * 1,0 + 1/2 * 1/3 * ((20 * 1,5) - (10 * 1))) = 84 \cdots kN$$

Now the equation 6.6 can be checked:

$$\Sigma F_{hor} \leq V_{Crit.shear.strength}$$

$84 \leq 534$ [kN]
Conclusion: The dam will not slide.
The fictive dam designed above will not slide due to horizontal forces. Special constructions for anchoring the dam in the banks are not included in this calculation. These constructions would make the dam more stable against sliding.

6.3.4 Internal stability of the BCS dam

The internal stability of the BCS dam is guaranteed by the following characteristics:

- High cohesion coefficient especially increased after compaction during the construction process.
- Relative low vertical and horizontal stresses because the dam is very low in relation to its width.
- Stability is provided by a firm layer of rocks and sand, designed in section 6.3.7
- Undrained BCS has rather high shear strength.

Because the expected internal stability, no calculations are carried out.

6.3.5 Settlement

To check the settlement that can be expected in the future, the following method is used [7]. The method is described and example calculations are given. This method can only be considered indicative. A more detailed study of settlement requires detailed soil parameters that are not available.
The process of settlement is divided into two stages:

1. Primary settlement = W_1 [m]
2. Secondary settlement. = W_2 [m]

<u>Primary settlement</u>
Where the following formulas can be applied:

$$W_1 = \frac{C_c}{1+e} * H * \log \frac{\sigma'_v + \Delta\sigma'_v}{\sigma'_v} \qquad (6.9)$$

The stresses in this equation are calculated in the middle of the settling layer.
$\sigma'_v =$Original vertical grain stress [kN/m^2] in H_{mid} = midpoint of layer = depth 2.5 m
$\Delta\sigma'_v =$ Added vertical grain stress in H_{mid}

These stresses have to be checked for the following situation, in which the forces on the foundation are expected to be maximal. In this situation, the upstream side of the dam is filled with water and sediment.

Primary settlement $W_{1\ [m]}$

$\sigma'_v =$1/2 * H * W_{BCS} * γ = 0.5 *5 *18 *1.2 = 54 kN/m^2

$\Delta\sigma'_v =$ H_{dam} * W_{dam} * γ = 1 * 22 * 1.5 = 33 kN/m^2

Now, the equation for the primary settlement can be used.

$$W_1 = \frac{C_c}{1+e} * H * \log\frac{\sigma'_v + \Delta\sigma'_v}{\sigma'_v} = \frac{0.237}{1+1.06} * 5 * \log\frac{54+33}{54} = 0{,}11 \text{ m}$$

For cohesive soils, the following method can be used to determine the total time used for primary settlement.
The time of the total primary settlement w_1 is reached after t_{100} :

$$t_{100} = \frac{2H_d^{\ 2}}{C_v} \quad [\text{s}] \tag{6.10}$$

Where:
H_d = ½ * H (6.11)

C_v = Consolidation coefficient = $\frac{k * E_{gr}}{w_w}$ [m^2/s] (6.12)

Total time primary settlement t_{100} [s]

An expected average value for *k* of 1 * 10^{-9} m/s is used.
H_d = ½ * H = 2.5 m

$C_v = \frac{k * E_{gr}}{w_w} = \frac{1*10^{-9}*3*10^3}{10}$ = 3.0 * 10^{-7} [m^2/s]

$t_{100} = \frac{2H_d^{\ 2}}{C_v} = \frac{2*2.5^2}{3.0*10^{-7}}$ = 41,6 *10^6 [s]

Conclusion: The time consumed for the primary settlement is 482 days = 1,3 year. It has to be taken into account that a permeability value of *k* = 1*10^{-8} would have led to a t_{100} of 48 days. The same way a *k* of 1*10^{-10} would have led to t_{100}= 13 years. Because these large differences it is difficult to predict the settlement behavior.

<u>Secondary settlement</u>

Secondary settlement can be considered to go on forever. The following equation uses a t_∞ 10.000 days as an estimation of the infinite duration of this settlement.

$$W_2 = C_\alpha * H * \log \frac{t_\infty}{t_1} \quad [\mathrm{m}] \tag{6.13}$$

Where:
t_1=1 [day] , starting time after finish of construction

Secondary settlement W_2 [m]

With t_∞ 10.000 and t_1=1, this comes to the following W_2:

$W_2 = C_\alpha * H * \log \frac{t_\infty}{t_1}$ =0.05*5*log $\frac{10.000}{1}$ = 1 m

This secondary settlement takes about 27 years.

<u>Comments on settlement</u>

The main characteristic of settlement is that it develops on a log-scale. This means that the main settlement can be expected in the first 5 years after construction. Estimated is that this settlement will consist in almost 50% of the total settlement, meaning almost 0,5 meters. Because the dam is already very low, its function performance will be endangered by this settlement. Two basic solutions might partly solve this problem:

1. Before constructing the dam, compact the foundation layer of BCS. For instance, by putting temporarily weight on the foundation area for several months.
2. After settlement, a new layer of BCS can be placed on the body of the dam, below the plastic. This will increase the weight of the dam but this will cause only little settlement due to the primary settlement.

Again, it has to be emphasized that the scientific value of the methods above has to be proven, as well as the parameters that are used in the various equations and formulas.

6.3.6 Foundation

Using a foundation of BCS has proven itself to be a dangerous undertaking. Few sand storage dams have been constructed near Machakos. A dam constructed on BCS sank away in one night after the soil below got saturated. It is clear that both the expansive character of BCS

and the fact that the montmorillonite particles make it a collapsible soil are threats to the performance of the dam and its foundation. [11]
In this section, remarks will be given on using the (fictive) 5 meter layer of BCS as a foundation for the BCS-core dam. Whether this layer is present at a suitable construction site for a dam has to be determined in the future.

Collapsible character
Collapsible soils are susceptible to sudden decreases in volume when they become saturated, and this tendency is magnified when saturation is combined with loading. Information obtained by the Kenya Soil Survey has already shown that the particle montmorillonite, known for its unstable influence, is found in the target area of southern Kitui. The main solution to prevent collapsing of the construction and its foundation is compaction of the foundation. Although this solution has proven itself useful in some situations, compacted soils are not always immune to collapse problems. Also, the result of poor compaction on the dry side of optimum can be a soil fabric susceptible to collapse.
One can conclude that the expected collapsible character of BCS is a threat to the dam. The method of compaction should be subject to investigation, as well as the moisture content of the BCS layer throughout the year.

Expansive character
As clay particles in a soil absorb moisture onto the surface of the particle, the soil mass increases in volume, and if water is removed from the clay particles, the soil volume decreases. Hence, dealing with expansive soils is a problem of control of moisture changes. The moisture content in the core of the dam is already secured by the plastic and kept at a level that ensures strength of the core. However, the moisture content of the foundation is a different problem. Moisture changes are found in the active layer of a soil, which can reach up to almost 5 meters. This means, that at the entire foundation layer is subject to the influence of moisture changes. To control the volume change in expansive soils, basically five methods can be used:

1. Remove the expansive material. This option is difficult if a layer of 5 meters is encountered. A thin layer could be excavated and for instance replaced by sand. However, the impermeable character of the BCS below the dam would be lost, and water from the reservoir would be allowed to run off beneath the dam.
2. Surcharge the material to prevent future expansion. Before constructing the dam, a load can be placed on top of the foundation to cause it to settle and shrink. This causes shrinkage that is irreversible if the real dam is built. For this purpose, BCS might be used. The shrinkage will be time consuming and might take up to a year. Drains can be applied next to the foundation to speed up the process of ground water running of because of over pressure in the foundation.
3. Membranes placed around the foundation. For thin layers, this solution can be used to keep the moisture content at a constant level.
4. Increased width of the dam. In the text border below, an example of this solution is given. A large width of the dam is used, combined with the low permeability of BCS to control moisture changes below the centre of the dam. Using this solution, it is best to keep the centre of the foundation as dry as possible to maintain the strength of the soil. The out side edges of the foundation can change in humidity, but the main load of the dam rests on strong dry BCS.

> “Geotechnical materials in construction” by Rollings and Rollings says the following on Black Cotton Soil found in Australia:
> „Low-volume roads on highly expansive Black Cotton Soil have been built successfully in Australia simply by increasing the width of the sealed pavement surface and keeping traffic in the centre. Moisture variation is concentrated along the outside edges of the pavement, where noticeable distortions occur. However, in the centre zone where the traffic is operating, moisture conditions remain relatively uniform, and volume changes are minimal. The low permeability of the Black Cotton Soil greatly slows water penetration to the centre”

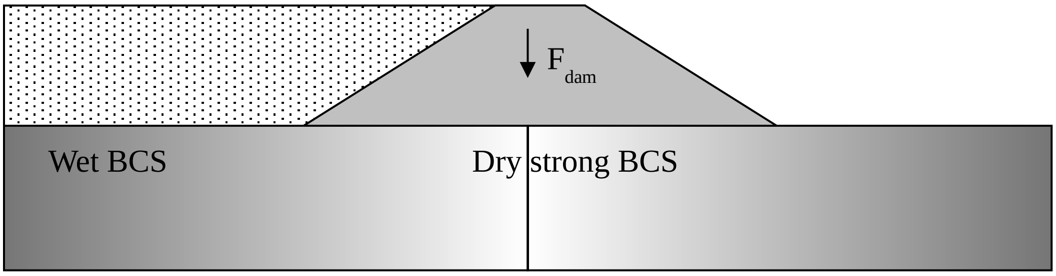


Figure 6.6: Compaction

5. Compaction as a solution to prevent future moisture changes was also used as a solution to protect the foundation against collapsing. Compaction with equipment that produces a dispersed particle structure may reduce future swelling.

All these methods have their own advantages and disadvantages. As mentioned earlier, better insight in the expected behaviour of the foundation can be obtained by tests and experiments. For the next group of Dutch students to arrive in Kenya on the 14th of May, a list of recommended research and experiments are given in Appendix III.

6.3.7 Protection-stone dimensions

Stone dimensions [12]:
To protect the BCS core of the dam and the impermeable plastic, rocks of various dimensions can be placed on top. Below, the determination process of the rocks dimensions is given. The Shields formulae give a relation between the stone diameter, the depth and the beginning of movement. The first calculation, which gives probably not the normative stone diameter, only counts by an already filled reservoir. The calculations can be used in many more situations to calculate the threshold of movement.

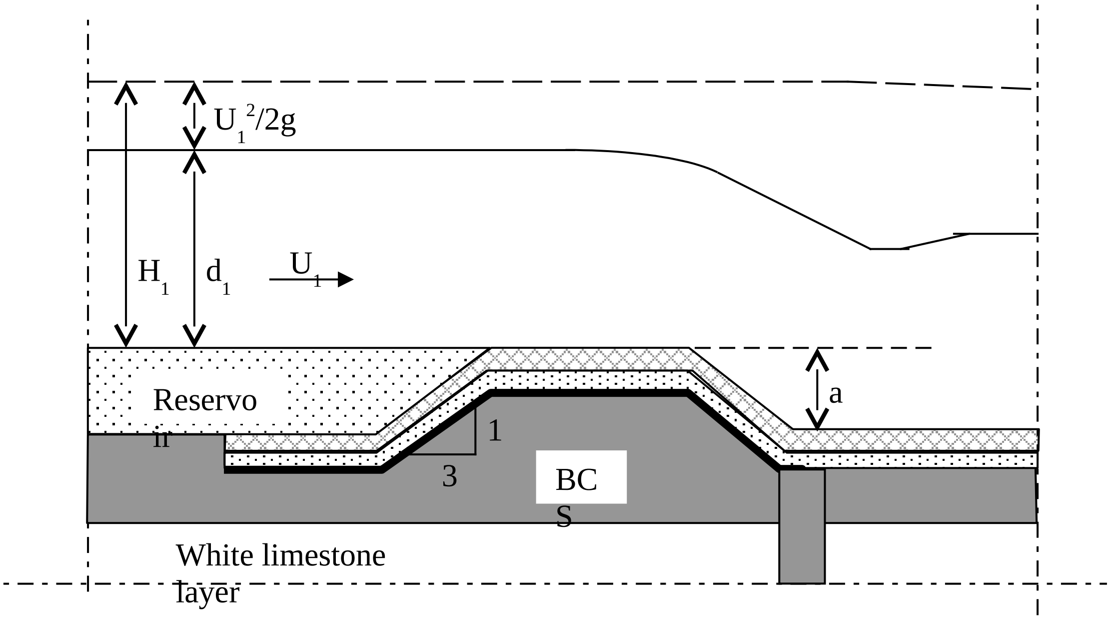


Figure 6.7: flow over sill after filling of the reservoir

For sediment in uniform flowing water the relations are given by Shields formulae:

$$\psi_c = \frac{u_{*c}^2}{\Delta g d} = f(\text{Re}_*) \tag{6.14}$$

in which: $$u_* = \bar{u}\frac{\sqrt{g}}{C} \tag{6.15}$$

$$C = 18\log(12\frac{R}{k_r}) \tag{6.16}$$

$$\Delta = \frac{\rho_m - \rho_w}{\rho_w} \tag{6.17}$$

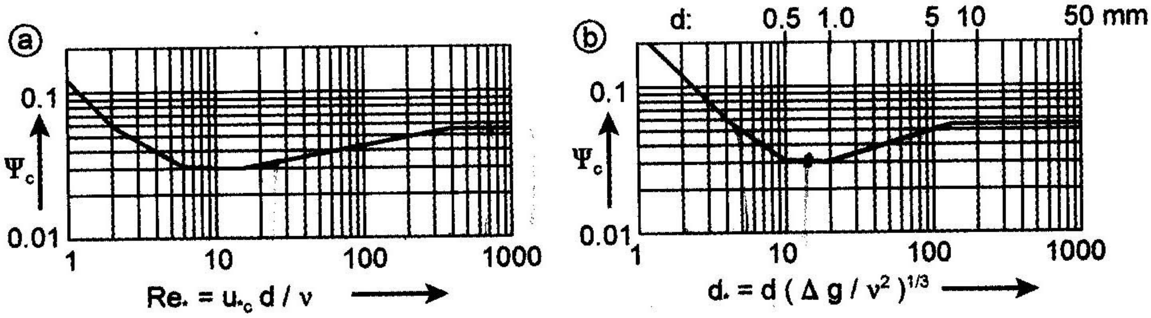


Figure 6.8: Critical shear stress according to Shields-van Rijn

Where:
Ψ_c = shields parameter [-]
d = water depth [m]
u_* = shear velocity [m/s] with subscript c for critical
$\bar{u}$ = velocity averaged over the vertical [m/s]
C = Chezy-coefficient for bottom roughness [$m^{1/2}/s$]
k_r = (equivalent) roughness of bottom = 2*d_{n50} [m]
Δ = relative density
ρ_w = specific weight of water [kg/m^3]
ρ_m = specific weight of the material [kg/m^3]

The process to determine the stone diameter is iterative. First d_{n50} or C has to be estimated, to know the k_r. Together with the R the Chezy-coefficient can be calculated. The Shields parameter ψ can be held on 0,03, this is a safe value for the threshold of motion. In the end with formula 6.18 the new d_{n50} is calculated. Now with the new value for d_{n50} the process has to be repeated till the entered d_{n50} is the same as the resulted d_{n50}.

$$d_{n50} = \frac{\bar{u}_c^2}{\psi_c \Delta C^2} \qquad (6.18)$$

We first calculate the stone diameter under the uniform flow in the river. In the river channel itself there is sediment transport allowed. On the crest of the sill after the reservoir has filled, the stone diameter must be sufficient to resist the drag and shear forces.

Stone dimension on the crest of the sill:

We assume that the flow velocity as earlier in this section is 2,33 m/s. We apply a stone with d_{n50} = 0,15 m and assume that the Shields parameter is ψ = 0,03, this is always a safe choice for the threshold of motion. The Chezy-coefficient (C) is now 35 $m^{1/2}/s$.
And the d_{n50} is:

$$d_{n50} = \frac{2{,}33^2}{0{,}03 * 1{,}65 * 35^2} = 0{,}089\ m$$

The new Chezy-coefficient (C) is 39,2 $m^{1/2}/s$. With the same formula we calculate d_{n50} again and it will be then 0,072 m. After a few calculations we end with a d_{n50} = 0,062 and a C = 42 $m^{1/2}/s$. This is the stone diameter, which is resistant against the forces of the flow.

The stones with this d_{n50} will be resistant against the forces caused by the flow. There are several reduction factors, concerning the sloping bed and acceleration/ deceleration.

On the downstream slope the rocks have less resistance from the underground, the correction factor is given by:

$$K(\alpha_{//}) = \frac{\sin(\phi - \alpha)}{\sin\phi} \tag{6.19}$$

Where:
$K(\alpha_{//})$ = the correction factor for flow parallel to the slope
α = slope angle [˚]
φ = angle of repose [˚]

This factor has to be applied in the denominator of equation 6.18.

Stone diameter on downstream slope

We assume a slope of 1 on 3, this is an angle of 18,5˚. The angle of repose for rock is 40˚. This means a correction factor for the slope:

$$K(\alpha_{//}) = \frac{\sin(40 - 18{,}4)}{\sin 40} = \frac{0{,}368}{0{,}64} = 0{,}57$$

The stone diameter d_{n50} = 0,062/0,57 = 0,108 m.

In a not uniform flow on top of a sill, more unfavorable relations can be expected. Due to acceleration there is an increase of the shear stresses and a decrease of the relative turbulence. On the downstream side the first damage will occur. There the velocity is maximal and the strength minimal, because of the downward slopes.

When the flow velocity above the dam and the depth of the water is known the size of the protection stones can be determined. The relations between these parameters are experimental determined. The results are in figure 6.9 compared with the results when Shields is applied using the velocity on top of the sill.

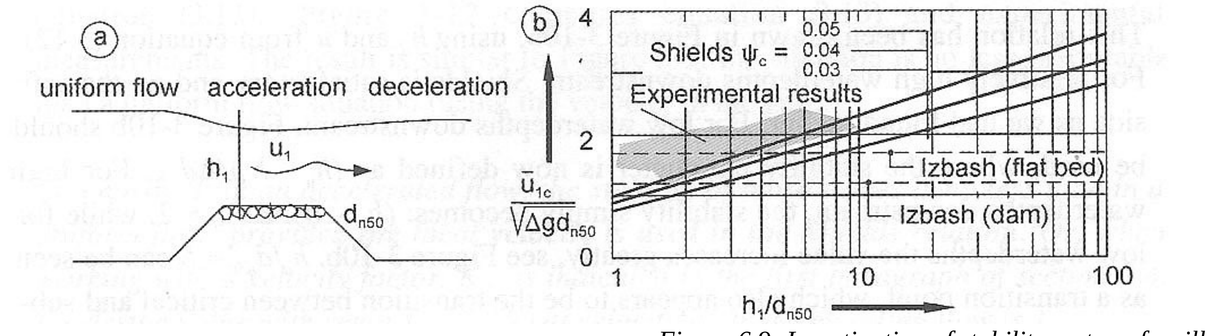


Figure 6.9: Investigation of stability on top of a sill

On the horizontal axis there is the ratio of the depth of the water above the sill and the nominal stone diameter:

$$\frac{h_1}{d_{n50}} \tag{6.20}$$

and on the vertical axis is the relation with the critical velocity:

$$\frac{\bar{u}_{1c}}{\sqrt{\Delta g d_{n50}}} \tag{6.21}$$

Where:
$h_1 = d_2$ (from earlier calculations) [m]
d_{n50} = nominal stone diameter [m]
$\bar{u}_{1c}$ = the critical velocity on top the sill [m/s]

Stone diameter on top of the sill

The flow velocity was calculated with Bernoulli and was 3,52 m/s if we take d_{n50} = 0,062 m the first term h_1 / d_{n50} = 2,8 / 0,062 = 45. In the figure we see that when we still use ψ = 0,03 the second term must be about 2,5. And the term is:

$$\frac{3{,}52}{\sqrt{1{,}65*10*0{,}062}}=3{,}48$$

This means that d_{n50} must be higher, so the both terms decrease. When we apply d_{n50} = 0,10 we have h_1 / d_{n50} = 28 and the term on the vertical axis is 2,74. The coordinates equal the line of Shields at d_{n50} = 0,18 when the terms are 15,5 and 2,0.

6.3.8 Geometrically closed filter

It is impossible to place the stones on the impermeable plastic. Rocks are mostly sharp and smaller stones or sand grains are more rounded. Under the protection layer a base layer has to be placed. But the design of the new layer has three demands [12].

The filter layer is the top layer, in this case the protection layer. The base layer is the layer between the plastic and the protection layer. A base layer often exists of more layers with different diameters. The 'd' stands for diameter and the number subscribed means the percentage of the mass of the grains passing the sieve. d_{15F} means that at this diameter only 15 % of the mass of the grains of the filter layer has passed the sieve.

The grains of the base layer may not wash out through the pores of the filter layer. The largest grains of the base layer get stuck in the pores of the filter layer when the next relation counts:

Stability: $\frac{d_{15F}}{d_{85B}} \leq 5$ (6.22)

The largest grains in the base layer must be not too large, to block the smaller grains of the base layer. This means the base layer must be internally stable:

Internal stability: $\frac{d_{60}}{d_{10}} \leq 10$ (6.23)

The permeability of the filter layer has to be larger then the permeability of the base layer. The smallest grains define the permeability, so this leads to the last relation:

Permeability: $\frac{d_{15F}}{d_{15B}} \geq 5$

(6.24)

Where:
d = diameter [m]

$_{15}$ = % of the mass of the grains which passed the sieve
$_{B\ or\ F}$ = indication for base or filter layer.

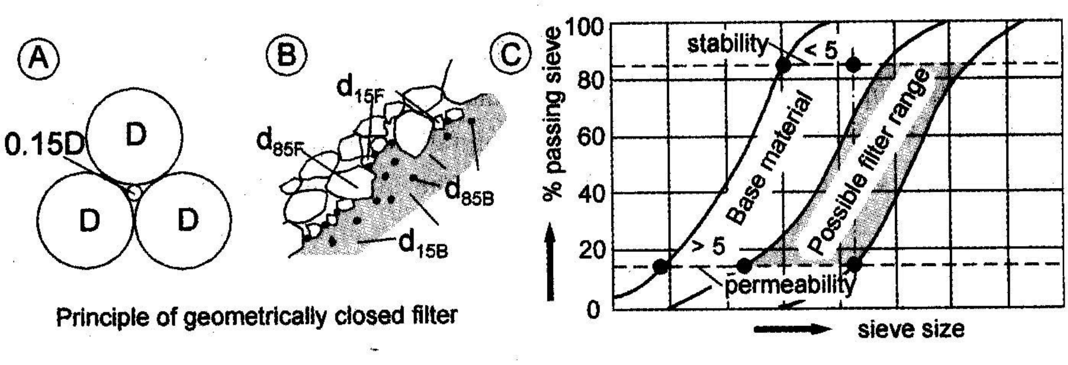


Figure 6.10: Principle of geometrically closed filter

There are general rules about the thickness of the layers. The minimal thickness is 2 times the nominal 50% diameter. (d_{n50}) For a better and more secure filter thicker layers are recommended.

> Base layers
>
> When we apply a stone size of 0,20 m, this can be a stone class of d_{15}/d_{85} of 200/350 mm the d_{15} is 200 mm, to protect against the flow forces, we can't place them on the plastic. A base layer is needed. The d_{15} of the base layer has to be smaller than 200/5 for the permeability and the d_{85B} has to be larger than 200/5. The d_{60}/d_{10} of 10 corresponds with a d_{15}/d_{85} of 12 –15. A stone class of 20/60 mm will do. This can't be placed on the plastic, so we repeat the same calculation for the second base layer and we see that fine gravel of 2 to 6 mm will do. This material can be placed on the geotextile or plastic foil, which prevents the dam from dehydration.
>
> Layer thickness:
> The upper layer must be 2 * d_{n50} = 0,36 m.
> The first base layer is set on 0,18 m.
> And the second base layer is 0,1 m.
> The last layers are assumed, but are on the safe side. The total thickness of the filter and base layers is 0,64 m.

6.3.9 Plastic foil

To protect the dam from dehydration and to keep the moisture content constant, an impermeable foil will cover the dams core. The kind of geotextile/plastic foil, which will be used, is not determined. Demands, characteristics and some attentions about the foils are shown in this section.

There are three special demands [12]:

Thickness:
The plastic must be resistant against sharp stones and roots from trees. Little leakage is not seen as a major problem, but leakage can rapidly increase when little holes turn into cracks. Another problem is the tensile stress (F_T), caused by the filter layers lying on the plastic.

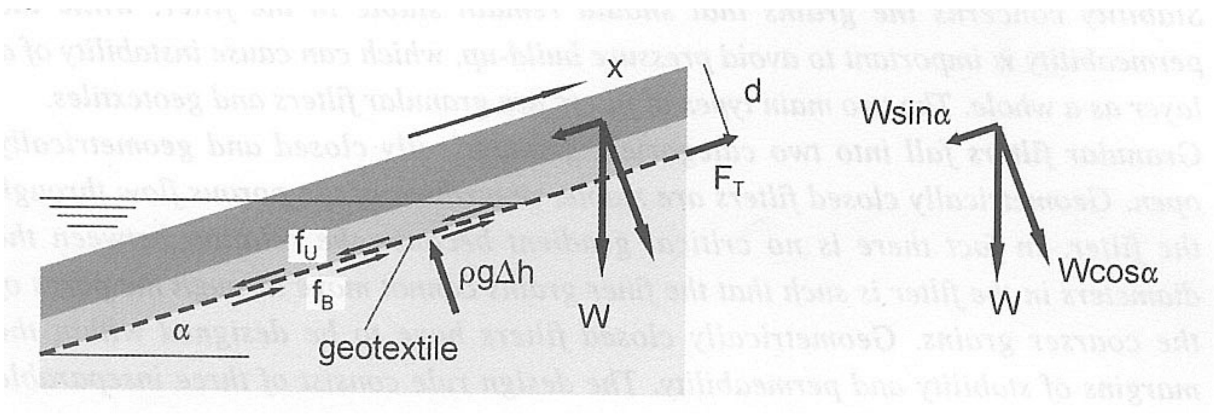


Figure 6.10: Overall stability of filter with plastic foil

Roughness:
To prevent the stone layers on the plastic from sliding down the slope, friction is needed between the filter layer and the plastic. The amount of friction follows from:

$$f_U W \cos\alpha \geq W \sin\alpha \qquad (6.25)$$

Where f_u is the friction factor and thus must be larger than tanα. The equilibrium demand for the whole protection, including the foil, reads:

$$f_B \left| \rho_{mEFF}\, g d \Delta x \cos\alpha - \rho_w g \Delta h \Delta x \right| + F_T \geq \rho_{mEFF}\, g d \Delta x \sin\alpha \qquad (6.26)$$

Where:
F_T = force in the foil [N/mm^2]
ρ_{mEFF} = the effective density of the layer as a whole [kg/m^3]
f_b = the friction factor [-]
d = thickness of the layer [m]
Δx = distance of the connection between the layers and the foil [m]
Δh = pressure difference across the geotextile [m]

Depending on the density of the stones the ρ_{mEFF} varies. If we assume the specific weight to be 2650 kg/m^3 with a porosity of 40%, under water ρ_{mEFF} = 1000 kg/m^3 and above it is 1600 kg/m^3.

Manageability/flexibility:
The plastic has to be flexible to bend in the corners and for the connection in the banks. To connect the foils to each other it can be possible to sew, lime or overlap. Connecting the foils to each other, the impermeability has to be held in mind and kept as high as possible.

6.3.10 Impermeable shield underneath the dam

In this chapter we used a BCS layer underneath the dam of 5 m deep. When the layer is thin, it might be feasible to put an impermeable shield through the white layer to block the water in this layer. In the evaluation we spend attention to the material of this shield. The most favorable is the BCS shield. Chapter 7 and 8 give designs for impermeable shields but then as a sub-surface dam. For further information we refer to that chapters.

6.3.11 Stilling basin

In the report on "improved design of sand-storage dams"[4] the design rules and different kind of stilling basins are given. In case of this BCS-dam no spillway is used and there is no contraction of the flow. We will use other design rules from [12] to determine the length of the protection after the dam. It can be recommended to look at the different concrete stilling basins to compare with the new-presented method.

Above the dam, the flow accelerates and after the dam the flow decelerates. The jet enters the water layer behind the dam and the mixing layer with the increased turbulence will spread. The point where the mixing layer hits the riverbed is called the reattachment point. Between the mixing layer and the dam there will be a circular flow. The riverbed has to be protected to just downstream this point.

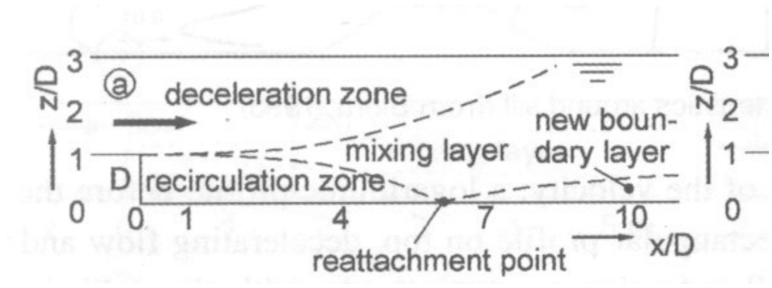


Figure 6.11: Reattachment point

In the figure on the vertical axis the relation between the depth and the dam height is given as z/D. This parameter is only of importance to the mixing layer spreading to the water surface. The horizontal axis shows the ratio between the distance downstream and the dam height as x/D.

Reattachment point
The designed dam is 1,0 meter high and thus the x/D = 6, so the reattachment point is at 6 meters downstream. When the dam is 2 meters high and x/D = 6 then the distance x = 6 * 2 = 12 meters

The downstream side of the dam, which is under an angle, has no influence on the mixing layer, because the spreading starts slow. With an angle of 1:3 there is only three meters left to protect downstream of the dam.

6.4 Construction method

To build a BCS-dam several steps must be taken in a specific order. Some dimensions used in this section are designed for the fictive dam from section 6.3. The knowledge on working with communities is present to SASOL. In this section only the acts for building are given. Transport, the collecting of stones and other side-acts are up to SASOL.

1. <u>Impermeable shield</u>

Dependent on the depth of the BCS layer and the depth of the white limestone layer an impermeable shield can block the water in the white layer. To built this impermeable shield of BCS the following steps are taken:

- First, measure the ground layers and find out if an impermeable shield under the dam is feasible on this site.
- Excavate the trench. To dig the last part, the water probably has to be removed. This is possible with a manual pump, if available. The trench must reach to the impermeable layer.
- Wet but not fully saturated clay, so that the deformations are plastic, must be found in the neighborhood. Put the clay in little amounts in the dry trench, in little amounts of about 10cm height and compact the clay by pressuring it by feet. Make sure all the spaces between the different clay humps are disappeared. Rocks and other permeable objects in the BCS are to be removed. Fill up the whole trench.
- Fill the whole trench and make sure the clay connects well with the BCS-layer.

2. Compaction of the BCS layer

To protect the structure against settlement and expansion processes, a few methods are explained in section 6.3.6. The operations required, have to be done in this part of the construction process.

3. Dam core

The core of the dam consists of BCS. The core must connect properly to the banks to prevent the water seeping along the dam. The site must have banks consisting of BCS.

- Remove all sediment and dirt of 11m length in the direction of the river, till a clean pure BCS layer is on the surface.
- To create a homogeneous BCS layer, replace other soil with BCS. Compact the new added BCS on the way described at the impermeable shield.
- Because of the protection layer of approximately 0,5m some parts of the riverbed have to be excavated (protection to the reattachment point for example). The excavated BCS can be used to construct the core.
- Add small layers of BCS to the core and make sure they are well compacted. The clay has to be plastic and handy. Not to wet and not to dry. The best BCS must be found by trial-and-error. The area around the construction site has to be explored for good and useful BCS.
- Wet the slopes and add little pieces of BCS. Cut other extending pieces, so the slope will be smooth.
- Excavate parts of the banks to create connection points between the banks and the body of the dam. This connection has to be firm and as compacted as possible.

4. Plastic

The foil, which will be used, must be determined by the factors given in section 6.3.9. The following steps care for a good placement of the plastic.

- Make the slopes slightly wet and place the foil without spaces of air on the BCS.
- Extend the foil in the banks, so the core will not dry out.
- Upstream of the dam, where the sediment settles, the foil is not needed because the sediment will protect the dam from drying out. Downstream the foil must be extended under the protection.

5. Filter and base layer

The protection of the dam will be constructed as following:

- Find sand with the calculated sieve diameters. When this sand is found, put a layer on the foil of minimal two times the d_{n50}. In the drawing we placed a layer of 10cm for extra security, because the diameter is very small.
- Find the stones of the next layer and place them on the dam. Make sure the base layer stays homogeneous. Again this layer must be more than two times the d_{n50} thick.
- Place as many layers as needed and in the end place the protection layer with the stone diameter, which is resistant to the drag and shear forces.
- On the banks and beds the connection with the BCS must be firm. Between the placed stones BCS can be placed. This is also possible in the rest of the structure to adhere the stones.

6. Finishing and maintenance

A good check on the foil and the protection is important to prevent early failure. Next attentions must be made:

- Replace the BCS in the banks and protect it if necessary with stones as well.
- Check the foil to be protected everywhere. In the banks BCS must be over it and on the dam enough stones, so the flow can't get under the foil.
- Monitor the amount of stones on the dam and the erosion. And if necessary fill up the eroded places with stones of the correct diameter.
- After some occurred settlements it is possible to remove the protection and raise the dam with BCS and replace the protection.

6.5 Finance and feasibility

The method of using BCS as the core of a sand storage dam, covered with an impermeable plastic and several protective layers is a new concept to SASOL. Although the principal of this concept might succeed in theory, the practical part is an unknown different ball game. In this section, thoughts on feasibility and expenses are pointed out. Also, a short description on the possible involvement of local communities is given.

6.5.1 Expenses

Various expenses will cross the path of constructing a BCS-core dam. The three main expenses can be divided into labour, materials and transport.

Labour

Constructing a dam, as described in section 6.4, demands for several construction specialists. Placing of the plastic around the core and the top protection layer are all delicate parts of the construction process. SASOL already has its own masons, but for this type of dam, other skilled workers might have to be hired. The expenses this will bring are yet unknown. The labour involvement of community is described in section 6.5.2.

Materials

A new material used for the sand storage dam is plastic. This plastic, as described in 6.3.9 is fairly cheap and available in almost every hardware store. Although a large surface has to be covered by the plastic, it will not be of great influence on the costs of the dam.
The rocks that are placed as a protection layer are not expensive if found nearby the building site. Community can be used for digging the rocks. If rocks are not found in the area, the costs

for obtaining them somewhere else can be expected to be very high. Hiring trucks to travel long distances (around 50 kilometres) on difficult roads is expensive.
BCS is expected to be available everywhere in the area in sufficient amounts. It is either free or very cheap.
Materials used for a possible shield below the dam to a great depth are described in section 7.1.

<u>Transport</u>
The location of the construction site and available materials in the area will determine the influence of the transport costs. As already mentioned above, transporting rocks will be very expensive. Also, if an area for digging rocks can be found, the transport of the community to the digging site will cause a logistic problem that has to be faced.
BCS can be found anywhere near the area and can be transported by hand and wheelbarrow
Plastic is rather light and found on rolls that are easy to carry. They require no special transportation and can be moved by hand, car, bus and even matatu.

6.5.2 Community involvement

- The stone masonry dams in northern Kitui are very suitable for community involvement. The new construction principal of the BCS-dam asks for new ways for community to participate in the construction process. For instance:
- Transporting rocks from distance asks for transport of community-diggers.
- Community members can easily do excavating BCS.
- The layering of the plastic is a delicate process. Community will need good directions to succeed in doing this themselves.
- The layering of the rocks has to be done carefully. Community can do sorting the rocks on their various dimensions, as they are determined in section 6.3.7 and 6.3.8.

6.5.3 Feasibility

The feasibility of the BCS-core dam is a difficult subject. The expenses of the dam compared to the storage capacity of the reservoir and its hydrologic value are difficult to predict. To get an idea on the feasibility the following considerations have to be reckoned with. These considerations are partly recommendations and will also be described in section 6.7.

- Handling BCS, compacting it and putting in the core of the dam is a possible difficult method.
- The use of plastic shield to detain water in BCS is a new method and should prove itself on a small-scale test site.
- The availability of rocks is of big importance to the feasibility due to its potential high costs.
- The dams that can be constructed are rather low because of the low river depth. This will not create a deep reservoir as the dam constructed in northern Kitui.
- The life expectancy of the dam will strongly depend on settlement described in section 6.3.4.

Obviously, a lot of inquiries have to be done to determine the feasibility of a BCS-core dam. Again, it can be emphasized that ‘expensive water’ is better than ‘no-water’, where ‘no-water’ consists in daily walks up to 7 hours with donkeys to obtain water in barrels. Any effort made to improve the water situation, successful or not, can be considered useful for the long term development and it will always attribute to a larger data base on water containment.

6.6 Conclusions

In this chapter, the option of building a sand-storage dam with a BCS core on foundation layer has been reviewed. From the various evaluations and calculations, a conclusion can be drawn on constructing a BCS-core dam.

Conclusion
With the present knowledge, know-how and expertise it is not recommended to construct a sand-storage dam with a BCS-core in the nearby future. The following five gaps of data are considered the base for this conclusion.

- Unknown river discharge
- Unknown plastic performance
- Unknown BCS characteristics
- Unknown behaviour of groundlayers and foundation
- Difficult construction method and use of materials

Short remarks are given below.

Unknown riverdischarge
To determine the required protection for the dam, it is important to know the peak riverdischarge. To protect the dam, an optimum of required rocks has to be found. The dimensions of the rocks, and the needed amount are depending on the peak riverdischarge.

Unknown plastic performance
The plastic put around the dam to control its moisture content is a new method in construction. Therefore, its performance is difficult to predict.

Unknown BCS characteristics
The knowledge on BCS at this time mainly consists in experience by the local community with this soil. No scientific data is yet at hand. This means that designing a dam cannot be done on scientific grounds.

Unknown behaviour of groundlayer and foundation
Unknown soil profiles, permeability and possible settlement stand in the way of detailed reliable foundation design.

Difficult construction method and use of new materials
The use of a BCS-core, with plastic and rocks protection creates a new construction field for both SASOL and involved communities. The process of applying this new kind of dam can therefore be considered a very difficult and time-consuming path.

6.7 Recommendations

For the reader of this chapter it must have become clear that a lack of knowledge, experience and data is at this moment blocking the way to a good design for a BCS-core sand storage dam in Kitui. To deal with this situation, various recommendations are made in this section.

Monitoring the river discharge
The stone diameter of the protection is determined by experimental results. The results of Shields give the threshold of motion. Relations with permitted erosion may have a more

favourable outcome. A smaller stone-diameter with more erosion and more maintenance can be more favourable.
In this case the river has a wide variety of discharge. The peak discharge probably occurs a few times a year. The expected erosion of the protection layer can be calculated with a sum up of erosions by different flow velocities and the time the velocities are lasting.
It is recommended to monitor the river discharge and measure the flow velocities and the time they occur. Find new relations in lecture with relation between erosion and flow velocity, d_{n50} and time.
It may be that a smaller d_{n50} gives more erosion and hence more maintenance, but is still cheaper than the large stones.

Optimisation of the dam height
There is an important relation between the dam height and the stone diameter. A higher dam will cause higher flow velocities and thus the dam needs bigger stones as a protection. Of course, a higher dam will increase the reservoir volume. The optimisation can be determined iterative.
When there is insight in the availability of stones, one can calculate the extra costs of the dam and especially the stones compared with the spin-off of the extra storage capacity.

Optimisation of the slope angles
Steeper slopes need bigger stones, and milder slopes need more material. The optimisation is very important to built the cheapest design of the dam.

Dehydration of BCS-core
The core of the dam is believed to dry out. In our design, plastic is put all under the erosion protection to prevent it from dehydration. The anchoring of plastic in the banks and the bed is an important factor for extra costs. Extra plastic means extra costs. Research and experiments should be carried out to determine the dehydration character of the core and the plastic that is needed to prevent it.

Constructing with BCS
It is not clear at what humidity level the BCS is the easiest to handle. If the BCS is too dry will burst and crack. If the BCS is too wet, it will lose its adhere and strength. The compaction of the BCS is also unknown. The best way to compact it can only be determined experimentally. Experiments can consist in putting loads on samples of BCS and slowly add water to the sample.

Other applications of this design
The use of BCS-core dams can also be used for different purposes than sand storage. These dams might also be useful in , for instance, the floodplains. They can serve here to prevent the surface water from running off fast and leaving the area. Water can be slowed down and given more time to seep into the ground or to be absorbed by vegetation.
Another purpose of these dams might be to protect communities that are troubled by quick run off and high water.

Concrete-protected dam
In the evaluation given in section 6.2 at forehand the stone-protected concept seems the best. After the design and the conclusions the stone-protected BCS dam is likely to be not feasible. It is recommended to design a concrete-protected dam or a gabion-protected dam.

Stone-masonry dam

Further research on stone-masonry and the foundation on the white layer are useful to investigate.

7. Impermeable shield through BCS-layer

In this chapter the possibility of putting impermeable shields, through the BCS-layer and the white layer, into an impermeable firm layer underneath, will be investigated. The firm impermeable layer is assumed to be at a feasible depth.
The possible construction materials will be discussed and evaluated in the first two paragraphs. A design is made in the third paragraph and checked on stability.
The construction method will be looked into. Whether the design will be feasible is dealt with in the fifth paragraph and finally the conclusions and recommendations will be given in the last paragraph.

7.1 Materials

Different materials can be used to construct the impermeable shields. Advantages and disadvantages will be discussed in this paragraph. In the next paragraph the different materials will be evaluated and compared.

1. Iron shields

The cheapest and most common shields are made of iron and are known as mabati. Mabati are waved shields of iron. The biggest size of available mabati shields is 1 by 3 meters. These shields can be connected to each other in different ways. They can be welded together, but you will need a skilled worker and electricity to do that. Another possibility is to overlap one shield with another and connect them with screws and bolts.

The shields have to be protected against rust (corrosion). The special coatings are believed to be expensive. Probably using a simple paint could be an option as well, which will be much cheaper.

Advantages: Cheap, available, impermeable construction
Disadvantage: Short life expectancy because of damage by rust or expensive protection against rust needed.

2. Plastic shields

Plastic shields can also be used as an impermeable shield in the same way as iron mabati. They are not as heavy as the iron ones so a foundation layer is probably not necessary. It will be more difficult to connect the shields. Welding is not possible and screws might crack the shields. An option might be to glue them together, but little is known about the cost and availability of glues. Another option is to overlap one shield with another. This is by far the cheapest solution, because no other materials are used.
According to experts at the retail locations, the plastic mabati is believed to be stronger than iron mabati.

Advantages: lighter material than iron, strength
Disadvantages: expensive, availability

3. Tarpaulins / Plastic membrane

Plastic membranes are rather flexible impervious materials. To get it lined up in a straight way, the membrane can be nailed on to a wooden framework or stitched around a frame of

iron pipes. It might be enough just to attach the plastic membrane to a beam at the top and bottom of the trench. The bottom beam has to be quite heavy to make sure that the plastic membrane will not move upwards when the water puts pressure on it.
Putting the tarpaulin into the ground has to be done with great care in order not to rip the plastic membrane, especially with the rough texture of the white layer.
Attention has to be paid to the seal between the plastic membrane and the impermeable layer. Seepage of water is undesired.

Advantages: light construction, a plastic membrane can adapt to small ground movements
Disadvantages: the plastic membrane might easily rip, which will cause leakage problems, vulnerable at big depths because of a coarse white layer.

4. <u>Sub surface brick wall</u>

A trench has to be excavated in which a brick wall will be built. Stones are not available, but it might be possible to use the loam bricks, which are used to build houses as well. The construction will be heavy; a foundation has to be built to make sure that the construction will not sink into the BCS layer.

Advantages: local community generally manufactures bricks
Disadvantages: stability, heavy construction, difficult to construct in rainy season: drying process of the mortar will progress slowly

5. <u>Trench filled with concrete/ cement</u>

In this option, a trench is excavated and filled up with concrete. The concrete will be completely watertight. It will be quite heavy though, and might sink into the BCS layer. Another thing is that it is not very flexible and might crack, because of the swelling forces of the BCS. It is an expensive solution, because stones are not nearby and transportation is expensive. Cement is even more expensive.

Advantage: strong, watertight
Disadvantage: expensive, difficult to construct in rainy season: drying process of the concrete will progress slowly, heavy

6. <u>BCS filled trench</u>

As an impermeable shield, a trench is excavated and filled up with BCS. To improve the strength and impermeability of the BCS, it has to be compacted well (see paragraph 6.1 compaction). This can be done by wetting the BCS and pound it down.
It might be a good solution to combine the plastic membrane shield with a BCS filled trench.

Advantage: cheap, when available nearby
Disadvantage: complete compaction will be difficult, swelling/ shrinking character of the BCS

7.2 Material evaluation

The evaluation will be conducted in the same way as already explained in chapter 6.2.
The criterion of ‘maintenance’ is not taken into account, because maintenance on deep shields will be very difficult to carry out.

7.2.1 Table of criteria

	Shield →	Iron[1]	Plastic	Plastic membrane	Brick Wall	Con-crete	BCS
Criteria:	*Weights:*						
Costs	25	5	5	6	6	4	9
Durability	10	7	7	5	4	9	6
Vulnerability	15	6	7	3	3	9	6
Availability	15	7	6	7	7	5	9
Construction	20	4	6	7	6	3	9
Extendibility (in lateral direction)	10	6	7	7	5	4	7
Water tightness	5	8	7	7	4	7	7
		570	615	595	530	535	795

Table 7.1: evaluation of different construction materials

7.2.2 Conclusion

Conclusion for the material of choice for constructing a shield till the depth of an impermeable layer to hold the surface run-off water: BCS is the best method if it works. It is widely available, therefore low in costs. The construction method does not require skilled workers; there is only digging to be done and filling the trench with BCS. The only difficulty might be the compacting of the soil.
However there is still a significant lack of knowledge on the possibilities of using BCS as a construction material and whether BCS truly is impermeable after decomposing it. Calculations on constructions with BCS will still be too imprecise due to lack of knowledge on the characteristics of this soil. The best way to find out about the possibilities of BCS is to build an experimental dam and do tests on BCS. Recommendations for research will be given together with the conclusions in the last paragraph of this chapter and in Appendix III, a more detailed plan for a building an experimental dam and desired research will be given.

The second material of choice is a shield made out plastic. These shields are not that expensive, they are impermeable and the construction will be low in weight, so they won’t sink away into the soil. They have a long life span.

[1] Iron shield protected against corrosion with coatings

7.3 Design

7.3.1 Situation and assumptions

[6] The situation, which will be looked at, is an impermeable shield reaching a firm impermeable layer at a depth of 10 m. The soil profile used for the calculations is as described in chapter 5, situation 1.

- Sediment layer: 0 - 1,5 m

γ_{dry} = 18 kN/m^3, γ_{sat} = 20 kN/m^3

- BCS: 1,5 m – 3 m

γ_{humid} = 17 kN/m3, γ_{sat} = 20 kN/m^3

- BCS mixture with limestone: 3 m – 5 m

γ_{humid} = 16 kN/m3, γ_{sat} = 18 kN/m^3

- White layer: 5 m – 10 m

γ_{sat} = 16 kN/m^3

- Impermeable layer: 10 m - ∞

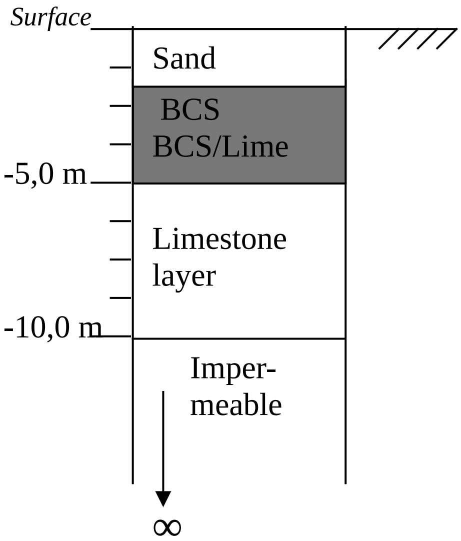
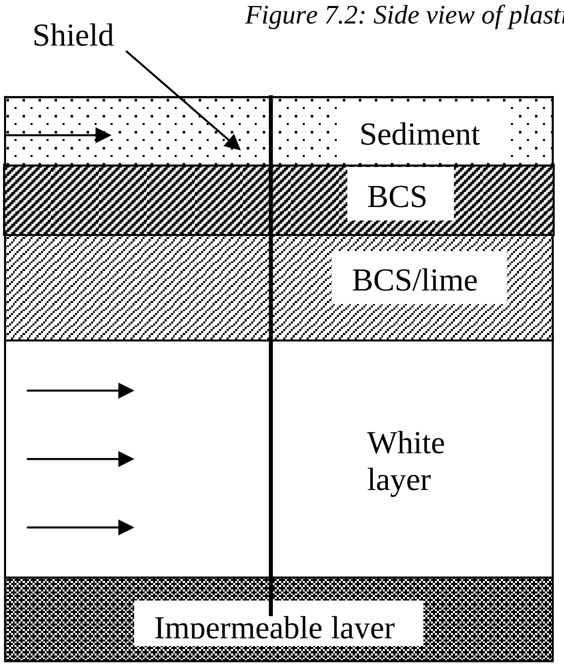


Figure 7.1: soil profile

To perform a check on the stability of the structure in the soil, knowledge on the ground water levels is required.
The water table downstream of the construction is determined at a depth of 3,5 m below the surface. Upstream of the dam the water is assumed to reach the surface level. The water pressure working on the shield is assumed to be hydrostatic. There is no capillary rise into the BCS (assumption), therefore the water pressure is assumed to be hydrostatic.
To simplify the calculations it is presumed that the shield is fixed in the white layer. In other words, the white layer can withstand the horizontal forces caused by the water pressure and ground pressure and will not deform. The assumption that the white layer can hold the horizontal forces is made, because a masonry dam in the Semea River has been successfully founded on this white layer. To check whether this layer does not crumble under the pressure, it is highly recommended that a pressure test will be performed on this type of soil before engaging in any type of construction.
The shield needs to pass through this layer, since this layer is porous and will otherwise allow too much water to seep away.
In the following paragraphs the river is determined to have a width of 10 meters.
The banks of the river rise 2 m above the surface of the sediment.

7.3.2 Design features

Figure 7.2: Side view of plastic shield into an impermeable layer



A plastic impermeable sheet is put in the ground first through a layer of sediment, then BCS, then a layer of BCS mixed with a lime stone and finally through a layer that is believed to be of lime stone. Underneath this limestone an impermeable layer is assumed at a reachable depth of ten meters.

First, calculations will be done on this shield to make sure that it can withstand the forces and after that the details on the design will be given.

7.3.3 Forces on the structure

<u>Determination of the vertical pressure on the soil [13]</u>

The resultant force can be calculated by adding the individual resultant horizontal forces of water pressure and earth-pressure. All forces are calculated using a safety factor which varies for favourable or unfavourable and permanent or variable forces.

Vertical pressure (σ_{zz}) due to the specific weight (w) of the various layers at a depth *d*:

$$\sigma_{zz} = w * d$$

Pressure in the groundwater (specific weight w_w) at a depth *d* equals the weight of the column of that height. The pressure of water is the same in every direction:

$$p = w_w * d$$

Effective ground pressure (σ'_{zz}) at a depth d:

$$\sigma'_{zz} = (w - w_w) * d$$

or

$$\sigma'_{zz} = \sigma_{zz} - p$$

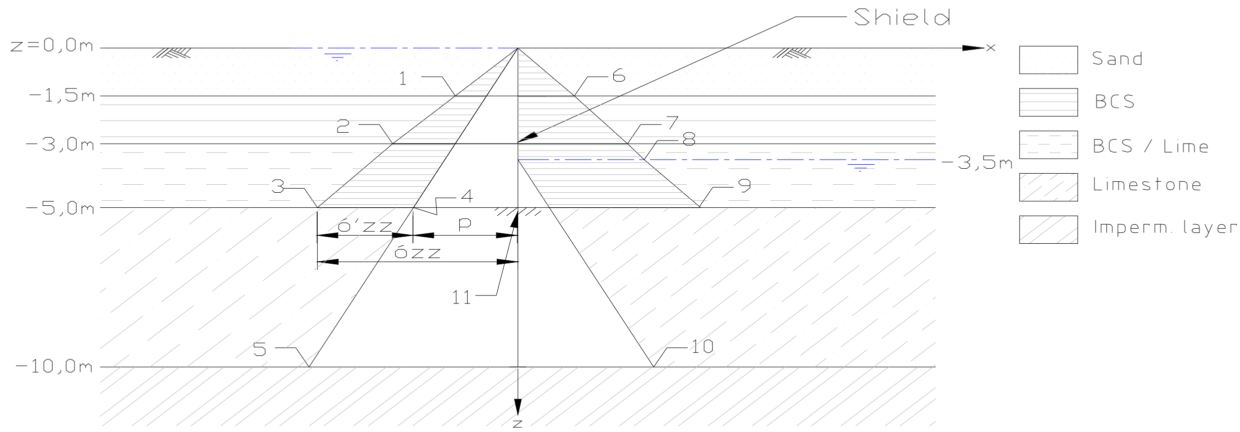


Figure 7.2: Vertical Pressure

Because of the different specific weights of the different layers the pressure will vary and has to be calculated for every boundary between layers. The pressure is calculated for the points 1-10:

1. $\sigma_{zz,1} = w * d = 20kN/m^3 * 1.5m = 30kN/m^2$

   $p = w_w * d = 10kN/m^3 * 1.5m = 15kN/m^2$

   $\sigma'_{zz,1} = (w - w_w) * d = (20kN/m^3 - 10kN/m^3) * 1.5m = 15kN/m^2$

2. $\sigma_{zz,2} = \sigma_{zz,1} + w_{1-2} * d = 30kN/m^2 + 20kn/m^3 * 1{,}5m = 60kN/m^2$

   $p = 10kN/m^3 * 3.0m = 30kN/m^2$

   $\sigma'_{zz,2} = \sigma_{zz} - p = 60kN/m^2 - 30kN/m^2 = 30kN/m^2$

3. $\sigma_{zz,3} = 60kN/m^3 + 18kN/m^3 * 2{,}0m = 96kN/m^2$

   $p = 10kN/m^3 * 5.0m = 50kN/m^2$

   $\sigma'_{zz,3} = 96kN/m^2 - 50kN/m^2 = 46kN/m^2$

4. $\sigma_{zz,4} = 10kN/m^3 * 5.0m = 50kN/m^2$

   $p = 10kN/m^3 * 5.0m = 50kN/m^2$

$\sigma'_{zz,4} = 0$ (Effective Ground pressure is 0 because of the solid structure of the limestone)

5. $\sigma_{zz,5} = 10kN/m^3 * 10m = 100kN/m^2$
$p = 10kN/m^3 * 10m = 100kN/m^2$
$\sigma'_{zz,5} = 0$

6. $\sigma_{zz,6} = 18kN/m^3 * 1.5m = 27kN/m^2$
$p = 0$
$\sigma'_{zz,6} = 27kN/m^2$

7. $\sigma_{zz,7} = 27kN/m^2 + 17kN/m^3 * 1.5m = 52.5kN/m^2$
$p = 0$
$\sigma'_{zz,7} = 52.5kN/m^2$

8. $\sigma_{zz,8} = 52.5kN/m^2 + 16kN/m^3 * 0.5m = 60.5kN/m^2$
$p = 0$
$\sigma'_{zz,9} = 60.5kN/m^2$

9. $\sigma_{zz,9} = 60.5kN/m^2 + 18kN/m^3 * 1.5m = 87.5kN/m^2$
$p = 10kN/m^3 * 1.5m = 15kN/m^2$
$\sigma'_{zz,9} = 87.5kN/m^2 - 15kN/m^2 = 72.5kN/m^2$

10. $\sigma_{zz,10} = 10kN/m^3 * 6.5m = 65kN/m^2$
$p = 10kN/m^3 * 6.5m = 65kN/m^2$
$\sigma'_{zz,10} = 0$

11. The shield can be considered as fixed in the white layer. For the effective horizontal grain stress this will mean that it can be left out of the equation. Since the layer is porous there will be water particles present, so the water will remain under pressure.

<u>Determination of the horizontal pressure on the soil</u>

The horizontal pressure of the soil is determined as:

$$\sigma'_{xx} = \sigma'_{yy} = K\sigma'_{zz}$$

where :
σ'_{xx} = Horizontal soil pressure
K = Pressure coefficient (ratio between the horizontal and vertical effective pressure)

In case of active pressure (when the soil pressure works on the structure) K is determined as:

$$K_a = \frac{1 - \sin\phi}{1 + \sin\phi}$$

where:
K_a = Active soil pressure coefficient
ϕ = angle of repose

The equation for active horizontal soil pressure, if the cohesion of the soil is taken into account, is given by:

$$\sigma'_{xx} = K_a \sigma'_{zz} - 2 * c * \sqrt{K_a}$$

where:
c = cohesion

In case of passive pressure (the structure is pressing on the soil) K is determined as:

$$K_p = \frac{1 + \sin\phi}{1 - \sin\phi}$$

where:
K_p = Passive soil pressure coefficient

The equation for active horizontal soil pressure, if the cohesion of the soil is taken into account, is given by:

$$\sigma'_{xx} = K_p \sigma'_{zz} + 2 * c * \sqrt{K_p}$$

However there is little known about the cohesion of the BCS, so the cohesion is left out of the calculation. This will not endanger the structure in any way, because the cohesion only works in favour of the forces on the structure. Leaving cohesion out of the calculation pictures a scenario where the forces are stronger than they would be in real life. So if the structure is still stable without taking cohesion into account, it will certainly be the case if cohesion is added to the equation.

Now the different K's for the different layers can be determined:

- Sediment layer: 0 - 1,5 m

$\phi_{sediment} = 32.5^\circ \Rightarrow K_a = 0.30, K_p = 3.32$

- BCS: 1,5 m – 3 m

$\phi_{BCS} = 17.5^\circ \Rightarrow K_a = 0.53, K_p = 1.86$

- BCS mixture with limestone: 3 m – 5 m

$\phi_{BCS/Lime} = 25^\circ \Rightarrow K_a = 0.41, K_p = 2.46$

- White layer: 5 m – 10 m

$\phi = 0$

Now that the ratio between the horizontal and vertical pressure is known, the σ'_{xx} for the different points can be calculated. It has to be taking into account that points, just above or below a boundary between two layers with the same vertical pressure, will have different horizontal pressure.

Active horizontal soil pressure:

1. $\sigma'_{xx,1,sed} = K_{a,sed} * \sigma'_{zz,1} = 0.3 * 15 kN/m^2 = 4{,}5 kN/m^2$

   $\sigma'_{xx,1,BCS} = K_{a,BCS} * \sigma'_{zz,1} = 0.53 * 15 kN/m^2 = 7.95 kN/m^2$
2. $\sigma'_{xx,2,BCS} = 0.53 * 30 = 15.9 kN/m^2, \sigma'_{xx,2,BCS/Lime} = 0.41 * 30 = 12.3 kN/m^2$
3. $\sigma'_{xx,3,BCS/Lime} = 0.41 * 46 = 18.86 kN/m^2, \sigma'_{xx,3,\lim e} = 0$
4. $\sigma'_{xx,4,Lime} = 0$
5. $\sigma'_{xx,5,Lime} = 0$

Passive horizontal soil presssure:

6. $\sigma'_{xx,6,sed} = K_{p,sed} * \sigma'_{zz,6} = 3.32 * 27 kN/m^2 = 86.64 kN/m^2$

   $\sigma'_{xx,6,BCS} = K_{p,BCS} * \sigma'_{zz,6} = 1.86 * 27 kN/m^2 = 50.22 kN/m^2$
7. $\sigma'_{xx,7,BCS} = 1.86 * 52.5 = 97.65 kN/m^2, \sigma'_{xx,7,BCS/Lime} = 2.46 * 52.5 = 129.15 kN/m^2$
8. $\sigma'_{xx,8,BCS/Lime} = 2.46 * 60.5 = 148.83 kN/m^2$
9. $\sigma'_{xx,9,BCS/Lime} = 2.46 * 72.5 = 178.35 kN/m^2, \sigma'_{xx,9,Lime} = 0$
10. $\sigma'_{xx,10,Lime} = 0$

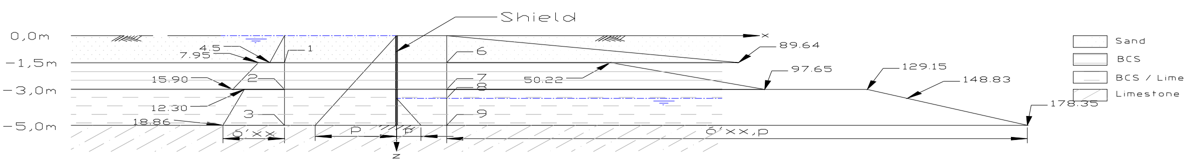


Figure 7.3: Horizontal soil pressure

<u>Horizontal Forces on the structure</u>

The resultant force on the structure with a height *z* can be calculated by integrating the load from z = 0 till z = d and multiplying this by a safety factor:

$$Fhor = \frac{1}{2} * \gamma * \sigma_{xx} * z$$

where:

F_{hor} = The resultant horizontal force on the structure

γ = safety factor
σ_{xx} = Horizontal load
z = Height of the structure

Safety factors:
$\gamma_g \Rightarrow$ Permanent load
$\gamma_q \Rightarrow$ Variable load

Unfavourable permanent load $\Rightarrow \gamma_g = 1.2$
Favourable permanent load $\Rightarrow \gamma_g = 0.9$
Unfavourable variable load $\Rightarrow \gamma_q = 1.5$
Favourable variable load $\Rightarrow \gamma_q = 0.9$
Water $\Rightarrow \gamma = 1$

Horizontal Forces due to water pressure:

$$F_{w,1} = \frac{1}{2} * \gamma_w * p_4 * z_{4-0} = \frac{1}{2} * 1 * 50 kN/m^2 * 5m = 125 kN/m^1$$

$$F_{w,2} = \frac{1}{2} * \gamma_w * p_9 * z_{9-8} = \frac{1}{2} * 1 * 15 * 1.5 = 11.25 kN/m^1$$

Horizontal forces due to the effective ground pressure:

Active ground pressure, unfavourable load (so $\gamma_g = 1.2$):

$$F_{g,1} = \frac{1}{2} * \gamma_g * \sigma'_{xx,1,sed} * z = \frac{1}{2} * 1.2 * 4.5 kN/m^2 * 1.5m = 4.05 kN/m^1$$

$$F_{g,2} = \gamma_g * \sigma'_{xx,1,BCS} * z_{2-1} = 1.2 * 7.95 kN/m^2 * 1.5m = 14.31 kN/m^1$$

$$F_{g,3} = \frac{1}{2} * \gamma_g * (\sigma'_{xx,2,BCS} - \sigma'_{xx,1,BCS}) * z_{2-1} = \frac{1}{2} * 1.2 * (15.90 - 7.95) * 1.5 = 7.155 kN/m^1$$

$$F_{g,4} = \gamma_g * \sigma'_{xx,2,BCS/Lime} * z_{3-2} = 1.2 * 12.30 * 2 = 29.52 kN/m^1$$

$$F_{g,5} = \frac{1}{2} * \gamma_g * (\sigma'_{xx,3,BCS/Lime} - \sigma'_{xx,2,BCS/Lime}) * z_{3-2} = \frac{1}{2} * 1.2 * (18.86 - 12.30) * 2 = 7.98 kN/m^1$$

Possible load on the soil (Passive pressure, this is a favourable load γ_q =0.9):

$$F_{g,6} = \frac{1}{2} * \gamma_q * \sigma'_{xx,6,sed} * z_{6-0} = \frac{1}{2} * 0.9 * 89.64 * 1.5 = 60.51 kN/m^1$$

$$F_{g,7} = \gamma_q * \sigma'_{xx,6,BCS} * z_{7-6} = 0.9 * 50.22 * 1.5 = 67.80 kN/m^1$$

$$F_{g,8} = \frac{1}{2} * \gamma_q * (\sigma'_{xx,7,BCS} - \sigma'_{xx,6,BCS}) * z_{7-6} = \frac{1}{2} * 0.9 * (97.65 - 50.22) * 1.5 = 32.02 kN/m^1$$

$$F_{g,9} = \gamma_g * \sigma'_{xx,7,BCS/Lime} * z_{9-7} = 0.9 * 129.15 * 2 = 232.47 kN/m^1$$

$$F_{g,10} = \frac{1}{2} * \gamma_g * (\sigma'_{xx,9,BCS/Lime} - \sigma'_{xx,7,BCS/Lime}) * z_{9-7} = \frac{1}{2} * 0.9 * 49.2 * 2 = 44.28 kN/m^1$$

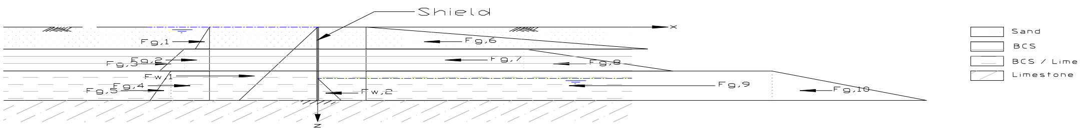


Figure 7.4: Horizontal forces on structure

The resultant horizontal forces on the structure on either side of the structure are approximately in line with each other. The passive horizontal soil pressures, downstream of the dam, are more than capable to withstand the force caused by the weight of the soil and the water table on the upstream side of the dam.
The shield is stable and will not move.
Whether the shield can withstand the pressure depends on whether the load is evenly distributed over its surface. If there aren't any gaps between the soil and the shield, the force on the shield will be equal on both sides. The plastic can then handle the pressure.

7.3.4 Design details

In Appendix IV a technical drawing is added with the different views of the design, like various cross sections and a bird-eye view. The blue print of the shield is made with the following list of constructional requirements.

Bottom end of the plastic shield:

- The connection with the impermeable layer has to be watertight by putting it in the impermeable layer for 0,2 m and making sure that the trench is sealed.

Middle part of the shield:

- In the white layer the shield is supposed to be fixed. Any gaps have to be filled so there will not be allowed any movement.

Top end of the shield:

- Shield 0,20 m underneath the surface of the sediment to ensure that it does not get exposed at the surface and possibly damaged. This might happen when sediment is eroded around the shield and none is been deposited.
- Any transport of the sediment positioned above shield has to be prevented by erosion protection.

Side shields:

- In section 5.5.2 the principle of the side-shields is discussed. The design is similar to that of the other shields, only the side shields are placed in longitudinal direction.

<u>Materials:</u>

Plastic waved shield:

- A number of different materials have been found in the shop that can be used; a variety of plastics with different thickness. Sometimes fibreglass is used to strength the shield. Prices differ; a comparison has to be made to find the best quality/ price ratio.
- Standard size is1 by 3 meters, the plastic is transparent
- To connect the different shields of plastic together there are different options; gluing, heat-sealing, using screws, etc. The cheapest option is to overlap one shield with another, but it is uncertain whether this will be strong enough and impermeable. The best method still needs to be looked into, but shall not be discussed any further. When the sheets overlap a number of waves the water tightness improves.

7.3 Construction

This paragraph will take you through the different steps of constructing a plastic shield in the impermeable layer.

Step 1: Location choice

- Sediment has to be present, and expected to stay present in the future
- The wider the river, the more water you catch; a river with rather steep banks is preferable.
- The impermeable layer is reachable

Step 2: Excavating

- A trench, which is just wide enough for a person to work in, has to be dug through the sediment and the BCS layer.
- Digging through the white layer might be rather difficult. Wetting the layer will help to get through.
- When the groundwater table is reached and the impermeable layer is still at substantial depth the excavating could face some problems. It has to be found out if and how quick the groundwater fills up the trench. A pump might be needed to get rid of this water, so the excavating can continue and the impermeable layer can be reached. Because electricity is not at hand, a power generator or hand pump should be used. Maybe it will only be possible to build the shields with the help of a big pit which is sealed and where it is impossible for water to seep into. This would be quite an expensive way to put shields in the ground. The groundwater level during rainy season is expected to be much higher than during dry season. It might be a solution to dig the trench in the dry season.

Step 3: Fixing a watertight connection with the impermeable layer

- When the trench doesn't fill up with water, concrete can be used as a watertight connection between the impermeable layer and the plastic shield. Dump the concrete at the bottom of the trench and place the plastic shields in this layer before it dries.
- At the sides the shields have to be fixed in the riverbanks.
- The BCS around the shield has to be compacted by slightly wetting and pounding it.

Step 4: Filling the trench
- Refill the trench with sand (only when the bottom connection is absolutely watertight, otherwise the water will easily seep away) or compacted BCS whilst placing the shields in the desired way until you reach the level of 0,2 m below the surface of the sediment.
- Cover the place up with sediment.

Step 5: Erosion protection
- Apply a layer of rocks or a material of your choice to stop the sediment from being taken away by the current.

Step 6: Maintenance
- It will be hard to repair the shields when one finds out that there is a leakage. Fixing the crack is not the biggest problem, but it is very hard to find the exact spot.
- The erosion protection might need some maintenance once in a while. This only exists of replacing the stones. A survey after heavy rain can guard the protection layer.

If the trench fills up with water and a pump cannot be used, this construction method won't work. It might be possible then to hit the shields into the ground, but it will be hard to go through the white layer, the shields might crack and the connection will not be as watertight as in the construction method mentioned above.

7.4 Finance and feasibility

Indications of the costs of a design are discussed in this paragraph. As this project is in its early stages, this will be more like a comparison of the different aspects that make up the costs of a design.
In appendix III an indication of the costs of materials that have been found after a small research conducted in several shops in Nairobi is written down. This will give an indication of the estimated costs of a water containment system for a BCS area.

7.4.1 Expenses

The costs of this design are mostly influenced by the material and labour costs. The excavating will require lots of labour. This should not be a problem, because the community-based approach of SASOL is applicable for this design.
The budget will be spent on buying materials for the biggest part, although plastic shields are rather cheap. Because of the depth a lot of shields are needed. It depends on the method chosen to connect the shields if there are any other material costs (like screws, glue, etc.). Plastic shields are most likely to be available in the neighbourhood, so transport costs will not be excessive. The shields aren't very heavy, but their size probably makes the transport a bit inconvenient.

If erosion appears to be a substantial factor, the plastic shields might damage when they appear at the surface. It is worth investing in erosion protection, in stead of going through the effort of replenishing the lost sediment or repairing the damaged shields (if there is no replenishment).

7.4.2 Feasibility

The feasibility of a water containment system is determined by the ratio: storage-capacity / costs. It is hard to determine what effect one shield will have precisely as yet. There is a number of factors involved which can make the design either succeed or fail.

The water, which is stored in the upper sediment layer, can be caught by scoop holes. This reservoir is mostly filled by run-off water. The amount of rainfall is low . This means that the reservoir only fills ones in a while, allowing the reservoir to empty. For household purposes it is better to use the groundwater, which is captured in the white layer. The shield holds the water in this layer. It can be reached by building a well or excavating the BCS layer upstream from the shield (overpressure principle, see chapter 5).

Another effect of the shield will be the slowing down of the run-off (both surface and subsurface). The water will be hold in the ground for a longer period making it available for the roots of vegetation; this will change the hydrologic situation. On long-term base it may even change the ecological system. Changing the cultivation of the area will only be possible if shields are built in the whole river system. It will take time before a new balance will set in.

The feasibility of this design depends on too many uncertain aspects to give a clear answer. It will certainly slow down the water, but the building of the shields is very labour-intensive and it will take time before the results are visible.
If one wants to extract water for household purposes one needs to build wells as well, because the water will mostly remain underneath the BCS and can therefore not be reached.
Building shields on the sides of the reservoir down to the impermeable layer will increase the water storage capacity. Research has to be done on leakage problems when building the side-shields. It is uncertain if the storage-capacity/ costs ratio will increase, when you build the extra side-shields, because of the depth of the white layer. A great amount of extra material and labour is needed.

7.5 Conclusions and recommendations

If an impermeable layer is reachable, it is possible to contain ground water with this design. Catching water for household purposes will need some extra measures, like building wells or excavating the BCS layer. Recharging the area and holding/ slowing down the water is another important goal of this design. It will only work when many shields are built the BCS area.

To be able to come up with the design, a number of assumptions were made and these need to be checked out. Then elucidation can be achieved on the working of the design. The quickest way to find out about these assumptions is to build an experimental dam.

This chapter is based on the assumption that the white layer is reachable and that there is an impermeable layer underneath it. If one finds out that the impermeable layer is unreachable, it might be an interesting experiment to build a plastic shield in the reservoir (which just goes into the BCS layer and only holds the water in the top sediment layer). In the next chapter a design for this option is given. Appendix III will give guideline for the construction of an experimental shield of plastic in the Semea River, possibly constructed by a next group of students to arrive in Kenya in May 2002.

Next to the recommendation of building an experimental shield here is a list of recommendations for this situation:

- Find out more characteristics of BCS
- Find out about whether BCS is usable as a construction material (impermeable shield of compacted BCS)
- Iron shields will corrode if they are not treated. Find out if there is a cheap way possible to protect them. If the costs are cut, iron shields are an attractive material because of the wide availability and construction possibilities.
- Knowledge needs to be gained on the transport of sediment after heavy rainfall and if so the sediment needs to be kept in place.
- Research has to be done on the white layer. How hard will it be to excavate? It has to be found out how fast the trench fills itself with ground water. Is a pump needed and available? Maybe the shield can only be build during dry season. Tests need to be done on the soil with regards to the strength of this layer; the assumption is made that it can withstand the horizontal pressures and therefore considered to hold the shield as fixed in this layer.
- In principal one creates extra water pressure by building side shields and water will be pushed up if a trench of permeable soil is placed next to the shield. Whether enough pressure is achieved to make this process occur is uncertain. Research on the possibilities can be of great value, because this solution will supply a reservoir of significant proportions.

8. Impermeable shields in the sediment layer

In this chapter the option of holding water in an already present layer of sediment will be looked into. This design can be used when sediment is already present in the riverbed and an impermeable layer underneath the white layer is not reachable. The shield will end in the rather impermeable BCS layer and hold water in the sediment this way. This option is less effective then when an impermeable layer can be found, because the storage capacity is far less. This option only captures the surface run-off water and does not affect the groundwater table.
This situation varies from the one mentioned in the former chapter; so another evaluation is made for materials.

8.1 Materials

The same materials as in paragraph 7.1 will be evaluated with added points of attention for this specific situation.

7. <u>Iron shields</u>

Resting the shields on the BCS might cause problems. To spread the weight of the shields to prevent them from sinking one can construct a small foundation strip underneath. A wooden beam or a small layer of concrete can be used for this. When using wood, it has to be protected against decay. It might also be possible to bend (90 degrees) the last part of the shield. It will carry its own weight.
Because the shields don't end in a completely impermeable layer the water might find a path to flow underneath the shields. Using the foundation to create a watertight seal is likely to be the easiest to prevent this from happening.

8. <u>Plastic shields</u>

The plastic material is lighter than iron and therefore is less likely to sink into the soil. Foundations aren't essential.
Extra attention has to be paid to the seepage underneath the shields as with the iron shields, for instance by backtracking the plastic at the bottom of the shield for half a metre upstream and making sure the BCS is nicely compacted around the shield.

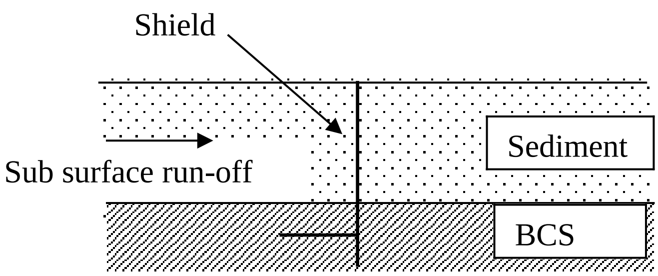


Figure 8.1: Backtracking of the plastic shield.

9. <u>Tarpaulins / Plastic membrane</u>

The disadvantage of the vulnerability of the material is less of a problem in this situation compared to the situation in the last chapter, because the sheet doesn't go that deep. Sediment

is more easily excavated than BCS or the white layer, so putting the plastic membrane in the ground is less hazardous.
The sides of the trench can be filled up with BCS to give extra protection against seepage. This is better than using sand to fill this space, because the permeability of the sand will make it easy for the water to seep underneath or around the plastic membrane.

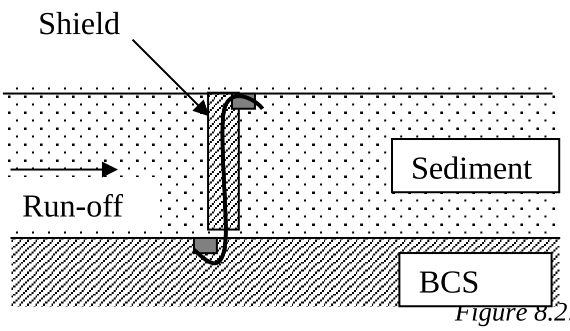


Figure 8.2: S-shaped plastic membrane shield

<u>4. Sub surface brick wall</u>
The wall might sink into the soil under its own weight, so a foundation is probably necessary.

<u>5. Trench filled with concrete/ cement</u>
The problem with having to construct a foundation applies in this case as well.

<u>6. BCS-filled trench</u>
The main problem that can occur with this option will be the connection between the trench of BCS and the horizontal layer of BCS. Wetting the spot on construction to ensure cohesion between the two layers can reinforce this weak connection.

8.2 Material evaluation

The evaluation will be conducted in the same way as already explained in chapter 6.

8.2.1 Evaluation

The evaluation of the materials in this situation is not a comparison with the situation in chapter 7, but an evaluation of the materials for this specific situation.
For example the overall costs will decrease compared to the situation in chapter 7 (less excavating, less material needed, etc.), but the ratio between the different materials happens to be the same in this situation as well.
Mayor differences with the last situation in chapter 7 concerning vulnerability, construction, etc. will be highlighted and explained.

	Shield →	Iron[2]	Plastic	Plastic membrane	Brick wall	Con-crete	BCS
Criteria:	*Weights:*						
Costs	25	5	5	6	6	4	9
Durability	10	8	7	5	4	9	6
Vulnerability	15	6	7	**6**	3	9	6
Availability	15	7	6	7	7	5	9
Construction	20	**3**	**7**	**7**	**5**	**2**	9
Extendibility (in lateral direction)	10	7	7	7	5	4	7
Water tightness	5	8	**8**	**8**	4	7	7
		570	**640**	**645**	510	515	795

Table 8.1: Evaluation impermeable shields in reservoir

Explanations of the highlighted figures:

Vulnerability:

- Vulnerability of the plastic membrane has decreased because the coarse layer of white soil is not going to be reached.

Construction:

- Iron shields need foundation where as in the previous design did not. Construction needs more technical skill and therefore goes down in appreciation.
- Plastic needs no foundation and is therefore rewarded with a 7 compared with the other options.
- The plastic membrane is easier to construct compared with the situation in chapter 7 because it is less hard to put the plastic membrane in the ground at lower depth. When the plastic membrane is laid in an S-shape it makes it a bit harder so it evens out and the grade stays a 7.
- Brick wall and concrete both need a more complicated foundation than in the previous design. Construction needs more technical skill and therefore goes down in appreciation.

Water tightness:

- The plastic membrane and plastic shield score the highest because the shape of the construction renders itself well against the problem of seepage.

8.2.2 Conclusion

BCS could be the most preferable material to use for the impermeable shields because of the wide availability, low costs and easy construction. But as already mentioned in the previous chapter the possibilities of using BCS for these purposes have to be investigated further. The materials properties are still questions marks.
So under the circumstances the first material of choice is a plastic membrane: widely available and found to be quite cheap. This solution wins it from plastic waved shields because at shallow depth it has more advantages.
The plastic shield is also a good solution but will resemble the option given in chapter 7 a lot. The only difference is the depth of application. The forces on the construction in this instance are similar to those on the top half of the previously calculated construction.

[2] Iron shield with special coatings against corrosion

In the next paragraph design aspects of a construction with plastic membrane will be given.

8.3 Design

8.3.1 Situation and assumptions

The soil characteristics are the same as earlier in chapter 7.
The layers of soil are as follows:

- Sediment layer: 0 - 1,5 m
- BCS: 1,5 m – 3 m
- BCS mixture with limestone: 3 m – ?
- Impermeable layer unreachable

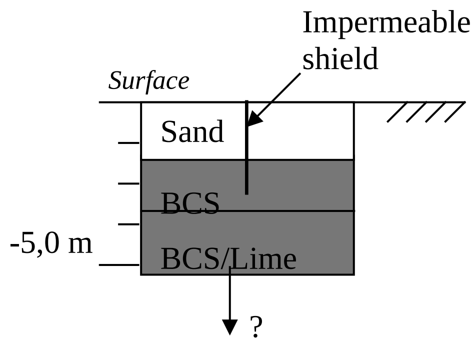


Figure 8.3: considered soil profile

The shield will reach deep enough into the BCS layer that a watertight seal can be made.
The BCS layer is assumed to be impermeable; the water will not seep from the reservoir through the BCS layer.
The water, which is kept in the reservoir, is only the result of catching run-off water after rainfall. The groundwater table is suspected to remain underneath the impermeable BCS and does not recharge the reservoir.
The main function of the shield is to hold the sub surface run-off water. The created reservoir will not retain the groundwater because it will still continue flowing unchanged underneath the BCS.
Even if the BCS is not as impermeable as believed to be, this solution will still slow the run-off water down. Even just keeping the water in the river system for a longer period of time may proof to be of great value to the hydrologic situation in the area.

8.3.2 Design features

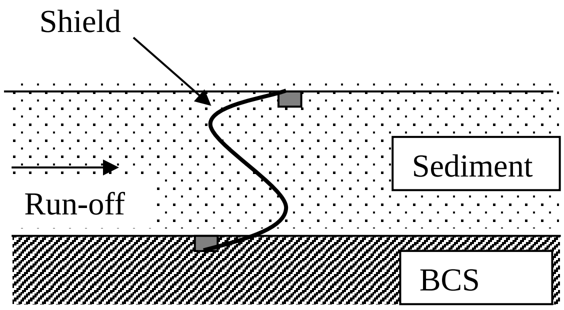


Figure 8.4: Side view of the S-shaped plastic membrane shield

As an extra safety precaution the plastic membrane is laid in the soil in a way that allows for some movement. The S-shape can deform under changes of pressure without putting strain on the material. This method is advised because there have not been any attempts to hold water using a plastic membrane shield yet, so it is uncertain whether the soil will move.
The shield is attached to beams at the top and bottom to keep it fixed on its spot.

8.3.3 Forces on the structure

The forces on the structure are determined by the presence of water and the type of soil adjacent to the shield. The forces working on this concept are the same as the forces in the upper layers as described in chapter 7.3.3.

Strength of the shield
The material can stretch a little because it is made out of a plastic. Till what extent the material can stretch depends on what plastic is used for the plastic membrane. Generally this type of material is not suitable for pressures in a specific point, since these will penetrate the shield.
Plastic material is flexible and can be curved without any difficulty. This characteristic can be used to an advantage when it comes to withstanding the forces on the structure. When it is put in the ground in the shape of an S, one uses the extra length of the plastic membrane to allow for some movement.

8.3.4 Design details

In Appendix IV a technical drawing is added with the different views of the design, like various cross sections and a bird-eye view. The blue print of the shield is made with the following list of constructional requirements as known so far.

Bottom end of the plastic membrane:

- Horizontal stretch of plastic membrane at the bottom end in the BCS: 0,5 m – 1 m (this prevents seepage), under a slight angle with the purpose of reaching the sediment layer
- Depth of the bottom of the shield in the BCS: 0,20 m of coverage with BCS (in this case at a depth of -1,7 m)
- Plastic membrane is held in place by a beam (for details see materials)
- Extra folds can be put in the plastic membrane above the BCS to make sure that any movement at the bottom part of the shield between the BCS and the sediment will not cause any problems like ripping or stretching of the plastic membrane.

Top end of the plastic membrane:

- Shield 0,20 m underneath the surface of the sediment to ensure that it does not get exposed at the surface and possibly damaged
- The stretch of horizontal plastic membrane at the top end in the sediment: 0,70 m – 0,80 m (it only goes through the sediment and there is no need for seepage prevention)
- Plastic membrane is held in place by a beam
- In case of heavy rainfall sediment transport can be prevented by the use of erosion protection (for example stones, nets, logs, etc.)

Middle part of the plastic membrane:

- The middle part of the plastic membrane backtracks under an angle of 30° - 60°

<u>Materials:</u>

Supporting beams:

- A beam is required at the top end as well as the bottom end to ensure that the plastic membrane is fixed

- The beams can be kept in place by digging them in to the riverbanks
- Support might be needed for the plastic membrane at the sides in the banks by S-shaped frame works
- Possible materials for the beams are wood (protected against decay), iron and plastic (for instance rain pipes).

Plastic membrane:

- A number of different materials have been found in the shop that can be used; a variety of agricultural purposed plastics with different thickness and dimensions
- To connect the different peaces of plastic together there are different options; sewing (probably not completely watertight), gluing, heat sealing, using tape, etc. The best method still needs to be looked into, but shall not be discussed any further.
- Unless there is BCS present in the banks, in which the plastic membrane can be held quite firmly after compacting, some support could be given through the help of a framework like mentioned in the paragraph on beams
- Make sure a safe margin of material is used to prevent the plastic membrane from ripping under pressure or wear and tear

8.4 Construction

This paragraph will take you through the different steps of constructing a shield in the sediment layer.

Step 1: Location choice

- Sediment has to be present
- A wide stretch of river will create more storage capacity than a narrow stretch.
- The impermeable layer is not reachable (otherwise chapter 7 is applicable)

Step 2: Excavating

- A trench of approximately 2 m wide has to be dug through the sediment layer and about 0,2 m into the BCS.

Step 3: Fixing the bottom beam

- The plastic membrane has to be attached to the beam before the beam is laid into place
- If necessary the beam has to be fixed in the river banks, if found instable
- The BCS around the beam has to be compacted by slightly wetting and pounding it, whilst taking care not to damage the plastic membrane.
- A layer of BCS has to be spread on the first horizontal stretch of BCS and needs to be slightly compacted as well

Step 4: Layering the plastic membrane

- Just above the BCS in the sediment layer, if necessary, fold in extra material to allow for some movement between the two layers of soil.
- Refill the trench with the sediment whilst placing the plastic membrane in the desired way until you reach the level of 0,2 m below the surface of the sediment.

Step 5: Fixing the top beam

- Attach the beam to the plastic membrane
- If necessary the beam has to be fixed in the river banks, if it is not stabile enough

- Cover the place up with sediment

Step 6: Erosion protection
- Apply a layer of rocks or a material of your choice to stop the sediment from being taken away by the current

Step 7: Maintenance
- Replace the erosion protection once in a while if necessary
- Locate the damaged spot (this will be the most difficult part, probably you have to re-excavate the whole reservoir) and fix it with a simple strip of duct tape.

8.5 Finance and feasibility

As mentioned in earlier chapters it is hard to give a detailed insight in the costs in this early stage, but it is possible to give a comparison of the different aspects that make up the costs of a design.
In appendix III a short indication of the costs of materials that have been found after a small research conducted in several shops in Nairobi is given.

8.5.1 Expenses

The costs of a design are greatly affected by the costs of material.
The biggest entry of purchased goods will in this case be the plastic membrane. The beams can be obtained locally and should be bought at a competitive price. The amount of beams required depends on the width of the river, but can be considered relatively low.

Transport costs are estimated to be a minor expense due to the fact that plastic membrane is a light material and efficient in transport. The beams should be available in the surroundings, so even though transport can be impractical this will not add greatly to the overall costs.

Labour can be done by people from nearby communities, since there is no need for skilled workers. The community-based approach of SASOL is applicable for this design. Transport of the workers to the construction site is not necessary.
Digging the trench isn't labour intensive, because of its shallowness.
Another point of interest for the costs is the connecting of the plastic membrane sheets. This depends on the method used; it might require a skilled worker or seamstresses. In the case of using seamstresses, they usually live in the nearby towns. Additional materials like glue, tape, thread and sewing machines, heat-sealing equipment, etc. might add some costs as well.
To prevent extra costs attributable to maintenance, it is recommended that one does not cut down on the use of plastic membrane: plastic membrane is less expensive than restoring damaged parts. If erosion appears to be a substantial factor, the plastic membrane might damage when exposed to the surface. It's worth investing in erosion protection in stead of going through the effort of replenishing the lost sediment or repairing the damaged plastic membrane (if there is no replenishment)
Damage can easily be fixed, if one knows where the damaged spot is located, by using a simple strip of duct tape. However finding the leak can be a costly exercise.

8.5.2 Feasibility

The feasibility of a water containment system is determined by the ratio: storage-capacity / costs. It is hard to determine what effect one shield will have precisely as yet. There is a number of factors involved which can make the design either work or fail.
The storage facility is mainly filled through the run-off water after rainfall. The amount of rainfall in this area is quite erratic. If there is a long period of draught it is quite likely that the reservoir is going to be dry. This solution will probably not supply enough water for household purposes throughout the whole year. Chances are that one needs to tap into the groundwater for that. The groundwater table will not be reached with this design.
Building a number of shields will amplify the effect of the shield. The cost price of a shield is not that high and the construction time will take less than that of a masonry dam.
The strength of this design will be the slowing down of the run-off water and possibly recharging the area laterally as well as longitudinally. Keeping the water in the system for a longer period may change the whole ecological system. Changing the cultivation of the area will only be possible if shields are built in the whole river system. It will take some time before a new balance will set in.
Even though the storage capacity of a shield is low, the costs are not that high. Given the fact that the shields will influence the area in a positive way, it is believed to be a feasible solution on the long run for a BCS-area where an impermeable layer is unreachable.

8.6 Conclusions and recommendations

If an impermeable layer is unreachable this design is thought to be a good solution for the BCS-area on the long run. The goal of these shields is more the recharging the area and holding the water in the river system than supplying water for household purposes.

To be able to come up with the design a number of assumptions were made and these need to be checked out. Then elucidation can be achieved on the working of the design. The quickest way to find out about these assumptions is to build an experimental dam.
Appendix III will give guideline for the construction of an experimental shield of plastic membrane in the Semea River, possibly constructed by a next group of students to arrive in Kenya in May 2002.

Next to the recommendation of building an experimental shield here is a list of recommendations for this situation:

- Find out more characteristics of BCS
- Find out about whether BCS is usable as a construction material
- Iron shields will corrode if they are not treated. Find out if there is a cheap way possible to protect them. If the costs are cut, they are an attractive material because of the wide availability and construction possibilities.
- Knowledge needs to be gained on the transport of sediment after heavy rainfall and if so the sediment needs to be kept in place.
- Find out more on the strength and thickness of available plastic membranes.

9. Conclusions

In this report the possibilities of constructing sand-storage dams, together with other means of water containment, have been reviewed for the southern parts of the Kitui District. After field research and the description of various generated concepts and solutions, conclusions can be drawn. The conclusions are divided into the following subjects:

<u>1. Field research Ikanga and the Semea River</u>
As described in chapter 4, a small-scale research has been conducted in southern Kitui, in the Semea River near the town Ikanga. From various augurments and community-inquiries can be concluded:

- A layer of sand/grain sediment is present in the river. The height of this layer varies between one and two meters. The river transports sediment.
- Below the sediment, a layer of BCS (mixed with very little sand) is found of about 2 meters. From there, the BCS mixes with lime, making it permeable. After about 3 meters of this layer a tough limestone is encountered. The thickness of this layer is unknown. A sand-storage dam in the Semea River is believed to be founded on this limestone and has not shown settlement. The dam is subject to seepage through this foundation layer and does not perform as targeted. It is unknown which organisation built the dam.
- The area around Ikanga and the Semea is rather flat with an approximate slope of 0.1 %, requiring different solutions than the rather steep area of northern Kitui.
- Near Ikanga, deep wells (about 6 meter) provide water all year. Up stream, the groundwater is believed to be at greater depths and no wells are used there. People walk up to 20 kilometres to get water.

<u>2. Black cotton soil</u>
Black cotton soil is a notorious soil, known for its expansive character and low strength when wetted. Further conclusions on BCS:

- BCS becomes very impermeable when wetted. In periods of rain, the top layer of BCS closes up, preventing surface water to seep. This surface water runs off very fast. Vegetation is given little chance to absorb the water.
- BCS is a fertile soil. Therefore, the area is considered a high potential area for agriculture, if water can be contained or slowed down.
- BCS is easy to excavate when wetted. Strength can possibly be increased by means of compaction.
- The BCS is impure. It is slightly mixed with sand. At larger depths, more lime is mixed through the BCS.
- No technical data on BCS are found.
- SASOL has no experience with foundations on BCS.

<u>3. Various concepts and solutions</u>
The concepts and solutions presented in chapter 6, 7 and 8 can be considered indications for future designs. If more data is available the suitability of each concept can be valued and applied to encountered situations. The designed concepts consist in the following:

A. Sand storage dam with a BSC core, protected with plastic against saturation and rocks against erosion. This principal is totally new to the area and is not ready for application yet.
B. Impermeable shield to a deep impervious layer. If a deep impervious layer is found, a shield can be placed up to this layer. This way, groundwater is either contained or slowed

down. This shield can be applied when an impervious layer is found at a reachable depth. The behaviour of the groundwater is unknown as well as the characteristics of the various encountered layers. This makes this solution of high risk. Applicable materials, soil profiles and groundwater are subject to further research.

C. Impermeable shield in the river sediment layer. A subsurface shield in the riverbed through the sediment layer can be considered a good option to contain water or slow down the river discharge. This solution asks for a rather small amount of material, lowering the costs. Excavation of a trench to place the shield is done by community.

Final conclusion

In this early development stage of water containment in the area by SASOL, a lack of knowledge stands in the way of constructing either sub-surface dams or sand-storage dams.
This report can be considered to be an indicative start to future activities and research.
The value of presented concepts will prove itself after experiments and research.
The southern part of Kitui is a high-potential area. It can, when the water containment system succeeds, produce a prosperous agricultural community with economic value.

List of references:

1. Akker, Prof.dr.ir. C. van den; Boomgaard, ir. M.E. – *Hydrologie* - TU Delft, Faculty of Civil Engineering and Geosciences - Delft – 1999
2. Barends, Prof.dr.ir. F.B.J.; Uffink, Dr.ir. G.J.M. - G*roundwater mechanics, flow and transport* – TU Delft, Faculty of Civil Engineering and Geosciences - Delft – 2000
3. Battjes, Prof.dr.ir. J.A. Battjes – *Vloeistofmechanica* - TU Delft, Faculty of Civil Engineering and Geosciences - Delft – 1999
4. Beimers, P.B.; Eijk A.J. van; Lam, K.S.; Roos, B. – *Improved design sand-storage dams*– Nairobi – 2001.
5. Beimers, P.B.; Eijk A.J. van; Lam, K.S.; Roos, B. – *Sand-storage dams in arid and semi-arid areas* – Nairobi – 2001.
6. Beimers, P.B.; Eijk A.J. van; Lam, K.S.; Roos, B. – *SASOL Sand-storage dams proposal hydrological study* – Nairobi – 2001.
7. Briedé, K.J.; Blok, R. – *Tabellen voor bouw- en waterbouwkunde* – Leiden 1995
8. Bronswijk, H – *Magnitude, modelling and significance of swelling and shrinkage processes in clay soils*.
9. Finkel, H.J. – *Semi-arid soil and water conservation* – 1986
10. Republic of Kenya, Ministry of Agriculture – *Reconnaissance Soil Survey Machakos* – Kitui – Embu Area Republic of Kenya – Nairobi – 1978
11. Rollings, M.P and R.S. – *Geotechnical materials in construction*
12. Schiereck, Gerrit J. – *Introduction to bed, bank and shore protection* - TU Delft, Faculty of Civil Engineering and Geosciences - Delft – 2000
13. Sectie Land- en Waterbeheer – *Waterbeheersing* - TU Delft, Faculty of Civil Engineering and Geosciences - Delft – 2000
14. Tol, Prof.ir. A.F. van – *Funderingstechnieken* - TU Delft, Faculty of Civil Engineering and Geosciences - Delft – 2000
15. Verruijt, A – *Grondmechanica* - TU Delft, Faculty of Civil Engineering and Geosciences - Delft – 1999
16. Vriend, Prof.dr.ir. H.J. de – *Rivierwaterbouwkunde* - TU Delft, Faculty of Civil Engineering and Geosciences - Delft – 1999

10. Recommendations

With regard to the conclusions noted in chapter 9, recommendations can be made for future activities. Future student-teams and SASOL can use these recommendations as a guideline to deal for the water shortage in the southern parts of Kitui.

In this chapter, recommended research and activities are listed under the same subjects as the conclusions from chapter 9. A special list of activities for the student group that arrives in Kenya in May 2002 is given in Appendix III.

<u>1. Field research Ikanga and the Semea River</u>

Although the research in chapter 4 has revealed a lot of information of the area, it also arose even more questions.

- The soil profile in the Semea River has been determined by augurments. Considering the large area, the number of augurments was rather low. It is recommended to do more research, especially through the encountered layer of limestone.
- Information on the hydrologic system was gathered by interviewing local people. Although this information can be considered indicative, scientific measurements should be carried out through a long period of years. Detailed research on rain, evaporation, seepage and run-off is recommended for future determination of dam locations.
- The behaviour and location of groundwater is unknown in the area. This information is hard to obtain and this might be possible to gather by the use of special seismic research. It is recommended to look into the possibilities of seismic research, to determine the groundwater level and a possible outlet of the area. It is also recommended to look into cheaper ways to determine the groundwater level in a way it can be done by local communities.

<u>2. Black Cotton Soil</u>

To deal with BCS and its behaviour, the following recommendations are made:

- A general geo-hydrologic study on the soil characteristics of BCS.
- Apply research on possible strength increase by compaction.
- In general, it is recommended to look into the possibilities of BCS as a construction material for constructing dams or impermeable shields. These experiments can be carried out on a small scale. The humidity ratios in BCS each have their own influence on its performance and strength.
- World wide, more organisations have dealt with the problem called Black Cotton Soil. A thorough literature study might prove itself useful for SASOL.

<u>3. Concepts and solutions</u>

A. The concept of a BCS-core dam with plastic and rock protection is a new principal to SASOL. Because there is not a lot of data at hand to design this dam scientifically, it is recommended to build a small-scale dam as an experiment. BCS-dams without protection can be tested experimentally in the flood plains to slow run-off water.

B. The feasibility of impermeable shields on a deep impervious layer is strongly depending on the behaviour of the ground water. Also the storage capacity is uncertain and whether pressure can be built up using side-shields remains a question mark. As mentioned earlier in this chapter further research has to be conducted.

C. Since constructing shields through the sediment in the riverbed is a fairly cheap solution that is easy to construct, it is recommended to build a test site. In appendix III, an extended recommendation is done for a constructive experiment to be carried out by the next student group.

4. Final recommendation

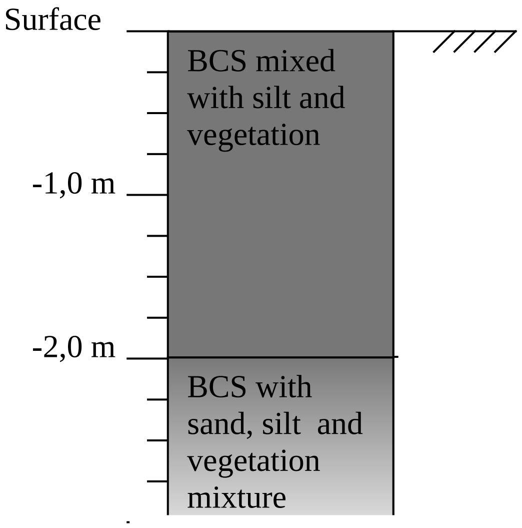
As this report is the first extensive report on water containment in the BCS area of Kitui, the recommendations cover a wide area of subjects. Research on groundwater, the hydrologic system, the BCS characteristics and the construction of experimental shields are considered the main recommendations.

Appendix I: maps of Kenya and Semea River

Appendix II: Soil profiles

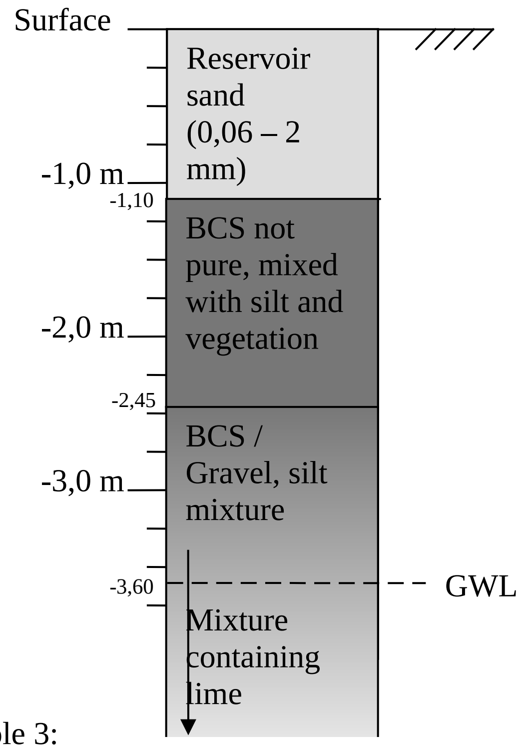
In this appendix a sum up of the soil measurements we did is given.

Borehole 1: In the riverbank +/- 2 meter near the riverbed.



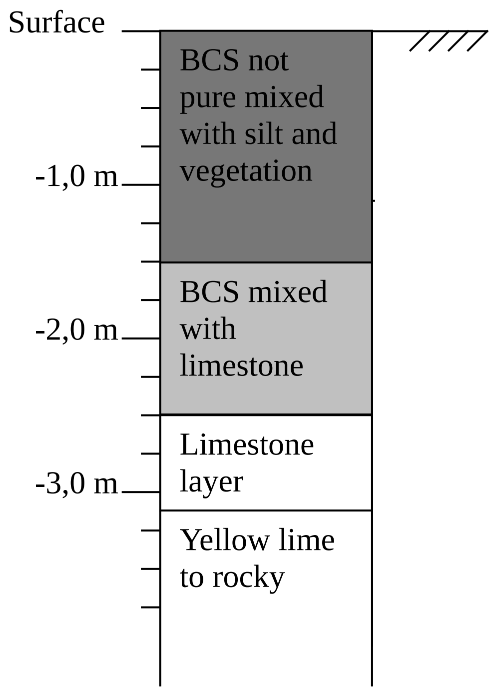
Borehole 2:

Upstream in riverbed +/- 1 km from existing dam. Measured till –3,60m, this is also the groundwater level. Mixture will contain more lime when getting deeper. Expected white limestone layer underneath.



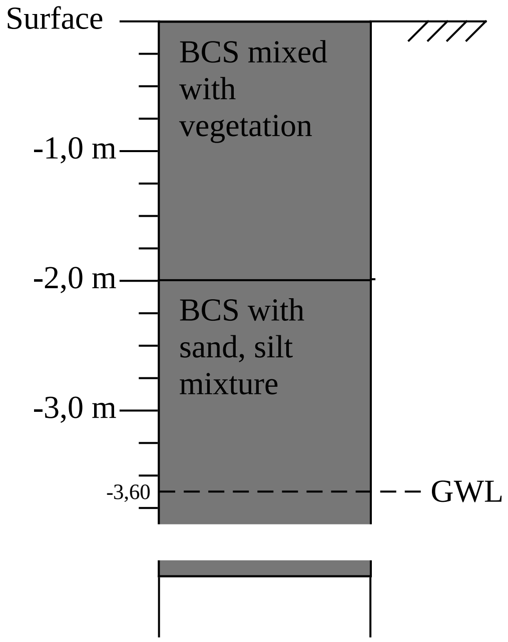
Borehole 3:

In the riverbed next to bank. (see picture)



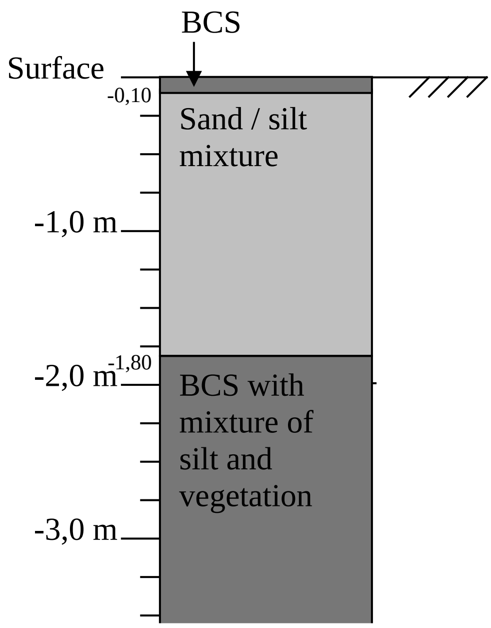
Borehole 4:

In the riverbank +/- 100 meters from the river channel. The sand/silt mixture contains various lime particles concentrations at some places. But there is no indication that the mixture is becoming whiter and thus also no indication of a limestone layer nearby.



Borehole 5:

In the floodplain. There are no limestone particles in the BCS so there is no indication of a white layer. At the depth of 3,50m when we stopped, the soil became wetter so the groundwater level is not far below this depth.



Appendix III: proposal next group

As this project is in its early stages a lot of research still has to be done. A great amount of recommendations have been done at the end of the chapters. In the following a list of activities is given in which the importance of every single research is explained. The next group can use it as a guide for their practical work activities. Also some points of attention are given which SASOL can use to gain more data, which can be useful for a next group to evaluate the experimental dams.

Week 1 and 2

Further research ground profile

A test site has been found, where the white layer is expected to be at a reasonable depth. This site is described in chapter 4 (borehole 3).

- Try to reach the white layer by digging several holes
- Try to get through the white layer to see what is underneath and to know the thickness of the white layer
- Try to answer the following questions:
    - Of what material does the white layer exist?
    - How fast does water run through the white layer?
    - How fast does a trench fill when you dig below the groundwater level?
    - Can the white layer withstand horizontal forces?
    - Does the layer crumble under pressure?
    - At what depth is the groundwater level found during dry season (June)?

Week 3

Location choice

Choose the best location for building several experimental shields. Keep the following points of attention in mind:

- A layer of at least 1.5 meters of sediment has to present
- Underneath the sediment there has to be a layer of BCS
- The river should not be too wide. This will take too much excavating time and material.
- A community has to live nearby, so that they can help digging
- The river has to be as straight as possible
- It is preferable that the banks are rather high; this will decrease the chance that the water is flowing along the shield.
- To make sure that the different experimental shields will not influence each other, the distance in between the shields should at least be one kilometre. One has to be sure that the shields do not have any influence on each other to come to a good evaluation of their individual performance. Later on, when has been decided which material is the best to use, further research has to be done to the optimal distance in between dams, so that they influence each other in a positive way.

Mobilise community

Give the community explanation on the goals of these experimental shields.

- With the help of SASOL activate people to help digging

Collecting materials

Order all the materials that are expected to be need during construction.

- Visit several shops to find out which materials are best to be used, both in Kitui Town and Ikanga (best price- quality ratio)
- Ask the community to dig stones for erosion protection
- Think about the supporting materials, like beams, screws, glue, framework etc.

In the following table the results of a small material research in the surroundings of Nairobi are given. This is just to give an indication; further research has to be done in Kitui.

Material	Size	Price	Remarks
Plastic shield	1 by 3 meters	620 Ksh	Transparent, fibre glass
Iron shield	1 by 3 meters	380 Ksh	Not corrosion protected
Iron shield with protective paint	1 by 3 meters	420 Ksh	Gal-sheet
Tarpaulin	1 by 1.80 meters	80 Ksh	Transparent

Table III: material research

Week 4 and 5

Building experimental plastic shield

This shield has the same design as in chapter 7, but it will only be built in the sediment layer and will not reach the impermeable layer. Even if the impermeable layer is reached in the first two weeks, it seems to be better to start with an experiment in the sediment at first. Possible failures can discovered. The material costs are less and so is the labour. The risks are less. In case of failure the disappointment will not be as big for the community and it will be easier to motivate them another time.

- A trench, which is just wide enough for a person to work in, has to be dug through the sediment and about 0,2 m into the BCS.
- Cut the shield in the right dimensions for the test site
- Place the plastic shields, with the connection overlapping one shield with another. If possible connect them also with some screws (without cracking the shields) or with other connecting devices.
- At the sides the shields have to be fixed in the river banks
- The BCS around the shield has to be compacted by wetting and pounding it.
- Refill the trench with sand (only when the bottom connection is absolutely watertight, otherwise the water will easily seep away) or compacted BCS until you reach the level of 0,2 m below the surface of the sediment.
- Cover the place up with sediment
- Apply a layer of rocks or a material of your choice to stop the sediment from being taken away by the current

Week 6 and 7

Building experimental tarpaulin shield

This shield will be build like the design in chapter 8

- Use the construction method as explained in 8.4
- If there is time, it might be possible to do some experiments on the best way to compact the BCS.

Week 8 and 9

Research to outlet possibilities

In chapter 5.8 the possibility of blocking the outlet of the BCS area is mentioned

- Further research has to be done on the presence of an outlet.
- Try to answer the following questions:
    - Is it possible to locate any outlet system?
    - How wide is this outlet?
    - Is there a good location to block this outlet by a dam?
    - At what depth do you find the white layer here?
    - Is there an impermeable layer at a reasonable depth?
    - What is the ground profile at the other side of the outlet?

It is hard to give a good time schedule for the listed activities above. It might take much longer, because of bad weather, materials which are not available, or longer excavating time. If things are going well, and if it is possible to coordinate labour at two construction sites at a time, it might be feasible to build an experimental iron shield at the same time as well.
If there is any time left, it would also be very worthwhile to teach the communities about the importance of gaining data. It would be very useful to give one person the responsibility to measure the groundwater level every other week to make it possible to evaluate the shields during a year.
Another good thing would be to set up a measuring system to gain data on rainfall. This could be done by supplying the local primary schools with rain gages and test-result forms as explained in 4.7.1.

Appendix IV: autocad