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# Retaining water in the Black Cotton Soil Area near Ikanga, Kenya

## A study carried out by SaSol

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# FINAL REPORT

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## Preface

The practical work period described in this report is part of the 4th year of the study Civil Engineering at the Technical University of Delft. The opportunity to go to Kenya and work on such a project was really interesting.

We thank our sponsor Gemeente Waterleidingen Amsterdam for their financial support. We also thank Sam Mutiso and prof. G.C.M. Mutiso. They gave us a lot of advice in a subtle way and let us learn a lot in the field.
Special thanks goes to Joseph Munyoki. Undoubtly he had a hard time with three mzungu, but without his help and knowledge we would not have find our way through the area.

We hope SaSol find more solutions to improve the water retainment in the area and the experiments will turn out working after the rainy season.

Erik Arnold
Cees Anton van den Dool
Jaap Joosse

## Summary

The project area is the river Semea in the BCS-area near Ikanga. This is a seasonal river. The groundwater flow through the sediment occurs only a few weeks after the rainy season. Most of the year people living near the Semea are dependent of groundwater in the Nzeu, a river at a distance of 5 km.
In the project area the slopes are mild and the underground consists of Black Cotton Soil (BCS). SASOL is planning to design and construct dams in this area, but has not operated with such circumstances before.

The objective of this project is to find implementable solutions for water retainment in the BCS area in the Semea River near Ikanga and implement an experimental version to gain more knowledge about its behaviour under the present circumstances.
Therefore the river is divided in three parts with each its own characterstics and consequently its own solutions for water retainment.

*Dams on rock*
The upper part of the Semea seems to be suitable for the construction of a stone masonry-dam. The design and constructing of the dam can be quite similar to what Sasol is used to, only extra attention has to be paid on design of the wings.

*Dams on clay*
A plastic foil as impermeable shield is used to retain water upstream in the sediment in the middle part of the river. Advantages of plastic are the wide availability and the low costs. The reservoir of the subsurface dam is not big enough to provide water for household purposes throughout the year. Other alternatives for domestic water supply are necessary. The storage capacity is between 1000 and 1200 $m^3$.

*Dams in floodplain*
The construction of an earth dam in the lower part, the floodplain, is a possibility to increase the fertility of the floodplain. Cooperation with an agricultural expert has to be sought to choose optimal crops.
The blocking of the white layer in the floodplain is not recommended because the most positive influence of the blocking upstream will be the heightening of the water table in the upstream wells. The amount of available water will not be significant increased

Black Cotton Soil is also a possible option to build an impermeable shield of but the characteristics of BCS are not properly known yet. Therefore further research to the extend of the BCS layer under the riverbed and permeability is carried out. Research to the extend of the layer has shown that in the greater part the thickness is over half a meter, but locally the river has eroded the whole layer.

The results of digging and auger tests to the Danida dam, a more than 20 year old, stone masonry dam, are not sufficient to determine the failure mechanism of the Danida dam. To be sure which failure mechanism takes place it is necessary to excavate the whole dam.

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Appendices

# 1 Introduction

The Semea River is an ephemeral or seasonal river in a Black Cotton Soil area near Ikanga in Kitui District, Kenya. In the area is a lack of water supply and people living near the Semea River have to walk more than 3 kilometers to the nearest water supply, the Nzeu River or wells far downstream of the Semea River. Black cotton soil is very fertile, the area can be far more productive if there should be water.
In this report a research is described, which has the purpose to find solutions for the lack of water in the BCS area in the Semea River. Part of the research is the construction of two experimental dams and investigation of the soil layers by augerings and at the possible outlet with a terrameter. The research is a continuation on the report of CF628.
The research and construction is done by Erik Arnold, Cees Anton van den Dool and Jaap Joosse as their practical work period, which is part of their study Civil Engineering at TU Delft. The research is executed for SASOL, a NGO based in Kitui. SASOL's main target is finding and realizing solutions for water supply in semi arid areas. In the past the activities where particularly building stone masonry dams in rocky areas, but now is searched for solutions in black cotton soil areas.

The report is mainly divided into three parts, each part corresponds with a section of a river, upper part, middle part and floodplain and outlet. Each part has his own characteristics and therefore also his own solutions. After this introduction a situation analysis is given, which is succeeded by chapter 3: Problem analysis. Then in chapter 4 Dams on rock, solutions for the upper part are discussed, in chapter 5 Dams on clay, solutions for the middle part and in chapter 6 Dams in floodplain and outlet, solutions for the last part the floodplain and outlet are given. In chapter 7 the conclusions are drawn and recommendations are given. Further some appendices are added that contain the data of augerings, leveling, permeability tests and research on the kunkar limestone layer and the black cotton soil layer. Also an appendix with the research on an already existing, but failing dam is added.
Notice that in the remainder of this report, the entitling black cotton soil is abbreviated to BCS.

# 2 Situation description

## 2.1 Introduction

The project area is located in Kitui district in the southeastern part of Kenya. The capital of this semi arid area is Kitui. People living in this area are mainly of the Akamba-tribe. The Kitui-district is divided in several divisions. The Mutomo division includes Ikanga sublocation and other sublocations. The Ikanga sublocation consists of Ikanga and neighboring villages. The population in Ikanga sublocation is estimated by de District Documentation Center on 18057 people in 2002. The important factors in the economy of Ikanga are agriculture, cattle and trade.

The Nzeu is a seasonal river near Ikanga. This river is an important source of water because the groundwater flow is permanent trough the year. The other seasonal river is the Semea, which discharges itself into the Nzeu. The groundwater flow through the sediment in this river occurs only a few weeks after the rainy season. Most of the year people living near the Semea are dependent of groundwater in the Nzeu. The Semea is flowing through a Black Cotton Soil-area.

The Project area of this project is the river Semea in the BCS-area near Ikanga. See figure 2.1

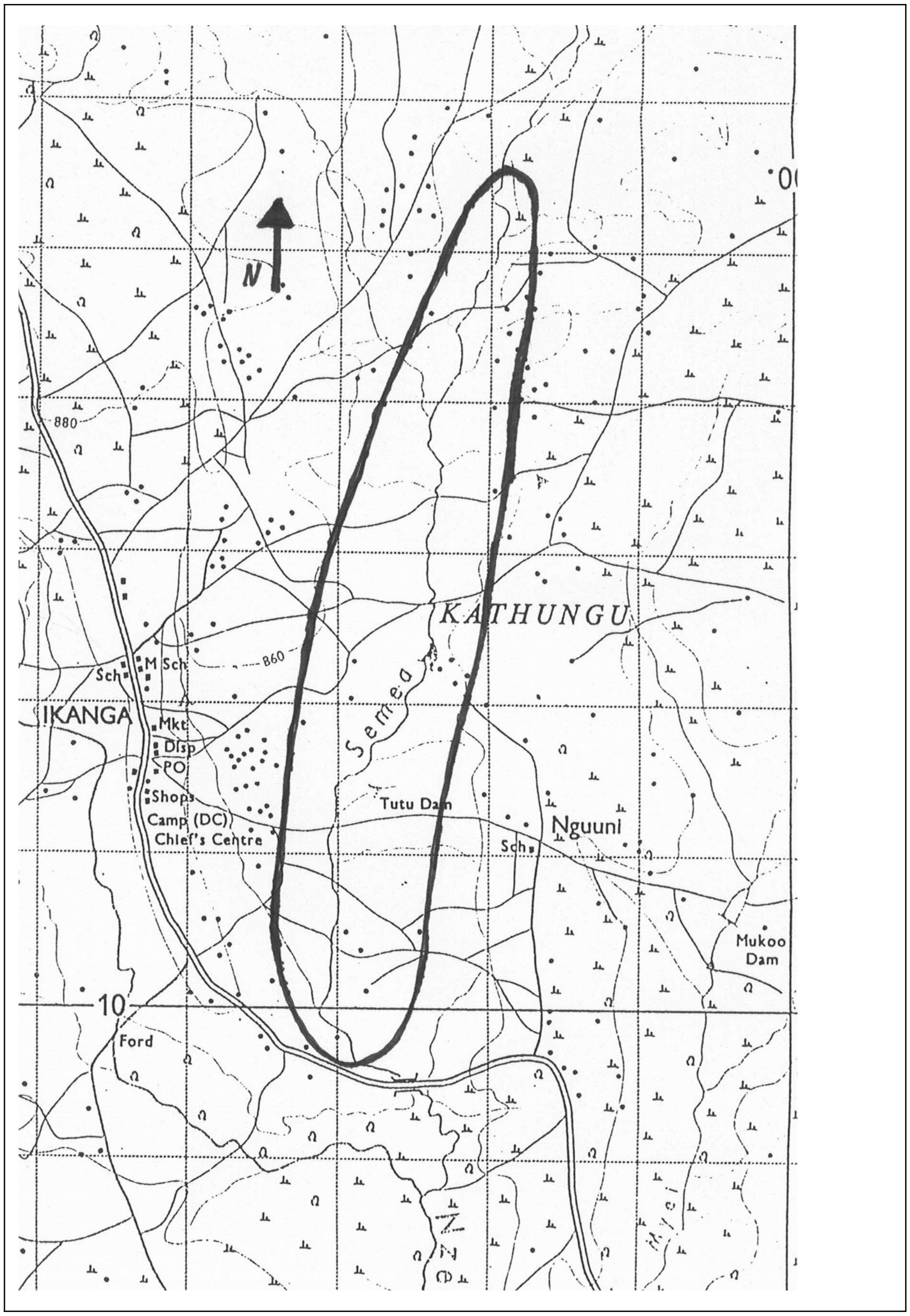

*Figure 2.1: project area (scale 1:50000) [Appendix I]*

## 2.2 Geomorphology of the BCS-area

*2.2.1Topography*
The BCS-area's in Kitui district are relatively flat compared with the hilly and rocky red-soil areas. Measured slopes of the Semea riverbed vary from 1:400 to 1:600. This flatness can be

explained by de origin of the BCS-area as swamp. The width of the BCS-area (transversal on the Semea) can vary from fifty meters up to hundreds of meters. The length of the BCS area is approximately 10 km.

*2.2.2BCS*

The BCS layer covers the bottom of the Semea River Valley. The rivers have eroded a trench through this layer. Augerings have shown that the river locally has eroded the whole layer, see also Appendix VII: BCS layer Research. This is mostly restricted to outer river bends. In recent times the riverbed partly is filled with sediment.
The permeability of the BCS is approximately $0.2*10^{-7}$ – $0.5*10^{-7}$, See also Appendix VI: Permeability.

*2.2.3Kunkar limestone layer*

The gray-whitish limestone layer is found directly underneath the BCS-layer and on top of the rock. The limestone mainly consists of CaCO3, which has a poor solubility in water. The limestone is nearly fluid when wetted, but hard when dried.
The porosity is estimated approximately on 0.32-0.42 (appendix V: Porosity) and the permeability on $2.15*10^{-5}$ for not compacted limestone $3.33*10^{-7}$ for compacted limestone (appendix VI: Permeability). This indicates that the limestone layer is relatively permeable compared with BCS and can be used as aquifer. Most of the wells in the neighborhood are dug into the limestone layer (called white layer by locals) according to interviews with local people. Kunkar limestone is in contrary to coral limestone found in small areas and formed by geochemical accident. The limestone is formed by precipitation of CaCO3. See Appendix VIII: limestone research for detailed information about the presence and formation of kunkar limestone.
According to the augerings in the Semea the limestone layer is present everywhere under the riverbed.

## 2.3 Hydrological system

*2.3.1Rainfall*

The rainfall in Ikanga is shown in table 2.1. Due to high temperatures the evaporation rates are very high: 2000-2200 mm/year according to information obtained from de Water Office of Kitui. The origin of water in the Semea is runoff from BCS area and from the red soil area upstream in the upper part of the Semea.

*Table 2.1: Rainfall data of Ikanga [Van der Zee, 1991]*

| | Annual | Long rains (Aug-Jan) | Short rains (Feb-Jul) |
|---|---|---|---|
| Years | 17 | 19 | 17 |
| Mean (mm) | 642 | 256 | 395 |
| Max (mm) | 1293 | 829 | 913 |
| 25% (mm) | 723 | 305 | 476 |
| 50% (mm) | 615 | 214 | 374 |
| 75% (mm) | 478 | 125 | 293 |
| Min (mm) | 282 | 54 | 83 |

*2.3.2Soil characteristics: Aquifers and aquitards*

Due to the difference in permeability of the three main soil layers aquifers and aquitards can be distinguished. The sand is mainly present in riverbed and has a high permeability. After the rainy season the sand will contain water. But after a few weeks the groundwater has flown away towards the Nzeu due to the high permeability.
The permeability of BCS is very low en can be seen as impermeable. The water flow in the BCS is not significant.
The permeability of the kunkar limestone is in between the permeability of sand and BCS. This causes the water flow in the limestone layer to be relatively constant. Water is available throughout the year in the limestone layer in the downstream part of the Semea River.

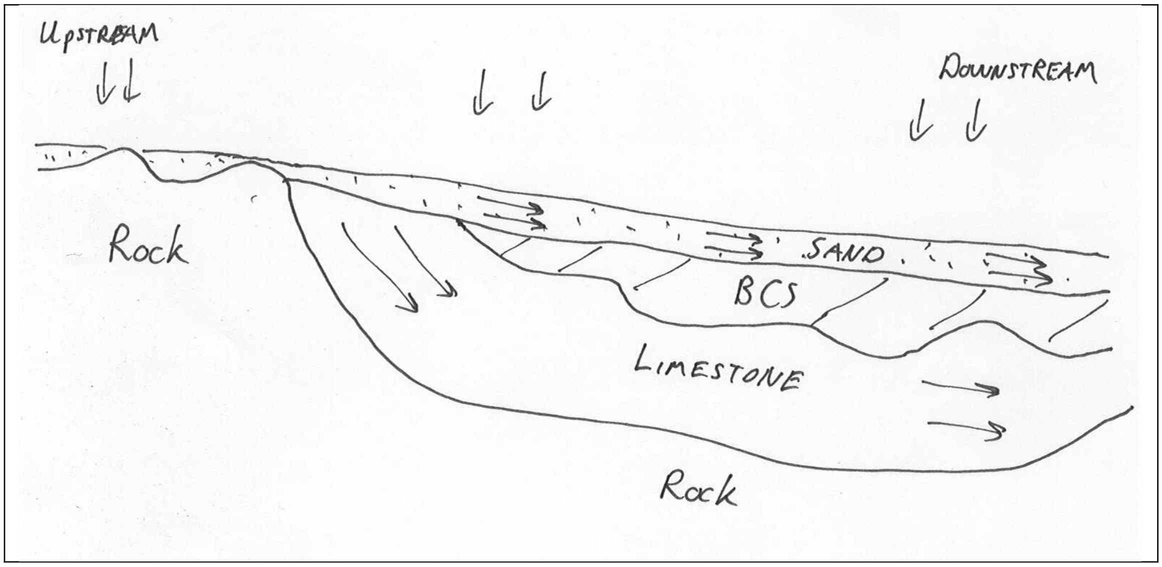

*Figure 2.2: impression of the hydrological system*

*2.3.3Present water supply*

Near the Semea there are several wells dug into the limestone layer. The wells in the floodplain provide water throughout the year, and some pools in the floodplain are also permanent. On several locations upstream of the Semea there are pools next to the river in the BCS for providing water for cattle. These pools are temporally.
In the Semea near Ikanga a stone masonry dam is constructed. The donor is believed to be a Danish organization called Danida. This dam does not provide any water. For more information about this dam see appendix IX: Danida dam.
In Ikanga, there is one deep well providing water for surrounding villages. This system is not in use at the moment.

# 3 Problem analysis

## 3.1 Problem description

SaSol is planning to design and construct dams in an area, where they have not operated before. In this area the slopes are milder and the underground in this area consist of Black Cotton Soil (BCS). Till now there are no dams built by SaSol in this area, because of a lack of knowledge about the behavior of dams in a BCS environment, like cracking and collapsing. In the area the usual building material stone is not easy available and also a good base layer is not present.

## 3.2 Problem definition

There is a lack of knowledge about the vertical and horizontal extend of soil layers and the behavior of solutions for water supply and water retainment in BCS areas.

## 3.3 Objective

Find implementable solutions for water retainment in the BCS area in the Semea River near Ikanga and implement an experimental version to gain more knowledge about its behaviour.

# 4 Stone-masonry in upper part of Semea River

## 4.1 Introduction

In this chapter the possibility of a stone-masonry dam in the upper part of the Semea River (see figure 4.1) is being discussed. Although Sasol has a lot of experience in constructing stone-masonry dams in rocky red soil areas, the constructing of such a dam in BCS-area is never done by Sasol. Sasol is interested in providing water in this area, this chapter will make a start with designing a stone-masonry dam in BCS-area.
In paragraph 4.2 the general outline of the upper part of the Semea is described. After that the design of the stone-masonry dam in this area is being discussed in comparison with the design of the dams built by Sasol. Emphasis is on the wings of the dams, because the banks are very different from the banks in the rocky red soil area. At last the possibility of constructing a stone masonry dam in this area is discussed and recommendations are given.

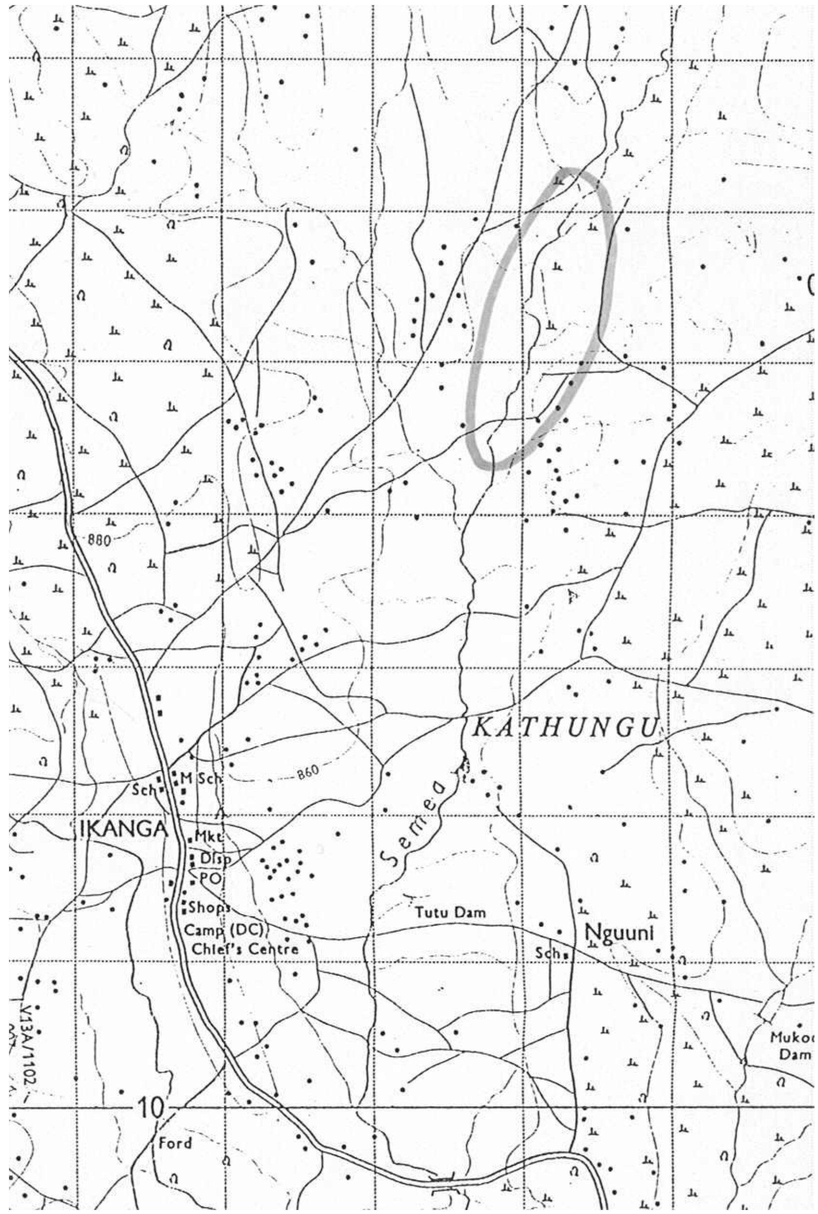

*Figure 4.1: location of rocks (scale 1:50000) [Appendix I]*

## 4.2 Description of the upper part of the Semea

In the upper part of our project area (see figure 4.1: map of area) there are rock formations found in the riverbed of the Semea River (See appendix II: augerings). The visible surface rock consists of weathered granitoid gneiss and biotide gneiss. The banks in this area consist of BCS and maybe kunkar limestone. According to the research done on the limestone layer in Appendix VIII it is likely to presume and small horizontal extent of this limestone layer in the banks (See appendix VIII: Limestone Research). A graphical impression of the soil is given by figure 4.2.

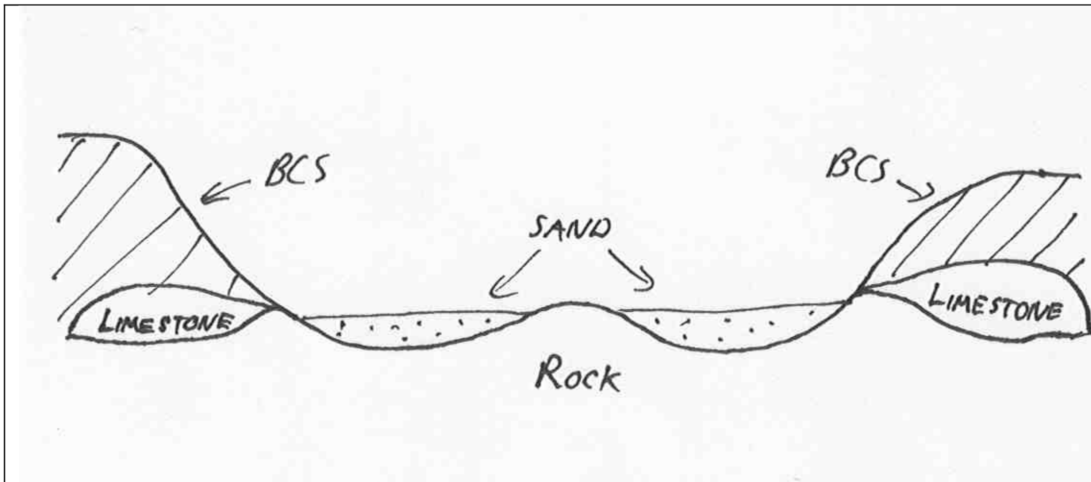

*Figure 4.2: Graphical impression of soil in upper part of Semea River*

The soil profile shown in figure 4.2 is suitable for construction of stone-masonry dams. The rock can support the weight of the dam and the fresh rock forms an impermeable horizontal boundary. The BCS in the banks with an estimated permeability of 4E-08 can be used as a relatively impermeable vertical boundary (See appendix VI: Permeability).
The average slope of the riverbed according to data from 'appendix III: Longitudinal Section' is 1:400. This means that a small dam will have a big influence area and therefore a high potential. The geographical situation of the area makes it worth considering the construction of a stone masonry dam. After the rainy season the subsurface flow is stopping quickly and in the dry period the main source of water is the subsurface water in the Nzeu 5 km away (See figure 4.1).
According to interviews with local people, they seem to be very willing to cooperate in projects providing water on a shorter distance.

## 4.3 Design of a stone-masonry dam in the upper part of Semea

*4.3.1Resemblance with stone-masonry in north Kitui*
Sasol has built over 250 stone-masonry dams in the northern part of Kitui [Frima 2002] [Beimers 2001]. The dams in northern Kitui are founded on fresh rock and the wings embedded in the banks consisting mostly of weathered rock and red-soil.

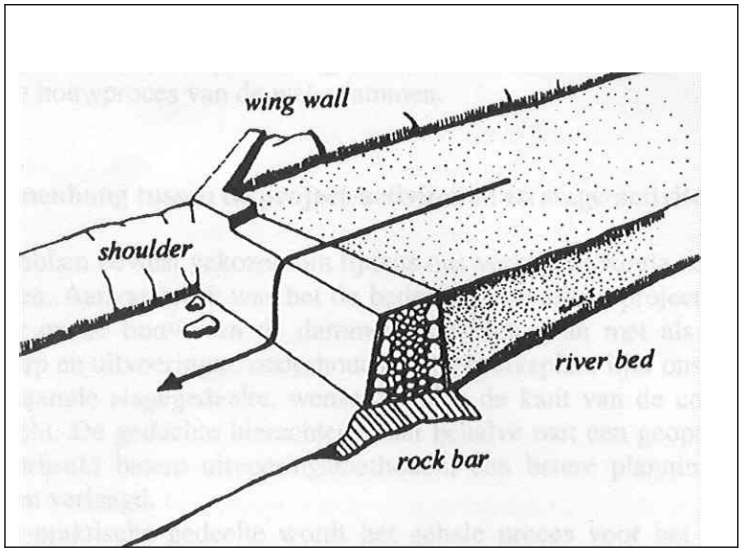

*Figure 4.3: Principal of stone-masonry dam [Beimers 2001]*

The way of founding the stone-masonry dam in the northern part of Kitui can be used in the southern part as well. To prevent piping through the weathered rock (also known as soft rock), the rock has to be excavated down to the fresh rock. Using vertical electrical sounding (Appendix VIII: Limestone Research) the extent of the weathered rock can be estimated.
Because Sasol has a lot of experience in building stone-masonry dams, there will be an elaboration in the following sub-paragraphs dealing only with the differing aspects of such a dam in BCS-area's.

*4.3.2Length of the wings*
Because of the low permeability of BCS, the seepage will be mainly through weathered rock and the limestone layer (See appendix VI: Permeability). The wings can be relatively short when the banks consist of BCS only. With a large vertical extent of the limestone layer and the weathered rock, the wings have to be large (See figure 4.4). One way of minimizing the costs of a dam is to extend the wings by excavating the limestone and weathered rock and filling it with BCS.
The horizontal extent of the limestone and rock aquifers determines the length of the wings. Knowledge about this extent is the key for estimating the feasibility of a stone masonry dam. Information about the limestone layer can be obtained by auguring when there is no water in this layer. The thickness of the weathered layer can be determined by vertical electrical sounding.

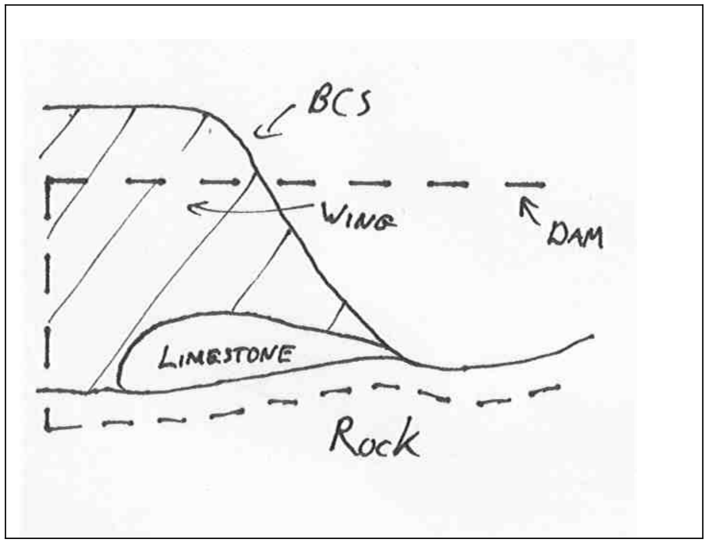


*Figure 4.4: Wings of stone masonry dam in BCS-area*

*4.3.3Cracking of the wings*

BCS is characterized as the swelling clay. Experiments done in the project area showed this swelling character. BCS is cracking fast when dried and swelling very fast when wetted. This phenomenon is occurring in particular on the surface of the BCS, under influence of sun and rain. The wings into the BCS may suffer from the horizontal forces occurring during the swelling of the clay. Although quantification of this phenomenon is very hard, it has to be taken into account in the design and constructing of the stone-masonry dam.

*4.3.4Changes of river course*

Because of the small slope in lateral direction it is possible that the river changes the course due to a new constructed dam [Frima 2002]. This will threaten the efficiency of the dam. One way of preventing this is constructing dams with their spillway far under the level of the surrounding area. Another way is planting plants to prevent erosion of the banks. In Northern Kitui Napier grass is used for this purpose.

*4.3.5Mutual distance and benefit*

The slope in the area is determined by leveling (See appendix). The average slope is estimated on 1:400. This means, for example, that a dam of 2 meter height has an influence area of more than 800 meter upstream. Optimizing the efficiency of the constructed dams means reducing the negative effects on their catchment. The next dam upstream from another dam has to be out of its influence area. In the used example this causes the optimal mutual distance until the upstream dam to be more than 800 meter.

For computing the capacity of a dam in BCS-area an example used. The average slope is 1:400. This means a dam of 2 meter height can forms a reservoir of 800 meters long.

With an average width of 10m the reservoir contains 4000 $m^3$ water. When the reservoir is filled with sand with a porosity of 40% the amount of contained water is 1600 $m^3$.

#### *4.3.6 Blocking of recharge of limestone layer*

As stated in Chapter 2 the origin of water in the limestone layer can be from infiltration in the upper part of the Semea. In this part of the river the BCS-layer is absent and water can flow directly from the sediment layer to the limestone layer. Building a dam near the start of the BCS layer can result in a reducing the recharge of the limestone layer.
On the other hand there can be a positive influence of the dam on the recharge of the limestone layer. Retaining the water longer upstream cause the water to flow far after the rainy season downstream of the dam, due to spilling of the water over the dam. This also causes a longer period of infiltration downstream.

## 4.4 Conclusion

Taking in to account the uncertainty about the exact lateral extent of the aquifers, the upper part of the Semea seems to be suitable for the construction of a stone masonry-dam. Because of the small slope, the potential water storage of the dam will be very high and the surrounding BCS can become fertile. This location far from water supply can be a good opportunity for Sasol to build the dam and the local people seem to be willing to cooperate. The design and constructing of the dam can be quite similar to what Sasol is used to. Extra attention has to be paid on design of the wings.

Proposing the next step for Sasol it is useful to examine the exact lateral extent of the aquifers using vertical electrical sounding. Based on these results a specific design can be made for the dam. Results of constructing and monitoring this dam can be input for more dams in BCS-area's.

# 5 Dams on clay

In this chapter the option of retaining water in the middle part of the Semea River will be looked into. A group of students before us did already research in the middle part of the Semea River and made a design for a subsurface dam for this part of the river. This chapter is written after we have finished two subsurface dams in the Semea River. In this chapter the design of the other group is elaborated and adapted at some points.

The structure of this chapter is: first the principle of a subsurface dam on clay is discussed. After that the first and the second subsurface dam are explained, the first subsurface dam in more detail than the second one. The last two chapters explain the measuring system. The measuring system is needed to determine if the dams are working or failing.

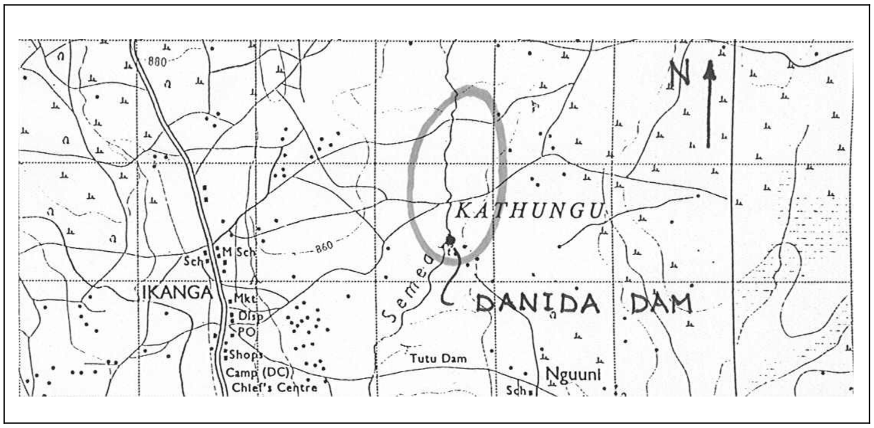


*Figure 5.1: Map of the middle part of the Semea river*

## 5.1 Principle of a subsurface dam on clay

The layers of the soil in the middle part of the Semea River are as follows:
Sand
Clay (BCS)
Lime soil
Impermeable layer (unreachable)

A shield put into the impermeable clay layer (BCS) or into the impermeable layer underneath the white layer (lime soil) will hold water upstream in the sediment. A shield till the clay layer only captures the surface run of water while a shield till the impermeable layer underneath the white layer will also block the ground water flow in the white layer.

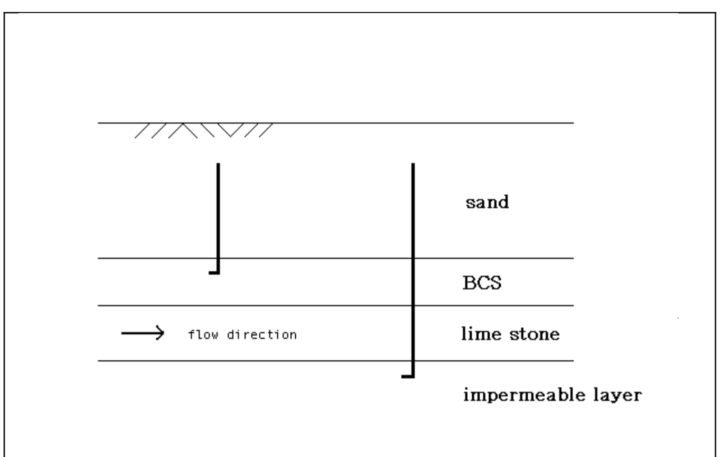


*Figure 5.2: Layering of the soil*

Advantages of an impermeable shield till the clay layer
Cheap: less digging and less material is needed
The groundwater flow in the white layer is not blocked. Avoiding drying out of the wells in the floodplain downstream of the shield. The wells abstract water from the white layer.

Disadvantages of an impermeable shield till the clay layer:
The storage capacity is less
The material is vulnerable, it is easy damaged or stolen

We choose for a shield fixed in the clay layer because we do not want that the wells in the floodplain will dry out. It is not useful to retain water in the middle part of the river with negative side effects like drying out of the wells downstream of the shield. Fixing a shield in the impermeable layer under the white layer is no option because the dept of this layer is unknown, due to practical limitations of the augur length.

## 5.2 Allocation of the experimental dams

To allocate the experimental dams, some restrictions has to be satisfied. The most important restrictions come from the design and the principles of the experimental dam, others are of more practical nature. The restrictions are:
Presence of BCS layer:
As bottom of the catchment there has to be an impermeable layer.
Presence of sediment upstream of the experimental dam:
To store a considerable amount of water in the catchment there has to be enough porous volume in the sediment upstream from the dam. Sand with big grains has a high porous volume.
Presence of flat area:
The slope of the riverbed at the upstream side of the dam is providing the main measure of the catchment. A steep slope is decreasing the size of the catchment and has therefore to be avoided.
Absence of bends:
Bends in the river has a positive contribution to the turbulence and therefore also to the amount of erosion.
Absence of influences of other constructions:
To avoid unclear measurements and influences of other constructions in the river, the location of the experimental dam should have enough distance to them.
Also to make easier the building stage the distance to the village is taken into account.

To find a suitable site, a fieldwalk is done. During this walk a long straight section of the river is spotted where further investigations is done by boreholes to determine the precence and thickness of the BCS layer, type of sediment in the catchment and by levelling to connect the levels of the several boreholes and to determine the slope of the riverbed and the slope of the upside of the BCS layer. The results of the levelling and drillings are shown in Appendix II and Appendix III. The first location is at a distance of 708 meters upstream from the Danida Dam in the Semea River. This location has very pure BCS banks and BCS layer. This in contrary to the second location, 256 meters upstream from the Danida Dam, where in the left bank the BCS seemed to be mixed with a little amount of sand. This is also of influence on the permeability of the soil. See also Appendix 6. Another difference between the two locations is straightness of the river. The second location has little bends, but is still suitable. Moreover the second location was the only other suitable site in the Semea River. In Appendix IV the cross-sections of the two locations are shown.

## 5.3 Experimental dam 1

### *5.3.1Design*

*Material*
The impermeable shield can be build of different kind of materials. Possible materials for the construction of the impermeable shield are: iron shields, plastic shields or membranes, wall of bricks, trench filled with concrete/cement or black cotton soil. An evaluation of the different kind of materials shows that the most preferable material to use for the impermeable shields is a plastic foil because of the wide availability and the low costs. A foundation is not necessary because a plastic foil is light [Sand-storage dams on black cotton soil, pag 106].
A disadvantage of a plastic foil is its vulnerability when it is exposed to the river flow after erosion. Applying a plastic foil like an impermeable shield is only a possibility when there is no or little erosion in the river. After some digging in the middle part of the Semea River the conclusion is that no or little erosion takes place in the Semea River because the upper layer of sand consists of small layers of sand.

Black cotton soil is also a possible option to build the impermeable shield of but it is risky because the properties are not known yet [Sand-storage dams on black cotton soil, pag 108]. In this report some properties of BCS are investigated, like the porosity and the permeability.

*Shape of the foil*
To avoid stress in the foil the plastic is laid in the soil in a way that allows some movement. The group before us suggested in their report a S-shape [Sand-storage dams on black cotton soil, pag 109]. A disadvantage of putting the foil this way is that it is only effective when the upper part of the sand layer is moving. When the lowest part of the sand layer is moving in the direction of the flow much stress is introduced in the foil directly above the clay layer. The strain in the foil can pull the foil out of the clay or damage the foil. A C-shape allows also some movement in the lower part of the sand layer.

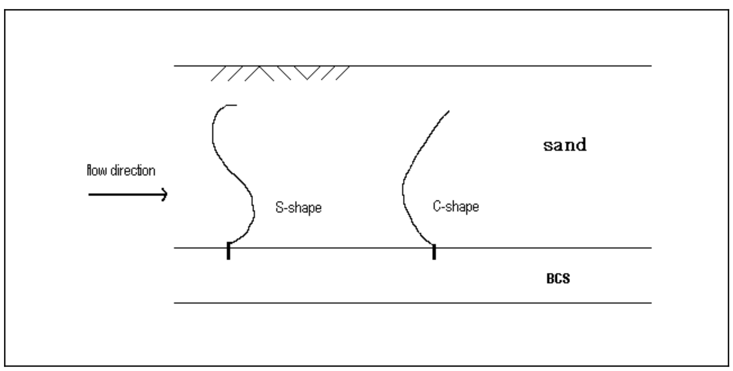

*Figure 5.3: Shape of the foil*

*Fixing the plastic foil in the clay under the riverbed*
Beams are used to fix the foil in the clay layer. An advantage of beams is that its surface is less smooth and therefore has more resistance when pulled than the surface of a plastic foil. So the beams prevent pulling the foil out of the clay.

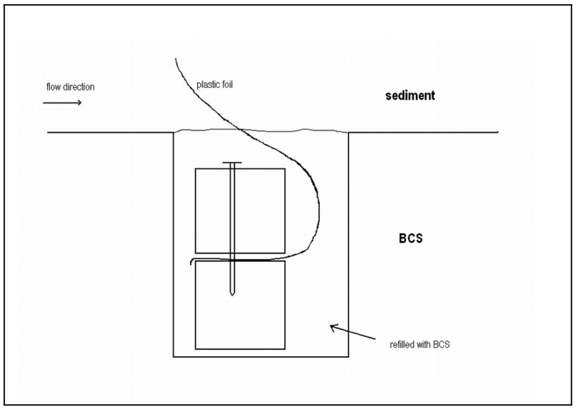


*Figure 5.4: Cross-section of fixing the plastic foil in the clay*

*Fixing the plastic foil in the clay under the riverbanks*
In both ends of the trench the foil is fold backwards. The space between the foil is filled with black cotton soil. The soil between the foil must prevent pulling the foil out of the clay under the banks. The resistance against pulling the foil out of the clay in the banks is assumed enough, also without beams, because of the considerable distance of the foil into the banks.

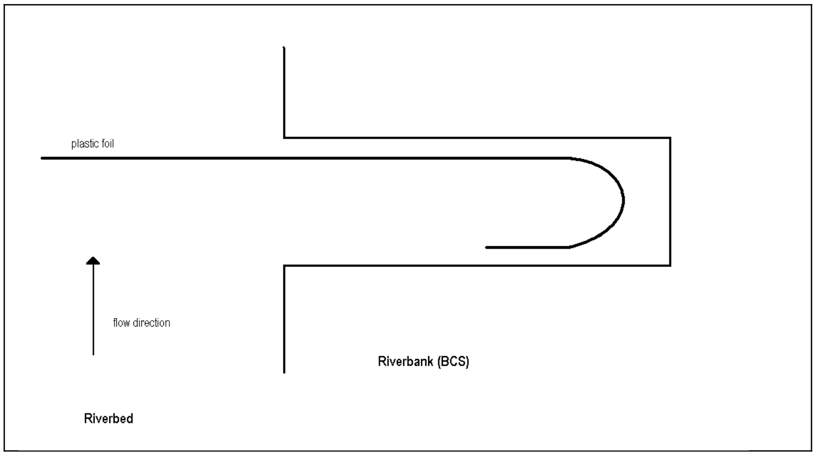


*Figure 5.5: Bird-eye view of a plastic foil in the clay under the riverbed*

*Dimensions*
Figure 5.5 shows a cross-section of the trench. The average depth of the trench is 1.5 meter. A plastic foil is needed with a length of about 18 meter and a width of 1.9 meter.

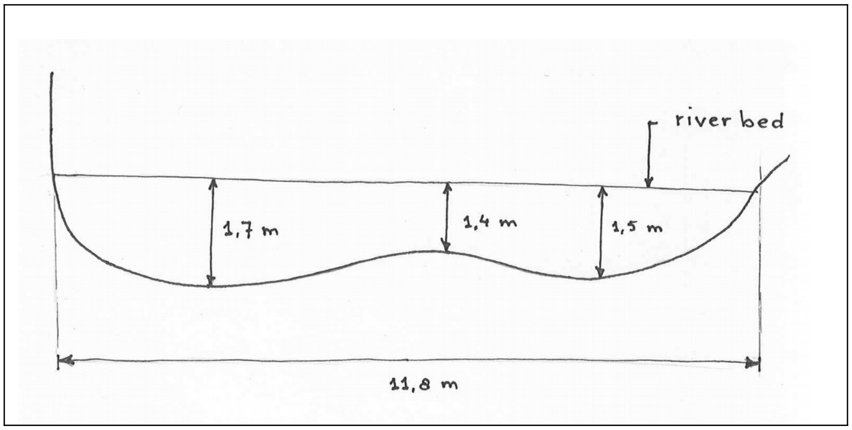


*Figure 5.6: Cross-section of the trench*

Forces at the foil

After a period of rainfall the water in the river will infiltrate in the sediment of the riverbed. The highest forces in the ground occur when there is still water upstream of the plastic foil and no or less water downstream of the foil. Apart from the point if this extreme situation will take places it is useful to check if the soil is able to resist the forces introduced by the plastic foil. A calculation shows that the ground is able to resist the forces.

Calculation:

To estimate the forces in the soil the following assumptions are done:
Hydrostatic water pressure (stagnant water)
Specific gravity of: dry sand $\gamma_{dry;sand} = 16$ kN/m$^3$
wet sand $\gamma_{wet;sand} = 20$ kN/m$^3$
Horizontal ground pressure:
active ground pressure = 1/3 * vertical grain pressure
passive ground pressure = 3 * vertical grain pressure

Horizontal ground pressure:
Upstream of the foil ⇒ active ground pressure
Downstream of the foil ⇒ passive ground pressure

Formula: $\sigma_g = \sigma_{gr} + \sigma_w$

$\sigma_g$ ground pressure
$\sigma_{gr}$ grain pressure
$\sigma_w$ water pressure

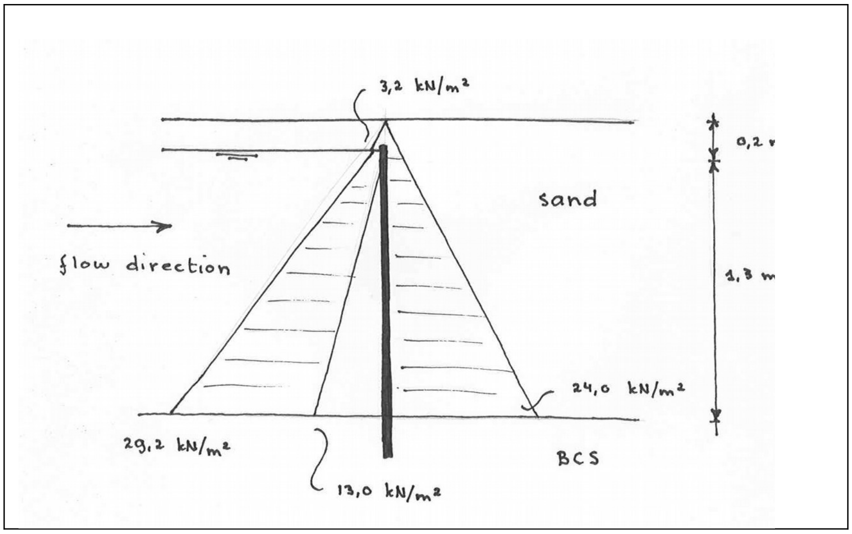


*Figure 5.7: Hydrostatic water pressure in reservoir*

Upstream of the foil:
$\sigma_{gr} = \sigma_g - \sigma_w = 29{,}2$ kN/m$^2$ – $13{,}0$ kN/m$^2$ = $16{,}2$ kN/m$^2$

horizontal ground pressure (active) = 1/3 * 16,2 kN/m$^2$ = 5,4 kN/m$^2$

Downstream of the foil:
$\sigma_{gr} = \sigma_g - \sigma_w$ = 24,0 kN/m$^2$ – 0 kN/m$^2$ = 24,0 kN/m$^2$
horizontal ground pressure (passive) = 3 * 24,0 kN/m$^2$ = 72,0 kN/m$^2$

The ground downstream of the foil is able to handle the pressure caused by the water reservoir and the ground upstream of the foil.

*5.3.2Construction*
In this chapter the different stages of the construction of the first subsurface dam in the middle part of the Semea River are explained. The stages are:
Digging of the big trench till the clay layer
Digging of the small trench in the clay layer
Fixing a timbre beam on top of the plastic foil
Placing of the foil in the trench
Fixing a beam at the bottom of the foil
Refilling the small trench with clay
Fixing the foil in the banks
Refilling the big trench with sand
The several stages will be discussed in more detail.

*Digging of the big trench till the clay layer*
The width of the trench in the riverbanks is less than in the riverbed. This is possible because the cohesion of the clay in the banks is much larger then of the sand in the riverbed. Also in the middle part of the trench more space is needed to put the foil into a C-shape. The advantage of making the trench in the riverbed much smaller is that you avoid much digging (removing clay is much more work than sand). To prevent seepage it is very important to separate the sand of the riverbed from the clay of the riverbanks. Refilling the riverbanks or the small trench with a mixture of clay and sand can cause seepage.

*Digging of the small trench in the clay layer*
To prevent seepage the foil is fixed about 20 centimeter into the clay layer.

*Fixing a timbre beam on top of the plastic foil*
The upper part of the foil will be reinforced with a timbre beam. A timbre beam on top of the plastic foil has some advantages:
It is easier to hold the foil horizontal during the construction

*Figure 5.8: Little pieces of wood are used to prevent tearing*

It is easier to hang the foil in the trench during the construction
The stiffness of the timbre beam prevent little local movements of the upper part of the foil after the construction
The timbre is attached to the foil with nails. To avoid tearing of the foil little pieces of wood are used between the timbre and the nails.

*Placing of the foil in the trench*

Figure 5.9 shows how the plastic foil is placed in the trench during the construction. Two or more timbre beams are placed over the trench. The timbre beams hold the upper part of the plastic foil in position during the construction.

*Fixing a beam at the bottom of the foil*

The bottom of the foil is fixed with timbre beams (figure 5.10). The dept of the clay layer varies in the trench so it is necessary to adjust the timbre beams to the profile of the clay layer.

*Figure 5.10: A beam at the bottom of the foil*

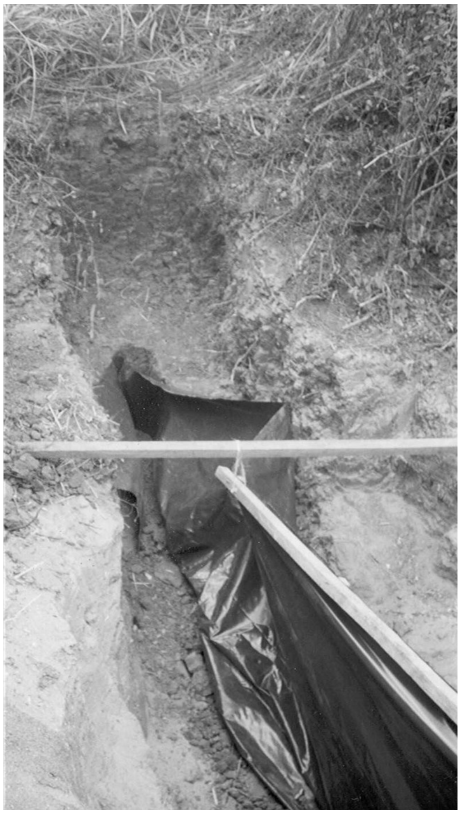

*Figure 5.9: Foil in the trench*

*Refilling the small trench with clay*

To prevent seepage under the plastic foil it is necessary to fix the foil into the clay layer. To save the amount of plastic some clay of the shallowest part is carried to the deepest part of the trench. In the shallow part of the trench the foil is fixed in a small trench in the clay. In the deepest part of the trench the foil is fixed by putting clay against the lower part of the foil.

*Fixing the foil in the banks*

The photo shows how the foil is fixed into the clay below the riverbanks. The foil is fixed 3 meters into the clay under the riverbank. On both ends of the trench the foil is folded backwards. The space between the foil is filled with black cotton soil.

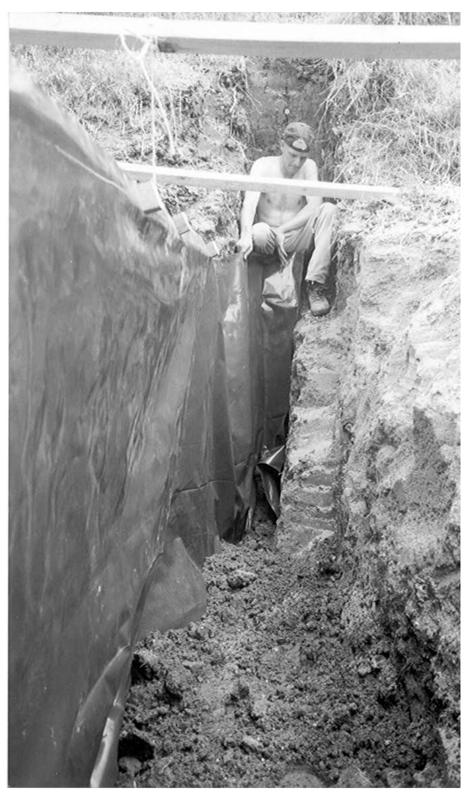

*Figure 5.11: Fixing the foil in the banks*

*Refilling the big trench with sand*
During the refilling of the big trench a person is staying in the trench to manage the process. To get the right shape into the foil it is very important that the soil is put back very carefully. Before refilling the big trench the tubes have to be placed for the measuring system.

*Figure 5.12: Refilling the big trench with sand*

*5.3.3Feasibility*

The feasibility of the subsurface dam is determined by the ratio: storage-capacity / costs.

Costs:

| Costs | Amounts | unit price | total price (Ksh) |
|---|---|---|---|
| Digging | 3 men 2 days | | 1500 |
| Plastic foil (1.9 meter) | 20 meter | 60 Ksh/m | 1200 |
| Timbre beams (2x2 inch) | 35 meter | 40 Ksh/meter | 1400 |
| Nails | 30 | | 100 |
| | | | 4200 |

Storage capacity:

To estimate the storage capacity of the subsurface dam the following assumptions are done:
The slope of the clay layer is the same as the slope of the riverbed
The water table in the reservoir is approximately horizontal with its level at the top of the shield

Q = 1/2 * L * D * T * n

Q is the capacity ($m^3$)
L is the length of the shield under the riverbed in (m)
D is the maximum depth (m)
T is the throwback (m)

L = 7 m
D = 1.3 m
T = 780 m (slope of the riverbed is 1:600)

Pore volume is n = 0.31 compacted sand [see Appendix VI]
n = 0.38 not compacted sand

The pore volume of the sand in the riverbed is estimated at 0.33. The storage capacity then becomes 1200 $m^3$

Water price per $m^3$ water: 4200/1200 = 3.5 Ksh/$m^3$ (= 0.05 euro/$m^3$)

The water price of a subsurface dam in a black cotton soil area is low compared with a stone stone-masonry dam on rock. But it is important to take into account that the sustainability of a stone-masonry dam is higher. An advantage of a subsurface dam is that the construction time will take less than of a stone-masonry dam, respectively 4 or 50 days.

It is important to keep in mind that the storage capacity is a rule of thumb. There are a number of factors involved which can make the design either work or fail. For example when the erosion is higher than expected the chance that the dam will fail is big. The effect of a subsurface dam in a black cotton soil area is unknown yet. It is presumable that the reservoir is going to be dry after a long period of draught. The reservoir is not big enough to provide water for household purposes throughout the year. Other alternatives for domestic water supply are necessary, for example a well into the white layer.

## Experimental dam 2

Also a second experimental dam is build. The reason for this is that there was time and money to do so and also to make more sure valuable data can be collected. Design and construction of the second dam is globally the same as the first experimental dam, only some small differences are made, which are discussed in this paragraph.

*5.3.4Design*

The design of the second experimental dam is somewhat changed. The differences are in the direction of saving money and so the second dam is a lighter version of the first one. There are three differences, two in the design and one of more locational nature:
The connection of the plastic foil and the BCS layer underneath is made by putting the foil in the clay like at the first experimental dam, but without timbre.
The length of the wings is shortened. The length of the wing is half a meter to one meter. It is not possible to determine this exactly for the start of the wing is where the soil consists over the full height of BCS. It is not possible to define that point exactly.
The surrounding soil is not of the same quality as in the case of the first one. The BCS is mixed with some sand and the permeability therefore higher. See also the permeability tests in Appendix III. Therefore the construction of a second experimental dam is very useful. So you can check if the principle also is working in less optimal circumstances.

*5.3.5Construction*

The construction of the second experimental dam is globally the same as the construction of the first one. See paragraph 5.3.2: Construction of dam 1. There are two small differences made during construction of the second dam:
Smaller space excavated for installing wing foil. This resulted in less excavating; just the width that was needed for a shovel and it had a positive effect of construction time and costs.
More stable installation to hold the foil in position during construction. At the construction of the first dam this was a little troublesome and needed to much attention during construction. At the second construction this was better fixed and therefore less delaying to the work.
Removing of the timbre beam at the upper side of the foil which is just used as a tool for creating a stable installation. At the first dam this beam is stolen after some days and thus also removed. Removing of this beam also has the advantage of reducing costs for there are only costs for hiring the beams.

*5.3.6Feasibility*

The storage capacity of the catchment and the costs of the second dam are estimated to find the ratio: costs/catchment.

The catchment of the second experimental dam is limited on the upstream side by the

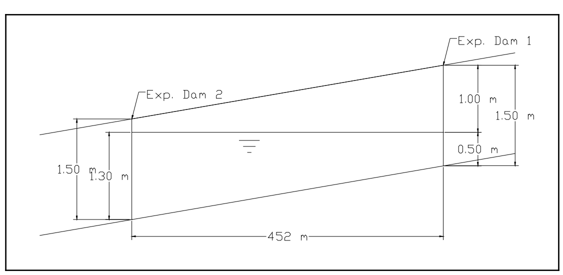


*Figure 5.13: Catchment second experimental dam*

first experimental dam, see figure 5.13. The area of the cross section of the catchment is 407 $m^2$. With a river width of 8.5 meter and a porosity of 0.33. This results in a storage capacity of 1140 $m^3$.

Costs:

| Costs | Amounts | Unit price | Total price (Ksh) |
|---|---|---|---|
| Digging | 3 men 2 days | | 1400,- |
| Plastic foil (1.9 meter) | 13 meter | 60,- Ksh/m | 780,- |
| Use of timbre beams (2x2 inch) | 18 meter | | 250,- |
| Nails | | | 15,- |
| Total | | | 2445,- |

Water price per $m^3$ water: 2445,-/1140 = 2.14 Ksh/$m^3$ (= 0.03 euro/$m^3$)

## 5.4 Measuring system

To know if the experimental dams fails or succeeds a measuring system is added. The system consists of tubes in which the water table can be read. At both sides of the dams at a distance of 1 meter a tube is inserted. See also figure 6.14. The tubes are penetrated with several holes at the

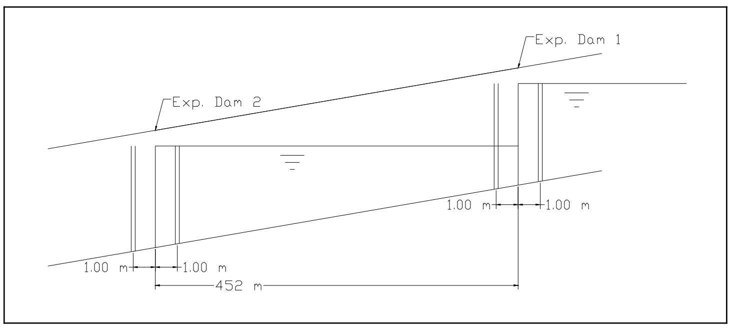


*Figure 5.14: Tubes at experimental dams*

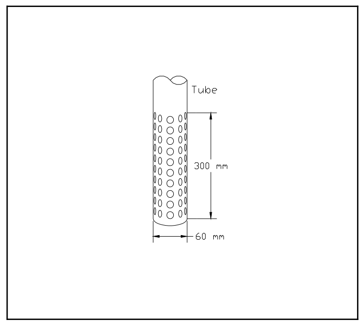


Figure 5.15: Downside of tube

downside to benefit the in stream of water, see figure 15 and covered to prevent sand coming in, which should obstruct reading of the water table.

## 5.5 Gathering of data

### *5.5.1 What kind of data is needed*

To conclude if the dams are working or failing it is necessary to measure the difference in water table upstream and downstream of the dam. If the dam works it is important to measure the water table upstream of the dam. It is presumable that the water table in the reservoir will drop after some time cause by abstraction for household purposes and by evaporation.

### *5.5.2 Measuring period*

The right time to measure the water table is after heavy rainfall when the reservoir is filled with water. The period of measuring after the rainy season depends of the dropping velocity of the water table in the reservoir.

### *5.5.3Location of the dams*

The subsurface dams are invisible therefore it is necessary to mark the location of the dams. Two methods are used to estimate the locations of the dams. The first method describes the environment in the neighborhood of the dams. A distance gives the exact location from a outstanding point in the environment for example a big tree. The second method uses two sticks. The sticks are put in the ground at one side of the riverbank. A distance gives the exact locations of the dams from the two sticks.

*Experimental dam 1*

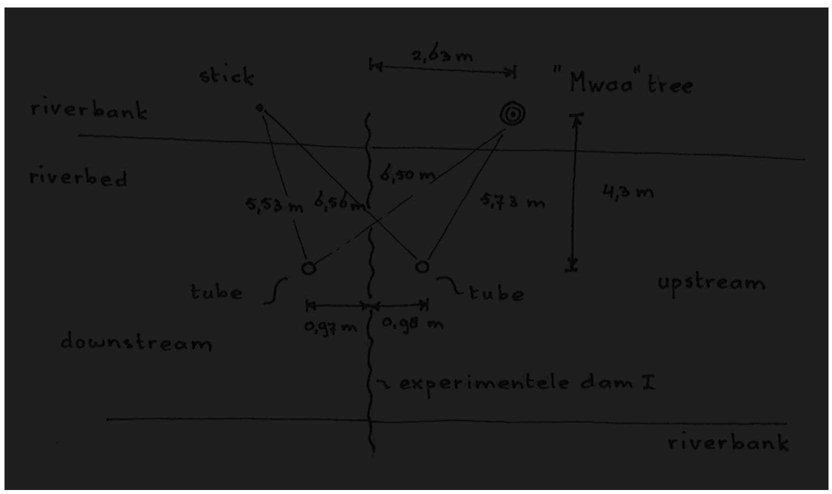


*Figure 5.15: Bird-eye view of the location of experimental dam 1*

The first location is at a distance of 708 meters upstream from the Danida Dam in the Semea River (see figure 5.1). The location of the dam is next to a “Mwaa” tree 2.63 meter down stream on perpendicular to the river coarse. The tree is on the right bank (facing down stream). The dam is placed in a straight stretch of the river of about 200 meter.

*Experimental dam 2*

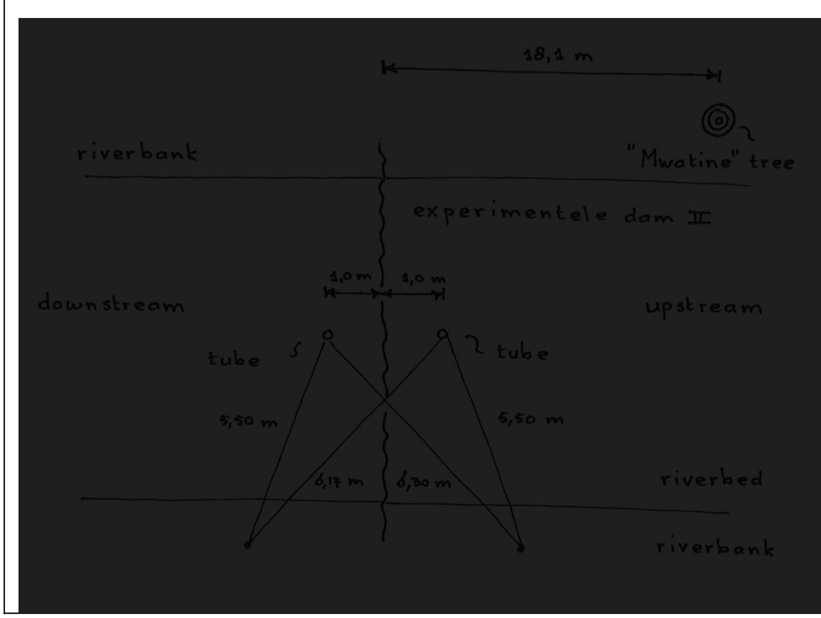


*Figure 5.16: Bird-eye view of the location of experimental dam 2*

The second location is at a distance of 708 meters upstream from the Danida Dam in the Semea River (see figure 5.1). The location of the dam is 18.1 meter from a perpendicular line from the middle of the diameter of a “Mwatine” tree on the upstream side of the dam. On the 18.1 meter from the “Mwatine” tree, standing on the right bank of the river there is a “Baobab” tree on the left bank (facing downstream) about 250 meter.

## 5.6 Evaluation of data

After measuring of the water levels, you know if the dams are working. It is valuable to measure at least two times to see the speed of declination of the water table. This is an indication for the size of possible leaks. There are two extreme situations: the dam is working or not. Although it is most likely reality is somewhere in between. The situation that the dam is working is very good, but not interesting in this paragraph, so only the case that the dam is not working will be discussed.
Failure mechanisms:
Leakage through the foil
This can be caused during construction, this is not likely because of the care token during construction. Before covering the foil was inspected and no gaps where found. Another cause for leakage through the foil is damaging of the foil after construction. This can be done by local people while digging out the foil for personal use or when there is heavy erosion during the rainseason followed by heavy sedimentation after the rain season.
Leaks through gaps in the BCS layer and the limestone layer
Research on the BCS layer has to prevent unnoticed gaps in the BCS layer under the sediment. The cause for these gaps is most likely heavy erosion in previous times. It is very difficult to prevent unnoticed gaps, because they can be very local and therefore the augerings must be very close to each other. Which implicates a lot of work.
Leaks through the banks
When this happens, it is expected to happen first at the second experimental dam, because the permeability of the soil in the banks was much higher than at the site of the first experimental dam. Leakage through the banks is caused by impure BCS in the banks. The banks can be infiltrated by sand layers or other permeable soil types.
Wateruse is to much, so the reservoir is emptied before measuring. This is not predicted, but when it happens it can be interpreted as a failure, while it is not.

## 5.7 Conclusions and recommendations

To see if the principle is working, measurements have to be taken after the rain season. Therefore it is not possible to draw conclusions about working or failure of the experiment. But there are some things learnt from building the two experimental dams, the main points are:
Building of a plastic foil dam is very easy and fast comparative to stone-masonry dams. In 4 or 5 days a dam is built.
Costs of building are very low.
Used materials are easily available.

It is presumable that the reservoir is going to be dry after a long period of draught. The reservoir is not big enough to provide water for household purposes throughout the year. Other alternatives for domestic water supply are necessary.

As said before with drawing conclusions about the principle has to be waited till after the rain season. But when it is working further optimizations can be made in the direction of scale of the dams and in less impermeable environments.

# 6 Earth dam and blocking of outlet in floodplain of Semea River

## 6.1 Introduction

In this chapter the possibilities of retaining water in the floodplain of the Semea River (see figure 6.1) near the outlet is being discussed. The water system in the floodplain can be divided in surface water above the impermeable BCS-layer and groundwater in the limestone layer under the BCS-layer. In the surface water system an earth dam in the floodplain is a possibility. For retaining water in the groundwater system, blocking the limestone layer at the outlet is being discussed.

In paragraph 6.2 the general outline of the floodplain is described. After that the possibility of earth dam and complications is dealt with. Then blocking groundwater flow in the limestone layer is being discussed. At last the conclusion and recommendations are given.

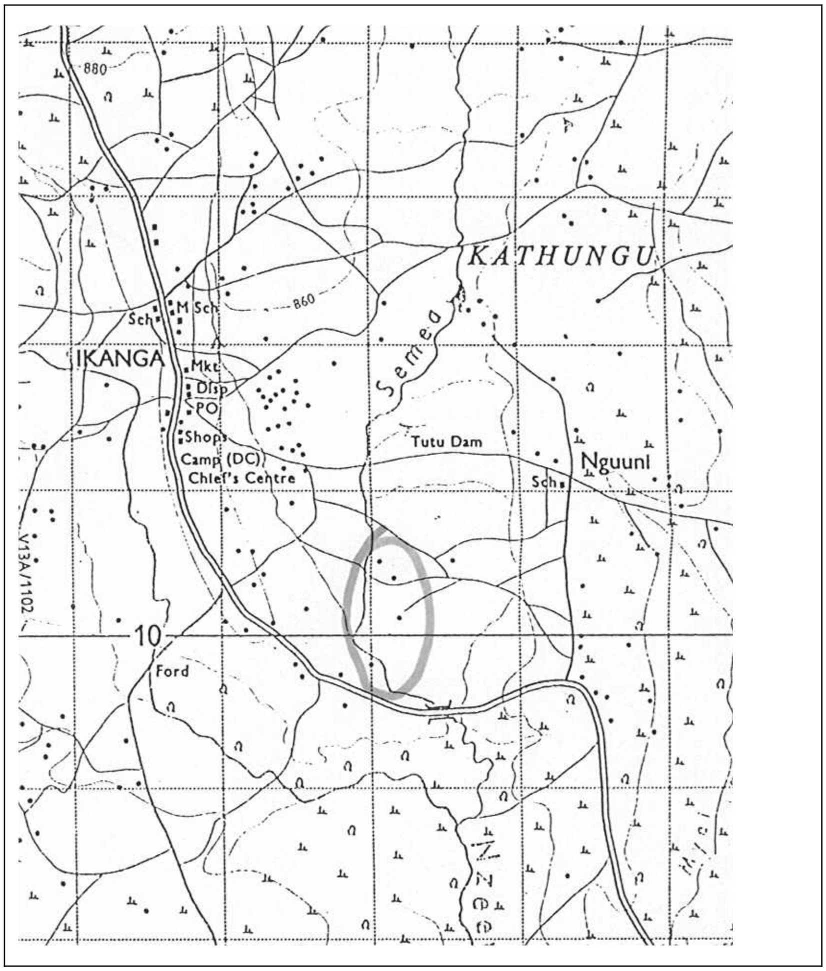


*Figure 6.1:location of floodplain (scale 1:50000) [Appendix I]*

## 6.2 Description of the floodplain

In the downstream part of our project area (see figure 6.1: map of area) a floodplain has been formed. The slope of this floodplain just upstream of the road Ikanga-Mutomo is estimated by leveling on 1:500 longitudinal and 1: 800 transversal. The transversal slope ascends from right to left looking in downstream direction. The width of the BCS-floodplain is approximately 300 meter and the river is located on approximately 110 meter from the right boundary looking in downstream direction.
The vegetation consists of bushes and little agriculture. The river coarse is varying from 3 meter deep and 5 meter width to not visible. The riverbed in this area consists of sand, then BCS and than kunkar limestone. (See appendix II: Augerings). The artesian water in the kunkar limestone is under an average pressure of 0.7 meter.
According to the research done on the limestone layer done in this area in appendix VIII it is likely to presume a small horizontal extent of this limestone layer. The extent is estimated on not more than 20 m in total.
In the area several shallow wells are dug into the limestone layer, providing water all year round.

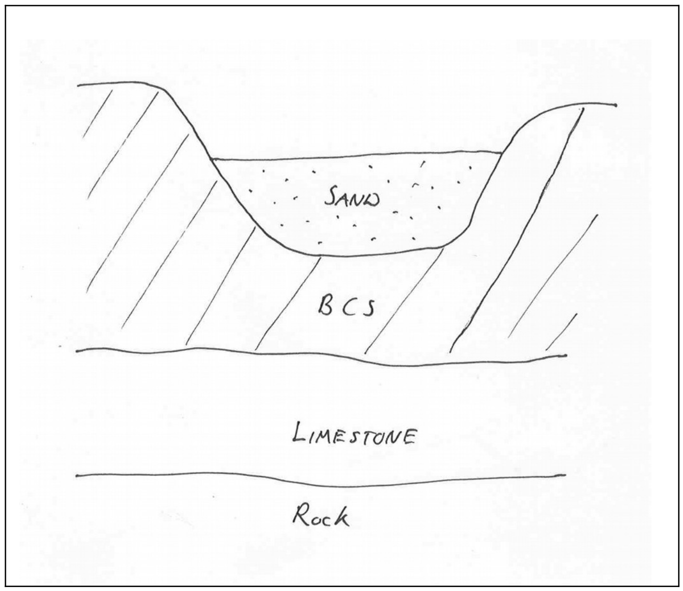

*Figure 6.2: Graphical impression of soil in floodplain of Semea*

The soil profile shown in figure 6.2 is suitable for construction of earth dams. The BCS with an estimated permeability of 4E-08 can be used as a relatively impermeable boundary (See appendix VI: Permeability). Enough BCS is available on the surface for constructing the dam with BCS. The average slope of the floodplain is 1:500. This means that a small dam will have a big influence area and therefore a high potential.

## 6.3 Earth dam in the floodplain of Semea

### *6.3.1 Purpose and principle*

One way of increasing the fertility of the floodplain is to extent the time of flooding of the plain. The BCS is absorbing more water and can be used for agriculture purposes. An earth dam can extent the time of flooding and in the sediment upstream of the dam, water for domestic use can be stored. An impression of such an earth dam is given in figure 6.3. In the following paragraphs different complications are being discussed.

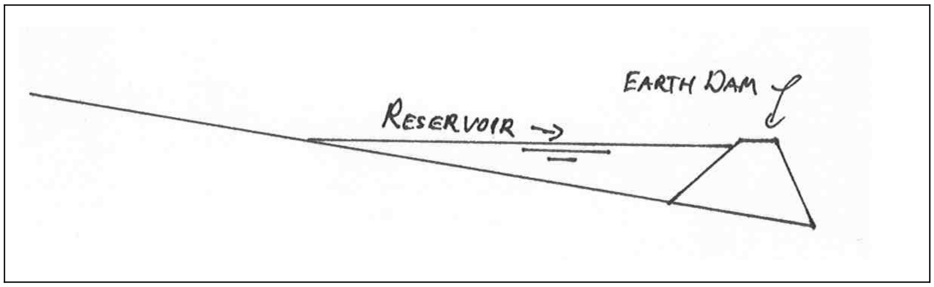


*Figure 1.3Principle of an earth dam*

*6.3.2Siltation*

A dam obstructs not only the transport of water, but also the transport of sediment. The flow of water just upstream of the dam will be slowed down. This will cause the river to silt with sand. Part of this silting is useful, because water for domestic use can be stored without the risk of contamination. The disadvantage of silting is that pure sand cannot be used for agriculture purposes. This points out that the silting of sand has to be confined to the riverbed.
One way of preventing the silting of the floodplain is constructing dams with their spillway far under the level of the surrounding area. Combined with a v-shaped spillway, the velocity of the water near the spillway is relatively high related to the discharge and silting will be reduced.

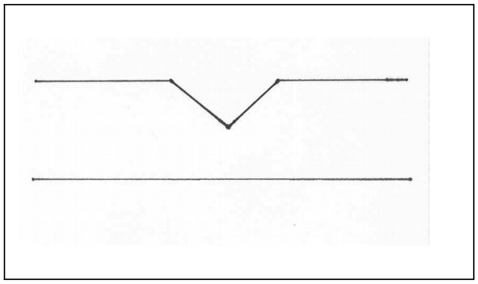

*Figure 6.3: V-shaped spillway*

*6.3.3Seepage and evaporation*

Experiments done in the project area showed the swelling character. BCS is cracking fast when dried and swelling very fast when wetted. This phenomenon can cause cracking of the surface of the earth dam. On the other hand, when the BCS is wetted the dam will be become relatively impermeable again.
The evaporation rates are very high in this district: 2000-2200 mm/year according to information obtained from de water office of Kitui. A lot of water will be lost due to this evaporation.

*6.3.4Maintenance*

To prevent lowering of the height of the dam due to subsiding and erosion, maintenance has to be done. Subsided parts have to be refilled as the eroded parts of the dam and spillway. Vegetation on the dam can prevent erosion, but also need maintenance.

Neglecting of maintenance will cause the dam to malfunction and eventually to disappear. Because maintenance on such a dam is a large-scale project, good management and a well-organized community are necessary.

## 6.4 Blocking of limestone layer

*6.4.1Purpose and principle of blocking of the limestone layer*

By blocking the water in the limestone layer the pressure in this layer will increase. This will cause a higher water level in the wells and more infiltration of water into the BCS-layer. This infiltration will be very slow, taking into account the permeability of BCS.
The blocking of the limestone layer will not increase the amount of water stored in this area. This is because the storage capacity is used to the maximum extent when the water is under pressure. An increasing of the amount of stored water far upstream (5 km) is possible, but likely to be negligible.

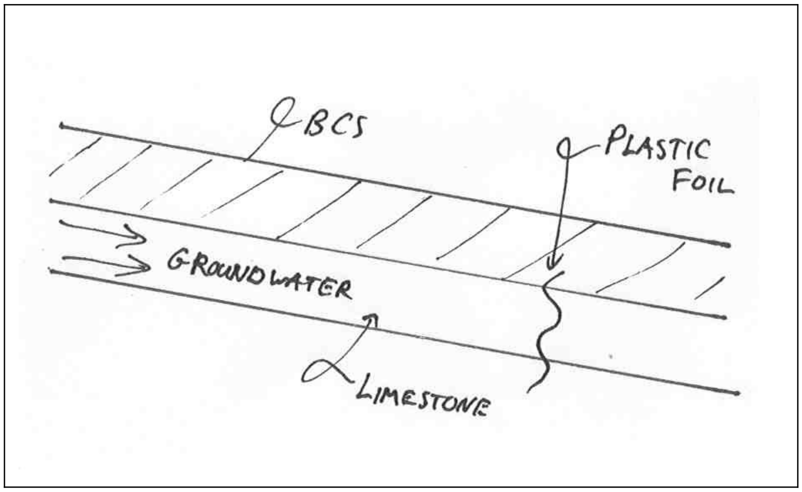


*Figure 6.3: Blocking of limestone layer*

*6.4.2Downstream influences*

Blocking of water will stop the recharge of water downstream of the blocking. This can causes downstream wells to dry up. This is the reason to locate the blocking of the limestone layer only near the outlet. The downstream area there is believed to be influenced more by the Nzeu than by the Semea. However blocking the limestone layer will always cause harm to the downstream area.

*6.4.3Construction*

Construction of the subsurface dam can be done by placing a plastic foil or BCS-wall into the limestone layer. To reduce the costs an optimal location with a little extent of the limestone can be sought by vertical electrical sounding. One of the biggest problems will be the excavation of the white-layer and constructing of the dam, since the water level in this limestone layer is high throughout the year. Pumping up the water during the construction will be expensive and can cause a remarkable lowering of the water table in the limestone layer.

## 6.5 Conclusion

Although a lot of attention has to be paid to the maintainability of an earth dam, the construction this type of dam is a possibility to increase the fertility of floodplain. Cooperation with an agricultural expert has to be sought to choose optimal crops. Experience from other earth dams built in south-Kitui by other organizations can improve the design and prevent failing.
The blocking of the white layer is not recommended. The most positive influence of the blocking upstream will be the heightening of the water table in the upstream wells. The amount of available water will not be significant increased. Moreover, the construction of the blocking will be a problem due to the high water table in the limestone layer throughout the year.

Proposing the next step for Sasol it is useful to examine the exact lateral extent of the aquifers using vertical electrical sounding. Based on these results a specific design can be made for the dam. Results of constructing and monitoring this dam can be input for more dams in BCS-area's.

# 7 Conclusions and Recommendations

Dams on rock
The upper part of the Semea seems to be suitable for the construction of a stone masonry-dam. The design and constructing of the dam can be quite similar to what Sasol is used to, only extra attention has to be paid on design of the wings.

Dams on clay
A plastic foil as impermeable shield is used to retain water upstream in the sediment in the middle part of the river. Advantages of plastic are the wide availability and the low costs. The reservoir of the subsurface dam is not big enough to provide water for household purposes throughout the year. Other alternatives for domestic water supply are necessary.

Dams in floodplain
The construction of an earth dam is a possibility to increase the fertility of the floodplain. Cooperation with an agricultural expert has to be sought to choose optimal crops.

The blocking of the white layer in the floodplain is not recommended because the most positive influence of the blocking upstream will be the heightening of the water table in the upstream wells. The amount of available water will not be significant increased

Porosity test
The purpose of this investigation was to provide an indication of the porosity of sand and limestone. For this purpose enough accuracy is obtained.

Permeability test
The permeability of sand of $1.0*10^{-3}$ resembles well with normal permeability of sand. The permeability of kunkar limestone aquifer is likely to be higher than the observed permeability. The observed permeability of BCS resembles with permeability of clay

BCS research
The research shows that the BCS layer has a thickness over half a meter, which is enough as impermeable layer under a dam in the middle part of the river. But there are some places where the BCS layer is not thick enough for such a purpose.

*Danida dam*
The results of the digging and the auger tests are not sufficient to determine the failure mechanism of the Danida dam. To be sure which failure mechanism takes place it is necessary to remove the sand around the Danida dam.

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